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# Detection and management of stressful situations to help the blind persons in their daily lives

Youssef Keryakos

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**THÈSE DE DOCTORAT**

**DE L'ÉTABLISSEMENT UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ**

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École doctorale n°37

Sciences Pour l'Ingénieur et Microtechniques

Doctorat d'Informatique

par

**YOUSSEF KERYAKOS**

**Detection and management of stressful situations to help  
the blind persons in their daily lives**

**Détection et gestion de situations de stress pour aider  
les non-voyants dans leur vie quotidienne**

Thèse présentée et soutenue à Belfort, le 13 Décembre 2024

Composition du Jury :

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# ABSTRACT

## Detection and management of stressful situations to help the blind persons in their daily lives

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University Bourgogne Franche-Comté, 2024

Supervisor: Michel Salomon  
Cosupervisor: Youssef Bou Issa

Stress is a universal human experience that has a substantial impact on people's day-to-day functioning, particularly for those who are visually impaired. Stress is characterized as a condition of tension, either bodily or mental, that results from events that cause anxiety, agitation, or frustration. The alarm, resistance, and exhaustion phases of the body's reaction to stress are outlined by the General Adaptation Syndrome (GAS), which also includes the release of stress hormones like cortisol and adrenaline. Blindness makes it especially difficult to recognize and manage stress, as blind people rely on non-visual sensory signals to navigate.

Being unable to notice barriers and changes in their surroundings causes blind persons to experience more stress when navigating. In unfamiliar or complicated outdoor and indoor environments, when conventional navigational aids like GPS and satellite images are useless, this stress is increased. Our research's findings have demonstrated a clear relationship between higher stress levels and the difficulty of navigation routes and the existence of barriers. Even with the invention of numerous assistive devices, such as white canes and braille compasses, these solutions frequently fail to offer complete assistance.

We address these issues by putting forth a novel hybrid navigation system that combines real-time stress detection with navigation assistance to help blind people. Our method makes use of a smart white cane that is outfitted with a network of biosensors to keep an eye on physiological stress markers including heart rate, muscular activity, and skin conductance. The system's goal is to identify stressful conditions and suggest less stressful navigation routes by evaluating these biosignals.

The suggested solution tackles navigational issues in both indoor and outdoor environments. The system creates stress and route difficulty indices for outdoor surroundings, enabling users to select and follow the least stressful path. Advanced image processing techniques are used to detect obstacles in real-time, and verbal commentary is provided to users to help them navigate safely. The technology uses augmented reality (AR) and a content management system (CMS) to build virtual maps based on floor plan photos for indoor environments where GPS and satellite data are not available. Thanks to a mobile application, users can load and interact with these virtual maps by scanning QR codes located within the indoor space.

Real-time stress detection and navigation support are integrated into the system, which is a major leap in assistive technology. The system's goal is to make navigation more efficient and less stressful for people who are blind or visually impaired. Subsequent studies will concentrate on assessing the system's effectiveness, examining user input, and improving the technology to guarantee peak performance and user contentment. For blind individuals, this method not only increases independence but also makes navigation easier and less stressful.

**KEYWORDS:** Blind individuals, stress detection, navigation system, physiological signals, white cane sensors, General Adaptation Syndrome (GAS), outdoor navigation, indoor navigation, real-time guidance, obstacle detection, stress management, mapping, augmented reality (AR), mobile application, voice feedback, accessibility technology, stress levels, route optimization.

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# RÉSUMÉ LONG EN FRANÇAIS

Détection et gestion de situations de stress  
pour aider les non-voyants dans leur vie quotidienne

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Le stress, une expérience commune à diverses activités humaines, affecte de manière significative la vie quotidienne des individus, en particulier ceux ayant des déficiences visuelles. Défini comme un état de tension physique ou mentale, le stress provient de situations qui induisent frustration, nervosité ou colère. Le Syndrome d'Adaptation Générale (SAG) décrit la réponse du corps au stress, englobant les phases d'Alarme, de Résistance et d'Épuisement, et implique la libération d'hormones de stress comme le cortisol et l'adrénaline. Identifier et gérer le stress chez les personnes aveugles est particulièrement difficile en raison de leur dépendance aux indices sensoriels non visuels pour la navigation.

Les personnes aveugles éprouvent un stress accru lors de la navigation en raison de l'incapacité à voir les obstacles et les changements dans leur environnement. Ce stress est exacerbé dans les environnements extérieurs et intérieurs inconnus ou complexes, où les aides traditionnelles à la navigation, telles que les GPS et les images satellites, sont inefficaces. Les résultats de notre travail ont établi que la présence d'obstacles et la complexité des itinéraires de navigation sont directement corrélées à des niveaux de stress accrus. Malgré le développement de divers outils d'assistance, tels que les compas en braille et les cannes blanches, ces solutions sont souvent insuffisantes pour fournir un soutien complet.

En réponse à ces défis, nous proposons un nouveau système de navigation hybride conçu pour aider les personnes aveugles en intégrant la détection du stress en temps réel et une aide à l'orientation lors de la navigation. Notre système utilise une canne

blanche intelligente équipée d'un réseau de capteurs biologiques pour surveiller les indicateurs physiologiques du stress, notamment la fréquence cardiaque, la conductance de la peau et l'activité musculaire. En analysant ces biosignaux, le système vise à identifier les situations induisant du stress et à recommander des itinéraires de navigation moins stressants.

Le système proposé répond aux défis de la navigation en extérieur et en intérieur. Pour les environnements extérieurs, le système génère des indices de difficulté et de stress des itinéraires, permettant aux utilisateurs de choisir et de suivre le chemin le moins stressant. La détection en temps réel des obstacles est réalisée grâce à des techniques avancées de traitement d'images, et les utilisateurs reçoivent des indications vocales pour naviguer efficacement. Pour les environnements intérieurs, où les données GPS et satellites sont indisponibles, le système utilise la réalité augmentée (RA) et un système de gestion de contenu (SGC) pour créer des cartes virtuelles basées sur des images de plans d'étage. Des codes QR dans l'espace intérieur permettent aux utilisateurs de charger et d'interagir avec ces cartes virtuelles via une application mobile.

L'intégration de la détection du stress en temps réel et du soutien à la navigation représente un avancement significatif dans la technologie d'assistance. En réduisant le stress et en améliorant l'efficacité de la navigation, le système vise à améliorer la qualité de vie des personnes malvoyantes. Les recherches futures se concentreront sur l'évaluation des performances du système, l'analyse des retours des utilisateurs et le raffinement de la technologie pour garantir une fonctionnalité optimale et la satisfaction des utilisateurs. Cette approche améliore non seulement l'indépendance, mais fournit également une expérience de navigation plus gérable et moins stressante pour les utilisateurs aveugles.

Concrètement, dans notre thèse, nous proposons quatre contributions majeures qui s'articulent autour de la détection et de la gestion du stress chez les personnes aveugles lors de leurs déplacements.

Dans une première contribution, nous avons présenté notre approche pour la détection et la gestion du stress. L'objectif principal étant d'utiliser des techniques d'apprentissage automatique, nous avons dû collecter et analyser une grande quantité de données afin de produire un modèle d'identification du stress. Pour ce faire, nous avons développé notre prototype interactif intelligent, l'ICane, qui sert de canne d'évitement d'obstacles pour les utilisateurs aveugles et nous aide à collecter des données pour les phases ultérieures de notre projet. Les expériences menées ont montré que les différents capteurs intégrés à l'ICane, capables de détecter divers signaux biologiques, mettent en évidence des corrélations avec des situations de stress. L'objectif final de notre projet est de détecter les situations stressantes afin de les atténuer en fournissant des informations de navigation utiles aux utilisateurs aveugles de l'ICane.

Dans une seconde contribution nous avons mis en évidence que se déplacer à pied représente un défi quotidien pour les personnes aveugles. Même sur un trajet familier, de nouveaux obstacles peuvent apparaître, rendant chaque parcours unique et source de stress. Nos expériences avec deux prototypes de cannes blanches intelligentes ont démontré que le stress peut être identifié lors de la navigation d'une personne aveugle et que les facteurs de stress peuvent être liés aux obstacles rencontrés. Les données collectées peuvent être exploitées concrètement à l'aide de techniques d'apprentissage automatique, notamment les réseaux de neurones, pour prédire le stress des utilisateurs aveugles pendant la navigation ou pour les classer selon leur état de stress à différents points du parcours. Sur cette base, nous pouvons aider les utilisateurs à mieux gérer leur stress, par exemple en les informant vocalement des obstacles ou en les redirigeant vers des chemins moins encombrés.

Dans une troisième contribution nous avons proposé un système de navigation destiné à aider les personnes aveugles à naviguer en toute sécurité et avec moins de stress. Ce système remplit deux fonctions principales : il suggère le chemin le moins stressant entre deux points et détecte en temps réel les obstacles que l'utilisateur peut rencontrer. Cette première fonction a été mise en œuvre sous forme d'application web, intégrée par la suite dans une application mobile. Ce système peut identifier de manière fiable les différentes routes possibles et proposer à l'utilisateur celle avec le niveau de stress le plus faible. La deuxième fonction permet la détection d'objets en temps réel, a également été implémentée dans l'application mobile.

Enfin, dans une quatrième contribution, nous avons introduit le concept d'un système de navigation intérieur et extérieur, intégrant les fonctionnalités existantes du système de navigation en extérieur tout en proposant des adaptations pour la navigation en intérieur, couplées à la détection de stress.

**Mots clés:** Personnes aveugles, détection du stress, système de navigation, signaux physiologiques, capteurs de canne blanche, Syndrome d'Adaptation Générale (SAG), navigation extérieure, navigation intérieure, orientation en temps réel, détection des obstacles, gestion du stress, cartographie, réalité augmentée (RA), application mobile, retour vocal, technologie d'accessibilité, niveaux de stress, optimisation des itinéraires.



# LIST OF ABBREVIATIONS

<b>ActiVis</b>	. . . . .	Active Vision with Human-in-the-Loop for the Visually Impaired
<b>ANS</b>	. . . . .	Autonomic Nervous System
<b>AODeP</b>	. . . . .	Augmented Objects Development Process
<b>AP</b>	. . . . .	Access Point (in the context of Wi-Fi networks)
<b>API</b>	. . . . .	Application Programming Interface
<b>AR</b>	. . . . .	Augmented Reality
<b>BLE</b>	. . . . .	Bluetooth Low Energy
<b>Bluetooth</b>	. . . . .	A wireless technology standard (commonly referred to as BLE in some contexts, though BLE is not explicitly mentioned here)
<b>bpm</b>	. . . . .	Beats Per Minute
<b>BVP</b>	. . . . .	Blood Volume Pulse
<b>CCD</b>	. . . . .	Charged-Coupled Device
<b>CMS</b>	. . . . .	Content Management System
<b>CSV</b>	. . . . .	Comma-Separated Values
<b>ECG</b>	. . . . .	Electrocardiography
<b>EDA</b>	. . . . .	Electrodermal activity
<b>EEG</b>	. . . . .	Electroencephalogram
<b>EMG</b>	. . . . .	Electromyography
<b>GAS</b>	. . . . .	General Adaptation Syndrome
<b>GHz</b>	. . . . .	Gigahertz
<b>GPS</b>	. . . . .	Global Positioning System
<b>GUI</b>	. . . . .	Graphical User Interface
<b>HR</b>	. . . . .	Heart Rate
<b>HRV</b>	. . . . .	Heart Rate Variability
$i_1$	. . . . .	Familiarity with road
$i_2$	. . . . .	Traveling alone
$i_3$	. . . . .	No cane or GPS



$i_4$	Fatigue value calculated from parameters
$i_5$	Initial heart rate value
$i_6$	Initial EDA value
$i_7$	Initial EMG value
<b>iBeacon</b>	Apple's Bluetooth Beacon Technology
<b>ID</b>	Index of Difficulty
<b>IDO</b>	Index of Difficulty for each obstacle.
<b>IDR</b>	Index of Difficulty for Route
<b>ISR</b>	Index of Stress for Route
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>IL-1B</b>	Interleukin 1 Beta
<b>IoT</b>	Internet of Things
<b>JSON</b>	JavaScript Object Notation
<b>LAN</b>	Local Area Network
<b>LE</b>	Low Energy
<b>LED</b>	Light Emitting Diode
<b>LOS</b>	Line of Sight
<b>Mbits/s</b>	Megabits per second
<b>MHz</b>	Megahertz
<b>ML</b>	Machine Learning
<b>NFC</b>	Near Field Communication
<b>OM</b>	Orientation and Mobility
<b>PDA</b>	Personal Digital Assistant
<b>PNS</b>	Parasympathetic Nervous System
<b>QR</b>	Quick Response (code)
<b>RFID</b>	Radio-Frequency Identification
<b>RGB-D</b>	Red Green Blue-Depth
<b>RLTM</b>	Real-Time Location System (related to Ubisense's system)
<b>RSS</b>	Received Signal Strength
<b>SNS</b>	Sympathetic Nervous System
<b>SPO2</b>	Oxygen Saturation (often represented as SpO2)
<b>SRR</b>	Skin Resistance Responses

<b>SSD</b>	Single Shot Detector
<b>ST</b>	Skin Temperature
<b>TEWL</b>	Transepidermal Water Loss
<b>UWB</b>	Ultra-Wide Band
<b>VI</b>	Visually Impaired
<b>WHO</b>	World Health Organization
<b>Wi-Fi</b>	Wireless Fidelity
$x_l$	Total length of the road.
$x_s$	Road slope.
$x_a$	Accessibility of the road.
$x_w$	Weather conditions.
$x_n$	Average number of obstacles per meter of road.
<b>XML</b>	Extensible Markup Language



# INTRODUCTION

This thesis aims to minimize stress for blind individuals during their most challenging daily activity: navigation. The first part of our work involved building a prototype and conducting experiments to gather biometric data aimed at detecting stress levels during outdoor navigation. In our second contribution, we explored the correlation between encountering obstacles in the path of blind individuals and their stress levels while navigating. In a third contribution, we have developed a navigation system specifically designed to mitigate stress for blind individuals. This system proposes the least stressful routes, provides real-time directional guidance, and detects obstacles to enhance the navigation experience. In a final contribution we have introduced the concept of an hybrid navigation system adapted to blind users for optimal stress-free indoor and outdoor mobility.

## 1.1/ BLINDNESS AND VISION LOSS

Millions of people worldwide are blind [1]. According to [2], which was published in March 2024, there were around 43.3 million blind and 295 million with moderate to severe vision impairment in 2020. Blindness is characterized as either partial or total loss of vision, ranging from poor vision, in which a person is still able to see, to a complete loss of vision. A person with a visual measurement of 20/200 or less is considered legally blind [1].

The challenges that blind individuals encounter are numerous and affect their everyday lives, as well as their ability to pursue education, careers, social relationships, and general quality of life. Social attitudes and structural obstacles that frequently restrict blind people's access and opportunities exacerbate these challenges. Many blind people manage to overcome these challenges and go on to exhibit incredible tenacity, adaptive skills, and a strong sense of independence.

Technological developments are essential to improving accessibility and enabling blind people to move around the world more freely. Access to information, communication, education, and employment prospects that were previously unattainable is made possible

by tools like screen readers, braille displays, navigation apps, and tactile assistance.

## 1.2/ STRESS AND CHALLENGES FACED BY BLIND PEOPLE

A blind person's journey is not without its difficulties and pressures. It is essential to comprehend the causes and effects of stress on blind people in order to create inclusive environments and efficient support networks. For those who are blind, stress can come from a variety of situations, such as navigating environments that are difficult to access, dealing with prejudice and misunderstandings in society, taking care of medical needs, and pursuing equal chances in work and school.

Blind people face major problems while navigating physical situations. A lack of tactile paving, audible crossing signals, and clear signage can disrupt independent mobility. Simple tasks like crossing the street or finding a certain area might become difficult without suitable accessibility features.

Stress in blind people is also influenced by social exclusion and stigma. Erroneous beliefs regarding blindness have the potential to cause prejudice, marginalization, and a lack of social contact and integration chances. These difficulties are exacerbated by the cultural view of blindness as a crippling illness rather than as a variation in vision and interaction.

For blind people, employment is still a major source of concern since they frequently run into difficulties finding and keeping work. Higher unemployment and economic insecurity within the blind community are caused by discriminatory recruiting practices, difficult work settings, and a lack of accommodations for blind personnel.

For those who are blind, getting healthcare services is another source of stress. Since medical information is frequently shown visually, blind people cannot access it without the necessary adjustments or other formats. Managing health concerns can be stressful, made more so by the difficulties associated with navigating healthcare facilities and comprehending medical procedures and medicines.

In educational settings, students who are blind encounter particular difficulties while trying to access educational resources and engage completely in class activities. The absence of technology, accessible textbooks, and resources catered to the requirements of visually impaired students may impede their academic progress and ability to integrate into mainstream educational settings.

For many blind people, depending on others to help with everyday duties is a reality. This dependence can result in emotions of frustration, loss of freedom, and elevated stress, whether it's on sighted guides for transportation, help reading printed materials, or using the internet to obtain information.

It is important to consider the psychological and emotional effects of blindness. Increased levels of stress, worry, sadness, and low self-esteem can be caused by adjusting to visual loss, managing related issues, and managing cultural attitudes and barriers. For those who are blind, technological developments have greatly increased accessibility and independence. Screen readers facilitate communication and access to digital content by turning text into speech or braille output. Braille displays make it easier for people to read and access information by providing a tactile representation of text on computer screens. Through the use of GPS and audio signals, navigation apps enable blind people to autonomously navigate both indoor and outdoor surroundings. In spite of these developments, accessibility is still a problem in the digital era. Many digital platforms, software programs, and websites lack accessibility features, which makes it challenging or impossible for blind people to utilize them on their own. Ensuring equitable access to information and opportunities for blind people requires improving digital accessibility through inclusive design approaches and adherence to accessibility standards.

Efforts to raise awareness and challenge cultural misunderstandings are crucial in ensuring inclusivity for blind people. We can create a more inclusive society where blind people can thrive and fully contribute to their communities by increasing awareness about the abilities and potential of blind people, pushing for legislative changes that support accessibility and inclusion, and cultivating welcoming environments that value diversity.

Developing solutions that effectively support blind individuals' independence, inclusion, and well-being requires an understanding of the different experiences and problems they face. We can work to create a more equitable and inclusive society where everyone, regardless of visual ability, has equal opportunities to live fulfilling and meaningful lives by addressing the sources of stress and barriers faced by blind people, advocating for technological advancements in accessibility, and cultivating societal acceptance and support.

### 1.3/ AREAS OF CONCERN AND THESIS OBJECTIVES

Due to vision loss, blind people rely on others to perform their daily activities. If for some reason they did not achieved to get help from others, they often suspend their activities and stay at home. Thus, due to vision loss, blind people lose their hobbies, leisure and ordinary day life activities. They will be negatively impacted in their life by onset depression, impaired self-esteem, less social active, face many challenges with relations and communications.

Blind people face environmental challenges such as outdoor navigation difficulties of unaccustomed spaces. Walking is a common and important mode of transportation for all individuals, but it can present challenges for those who are blind. While it may be a simple

task for healthy individuals with normal vision to navigate from one point to another, blind individuals may experience difficulty, stress, and challenges in doing so. Challenging situations can lead to stress through a combination of psychological appraisal processes (perceived threat, lack of control) and physiological responses (activation of stress hormones and physiological systems).

Every human being is subject to stressful situations, and obviously the most stressful situation or event in the daily lives of blind people is navigation. Visually impaired people cannot see objects in front of them. However, most of them are able to sense light and shadows only. Hence, navigation is challenging for blind people, especially in situations lacking suitable accessibility elements. When you are in outdoor environments, your digital navigation solution, like Google Maps, is based on satellite imagery, aerial photography and GPS signals. However, these spatial data obviously do not cover the inside of buildings, which means that you need a different service for mapping your venue and facilitating digital navigation indoors. Blind people need help to detect and avoid physical obstacles in their path, both indoors and outdoors.

Many assistive tools have been developed like braille compasses and white canes that help the visually impaired to navigate around in the environment. Moreover, they navigate around, based on their senses and experiences with the aids of guidance canes to detect and avoid obstacles while moving. Technology is a revolutionary force in addressing the challenges faced by people with visual impairments, providing innovative solutions that improve accessibility and independence. One of the main challenges that blind people encounter in their everyday lives is orientation and mobility in both outdoor and indoor scenarios which impact their social engagement and overall quality of life. This challenge is prevalent in both outdoor and indoor settings. It is particularly noticeable in public places like shopping malls, airports, offices, and other large indoor spaces. Unlike outdoor environments, indoor spaces are not accessible to GPS signals, making reliance on traditional navigation aids impractical. Indoor navigation is challenging due to complex layouts, dynamic obstacles, and unreliable visual cues. Finding and avoiding obstacles in their path is more challenging when there are no visual cues available. Receiving accurate and up-to-date information becomes more difficult when aiming to arrive at a destination quickly. Because decision-making and continuous spatial awareness demand a higher cognitive load, physical fatigue develops. Also, people get mental tiredness from cognitive fatigue because they are always processing touch and auditory cues to make sense of their environment. Lack of tailored support in unfamiliar indoor spaces worsens challenges, hindering blind individuals navigation independence and proficiency. While several technologies have emerged to assist individuals with visual impairments, they remain insufficient in fully addressing obstacles, overcoming barriers, and ensuring successful arrival at the intended destination.

In this thesis, we address several key challenges related to stress detection during navigation among visually impaired individuals. Firstly, we aim to detect stress during navigation activities. Secondly, we investigate the correlation between detected stress levels and the types of obstacles encountered by blind individuals during navigation. Lastly, we explore methods to facilitate stress-free navigation experiences for blind users. As a solution, we propose the development of an integrated indoor and outdoor navigation system tailored specifically for visually impaired users. This system aims to alleviate navigation-related stress by offering real-time navigation guidance and obstacle detection capabilities in both indoor and outdoor environments.

## 1.4/ OUTLINE

This thesis is divided into the following chapters:

- **Chapter 2:** – Related work. this chapter introduces stress definition. The physiological signs related to stress. Works related to stress detection (multiple approaches). Works related to stress detection specifically for blind people. Assistive technologies for blind people.
- **Chapter 3:** – Contribution 1: Analyzing stress situations for blind people. In this contribution we focus on the analysis and detection of stress in the daily life of blind people. We present a major step related to data collection to detect physiological signs of stress using a network of sensors implemented on a white cane.
- **Chapter 4:** – Contribution 2: Correlation between types of obstacles and stress level of blind people in outdoor navigation. We designed and proposed two prototypes using biological sensors connected to a cane for blind people to collect data in several scenarios. This contribution shows that stress can be identified and detected when a blind person is navigating a path, and even that the stress factors causing this stress can be related to obstacles along the path.
- **Chapter 5:** – Contribution 3: Introducing a stress management and navigation system for blind individuals. In this contribution we introduce and describe a navigation system that will provide two important tasks for blind individuals. At first the system will propose for the blind the least stressful road to navigate in between multiple possible roads to take between a starting point and a destination point. Finally, the system will navigate the blind and detect obstacles in real time.
- **Chapter 6:** – Contribution 4: Introducing the concept of a hybrid navigation system adapted to blind Users for optimal stress-free indoor and outdoor mobility. In our prior contributions, we established a connection between stress levels and the



challenges encountered by visually impaired individuals during outdoor navigation. To address this, we developed an outdoor navigation system capable of initially determining the least stressful route between two points, and subsequently delivering real-time navigation instructions and obstacle detection. This contribution introduces a novel concept: a hybrid navigation system designed to help visually impaired people navigate in unfamiliar environments, both indoors and outdoors, enabling them to successfully reach their destination while minimizing stress.

- **Chapter 7:** - Conclusion and future work

## RELATED WORK

### 2.1/ INTRODUCTION

Navigating is challenging for blind people and challenging situations can induce stress. In this chapter we delve into relevant research and studies that aligns with the objectives and the aims of our thesis work. We begin by focusing on different stress definitions, we then continue by exploring different approaches relevant to stress detection and the physiological signals of stress. These approaches are divided into multiple categories we can cite the approaches based on muscle stiffness and touch pressure, approaches based on the measurement of the electro-dermal activity and heart rate variability. Furthermore, we continue by exploring stress detection research and studies related to blind people. Finally, we explore multiple navigation and guidance systems designed to help the blind people in both environments indoor and outdoor. This final exploration is divided into five main areas: Localization Technologies, Obstacles Recognition Methods, Feedback Methods, Devices, and Software-based Systems. Localization technologies are crucial to these systems, allow to identify users position and support users in navigating their environment. We begin by examining several approaches in the localization category like Wi-Fi-based systems. These systems identify users position based on the Wi-Fi signal strength. We compare Wi-Fi-based approach with Bluetooth Low Energy (BLE) approach, which uses beacons to identify users position. Additionally , we review the use of camera-based systems like CamNav, which leverages computer vision to provide real-time navigation, and Infrared LED systems that use augmented canes to detect obstacles and provide guidance. We also discuss the integration of Ultra-Wide Band (UWB) technology, which offers high-accuracy mapping and positioning, and explore innovative solutions using LED lights and geomagnetic sensors to enhance indoor navigation. Each method is evaluated for its strengths, limitations, and practical implications, providing a comprehensive overview of current technologies aimed at improving mobility and independence for blind individuals.

## 2.2/ STRESS DEFINITION

Hans Selye first defined stress as any force that produces abnormalities, pressures or injuries to the human body [3]. John Mason also proved that two types of stress exist: psychological and physiological stresses [3]. Stress can be classified as acute or chronic. While acute stress is the short-term response to a particular challenge or daily activity, chronic stress is a longer-term response to extreme life experiences and challenges [4]. When stressed, the human body replies to stress with a response called General Adaptation Syndrome (GAS). The first step of this response involves the secretion of stress hormones: cortisol and adrenaline [3]. GAS involves three phases:

- **Alarm reaction:** in which the body takes an immediate reaction called “Fight or Flight”, is a phase that needs a lot of energy to fight or escape and the immune system is subject to infection.
- **Resistance:** in which body begins to adapt to stress, is a phase where energy is concentrated to stress only that is harmful for health [3].
- **Exhaustion:** which is the last phase of the GAS in which the body is subject to a long period of stress, body resistance decline, the immune system is ineffective, and the human subject to stress can experience chronic illness and cardiac diseases [3].

In the same context, Lazarus, R. S., Folkman, S. (1984) [5], defined stress as a dynamic process involving an individual’s appraisal of a situation and their coping resources. It emphasizes the interaction between the person and their environment, where stress arises when the demands exceed personal capabilities. Moreover, Kabat-Zinn, J. (1990) [6], defined stress as the balance (or imbalance) between external demands placed on an individual and their internal resources for coping. This definition points to the importance of mindfulness and awareness in managing stress. Additionally, McEwen, B. S. (2006) [7] defined stress as a physiological and psychological response to perceived threats or challenges, impacting the body’s homeostasis and leading to allostatic load, which can result in health problems over time. Also, Chrousos, G. P. (2009) [8] defined stress as a state of mental or emotional strain arising from adverse circumstances, underlining the influence of external factors on individual stress levels and health outcomes. Besides, Joëls, M., Baram, T. Z [9] defined stress as a complex neurobiological response to environmental challenges or threats that involve the activation of various neural circuits and hormonal systems. Furthermore, Koolhaas, J. M., *et al.* [10] defined stress as a state of threatened homeostasis, characterized by an imbalance between demands and resources, leading to physiological, behavioral, and cognitive changes.

## 2.3/ PHYSIOLOGICAL SIGNS OF STRESS

The sympathetic nervous system (SNS) of the autonomic nervous system (ANS) in the brain is responsible for triggering the fight or flight response, providing the whole body with sufficient energy to defeat the danger perceived, while the parasympathetic nervous system (PNS) works to maintain a stable functioning of the body. When the danger passes, the PNS triggers the “rest and digest” response that finally calms the body. After, the distress signal is sent by the amygdala to the hypothalamus that activates the SNS by sending signals through the autonomic nerves to the adrenal glands. The adrenal glands respond by ejecting the adrenaline hormone through the whole body. As the adrenaline circulates through the body, multiple physiological changes or physiological signs can be detected [11]:

- **Energy:** will be needed for the fight or flight reaction; it will be transformed or created. The fat stored in the cells will be transformed to glucose for faster need of energy and the liver will produce glucose in a faster way.
- **Cardiovascular Activities:** heart rate will increase, high blood pressure, veins will open up to ensure faster return of blood to heart.
- **Inhalation and Exhalation:** respiration rate increases, breathing deepens up for more oxygen absorption. Lungs, throat, and nostrils open up to breathe in and out at a higher rate.
- **Senses:** senses become sharpened and toughened, pupils enlarge to make visibility more clear, and endorphin secretion is a trigger to stay focused in case of an injury.
- **Digestion:** stops through constriction of the blood vessels of the stomach, kidney, intestines and dry mouth.
- **Skin:** reducing the blood loss as the blood vessels constrict in case of injury, sweat glands open to cool the body down.
- **Reproduction:** stops, as both productions of estrogen and testosterone decrease.

The two main signals related to stress are the electro-dermal activity (EDA) known as the GSR and the heart rate variability (HRV) [12]. GSR is the measure of the skin conductance due to activation of the sweat glands, which are activated by the SNS. A high average value of GSR is directly associated to stress. HRV is the physiological phenomenon of variation in the time interval between heartbeats. It is measured by the variation in the beat-to-beat interval. Generally, a low HRV or less variability in the heartbeats indicates that the body is under stress because of exercise, psychological events, or other internal or external stressors [12].

## 2.4/ STRESS DETECTION

Hans Selye first borrowed stress from the field of physics. He defined stress as a non-specific strain on the body caused by irregularities in normal body functions. Selye pioneered the field of stress and provided arguments that stress affected the health of the human body. However, he was limited to the physiological view of stress. John Mason conducted an experiment to prove that psychological stress exists, considering two groups of monkeys. The first group of monkey was alone, while the second group was watching the first group getting food. Those that saw others eating had higher stress hormones levels [3].

Literature mainly revealed that there are two main methods to detects or measure stress. The first measurement method is via self-reports and the second through physiological signals resulting of the fight or flight response. The self-report method is a measurement of stress based on the self-report of the human about his symptoms, his feelings, and his acts [13,14]. On the other hand, physiological signals collection is the most accurate way to detect and measure stress by detecting physiological signals. Thereafter we list some of the methods that use physiological signal measurement to detect stress

### 2.4.1/ APPROACHES BASED ON MUSCLE STIFFNESS AND TOUCH PRESSURE SIGNALS

Sun *et al.* [15] revealed that stress can be detected based on how a user handles a computer mouse. They explored stress measurements with common computer mouse operations and used a simple model of arm-hand dynamics to capture muscle stiffness during mouse movements. This method showed that the within-subject mouse-derived stress measure is quite strong.

In addition, Hernandez *et al.* [16] revealed the existence of stress based on the way a user handles a computer mouse and the pressure of tapping on computer keyboard. 24 participants explored with a pressure-sensitive keyboard and a capacitive mouse, during 30 minutes' session in which they were given tasks consisting of expressive writing, text transcription and mouse clicking. In stressful conditions, more than 79% of the participants showed significantly increased typing pressure and more than 75% showed more contact with the surface of the mouse.

On another hand, Gao *et al.* [17] detected stress based on how a human user manipulates and swipes a mobile phone's touch screen. Finger stroke features during game play on iPod were extracted and touch power was analysed. Machine learning algorithms were used to discriminate between four emotional states: excited, relaxed, frustrated, and bored. Accuracy reached 69% to 77% for the four emotional states.

Moreover, Paredes *et al.* [12] identified stress with just analysing the movement of a car steering wheel. They demonstrated that stress can be expressed through muscle tension in the limbs and measured through the way a person drives a car. As a result, they proved that stress can be detected with only a few turns during driving. Experiments were conducted on 25 participants: 13 women and 12 men, with ages ranging from 18 to 67.

Furthermore, Ferdous *et al.* [18] stress' detection method was based on the manipulation and the usage of different types of mobile applications. They explored patterns of usage of the mobile applications and analysed the relation between this patterns and the perceived stress scale. This method was made using a subject-centric behaviour model that could predict stress level based on smart phone application usage. The results showed an average accuracy of 75% and a precision of 85.7%.

#### 2.4.2/ APPROACHES BASED ON THE MEASUREMENT OF THE ELECTRO-DERMAL ACTIVITY AND HEART RATE VARIABILITY

The main approach of Costa *et al.* [19] consisted to detect stress based on HRV measurement and to build a portable device EmotionCheck that can change the user's perception of his heart rate through subtle variations on the wrist. EmotionCheck will give a false feedback of a slow heart rate when the user's heart rate is high. The experiments performed on a set of 67 participants showed that EmotionCheck helps the users regulate their anxiety through the false feedback of a slow heart rate.

Macleane *et al.* [20] developed MoodWings, a wearable butterfly that mirrors the stress of a user in real-time through actuated wing motions. The measurement of stress levels is based on the electro-dermal activity (EDA) and electrocardiography (ECG) signal. Two sensors placed on the sole of the foot collected EDA signal. The butterfly can be held in hand and the motion of its wings is correlated to the EDA signal. The prototype was tested while users were driving. As a result, users drove more safely with MoodWings, but experienced higher stress levels (physiologically and self-perceived). Users were enthusiastic about MoodWings and found it useful in several contexts of the experiment.

In the same context, Yoon *et al.* [21] developed a monitor patch for human stress detection. It consists of a small skin contact area and with high flexibility to enhance wearing comfort. Skin area minimization was achieved by the multilayer integration of the skin temperature, skin conductance, and a pulse wave sensor. The skin contact layer making the direct contact with the skin contains the skin temperature sensor and the skin conductance sensor, both using aluminum electrodes. The pulse wave-sensing layer contains the pulse wave sensor. For stress characterization, arterial pulse wave signals are required to be transformed in human heart rate variability (HRV).

While Villarejo *et al.* [22] designed a stress sensor detector based on the measurement of GSR and controlled by ZigBee. Experiments were conducted on 16 adults: 8 women and 8 men who completed a series of tests requiring certain degree of effort. Success rate of the experiments was about 76.56%. The main component of the stress detector consists of two electrodes. A person's skin acts like a resistance to the passage of the electrical current, since the two electrodes placed on finger will act like they were two terminals for one resistance and thus allow to calculate GSR. The more stressed is the person, the more his hands will sweat. As a consequence, the resistance of his skin will decrease, conductance of the skin will increase, and higher GSR with higher output voltage will be detected by the sensor.

Moreover, Egawa *et al.*'s [23] approach of detecting stress was based on skin, salivary and facial images parameters measurement. The purpose of the study was to identify potential biomarkers that were not determined in previous studies. The experiments involved 23 Japanese subjects staying for 2 weeks in a confined facility at Tsukuba Space Center. Increases in salivary cortisol were observed after waking up on the 4th and 11th days. Transdermal water loss (TEWL) and sebum content of the skin were higher compared with outside facility on the 4th and 1st days. Increases of IL-1B protein, which is released by cells under infection, could be observed in the stripped stratum corneum on the 14th day and 7 days after leaving and differences in facial expression symmetry on the 11th and 14th days. Salivary cortisol has been found to increase with acute stress. Increases in IL-1B in the stratum corneum and TEWL values indicate degradation of the skin due to stress (inflammatory reaction).

## 2.5/ STRESS DETECTION FOR BLIND PEOPLE

The study of Crudden *et al.* [24] has analysed stress caused by navigation and walking in public transportation. Experiments were conducted on visual impaired participants, while rating their stress levels experienced when completing different walking and navigation tasks in public transportation. As a result, they detected higher stress levels when navigating unfamiliar bus routes, walking across urban areas without sidewalks and walking in unfamiliar places. They observed significant predictors of stress in transportation like age, years since vision loss, dog guide use, and physical limitations. Older-age and self-reported physical limitations were associated with higher walking and public transportation stress, more frequent transportation use per month was associated with lower stress levels, dog guide use predicted lower stress level. Participants also indicated activities they avoided due to transportation stress such as entertainment, visiting friends and family.

In [25], the goal of Kalimeri *et al.* was to understand which environmental factors increase stress for blind people in indoor mobility. They developed an approach to detect stress for blind persons during indoor navigation based on the signals of the electroencephalogram (EEG) by the EmotivEpoc+ equipment, the signals of the EDA, and blood volume pulse (BVP) by the Empatica E4 equipment. The indoor navigation route experiment included five distinct environments representative of a variety of indoor mobility challenges. Participants had to enter through automated doors, use an elevator, move across a busy open space, walk down a large spiral staircase, and walk through other obstacles. The route was approximately 200 meters in length and took on average 5 minutes to walk (a range of 4–8 minutes).

Massot *et al.* [26] have presented a case study where a wearable device called EmoSense is used on blind pedestrians to monitor the Autonomic Nervous System (ANS) in an ambulatory, non-laboratory settings experiment. EmoSense is a small wrist device connected to several sensors, affording the measurement of physiological signals from the sympathetic and parasympathetic systems, such as Skin Resistance Responses (SRRs), Skin Temperature (ST) and Heart Rate (HR). The recording and the analysis of these signals were carried out to allow an objective evaluation of the stress for blind people moving in the city, and then to approach the phenomenon in a more precise way (by localization). The aim is to verify the hypothesis put forward by psychologists stating that the urban environment has an effect on the stress and vigilance of blind people.

Moreno *et al.* [27] presented a study to investigate the autonomic nervous system modulation on the heart of blind people and also on subjects benefiting from a normal vision and submitted to a low vision situation. Normal vision subjects and blind patients were submitted to Heart Rate Variability (HRV) analysis during resting, intervention and recovery periods. Intervention consisted of handling objects, taking short walks, and performing activities with pedagogic games while wearing sleeping masks.

Zubair *et al.* [28] designed a cost-effective, low-power, IoT based smart bracelet for healthcare that detects mental stress based on skin conductance. This bracelet can continuously monitor the user's mental stress and wirelessly transmit stress-related data to the user's smartphone.

Kalhorro *et al.* [29] presented a data collection protocol for the ambulatory recording of physiological parameters for stress measurement purposes. They presented a wearable sensor system for the ambulatory recording of ECG, EMG, respiration, and skin conductance. The system also recorded various context parameters: acceleration, temperature and relative humidity. They showed that the sensor system is capable of long-term, non-invasive, non-obtrusive and wireless physiological monitoring, and also presented some preliminary results of a stress estimation method.

In 2016 the Amulet [30] team conducted two studies to monitor stress. They collected



data from subjects where all of the participants wore devices respectively called the Amulet and the Zephyr. The Zephyr (chest device) transmitted heart rate data to the Amulet (wrist device). After each study the researchers developed an algorithm for stress detection. Many researchers have also worked on the design of intelligent canes.

Hence Huang *et al.* [31] used a smart cane that contains force sensors and a charged-coupled device (CCD) camera for a falling detection system. This work investigates whether the distance between the center of the legs and the cane can be used to classify the subject's activity. In the context of blind people, the following devices can be noticed.

EyeCane [32] aims to guide blind people using vibrations and sound effects where the intensity of sound and vibration depend on the proximity of the obstacles detected. UltraCane [33] has provided an alternative, namely an assistive technology that safely avoids obstacles and navigates around them. It also provides valuable protection at head and chest levels. UltraCane detects street furniture and other obstacles within 2.4 meters.

TomPouce [34] is an electronic box that can be fixed on an original white cane to automatically transform it into a smart cane. It is based on infrared and laser beams pointed to the front. The objective is to detect moving and static obstacles while indicating distances.

## 2.6/ NAVIGATION AND GUIDANCE SYSTEM FOR BLIND PEOPLE

Assisting blind individuals in traveling was and still is an important research area. Different approaches, technologies and navigation tools developed or used for the blind individuals, will be listed in this section. The different technologies and approaches are grouped into 5 categories: Localization technologies, Obstacles Recognition methods, Feedback methods, Devices, and Software-based systems.

### 2.6.1/ LOCALIZATION TECHNOLOGIES

In the following we list some triangulation localization techniques using different technologies and hardware.

**Wi-Fi-based:** The first solution, which was proposed by Hushe and Suryawanshi [35], implements an indoor navigation system that estimates the position of a user within a building and guides the user to reach a particular destination by using Wi-Fi technology. This will make it possible to find the desired destination in an unfamiliar place, and will be a small step towards making modern technology more accessible to the disabled in our society. The user must scan the available Wi-Fi network, when the one with maximum strength is found the application shows the current location, and the user can select the destination from the available options. This approach can lead to two different results:

*Wi-Fi found*: an image of the default map is displayed; *Wi-Fi not found*: the user's current location on the map is displayed. Then, when the user selects a destination, the app displays the route to the location in both speech and text form. On the one hand, this approach is convenient in terms of efficiency, low cost, easy implementation, and providing text-to-speech directions for visually impaired people. On the other hand, in terms of limitations, if a designated access point is faulty or absent or encounters network configuration issues, it can lead to inaccuracies in determining the user's position, and it does not implement object detection.

**CamNav versus BLE technologies:** Kunhoth *et al.* [36] developed a robust solution that accurately estimates the coordinates of users using different systems: a computer vision based system, called CamNav, and a Bluetooth Low Energy (BLE) system. This solution aims to enable dynamic real-time tracking in indoor areas at any given moment. The study, involving ten blindfolded participants, was conducted to examine the performance of the two navigation systems separately in terms of time taken for navigation and errors that occurred during it.

CamNav is a computer-vision based system that uses a trained deep learning model to recognize locations. This computer vision technology detects scenes and objects by matching the captured images with the pre-trained existing dataset. CamNav uses an Android application to capture the images and provide instructions for the user. The experiments conducted with the help of the 10 blindfolded people showed that CamNav has several advantages and limitations.

Among the advantages is improved accuracy, as indicated by decreased average errors in terms of the number of steps. It provides detailed information about the current location and surroundings, including information about doors and walls. This benefit, however, comes at a cost: users may experience a delay in receiving instructions, forcing them to wait a few seconds to comprehend the necessary information. Furthermore, the user's walking speed influences CamNav's performance and accuracy, since quicker speeds potentially result in blurred pictures, thus damaging the overall user experience. Another significant limitation is that users must maintain their mobile device in a fixed orientation, straight or pointing downward, for accurate location recognition. However, some users have encountered difficulty keeping this exact smartphone orientation for lengthy periods, presenting a significant usability obstacle to this approach.

**Bluetooth Low Energy (BLE):** Bluetooth Low Energy technology-based solutions consist of an Android application and employ BLE beacons to estimate the user's proximity. The BLE beacons are hardware devices connected to the walls or ceilings of the location. To estimate the user's position, the recorded Received Signal Strength (RSS) from BLE beacons using a smartphone or a radio frequency signal receiver is compared to the RSS stored in the database.

A BLE navigation system offers substantial advantages in terms of increased user speed and reduced navigation time. However, challenges arise in the accuracy of position estimation, as the system may encounter difficulties in providing precise instructions at junctions, leading to potential user misguidance. The system's limitation becomes evident when users bump into walls or doors, highlighting its occasional inaccuracy in determining the user's exact position. Nevertheless, BLE beacons demonstrate effectiveness in navigating straight paths within corridors, offering valuable location information.

**Wiimotes and Infrared LED system:** Guerrero *et al.* [37] have come up with a solution that can determine a person's position and direction of movement. With the use of this data, the system calculates the user's trajectory, finds potential obstacles along the way, and provides navigational guidance. The system's main components are an augmented white cane, two infrared cameras, a computer, and a smartphone.

The cane was chosen as the most suitable object to be augmented and thus represent the user position after applying the Augmented Objects Development Process (AODeP) methodology to a list of possible candidate objects. The borders of the environment are predefined by the developers, and all the objects in it are drawn. Based on that, the system generates the XML specification of the setting information. By analyzing this XML file, we can generate a complete map of the room, recognising the environment in which the user is located. The system follows a common-sense approach to message delivery.

By pressing a button on the cane, users can initiate this system and request navigational information. The infrared LEDs built into the cane, as shown in Figure 2.1, are then turned on. The software application instantly tries to determine the user's position and the presence of obstacles in the surrounding area. Figure 2.2 shows the infrared camera built into the Wiimotes that is used to detect the user's position and movement. These devices have a dedicated microchip to control the Bluetooth antenna, which transmits at 2.1 Mbits/s. The application then uses such information and also the XML file data that it has about the obstacles in the area to generate single navigation voice messages that are delivered through the user's smartphone. Figure 2.3 illustrates the flow of Wiimote and infrared LED system. The length and width of the room, the relative positions of each Wiimote, the angle at which the controls were fixed to the walls, and the relative positions of each object are a few of the data elements that must be included in the XML file.

Based on the evaluation process, in which five blindfolded volunteers participated in the system trial, several advantages and disadvantages were found. To begin with the positive aspects of this system, we can say the system seems to be accurate enough to support navigation for blind people in indoor environments. Moreover, this model is user-centric and feasible in terms of cost and availability. On the flip side, it presents some limitations, including the fact that the information that is provided to them only offers background data to assist them in choosing the best route on their own and does not specify

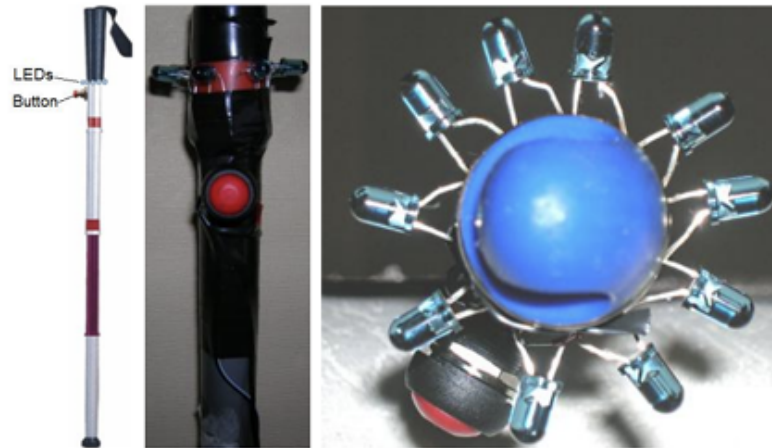


Figure 2.1: Smart cane with infrared LED system.



Figure 2.2: Wiimote component.

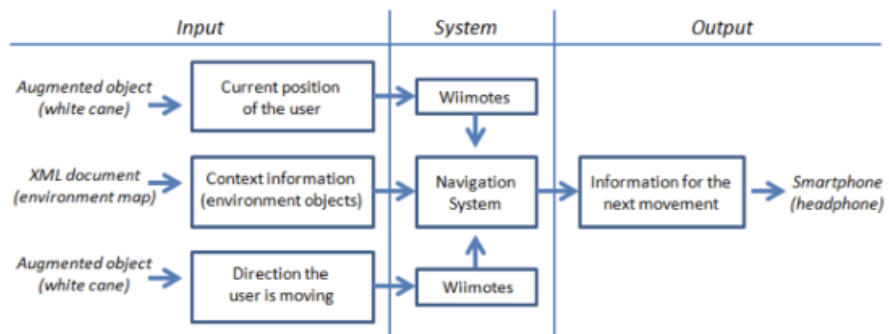


Figure 2.3: Flow of Wiimote and infrared LED system.

the route that should be taken. The system's primary drawback is the use of Bluetooth, which has a low communication threshold, even though it has the potential to manage large areas. Nevertheless, all it takes to overcome this restriction is Wi-Fi communication. Another limitation is that the map needs to be updated whenever an object in the surrounding area is moved. That being said, this might be used in locations that do not undergo frequent changes.

**Ultra-Wide Band:** Alnafessah *et al.* [38] have proposed a solution to aid Arabic-speaking blind individuals and save their time while navigating to desired destinations due to the lack of such systems in the Arabic world. The proposed system aims to integrate UWB technology and smartphones for guiding blind people from their current position to desired destination.

This system has four main functionalities: mapping, positioning, interface, and navigation. The mapping component is responsible for constructing and reading the map using a building XML representation in the localization server for a high degree of accuracy and another XML representation on the user's smartphones since the application needs to represent the map in a relatively small size. The positioning component is responsible for positioning and setting the tags in the desired places inside the building. The interface component has two interfaces: a data interface for the localization server and a graphical user interface on the user's smartphones. The graphical user interface (GUI) is a voice-based system in which the user listens to voice commands and interacts by touching the screen short or long and dragging it left or right. The navigation component is responsible for finding the best route using the setup Ubisense tags and keeping track of the user until he arrives at the desired destination. Figure 2.4 gives an overview of the UWB system.

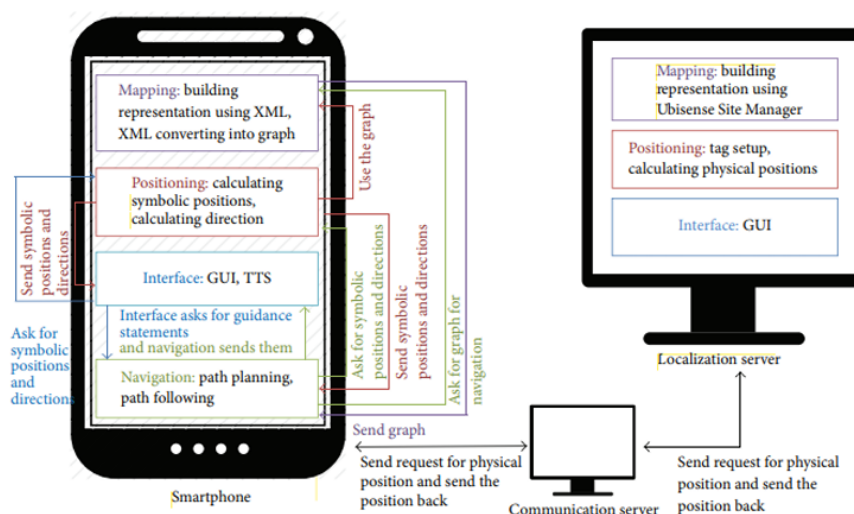


Figure 2.4: UWB system overview.

To implement these functionalities three main applications must be developed: an appli-

cation in the location server, an application in the communication server and an application in the smartphone. The localization server is based on Ubisense's real-time location system (RLTM). To track objects Ubisense uses tags and location software. Ubisense sensors use UWB pulses to find the tags and locate them, while Ubisense software manages the tags and sensors in the network. The communication server is an intermediary layer between the localization server and the smartphone since it needs to be connected to the Ubisense using Wi-Fi. Both the localization server and communication server must be connected to the same LAN. This system has achieved 100% user satisfaction in terms of touch interface and guidance statements. However, the system should include an obstacle avoidance mechanism to optimize efficiency. Moreover, the integration of speech recognition will enhance the accessibility of user interaction.

**LED Light and Geomagnetic Sensors:** In [39] the authors proposed an indoor navigation system for blind people using visible light communication and geomagnetic correction methods. Visible light communication is a method that uses light visible to the human eye and a visible light ID system. The main components of this system are LED lights, a smartphone with an integrated receiver, headphones, and indoor map data that is expressed using a geographic coordinate system.

First, users use the touch interface to long-press on the smartphone screen to initiate voice navigation. The smartphone requests comprehensive ground location information from the location base and, upon receiving that data, notifies the user of the target along with its corresponding number. When a user enters a destination number using voice recognition, the smartphone requests a route based on location and informs the user of the whole route. While traveling, a visible light ID is transmitted from the LED light using visible light communication and is received by the smartphone receiver. The smartphone acquires a visible light ID via Bluetooth, receives real-time location information using Wi-Fi, and calculates the driving direction and distance. Guidance will be delivered to the user using the data provided. If the user deviates from the route, he will be immediately notified with the route changes. This process is repeated until the goal is reached. Figure 2.5 sequence diagram outlines the interaction between the user and the system, as well as between the various components.

According to the test results, which were done on 6 people: 3 blind and 3 people with low vision, the first disadvantage is that when the smartphone is hung on a person's neck, it causes swinging more than anticipated, thus the position for which the geomagnetic value was obtained and the corrected value diverged, and hence it leads to system inaccuracy. Another main disadvantage of this system is the absence of obstacle detection. Moreover, due to floor modifications or the presence of magnetic materials in the actual space, there is a chance that circumstances will arise where the magnetic field changes and the correction is rendered ineffective.

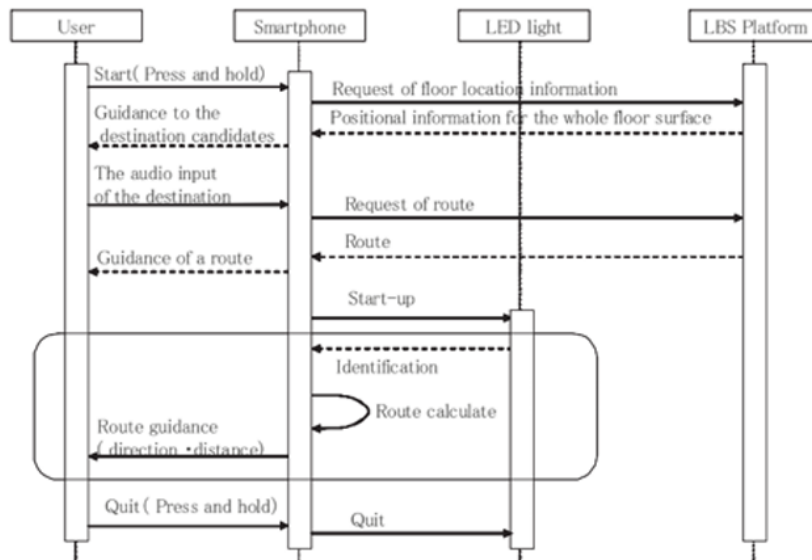


Figure 2.5: Sequence diagram for navigation system using LED light and geomagnetic sensors.

**Triangulation using GPS-based System:** The Global Positioning System (GPS), which uses satellites, is mainly used for outdoor navigation. The GPS receiver determines its distance from several satellites using data from the ephemeris that employs the triangulation principle, by which the time the data are sent is compared to the time it is received. This method requires the GPS receiver to be well exposed to the satellite, which prevents indoor locations. GPS systems are widely used for outdoor navigation [40]. The main disadvantage of GPS localization is that the GPS signal strongly degrades inside buildings, between tall buildings, or in dense forest areas (such as parks) [41].

**Triangulation using the ZigBee-based System:** ZigBee [42] is a wireless navigation that can be used in indoor/outdoor navigation systems. It has high accuracy in location, wide-coverage, simple infrastructure, reduced cost, quick real-time navigation, and lower power consumption. ZigBee triangulation is based on IEEE 802.15.4, which uses the 868 MHz band in Europe, the 915 MHz band in North America, and the 2.4 GHz band [43].

**Triangulation using a Bluetooth-based System:** It is based on the Bluetooth triangulation [44] method, as it is an easy method already deployed in mobile phones, cameras, handheld devices, and gadgets that can be connected over a shorter distance. It is low cost, has a reduced weight and reduced size, and provides power savings. However, a limitation of the system is that Bluetooth can communicate only over a short distance and cannot be used for long distance communication.

**Triangulation using a Wi-Fi-based System:** A Wi-Fi-based navigation [45] system enables device connection anytime, anywhere, at home, work, it is compatible with a wide variety of different systems. Wi-Fi has advantages over other communication systems but

has limitations: high power consumption and takes some time to establish a connection. The authors in [46] presented a system to locate indoor nurses and doctors, or other patients, in a hospital. The system can also be used to locate blind individuals. In [47], Wi-Fi triangulation was used to help blind people move about places near their location.

### 2.6.2/ OBSTACLES RECOGNITION METHODS

The following is a list of different obstacle recognition methods. Obstacles can be detected and recognized using different technologies, such as camera images, video processing or by using sensors.

**Camera-based Image Processing Navigation System:** This system uses a camera to identify and detect mobile and static obstacles. It can identify obstacles and nearby objects in real-time. While this system has a lot of advantages, it has also some limitations: high processing and power consumption [48]. In [49], the authors explained how cutting-edge machine vision methodologies offer tools to assist with basic human needs such as psychological capacity, individual movement, and activities of daily living. In [50] the system uses pre-stored images of the floor to guide people in finding the obstacle-free route by comparing current floor images with pre-stored images and checking for introduced obstacles.

**Ultrasonic Sensor-based Navigation Systems for Blinds:** systems are based on “ultrasound waves”. An ultrasonic transmitter will transmit an ultrasonic wave, this wave will be reflected by any object or obstacle. The time of arrival of the wave added to the time reflected will identify the distance between the transmitter and the reflector. The drawback of this technology is the “short communication range”, and the inclusion of LOS among obstacles and sensors is considered essential [51].

**Speech-to-Text-based Navigation System:** These systems let blind individuals translate vocal or spoken language into text. These systems use a variety of computational devices. The speech to text technology is also known as automatic speech recognition.

**Text-to-Speech-based Navigation System:** These systems render texts from documents or images into speech [52].

### 2.6.3/ FEEDBACK METHODS

Below we list a few methods that provide feedback to the user and warn of nearby obstacles.

**Haptic Feedback:** A cane called WeWalk uses haptic feedback and ultrasonic sensors to let blind individuals scan their surroundings [53]. In [54], a cane uses light and ultrasonic



sensors to scan surroundings and uses audio and haptic feedback/vibration to warn the user of nearby obstacles. In [55], the author presented a technology to assist the visually impaired (VI) person that uses haptic feedback. This unit detects obstacles above the knee via ultrasonic sensors. In [56], the author presented another technology for VI users that uses haptic feedback/vibration to warn the VI person of the obstacle. In [57], the author introduced another method based on the conduction feedback. The Smart Cane can detect the obstacles and faces of friends and family members within 10 meters. A Bluetooth earpiece based on bone conduction is used to convey information about the obstacles. Haptic feedback can be divided into three categories: vibrotactile, shape-changing, and kinesthetic feedback.

#### 2.6.4/ DEVICES

Below is a list of devices that can help users navigate safely. Some of these devices provide directions for the users when navigating.

**Braille Signs Tools:** These tools can simplify the route for visually impaired, but they cannot serve as routing tools. These days, numerous public regions, such as emergency clinics, railroad stations, instructive structures, entryways, lifts, and other aspects of the system, are outfitted with Braille signs. These tools can help the visually impaired identify their area but they cannot help in finding the path.

**Smart Cane Tools:** The objective of EyeCane [32] is to guide blind people using vibrations and sound effects where the intensity of sound and vibration depend on the proximity of the obstacles detected. Experiments on EyeCane were fulfilled outdoor on blind and blindfolded participants. After only 5 minutes of using EyeCane, both groups have been able to detect obstacles and move along. The success rate was approximately 70%. Other indoor experiments were completed with the same participants. Some of the participants were using the original white cane and others were using EyeCane. Participants using EyeCane hit three walls, while the participants using the original white cane touched an average of 28.2 walls.

UltraCane [33] provides an alternative, which is an assistive technology that allows safe obstacles avoidance and allows navigation around obstacles. It also gives a valuable protection at head and chest height. UltraCane detects street furniture and other obstacles within 2.4 meters. This is obtained by emitting ultrasonic waves from two sensors able to detect obstacles up to 1.5 meters ahead at chest and head height, while giving tactile feedback to the user through two vibrating buttons on the handle placed on the thumb of the user. The two buttons vibrate to indicate the direction of the obstacle and the approximate distance.

In the context of upgrading existing white canes, TomPouce [34] is an electronic case

that can be fixed on an original white cane in order to automatically transform it into an intelligent one. It is based on infrared and laser beams pointed to the front. The objective is to detect mobile and static obstacles while indicating the distances.

The following study, Xplor [58] has integrated image-processing capabilities for navigation in the streets. The main goal is the help blind people recognize other people that will cross streets. The prototype is equipped with camera, face recognition software, and a GPS sensor. The camera will cover 270 degrees of the facing environment. The face recognition software is connected to a cloud database. Once the camera detects a person's face, the image recognition algorithm will try to match the picture with a name and transmit it to the user via Bluetooth using text-to-speech technology. A similar approach is LightStick [59] that also integrates image-processing capabilities. It scans for surrounding texts and reads them for the user.

**Voice-Operated Tools:** This outdoor voice-operated navigation system is based on GPS, ultrasonic sensors, and voice. It provides alerts for the current position of the users and guidance for traveling. The problem with this system is that it failed in obstacle detection and warning alerts [60]. Another navigation system uses a microcontroller to detect the obstacles and a feedback system that alerts the users about obstacles through voice and vibration [61].

**RFID-based Map-Reading Tools:** RFID is a wireless technology that can assist and help blind individuals to navigate indoor and outdoor. Short communication range for RFID is one of the primary limitations. In [62], an indoor navigation system for blind and older adults was proposed, based on the RFID technique, to assist disabled people by offering and enabling self-navigation in indoor surroundings. The goal of creating this approach was to handle and manage interior navigation challenges while taking into consideration the accuracy and dynamics of various environments. The system was composed of two modules for navigation and localization—that is, a server and a wearable module containing a microcontroller, ultrasonic sensor, RFID, Wi-Fi module, and voice control module. The results showed 99% accuracy in experiments. The time the system takes to locate the obstacle is 0.6 seconds. Another map-reading system [63] based on RFID provides solutions for visually disabled persons to pass through public places using an RFID tag grid, a Bluetooth interface, a RFID cane reader, and a personal digital assistant. This system is costly, however, and there is a chance of collision in heavy traffic. A map-reading system is relatively expensive because of the hardware units it includes, and its limitation is that it is unreliable for areas with heavy traffic. Another navigation system based on passive RFID, proposed in [64], is equipped with a digital compass to assist the visually impaired. The RFID transponders are mounted on the floor, as tactile paving, to build RFID networks. Localization and positioning are equipped with a digital compass, and the guiding directions are given using voice commands.

### 2.6.5/ SOFTWARE-BASED SYSTEMS

Below we are listing some software-based systems that helps the blind users to navigate safely and provides directions for blind users while navigating. Some of these software's can also detect obstacles

Visually impaired individuals utilize a variety of tactile tools, such as raised point maps, small-scale prototypes, and magnet boards, following orientation and mobility (O&M) training. While these multimodal maps have been proposed to assist in navigation for the blind and visually impaired, they do have limitations, including the inability to update their content. To address these limitations, accessible interactive maps have been developed as a solution [65]. In one instance, the authors of [66] employed a participatory design approach to create an augmented reality map specifically for O&M classes. This prototype incorporates projection, audio output, and the use of tactile tokens, enabling visually impaired individuals to both explore and construct maps. Another innovative approach is the SmartTactMaps introduced by [67], which leverages smartphones to assist blind individuals in exploring tactile maps. Additionally, [68] presented a 3D environmental map generated using an red green blue-Depth (RGB-D sensor), capable of extracting semantic information from RGB images to aid visually impaired individuals in navigating their homes. Furthermore, a 3D Printed audiovisual tactile map named LucentMaps was proposed for the visually impaired in [69]. It aimed to simplify the integration of mobile devices with physical tactile maps. Lastly, the VizMap system [70] utilizes computer vision and crowdsourcing to gather diverse information from indoor environments. It employs on-site sighted volunteers to capture various videos, which are then semantically labeled and embedded into a reconstructed 3D model. This model serves as a queryable spatial representation of the environment.

Smartphone-based navigation solutions offer users the advantages of portability and convenience. For this reason, various solutions have been introduced on the smartphone platform to help visually impaired people. We look at some of these solutions in the following.

NavCog3, introduced by [71], represents an indoor navigation system designed to provide turn-by-turn instructions and immediate feedback in cases of incorrect orientation. Additionally, it offers information about landmarks and some nearby points of interest. The system communicates with users through audio feedback. Another innovative approach by Ganz *et al.* [72] is the PERCEPT-II application, where users receive navigation instructions to their selected destination by touching specific landmarks displayed on the mobile device. These destination spots are equipped with Near Field Communication (NFC) tags. However, it's worth noting that this system has a limitation concerning the need to install and maintain a substantial number of NFC tags.

Lin et al. [73] introduced a smartphone application designed to be integrated with an image recognition system, creating an assisted navigation system. Depending on network availability, the system can operate in two modes: online and offline. Upon initiation, the smartphone captures an image and transmits it to a server for processing. Deep learning algorithms [74, 75] on the server are then employed to identify various obstacles. Notably, the system faces significant limitations in terms of high energy consumption and the requirement for a high-speed network connection.

The TARSIOUS system, as outlined in [76], aimed to improve users' understanding of outdoor environments. Its components include the TARSIOUS mobile app, a web server, a remote help desk and Bluetooth LE/iBeacon tags placed at points of interest along streets. However, the main challenges of the TARSIOUS system are the cost and potential signal interference associated with placing Bluetooth beacons in streets.

ENVISION, as described in [77], employs a specific method to robustly and accurately detect static and dynamic obstacles in real-time video streaming captured by an average hardware capacity smartphone. Improvements can be made to the system by enhancing the obstacle recognition and classification modules to provide target users with a better understanding of their surroundings.

The "Active Vision with Human-in-the-Loop for the Visually Impaired" (ActiVis) project, developed by [78], introduced a multimodal user interface that utilizes audio and vibration cues to convey navigational information to users. The current implementation of the ActiVis system is an Android application based on a Tango device and a bone-conduction headset. Real-time adaptation to feedback parameters could enhance the system's performance.

The Tactile Wayfinder, detailed in [79], comprises a tactile belt and a Personal Digital Assistant (PDA) running a Wayfinder application. This application manages location and route information, transmitting path directions to the tactile display. Vibrators in the belt provide users with navigation guidance based on these directions.



# CONTRIBUTION 1: ANALYZING STRESS SITUATIONS FOR BLIND PEOPLE

## 3.1/ INTRODUCTION

All human beings experience many types of stressful situations in their daily life. Hans Selye first defined stress as any force that produces abnormalities, pressures or injuries to the human body and John Mason proved that two types of stress exist: psychological and physiological stresses [3]. When stressed, the human body replies with a response called General Adaptation Syndrome (GAS). The first step of this response involves the secretion of stress hormones (cortisol and adrenaline) [3]. GAS involves three phases: Alarm reaction, Resistance, and Exhaustion. Detecting stress in the daily life of blind people is a challenging task. In this chapter, our work focuses on the analysis and detection of stress in the daily life of blind people. We present a major step related to data collection in order to detect physiological signs of stress using a network of sensors implemented on a white cane. We present an overview of our system, with the objective of identifying situations that cause stress and predict them in order to assist the blind person with navigation directions along his walking path. The goal of these directions is to anticipate and avoid stress situations. This contribution is the result of a work done before the official start of the thesis. It was presented at the International Conference on Signal Image Technology and Internet-based Systems (SITIS), Nov. 2019, Sorrento, Italy [80].

The remainder of this chapter is organized as follows:

- **First:** The approach used to detect and manage stress is presented.
- **Second:** The prototype that we have built in order to experiment and collect data is introduced and described.
- **Third:** The experimental work is presented.
- **Finally:** The conclusion.

## 3.2/ STRESS DETECTION APPROACH

In the previous sections, we presented the existing studies related to stress detection for sighted users and for blind users. These approaches tackle the challenges faced in the daily life of blind users and tried to determine situations that induce stress. Our main objective is to create a system that detects and predicts all stressing situations, and incorporate them into an accessible navigation system in order to notify the user with all types of obstacles a user may face in his road. Our system is divided into three parts: data collection, data analysis, and finally stress reduction. After a presentation of the system, we focus more particularly on data collection and analysis.

### 3.2.1/ DATA COLLECTION

In order to detect stressing situations, we need a database of raw sensor data of physiological signs of stress. The sensor data include heart rate variability data, electrodermal skin activity data, and muscle contraction data extracted from electromyogram sensor. The database also includes obstacles detection and identification associated to specific GPS coordinates. In a later phase, image collection of street details in a specific geographic area is also needed to detect and recognize street objects. The aim of this image collection is to correlate between the obstacle detection and the corresponding objects in the street. Movable and moving objects will not be considered in this phase. In the stress reduction phase, live image processing will take account of this type of object. In this part, we also include a self-report analysis in which we seek to detect psychological stress. This self-report analysis is used to annotate the raw data for greater precision in the data analysis phase. Figure 3.1 summarises the data collection

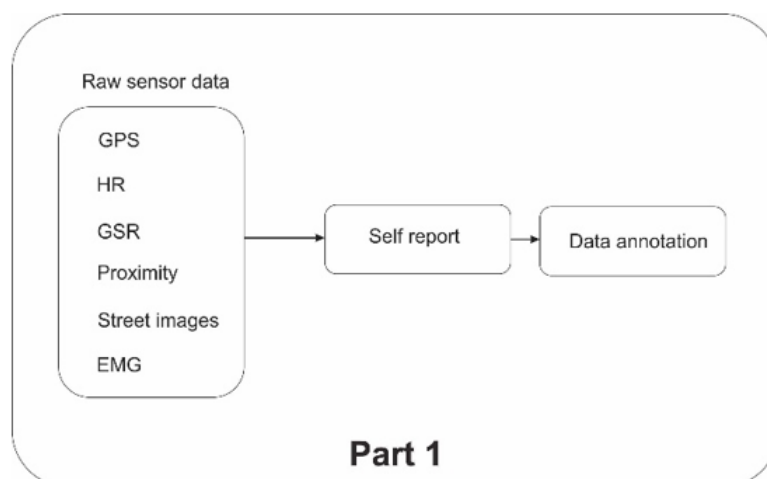


Figure 3.1: Data collection, first part of our stress detection approach.

### 3.2.2/ DATA ANALYSIS

Data is collected from users performing daily tasks like walking, using stairs, and navigating in the streets. Collected data serves to detect behavioral patterns and similarities between users in same situations. As shown in Figure 3.2, supervised machine learning techniques will be used to learn to detect these patterns and build the resultant mathematical model that will detect the stressing situations.

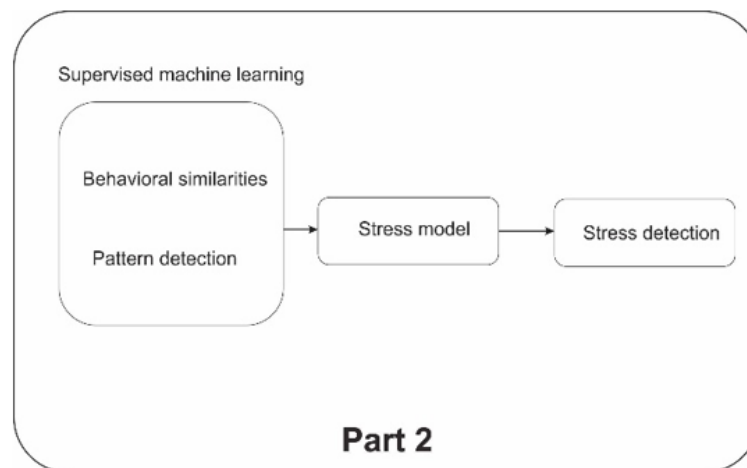


Figure 3.2: Supervised machine learning to detect stressing situations.

#### 3.2.2.1/ STRESS REDUCTION

The objective of this phase is to create a navigation system in which we predict stressing situations in order to avoid them. Once the mathematical model generates all the stressing situations, live data analysis and stress association are integrated in the navigation system. The user will receive notifications in real-time.

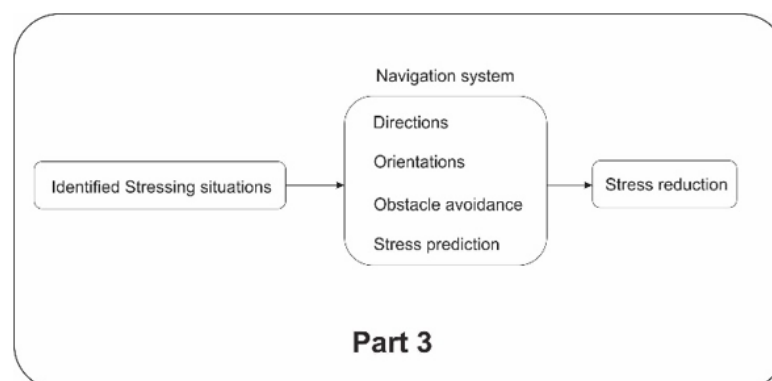


Figure 3.3: Navigation system to reduce stress.



### 3.3/ OUR PROTOTYPE FOR DATA COLLECTION

In order to collect data, we designed and developed an interactive, intelligent white cane prototype called ICane. We integrated on this cane a series of sensors to collect raw data. We also connected this cane to a mobile application for the navigation assistance. Figure 3.4 represents our prototype.



Figure 3.4: Prototype of intelligent white cane.

The white cane consists of the following components:

- **Three ultrasonic distance sensors:** These sensors are positioned at three height level locations. The purpose of this positioning is to detect three types of obstacles. The first type that is considered correspond to low height level obstacles like stairs, walls or any obstacle close to the ground. Medium height level obstacle is considered for suspended objects with no connection to the ground. Finally, the obstacles with higher height level, like windows or other suspended objects, are also taken into consideration with a third sensor. The last two obstacles are not detected by ordinary white canes and are very harmful if not detected. They may be an important source of stress to the blind in his daily life.
- **GSR sensor:** The GSR sensor detects the electrodermal activity of the skin.
- **EMG myoware sensor:** This sensor detects the muscle contractions using the differences in electrical muscle activity.
- **HR pulse sensor:** This sensor detects the heart rate variability.

The cane prototype is associated to the navigation system and the data storage system. The navigation system has the following functionalities:

- **Obstacle avoidance:** It provides the blind user with notifications on the three types of obstacles and levels using audio messages and sounds with different frequencies according to the distance to the obstacles.
- **Navigation:** It provides orientations and directions along the path specified.
- **Storage:** It receives every two seconds the raw data from sensors via Bluetooth and then associates them with GPS coordinates retrieved from the mobile device. Then the data is stored on a cloud database. Furthermore, data is also collected from an activity tracker that detects the types of activities practiced by the user. In addition, this tracker analyses heart rate to identify if the user is resting, calm or agitated. It also provides raw heart rate data, oxygen saturation (SPO2) data and resting heart rate for the user. Figure 3.5 summarizes the complete data collection process.

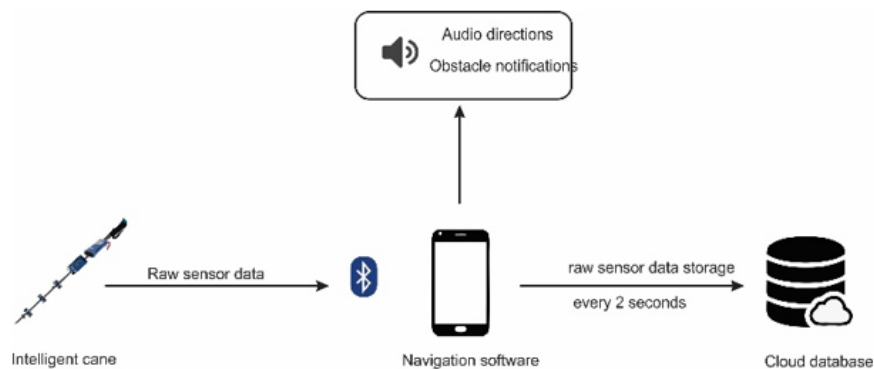


Figure 3.5: Data collection process

### 3.4/ DATA COLLECTION EXPERIMENTATION

In order to collect data, we proposed a navigation path to be followed by the users. The aim was to find a frequent and useful route. In our scenario, users had to travel by walk from a residential place to a public building in a city center. In our case, the scenario was implemented in the city of Jezzine, south Lebanon, from a residence situated at approximately 800 meters from the building of the municipality. The city infrastructure is not accessible and not friendly for blind users. Along the path, the person had to deal with different types of obstacles, road forks, mobile and static objects with random car traffic and normal people movement frequency on the road. Figure 3.6 displays the walking path taken by the users.



Figure 3.6: Walking route scenario of the data collection.

The experiment was carried out during daytime in a cool weather. Six blindfolded persons conducted the experiment and they were in a calm, rested situation before the start of the test. Among the six users, two were familiar with the road and the four others were experiencing the path for the first time. Each blindfolded user had to move from the start point to the destination using our prototype. Before each test, the preparation time of the prototype was registered. The duration of the whole test was also registered. The average duration of the walking path of the users was approximately 25 minutes and 12 seconds. Figure 3.7 represents a record in JavaScript Object Notation (JSON) format of the exploitable sensor values extracted.

The graph shown in the Figure 3.8 represents the electrodermal activity of the skin of three users along the navigation path. It shows for each user, a range of electrodermal activity with peaks. These peaks represent sudden change in dermal activity. This change is directly related to stressful situations. As for the muscle contractions, the Figure 3.9 represents a graph showing the EMG sensor values. The sensor is positioned in the forearm muscle of the user. When the user presses on the handle of the ICane, the forearm muscle contracts. Consequently, when the user is stressed, he presses more on the handle. When the muscle is relaxed, the value of the sensor is low. In the contrary, when the muscle is contracted the value of the sensor gets higher. In this graph, different peaks of contractions are visible. They may represent situations where the user faced difficulties in his route.

```

{ "date_user":"26-08-2019 07:27:44
PM","userN":"bouissa", "sensordata" : {
  "IR1" : "0",
  "beatvalue" : "54",
  "cm" : "260",
  "conductancevalue" : "218",
  "latitude" : "",
  "longitude" : "",
  "myovalue" : "20"
}

```

Figure 3.7: Example record of the sensor values.

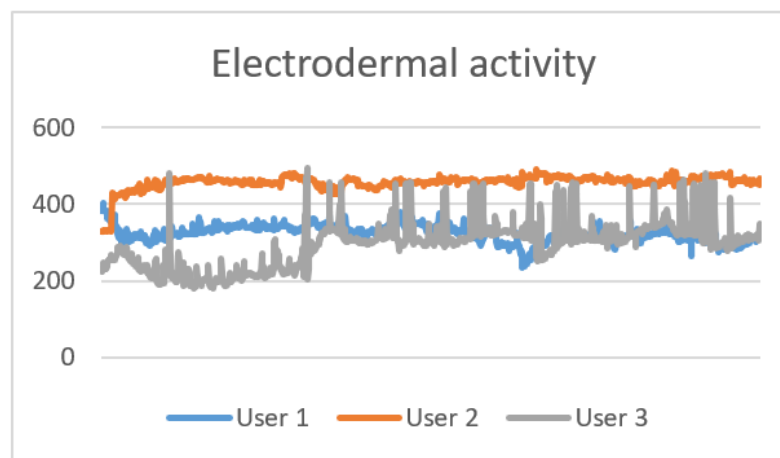


Figure 3.8: Electrodermal activity range of three users along the walking path.

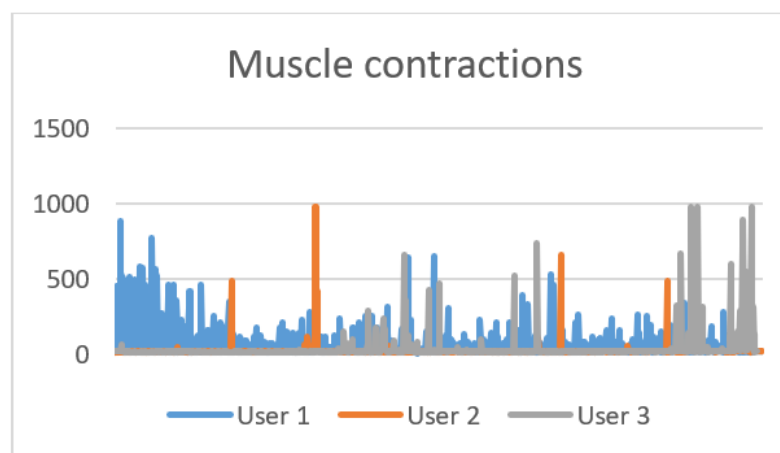


Figure 3.9: Sensor values corresponding to muscle contractions.

As for the heart rate, many characteristics can determine stress situations. According to [81] a resting heart rate for a young adult, ranges from 59 to 99 beats per minute. As for our testers, as they are performing a walking activity, the range of their heart rate is elevated. However, according to [82], both situations of surprise and stress induce elevated heart rate significantly. In a study they conducted on 8 young actors, they analysed

their reaction to an unexpected event. There was a clear tendency between the location of actors (onstage and offstage) and their heart rate in response to stress; the actors present offstage presented immediate elevation in heart the minute the surprising event occurred, but the actors present onstage at the time of the stressor reacted in the following 5-minutes period. This tendency regarding stress and heart rate is supported by previous studies; negative stimulus has a prolonged effect on heart rate in individuals who are directly impacted [82]. For these reasons, Figure 3.10, presents a prevailing elevated heart rate for all the users with an average of 109 beats per minute. The graph shows as well peaks for surprising situations.

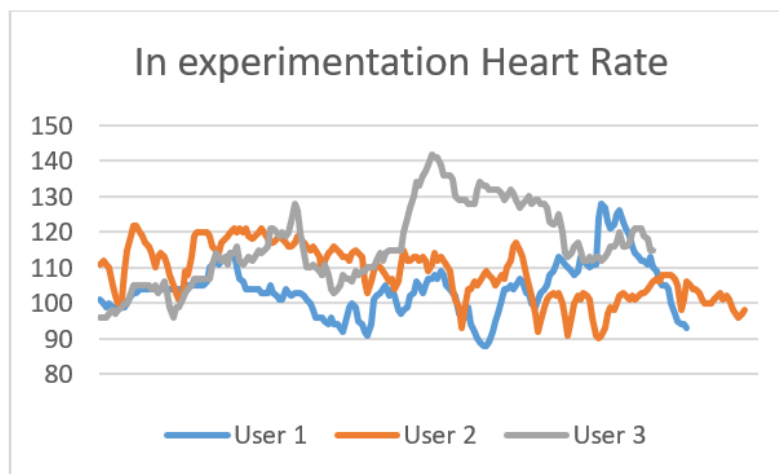


Figure 3.10: Heart rate variability of the users in the experimentation.

### 3.5/ CONCLUSION

In this chapter, we presented the approach we have developed for stress detection and management. As the objective is to use machine learning techniques, a huge amount of data had to be collected and analyze in order to produce a model for stress identification. For this purpose, we developed our own interactive intelligent prototype ICane that serves as an obstacle avoidance cane for the blind users and helps us to collect data for subsequent phases of our project. Experiments have shown that the various sensors implemented on the ICane, detecting various biological signals, highlight correlations with stress situations. The final objective of the project is to detect stressing situations in order to mitigate them by providing useful navigation information to blind users of the ICane.

## CONTRIBUTION 2: CORRELATION BETWEEN TYPES OF OBSTACLES AND STRESS LEVEL OF BLIND PEOPLE IN OUTDOOR NAVIGATION

### 4.1/ INTRODUCTION

Stress can be defined as a state of physical or mental tension resulting in different feelings or emotions. It comes from any situation that makes a human being frustrated, nervous and angry. Every human being is subject to stressful situations, and obviously the most stressful situation or event in the daily lives of blind people is autonomous navigation. Even if the navigation path is known, the changing dynamics of the environment related to different parameters such as the time of day, the nature of the obstacles that may be encountered, etc., turn this into a challenge. Stress can be directly related to many physiological signals, indeed when stressed, the human body reacts to stress with a response called General Adaptation Syndrome (GAS). GAS is divided into three stages. The first stage is called alarm, fight or flight, it is the stage on which this study has focused and is the body's immediate response to stress where heart rate, skin conductance and muscle activity increase [3, 4]. In Chapter 3, we focused on describing stress and its impact on human life, especially for blind people. Furthermore, this work also described how the human body responds to stress and how stress is related to certain biological signals. A prototype of cane was presented, which measures some biosignals, for blind people navigating an experimental path, as well as preliminary studies on the data collected using this smart white cane. This contribution extends and deepens the works of the authors' previous contribution. First, a second prototype has been designed to acquire more accurate biosignal measures thanks to a BITalino kit [83]. Second, further experiments were conducted using a slightly modified protocol: the experimental path was divided into

three sectors and users, blindfolded, indicated their stress level on a scale of 1 to 10 at the beginning, middle, and end of each sector. Third, this chapter focuses on identifying stress and specifically the correlation, if any, between stress and obstacles encountered in the path of blind users during navigation, in order to contribute to blind navigation by making this task less stressful and easier in the future. Note that this contribution was presented at the International Wireless Communications and Mobile Computing Conference, Jun. 2023, Marrakech, Morocco [84].

The remainder of this chapter is organized as follows:

- **First:** How physical data are collected, more particularly the two prototypes of smart canes that were designed and the experiment area as well as the kind of obstacles.
- **Second:** The experimental protocol and all the data obtained are described.
- **Third:** Data analysis is performed.
- **Fourth:** The results obtained are presented and discussed.
- **Finally:** A few concluding remarks were made.

## 4.2/ PHYSIOLOGICAL DATA COLLECTION

After publishing the first contribution [80] presented in Chapter 3, another prototype was built and evaluated. Indeed, over time, the existing prototype was expanded and further experiments were conducted using its updated version. To differentiate both versions, the first version can be referred to as the first prototype and the current version as the second prototype. The upgrade was the result of further research since the publication of first contribution and aimed at obtaining a more accurate measurement of biosignals.

### 4.2.1/ PROTOTYPES DESCRIPTION

The first prototype is an assembly of a cane, heartbeat, skin conductance, muscle activity sensors, and an Arduino controller board. The cane is also equipped with an ultrasonic sensor that allows a blindfolded user to scan his environment and measure the distance to obstacles. The ultrasonic sensor and physiological sensors are all connected to an Arduino board. The board transmits all the sensors measures each second via a Bluetooth module thanks to a mobile application. This mobile application stores all the data measured in a Firebase database.

As mentioned earlier the second prototype is the result of some modifications that were made on the first one to achieve more accurate data collection. Indeed, the physiological sensors of the first prototype were replaced by BITalino [85, 86] Plugged Kit and the Android application was updated to communicate successfully via the Bluetooth module integrated within the BITalino board. The BITalino kit is a versatile solution for designing different signal acquisition experiments. It comes with ECG (electrocardiogram), EMG (electromyography), EEG (electroencephalogram), and EDA (electrodermal activity) sensors. The EMG and EDA sensors were used, while the ECG sensor was replaced by the Xiaomi band 5 for heartbeat acquisition.

#### 4.2.2/ OBSTACLES OBSERVATION AND CLASSIFICATION

Figure 4.1 shows the experiment area where the walking path is highlighted in blue. As can be seen it is a road that starts from point A and reaches point B which represents the public municipality building in Jezzine, a town in south Lebanon. Many obstacles can be encountered when navigating the path. The ultrasonic sensor with a piezo speaker can notify the blind or blindfolded person about a nearby obstacle. Obstacles can also be detected in real time with real-time single shot detector (SSD) video detection built into the android mobile application.

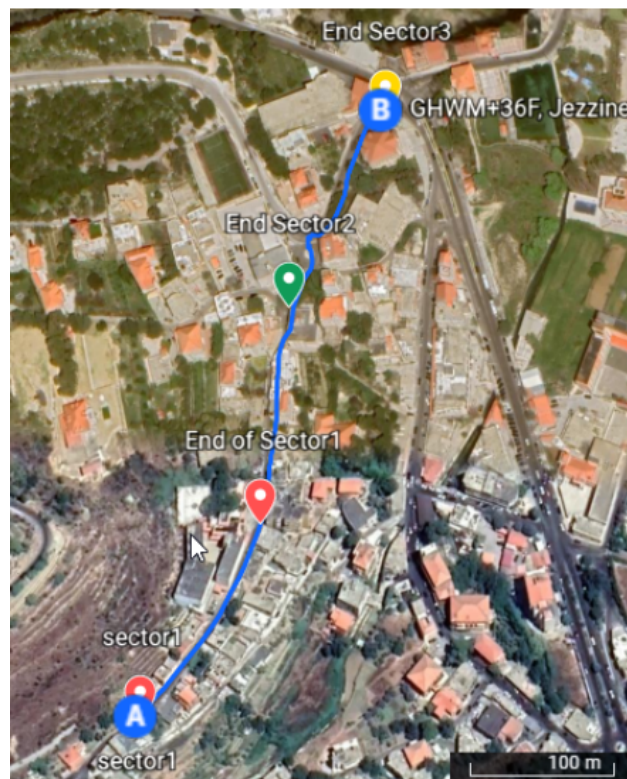


Figure 4.1: Experimental path divided into three sectors.



Obstacles can be classified into two categories: stationary and moving. Stationary obstacles are those that, by definition, do not move such as parked cars and buses, potted plants, sidewalks, walls, buildings, escalators, while mobile obstacles were cars, motorcycles, pedestrians navigating the route. Some of them are located at the same geographical points from one experiment to another. The number and density of obstacles detected at the starting point were lower than at the middle of the route and at the destination near the city center.

### 4.3/ EXPERIMENTATION PROTOCOL AND COLLECTED DATA

As described in the previous subsection, the experiment consisted in navigating a route from a residential location to the municipality's public building in the center of the city. The route's infrastructure is not accessible and is not user-friendly for blind users. Six blindfolded people conducted the experiment using the first prototype and six others used the improved BITalino prototype. The six users who conducted the experiment with the second prototype did so more than once, but at different times. Most of the users were between 20 and 35 years old, with only two users over 64 years old. The users were all active, healthy, physically fit, and able to walk a path on their legs, not to mention that none of the users had a heart condition. The experiments were conducted in daylight and in cool weather. For all the experiments, all the users were in a resting state before the start of the test. The preparation time before the start of the test was recorded as was the duration of the entire test for each user. The average time for a user to complete the path and the entire test was around 25 minutes. For the experiments using the second prototype, the path was divided into three sectors named Sector 1, Sector 2, and Sector 3 respectively, which are described in detail hereafter. The total distance of the path from start to finish is about 800 meters and each of the sectors has a distance of about 265 meters. Furthermore, all users been asked to note their stress level within a range from 0 (no stress) to 10 (the most stressed) in each sector three times: at the beginning of each sector, in the middle of the sector and at the end. Similarly, the starting time and the time of passage through the middle of a sector and at the end were recorded. Regarding the three sectors, their respective characteristics are as follows:

- Sector 1 is straightforward road, very large with minimum traffic level and low obstacles density.
- Sector 2 is a straight road, narrower than Sector 1 with a small slope that can be reached at the end, with a medium traffic level and medium obstacle density.
- Sector 3 is quite different, as it is a big slope situated near the center of the city, with heavy traffic level and heavy obstacles density.

#### 4.3.1/ DATASET

Figure 4.2 shows the example of a recording, already presented in Chapter 3, obtained at a given moment during a user's navigation. For each user, the data stored in database are first extracted in JSON format and then, using Python, converted to comma-separated values (CSV) format. This conversion allows us to manipulate, visualize, and analyze the data properly. The CSV data set for each user can contain more than 1000 records. The number of records for each user depends on the total number of seconds the user took to walk the experimental path. Any series of data recorded over time can be considered as a time series, which is the case of our data which are indexed by the column 'Dates'. A time series can be decomposed into systematic and non-systematic components. Systematic components are level, trend and seasonality, while there is one non-systematic component corresponding to the noise. These components can be defined as follows:

- Level is the average value in the series.
- Trend is the increasing or decreasing value in the series.
- Seasonality is the repeating short-term cycle in the series.
- Noise is the random variation of the series.

```
{ "date_user":"26-08-2019 07:27:44
PM","userN":"bouissa" ,"sensordata" : {
  "IR1" : "0",
  "beatvalue" : "54",
  "cm" : "260",
  "conductancevalue" : "218",
  "latitude" : "",
  "longitude" : "",
  "myovalue" : "20"
}
```

Figure 4.2: Example record of the values sensed on a user at a given time.

We tried to decompose several time series for each of the users, each separately. The decomposition was done on the physiological measurements and the distances of the detected obstacles over time. As a result, our time series can be said to have only a trend component. Two variables in the data can be related in three different ways:

- A variable can be the cause or depend on the values of another variable.
- A variable could be lightly associated with another.
- Two variables could depend on a third unknown variable.

## 4.4/ ANALYSIS OF COLLECTED DATA

### 4.4.1/ ANALYSIS OF DATA FROM FIRST (BASIC) PROTOTYPE

All of the analysis listed below were applied to a single user and to all users who have experimented the first prototype (6 users). The selected user has 1176 records and all users have 7753 records in total. A covariance study was performed on the data to assess the relationship between the distances to the obstacles and each of the physiological measures. Therefore the formula

$$\text{Cov}(X, Y) = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})$$

was used, where  $x_i$  is a data value of time series  $X$  and  $\bar{x}$  its mean,  $y_i$  and  $\bar{y}$  are similar for time series  $Y$ , and  $N$  is the number of data samples. The obtained values, which are summed up in Table 4.1, can be analysed as follows. The sign of the covariance can be interpreted as whether both variables change in the same direction (positive) or change in different directions (negative). The magnitude of the covariance is not easily interpreted, but a covariance value of zero indicates that both variables are completely independent. Thus it can be seen that heartbeats and muscle activity change in different direction with the distance from obstacles. Furthermore, it means that when the user is facing a near object (low values of distance from obstacles) heartbeats and muscle activity will have high values. A problem with the covariance as a statistical tool alone is that it is challenging to interpret. This leads us to the Pearson correlation coefficient which can be used to summarize the strength of the linear relationship between two variables.

Table 4.1: Covariance between the distances from obstacles and the physiological sensor measures

Single user	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-1393.6	618.9	-510.9
All users	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-2281.2	831.9	-3763.1

The Pearson coefficient is calculated as the covariance of the two variables divided by the product of their respective standard deviation. It is the normalization of the covariance between the two variables that provides an interpretable score. Indeed, the coefficient has a value between -1 and 1 which represents the limits of the correlation, from a totally negative correlation to a totally positive correlation. A value of 0 means no correlation. The value must be interpreted, where often a value less than -0.5 or greater than 0.5 indicates a significant correlation, and values less than these values suggest a less significant correlation. Table 4.2 shows the obtained coefficients and since the correlation values are not greater than 0.5 or less than -0.5, it means that there is no significant cor-

relation between the data. This also means that our data are not related to each other by a linear relationship and one can simply conclude that some of the data are increasing or decreasing together but not in a linear way. Two variables may be related by a nonlinear relationship, such that the relationship is stronger or weaker across the distribution of the variables. Furthermore, those two variables may have a non-Gaussian distribution. In this case, the Spearman's Rank correlation coefficient can be used to summarize the strength of the relation between both variables. Note that this test of relationship can also be used if there is a linear relationship, but may result to output lower coefficient scores. Table 4.3 shows the obtained Spearman correlation coefficients. As with the Pearson correlation coefficient, the scores are between -1 and 1 for perfectly negatively correlated variables and perfectly positively correlated variables, respectively. Instead of calculating the coefficient using the covariance and standard deviations on the samples themselves, these statistics are calculated from the relative rank of the values on each sample. A linear relationship between the variables is not assumed, although a monotonic relationship is assumed (monotonic is a mathematical name for an increasing or decreasing relationship between the two variables).

Table 4.2: Listing Pearson's correlation between distances from obstacles and the physiological sensor measures

Single user	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-0.074	0.13	-0.014
All users	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-0.1	0.016	-0.077

Table 4.3: Listing Spearman's correlation between distances from obstacles and the physiological sensor measures

Single user	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-0.19	0.095	-0.1
All users	Heartbeats	Skin conductance	Muscle activity
Distance from obstacles	-0.073	0.17	-0.035

#### 4.4.2/ NEURAL NETWORK ANALYSIS

Neural networks are a set of machine learning algorithms, or models, that endeavors to recognize underlying relationships in a set of data through a process that mimics the way the human brain operates. In this sense, neural networks refer to systems of neurons, either organic or artificial in nature. Neural networks can adapt to changing input, so the network generates the best possible result without needing to redesign the output criteria. Neural networks are broadly used, with applications for financial operations, enterprise planning, trading, business analytic and product maintenance. These networks

can distinguish subtle nonlinear inter-dependencies and patterns other methods of technical analysis cannot.

Since we are dealing with time series data, we have considered three commonly used recurrent neural networks in addition to a model consisting of a simple stack of layers, also known as a MultiLayer Perceptron. The three recurrent neural networks are as follows: Long Short-Term Memory (LSTM) [87], Gated Recurrent Unit (GRU) [88] and Bidirectional LSTM (BiLSTM) [89]. We used Python with Keras<sup>1</sup> in which the steps to design a neural network involve: load or working on dataset, choose or define a model of neural network, compile the model, fit the model, evaluate the model, and then make predictions or retrieve results. Our analysis was performed on a single user dataset and on a dataset of all users, always choosing heartbeat, skin conductance and muscle activity as inputs to the model, and distance to obstacles as outputs.

Figure 4.3 shows the prediction provided by the simple model, while Figures 4.4, 4.5, 4.6, shows the prediction provided by the LSTM model, the prediction provided by the GRU model and the prediction provided by the BiLSTM model.

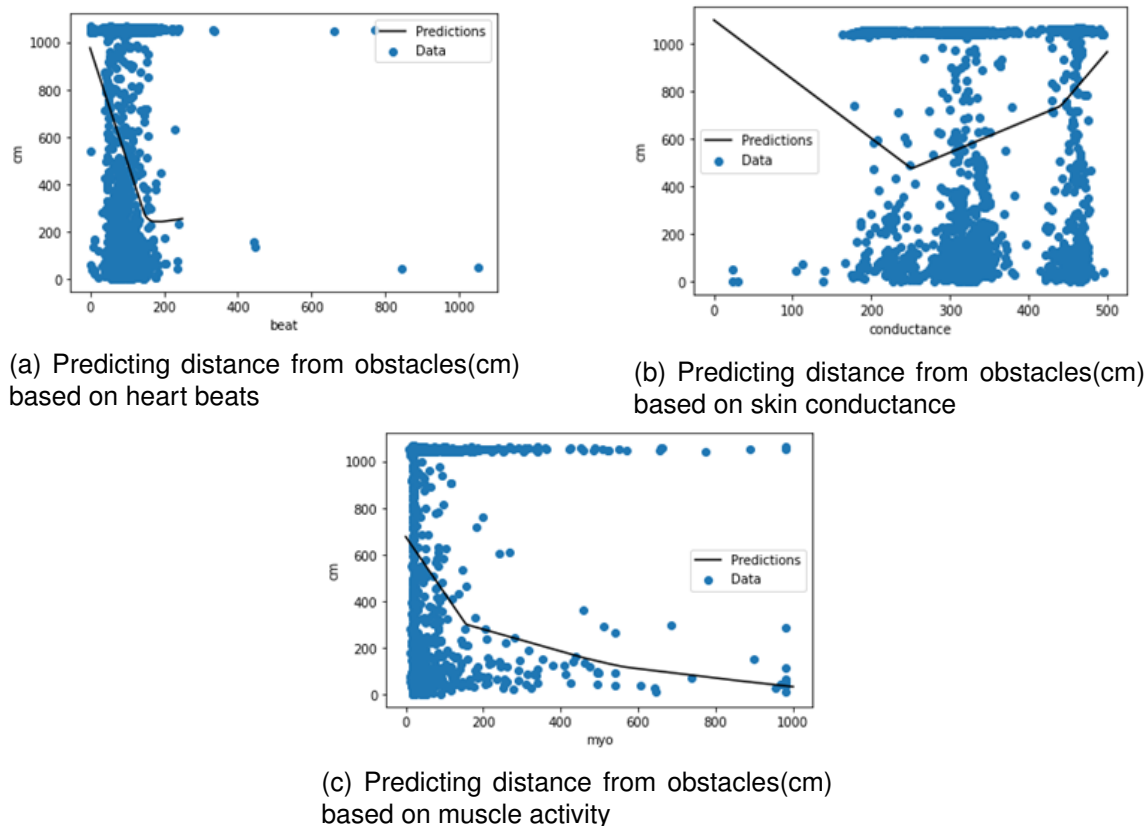


Figure 4.3: Predicting distance from obstacles using a model consisting of a simple stack of layers.

<sup>1</sup><https://keras.io/>

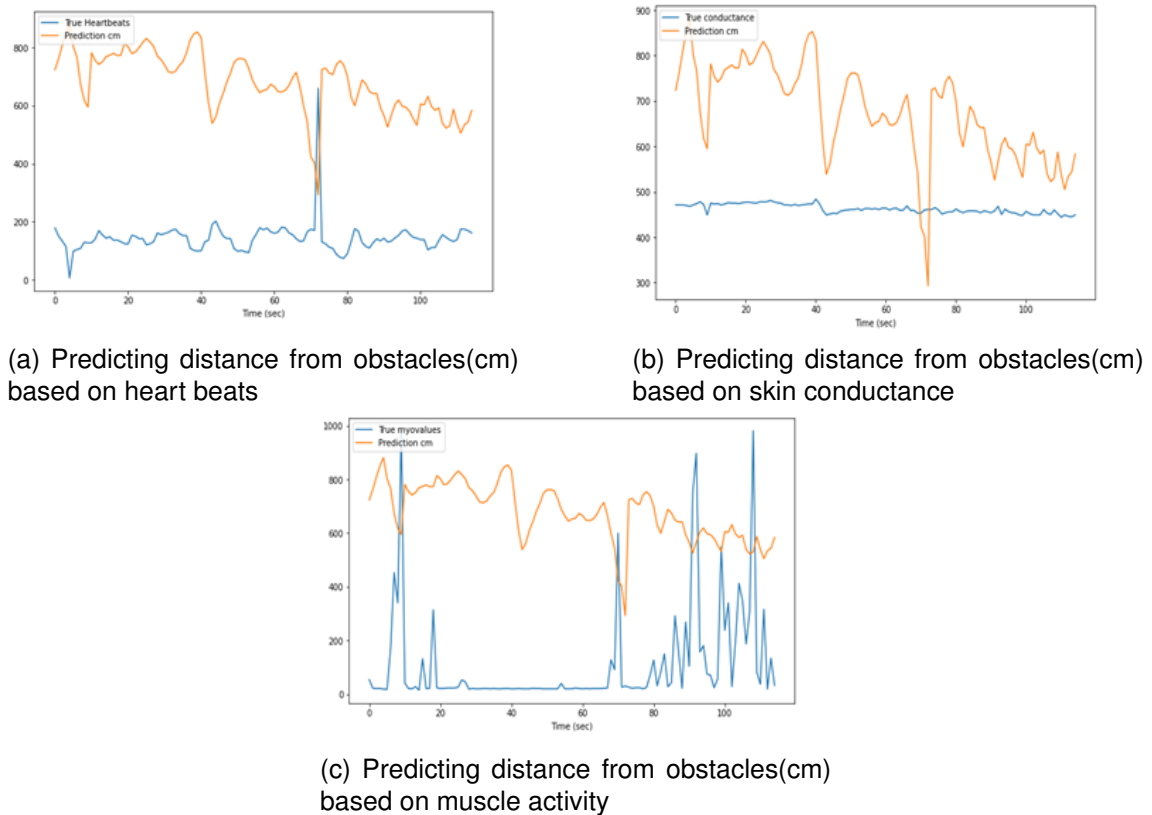


Figure 4.4: Predicting distance from obstacles using LSTM model.

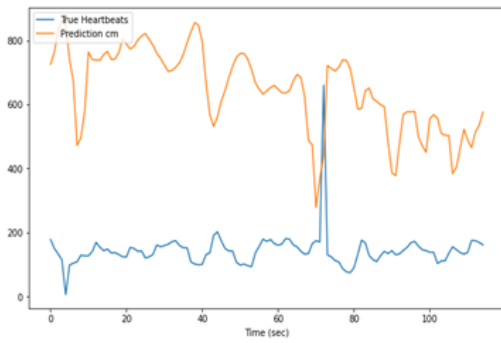
The observations that can be made in Figure 4.3 shows the prediction provided by the Keras sequential model, while Figures 4.4, 4.5, and 4.6, align with the findings obtained through covariance analysis, Pearson's correlation, and Spearman's correlation. All models indicate that when users Present elevated heart rate and muscle activity, they are more likely to perceive obstacles as being in close proximity.

Additionally, the models suggest a correlation between stress levels and the proximity of objects. Specifically, elevated heart rates and increased muscle activity are associated with the presence of nearby obstacles, which may induce stress. Conversely, when objects are positioned further away, users tend to display lower heart rates and reduced muscle activity, suggesting a decrease in stress levels.

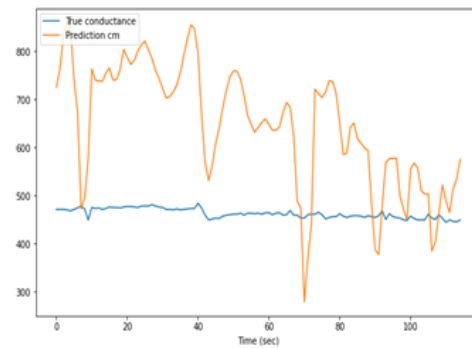
This link identify the important interaction between environmental stimuli and physiological responses, underlining the necessity of comprehending how users respond to their environment in terms of both emotional and physical states.

#### 4.4.3/ ANALYSIS OF DATA FROM SECOND (BITALINO) PROTOTYPE

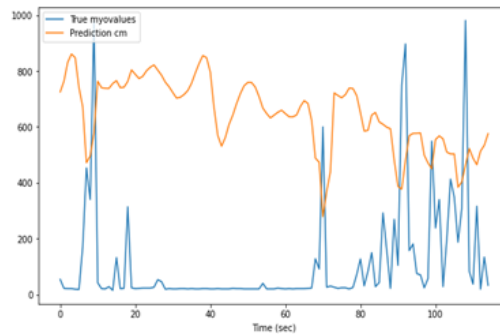
The data were saved and extracted using the same procedure as for the first prototype, only the heartbeat values were extracted for each experiment by Zepp Life, an Android



(a) Predicting distance from obstacles(cm) based on heart beats



(b) Predicting distance from obstacles(cm) based on skin conductance



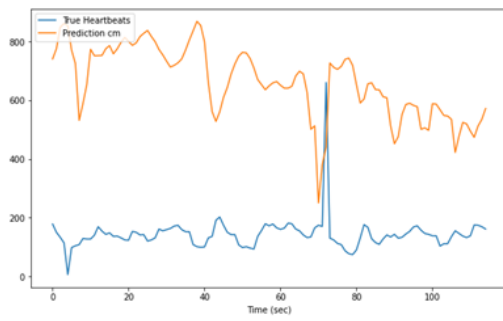
(c) Predicting distance from obstacles(cm) based on muscle activity

Figure 4.5: Predicting distance from obstacles using GRU model.

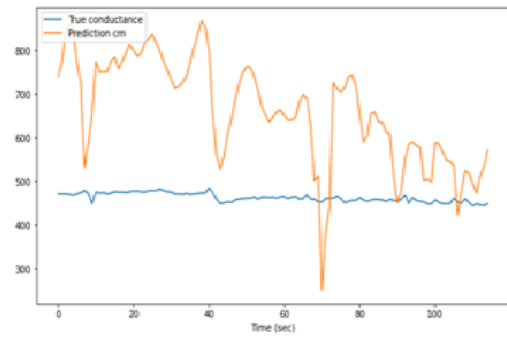
mobile application designed and developed by MiFit. As mentioned earlier, six users conducted experiments using this prototype. Each user performed the experiment more than once at different dates and times. The total number of experiments is eighteen.

Several observations can be made according to Figure 4.7, Figure 4.8, and Figure 4.9. First, the lowest levels for heartbeats, skin conductance and muscle activity values are identified in Sector 1. Second, the values of these three biosignals increment progressively after Sector 1 when navigating into Sector 2 and Sector 3. Note that the data of 13 experiments out of 18 can be interpreted in the same way. It can also be seen from 4.7 that the travel time of the sectors increases as one goes along even if all the sectors have the same distance.

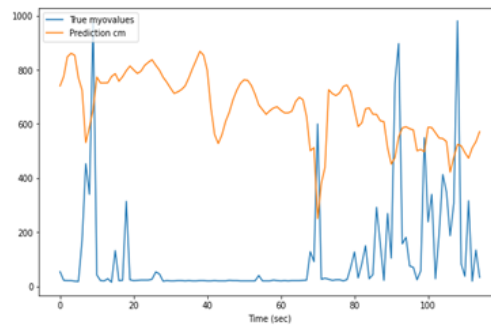
The heartbeats, skin conductance and muscle activity values of all users were added together and filtered individually sector by sector. Then the mean value for each of the measures was calculated for each sector and the obtained values are shown in Table 4.4. There is a notable difference between the sectors with respect to heartbeats and skin conductance values. It can be seen that the lowest means are found in Sector 1, then in Sector 2 and that the highest values are found in Sector 3. Additionally, as previously mentioned, each user has auto-reported his or her stress level at the beginning, the middle and the end of each sector. For each sector and for each user, the highest values



(a) Predicting distance from obstacles(cm) based on heart beats



(b) Predicting distance from obstacles(cm) based on skin conductance



(c) Predicting distance from obstacles(cm) based on muscle activity

Figure 4.6: Predicting distance from obstacles using BILSTM model.

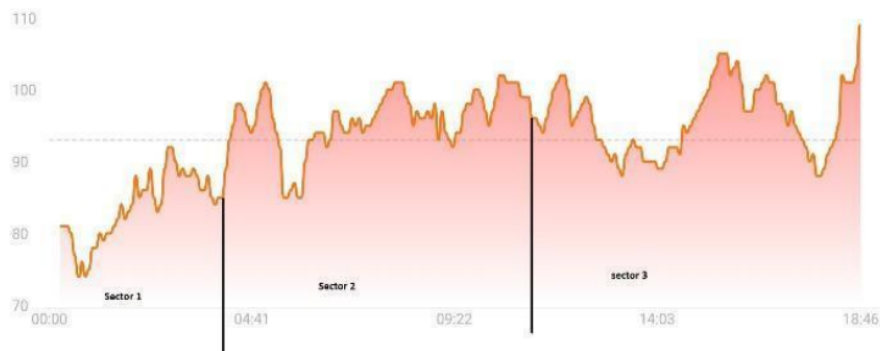


Figure 4.7: Heartbeat values over time for a single experimentation for a single user (black lines represent the end of each sector).

of stress reported were taken and added together. Next, the stress level was averaged for each sector, resulting in the values shown in Table 4.5. Clearly, the evolution of heartbeats and skin conductance values are linked to the stress level. Both can accurately reflect the stress level induced by the navigation path.



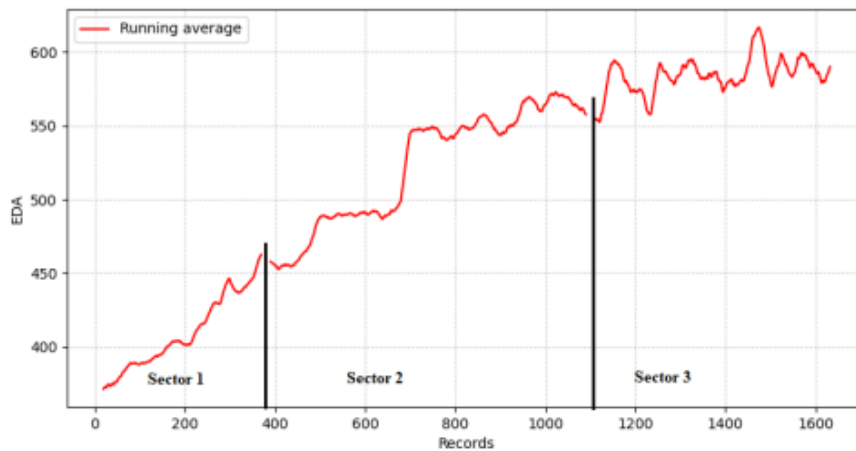


Figure 4.8: Running average of skin conductance values for a single user (window=20).

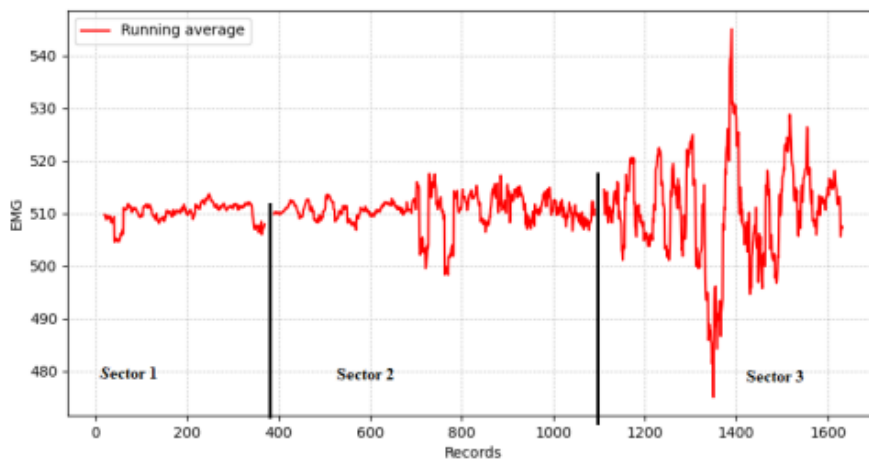


Figure 4.9: Running average of muscle activity values for a single user (window=20).

## 4.5/ DISCUSSION

The study and analysis of the data collected during the experimentation made with the first prototype, in addition to the outputs of the neural network analysis allowed to identify a significant relationship between the distance of the obstacles and the values of the heartbeats and the muscular activity. Both relationships were negatively signed, meaning that these biological signals move in a different direction with respect to the distances from an obstacle. Indeed, a close obstacle means higher heartbeats and muscle activity values, whereas a greater distance from the obstacles means lower heartbeats and muscle activity values. When experimenting with the second prototype, using a BITalino kit, with an experimental course divided into three sectors and adding self-reporting of the stress level by each user, one found that all physiological measures depended on the distance to the obstacles (heart rate, skin conductivity and muscle activity).

Table 4.4: Means of biosignals values for each sector

	Heartbeats(means)	Skin conductance(means)	Muscle activity(means)
Sector 1	99	325.3	510.8
Sector 2	101	364.7	510.9
Sector 3	102	378.8	510.8

Table 4.5: Means of stress levels for each sector

	Stress level (mean)
Sector 1	1.8
Sector 2	4
Sector 3	5.6

Practically, in Sector 1 the users have the lowest values for all the biosignals measures and the lowest stress self-reported stress levels and both the measures and stress levels increase respectively when passing from Sector 1 to Sector 2, and finally from Sector 2 to Sector 3. Adding to the above, even if the sectors have the same distance travel, Sector 1 was traveled the fastest by all users. All physiological measures and self-reported stress levels, as well as travel times, were found to be related to the characteristics of a sector, namely the density of obstacles and the level of traffic in it. Regarding the path, this one is relatively short since it is about 800 meters long. As for the sectors, Sectors 1 and 2 are straight and even if Sector 3 is a slope, no considerable physical effort is required. In addition, 4 of the 6 users were between 20 and 30 years old.

## 4.6/ CONCLUSION

Getting around on foot is a daily challenge for blind people. Even if they take a familiar route, new obstacles may appear, making no two trips the same and causing stress. We have shown through our experiments with two smart white cane prototypes that stress can be identified and detected when a blind person is navigating a path, and that the stressors causing the stress can be related to obstacles along the path. The data collected can be concretely exploited further with machine learning techniques and more particularly neural networks, either to predict more accurately the stress of blind people during navigation (regression) or to classify with more precision blind people according to whether they are stressed or not at different points of the navigation path (classification). In addition, based on the results of machine learning techniques, we can help blind people to cope with stress or anticipate it in different ways: we can enable blind people to avoid obstacles by vocally informing them about the obstacles and the remaining distance to the point of contact. We can redirect blind people to paths less cluttered with obstacles, we can anticipate stress with small stress-reduction exercises and, if possible, in many

more ways. Therefore, in the following chapter we will introduce a stress management and navigation system that will help blind individuals.

# CONTRIBUTION 3: INTRODUCING A STRESS MANAGEMENT AND NAVIGATION SYSTEM FOR BLIND INDIVIDUALS

## 5.1/ INTRODUCTION

Walking is a common and important mode of transportation for all individuals, but it can present challenges for those who are blind. While it may be a simple task for healthy individuals with normal vision to navigate from one point to another, blind individuals may experience difficulty, stress, and challenges in doing so. In previous contribution presented in Chapter 4 we have identified a correlation between obstacles along a path and the level of stress experienced by blind individuals navigating that path.

Specifically, we have shown in [84] that blind individuals navigating a road with many obstacles may experience higher levels of stress than those navigating a less obstructed road. Therefore, and since blind individuals lack visibility and cannot avoid obstacles encountered in their paths which can lead to harmful injuries, and since they cannot choose the right, less obstructed and stressful road we are proposing a stress manipulating and navigation system to assist blind individuals in navigating more safely and managing stress. At an initial phase the proposed system will identify the least stressful route for the blind individual to travel on.

To identify the least stressful route the system will generate an index of difficulty and an index of stress for each possible route between a start and destination point. By index we mean a numerical value, the road difficulty index is a value that primarily depends on parameters specific to the road and the road stress index is a value that primarily depends on the index difficulty of the road among blind person specific parameters.

After identifying the least stressful route to travel on, the system will be navigating the blind individual in real time. This task will be achieved by detecting the obstacles in real time using image processing techniques and using voice feedback within a mobile application to alert the users of obstacles encountered and directing the user within the entire path. In a future work results of the system will be evaluated by comparing the indexes of stress for blind users in case of round trips or navigating same path or route more than once.

The remainder of this chapter is organized as follows:

- **First:** Obstacles classification and properties.
- **Second:** The concept of our proposed navigation system.
- **Third:** The road difficulty index.
- **Fourth:** Simulations on the proposed navigation system.
- **Fifth:** Listing the technical details of the two main steps step of our proposed navigation system (identifying the less stressful route and real-time navigation).
- **Finally:** The conclusion.

## 5.2/ OBSTACLES CLASSIFICATION AND CHARACTERISTICS

While navigating a path a blind individual can encounter many different obstacles. After several safe and controlled re-enacting scenarios of a visually impaired person mobilizing the experiment path [84], we have identified two types of obstacles: Moving and Motionless. On the one hand, mobile obstacles are temporary obstacles that can be moved; pedestrians and animals are considered to be mobile obstacles. On the other hand, immobile obstacles are permanent obstacles that cannot be moved, such as power poles, walls or deteriorated concrete. Table 5.1 shows the two types of obstacles encountered during the experiments.

Listing all the moving and motionless obstacles is not possible, and the list that came out of our experiment is definitely not every single obstacle found on that street. A person can throw a glass bottle on the ground and that would lead to a creation of a new obstacle, which we did not specifically encounter but it is most likely to happen. Furthermore, we needed to go deeper with the classification. Based on the state of art and our obstacles listed in Table 5.1 above we have extracted the characteristics that obstacles share. The most critical characteristics that obstacles share is: size, position, risk, flexibility, velocity and sound.

In [90] a list of accident have been registered with blind individuals while navigation a road: Accidents with motorbikes and bicycles that rides on sidewalks, falling from stairs, falling

Table 5.1: List of most obvious and most common obstacles detected during experiments

Moving	Motionless
Cars	Light Poles
Potted Plant	Trees
Moving Signs	Holes
Animals	Bushes
Trash bins	Boardwalk edges
Piles of rock	Electric poles
Motorbikes	Concrete raised beds
Shop tents	Sewer caps
Potato chips shelves	Stairs
Ice cream refrigerators	Store decoration
Persons	Degraded ground concrete

into gaps between buses and their platform, bumping into building scaffolds and glass doors, Accidents with ironware and pipes transported over vehicles roof, Accidents with tree branches, telephone booths and charity boxes, bumping into objects along footpath, Accidents with passing bicycles, Accidents with passing vehicles, Accidents with parked automobiles, falling into holes, falling into pits, falling into underground rails.

In [91] various barriers were reported by blind individuals that impacted their safety: lack of precise location for a building entrance, unknown stairs and roadside holes, as well as obstacles above waist level, sidewalks and crossings, sidewalks often occupied by booths and bikes. Also, Public transport stops lacking audio information and traffic lights without audio output have been reported as an unsafe barrier by blind individuals.

In [92] a women reported the barriers that she has encountered: motorbikes parked on the sidewalks, potted plants, holes in the sidewalk, stairs, and uneven ground. She said she cannot count how often she had hurt her arm by bumping into motorbike handles, or hit her head or chin on something, or fallen into an uncovered ditch. She calls some of these sidewalks “death stations”. Also, a 36-year-old blind man said that his foot became stuck in a hole in the sidewalk, he fell and had surgery and still cannot fully bend his leg.

In [93] they have identified that blind individuals may use sound to navigate and identify types of obstacles: auditory changes in the walking surface, the sounds of flowing water, and the touch of breeze and sunshine on the skin helped in understanding the changes in the environment and served as navigation cues.

### 5.3/ THE CONCEPT OF OUR PROPOSED NAVIGATION SYSTEM

In real life context, if a blind individual is trying to navigate between two geographical points, he must adapt between many possible routes to achieve his destination. After

choosing a route he will begin to parade towards his destination, whether guided or not. An early step of many steps in our navigation system is to propose for the blind individuals the less stressful route among the many possible routes to take between two points. The concept of the navigation system we are proposing is as follows.

In step 1, the blind individual will use a mobile application to choose vocally two geographical points at start and destination positions, the system will then identify the possible routes to take between these two points and propose vocally to the blind individual the less stressful route. To identify the least stressful route, the system will first calculate the Index of Difficulty for each possible Route (IDR), which will then allow a stress index (ISR) to be calculated for each one, taking into account a number of parameters such as whether or not the blind person knows the route, whether or not he or she has assistance, and so on. Given the ISR values of different possible routes, the one with the lowest ISR value will be selected. Having proposed the least stressful route, the blind person should adopt it and their journey will begin.

In step 2, the blind individual will begin to walk to his destination, while walking the system will identify and detect in real time the obstacles encountered by the blind individuals. Notification and alerts will be forwarded vocally. The system will identify the type and the position of the obstacle.

## 5.4/ ROAD AND STRESS DIFFICULTY INDEXES (IDR AND ISR)

### 5.4.1/ IDR VARIABLES AND THEIR POTENTIAL VALUES

The index difficulty of a road depends on:

- Sum of Index of Difficulty for each Obstacle (IDO).
- Total number of obstacles on the road.
- Road total length ( $x_l$ ).
- Road slope ( $x_s$ ).
- Accessibility of the road ( $x_a$ ).
- Weather conditions ( $x_w$ ).
- Average number of obstacles per meter of road ( $x_n$ )

$$\text{IDR} = \frac{\sum \text{IDO}}{1000 \cdot x_n \cdot x_l} + x_l + \frac{|x_s|}{10} + x_w + x_a + \frac{x_n}{2}, \quad (5.1)$$

Table 5.2: Weighting of obstacle variables

Size	Position	Risk	Flexibility	Velocity	Sound
$s$	$p$	$r$	$f$	$v$	$m$
$\frac{2}{24}$	$\frac{5}{24}$	$\frac{8}{24}$	$\frac{3}{24}$	$\frac{4}{24}$	$\frac{2}{24}$

$$\text{where } 1 \leq \text{IDR} \leq 10 \quad (5.2)$$

Each obstacle depends on six variables: size, position, risk, flexibility, velocity, and sound. Moreover, each variable has been associated to a weighting coefficient as shown in Table 5.2. Based on these weighting coefficients, the Index of Difficulty of an Obstacle (IDO) is calculated as given by Eq. 5.3.

$$\text{IDO} = \frac{1}{24} (2s + 5p + 8r + 3f + 4v + 2m) \quad (5.3)$$

$$\text{where } 1 \leq \text{IDO} \leq 5 \quad (5.4)$$

Obstacles can have different sizes, human beings perceive size of objects compared to his size thus size  $s$  of an obstacle is identified as small, normal or large. Possible values for variable  $s$  are respectively +1 for a small obstacle, +3 for a normal obstacle, and +5 for a large obstacle.

An obstacle can have a position compared to ground. Position  $p$  can be assessed into two main categories: above or below ground. For above ground, position can be also assessed into two sub categories: below waist or above waist. An obstacle above the ground below waist can be detected much easier than an obstacle below ground or above waist. An obstacle below ground can be detected with a cane much easier than an obstacle above waist. Therefore, values of variable  $p$  are respectively +1 for an obstacle above ground below waist, +3 for an obstacle below ground, and +5 for an obstacle above ground above waist.

Obstacles when encountered can cause risks for humans. An obstacle can be not risky at all, an obstacle can cause small injuries and finally an obstacle can cause serious injuries. Therefore, values of variable  $r$  are respectively +1 for not causing risks, +3 for small injuries and +5 for serious injuries.

An obstacle can present three levels of flexibility. An obstacle can be flexible, stiff and medium. A stiff obstacle can harm the blind and cause injuries, blind will be stressed in front of this kind of obstacle and will try to estimate the size of the obstacle to avoid it. Values of variable  $f$  are respectively +1 for a flexible obstacle, +3 for a medium obstacle and +5 for a stiff obstacle.



An obstacle can be stationary (fix) or have the capability to move. Moving obstacles can have low speeds or high speeds. A fixed object compared to a moving obstacle can be easily detected by blind person's cane. Furthermore, low speeds compared to high speed obstacles can be easily detected by a blind person, although low speed obstacles can harm the blind but are less dangerous than high speed obstacles. Therefore, values of variable  $v$  are respectively +1 for fixed obstacles, +3 for moving obstacles with low speeds and +5 for moving obstacles with high speeds.

An obstacle can be a source of sound emission. The sound emitted by obstacles can be subbed into two categories: familiar sounds or unfamiliar ones. Obstacles with no sound are the hardest to detect because a blind person can use sounds to redirect and estimate the type of obstacles near him. Unfamiliar sounds will make the blind stressed but the blind can estimate or try to locate the source of the sound. Obstacles with familiar sounds are the easiest to detect or locate nearby (like car sounds, bike sounds, sound of human talking, etc.). Therefore, values of variable  $m$  are respectively +1 for an obstacle emitting familiar sounds, +3 for an obstacle emitting unfamiliar sounds and +5 for an obstacle not emitting sounds.

As an illustration, let us explain the IDO calculation for an obstacle with the below characteristics:

- Large obstacle in size:  $s \rightarrow +5$
- Position is below ground:  $p \rightarrow +3$
- Small injuries in risks :  $r \rightarrow +3$
- Flexibility is stiff:  $f \rightarrow +5$
- Stationary obstacle:  $v \rightarrow +1$
- No sounds emission:  $m \rightarrow +5$

Taking into account these values, Eq. (5.3) becomes

$$\text{IDO} = \frac{1}{24} (2 \cdot 5 + 5 \cdot 3 + 8 \cdot 3 + 3 \cdot 5 + 4 \cdot 1 + 2 \cdot 5) \quad (5.5)$$

thus we obtain

$$\text{IDO} = \frac{78}{24} = 3.25 \quad (5.6)$$

Roads are traveled by a blind person from a starting point to a destination. The distance between a starting point and a destination point is usually measured in meters and designated as road length. Therefore, the total length of a road ( $x_l$ ) is equal to road length divided by 1000.

A road can be horizontally straight or can present slopes. By road we mean from the starting point to the destination point of the blind user or routes that are parts of a road from start to destination where each route can be considered as a road in itself. Therefore, road slope ( $x_s$ ) is the value of the road slope between 0 and 100%.

Accessibility for blind people may vary from road to road and country to country. Accessibility of a road for a blind person involves ensuring that individuals with visual impairments can navigate and travel safely and independently. Here are some criteria that makes a road accessible for blind users: clear sidewalks and pathways, tactile paving, audible signals at crosswalks, tactile crosswalks, etc. Therefore, accessibility of the road for blind people ( $x_a$ ) values are respectively 0 if the road is well accessible for a blind person, 0.5 if the road presents a medium accessibility, and 0.75 if the road is not at all accessible for blind. When traveling roads weather conditions may vary. Therefore, values of weather conditions variable ( $x_w$ ) are respectively 0 if no rain, 0.5 if rainy, and 0.75 if snowy.

Finally, the last variable on which the IDR of a road depends is the average number of obstacles per meter of road ( $x_n$ ). Therefore, the value of  $x_n$  can be between 0 and a maximum of 2 obstacles/m (we considered that if this value were greater than 2, the blind user would be sucked in and would no longer be able to walk or move).

We show in the following an example of IDR calculation for a road with the below characteristics:

- Road total length:  $\rightarrow x_l = 250 \text{ m}/1000 = 0.25$
- Road slope:  $\rightarrow x_s = 5$
- Weather conditions rainy:  $\rightarrow x_w = 0.5$
- Accessibility of the road not at all:  $\rightarrow x_a = 0.75$
- Density of obstacles:  $\rightarrow x_n = 0.04 \text{ obstacles/m}$
- Total number of obstacles:  $\rightarrow 10$
- IDO = 1, 1.2, 3, 3.75, 2, 2.35, 1.3, 4.2, 1.1, 1.4

$$\text{IDR} = \frac{1 + 1.2 + 3 + 3.75 + 2 + 2.35 + 1.3 + 4.2 + 1.1 + 1.4}{10} + 0.25 + 0.5 + 0.5 + 0.75 + 0.02 \quad (5.7)$$

$$\text{IDR} = 4.15 \quad (5.8)$$

### 5.4.2/ ISR VARIABLES WITH THEIR POTENTIAL VALUES

Given a index of difficulty for a route, the corresponding stress index depends on following parameters:

- If blind person is used to the road ( $i_1$ )
- If the blind person is traveling alone or having assistance ( $i_2$ )
- If the blind person is having assistance from any hardware ( $i_3$ )
- Stress initial status of the blind ( $i_4, i_5, i_6, i_7$ )

$$ISR = IDR \times i_1 \times i_2 \times i_3 \times i_4 \times i_5 \times i_6 \times i_7 \quad (5.9)$$

$$0.015526 \leq ISR \leq 10 \quad (5.10)$$

Value of  $i_1$  is respectively +1 if the blind person is traveling the road for the first time, +0.75 if the blind has traveled the road a few times and +0.5 if the road is very well known.

Value of  $i_2$  is respectively +1 if the blind is traveling the road alone, +0.5 if he is traveling assisted by a dog and +0.25 if he is assisted by a person.

Value of  $i_3$  is respectively 1 if the user is not using either the cane or GPS, 0.75 if he is using any of the cane or GPS and 0.5 if he is using both of the cane and GPS.

$i_4$  represents the value of fatigue,  $i_4$  value ranges between 0.5 and 1.  $i_4$  depends on three parameters: time of experimentation ( $i_t$ ), age of the blind person ( $i_a$ ) and on earlier injuries ( $i_i$ ).  $i_t$  value is respectively +1 if experimentation is being held in the afternoon, 0.75 if it is being held in the noon and 0.5 if in the morning.  $i_a$  value are respectively +1 if user age is greater or equal than 60, 0.5 if user age is greater or equal than 30, and 0.25 if user age is lesser than 30.  $i_i$  value is respectively +1 if user presents earlier injuries in both hands and legs, 0.5 if user presents injuries in hands only or legs only, and 0.25 if the user does not have injuries at all. Finally,  $i_4$  is defined as the average of  $i_t$ ,  $i_a$ , and  $i_i$

$$i_4 = \frac{i_t + i_a + i_i}{3} \quad (5.11)$$

$i_5$  represents a value for the initial heart beat rate (bpm) at the starting point of the road,  $i_5$  value range between 0.5 and 1. Normal heart rate values range between 60 and 100 so we will consider that between this range  $i_5$  value will be equal to 0.5. The maximum bpm for any person is related to his age and calculated using the following equation

$$\text{max\_bpm} = 220 - \text{age} \quad (5.12)$$

## 5.5. SIMULATION OF THE IDENTIFICATION OF THE LEAST STRESSFUL ROUTE 65

Therefore,  $i_5$  value will be equal to 1 if initial heart beat rate was bigger or equal than max\_bpm. If initially a blind person has a heart rate of  $x$  such as

$$x > 100 \quad (5.13)$$

and

$$x < \text{max\_bpm} \quad (5.14)$$

$i_5$  value will be equal to

$$i_5 = 0.5 + \frac{0.5}{\text{max\_bpm} - 100} \cdot (x - 100) \quad (5.15)$$

$i_6$  represents a value for the initial EDA at the starting point of a road,  $i_6$  value ranges between 0.5 and 1. Normal EDA values collected with prototypes are distributed or range between 12 and 515. For an initial EDA value at the starting point of the road lesser or equal to 100,  $i_6$  will be equal to 0.5. For an initial EDA value at the starting point of the road bigger or equal to 500,  $i_6$  will be equal to 1. Whenever the initial EDA value ( $y$ ) at the starting point of the road is between 100 and 500,  $i_6$  will be equal to

$$i_6 = 0.5 + \frac{(y - 100) \cdot 0.5}{400} \quad (5.16)$$

$i_7$  represents a value for the initial EMG at the starting point of a road,  $i_7$  value ranges between 0.5 and 1. Normal EMG values collected with prototypes are distributed or range between 0 and 1000. For an initial EMG value at the starting point of the road lesser or equal to 200,  $i_7$  will be equal to 0.5. For an initial EDA value at the starting point of the road bigger or equal to 800,  $i_7$  will be equal to 1. Whenever the initial EMG value ( $z$ ) at the starting point of the road is in between 200 and 800,  $i_7$  will be equal to

$$i_7 = 0.5 + \frac{(z - 200) \cdot 0.5}{600} \quad (5.17)$$

## 5.5/ SIMULATION OF THE IDENTIFICATION OF THE LEAST STRESSFUL ROUTE ON TWO CASE STUDIES

Any blind person can choose to travel from a starting point to a destination point. A same destination can be reached using different roads. Each road will have its own index of difficulty and its own index of stress. Our system will suggest which route or segments to take based on the indexes.

In this section, we will describe the concept of our proposed navigation system by listing the details of two simulations. First simulation was taking the example of a blind user try-

ing to navigate in Toulouse (France), from University of Toulouse to Cathedral St-Etienne. The second simulation was done on our experimental path in Lebanon. There is a notable difference between the two simulations. In the first simulation no ISRs were calculated, since we do not have any recorded biosignal values for any blind user (ISR is related to parameters specific for a blind user such as heart beat, EDA, EMG, etc.).

### 5.5.1/ IDENTIFICATION OF THE LEAST STRESSFUL ROUTE IN TOULOUSE

Figure 5.1 is taken from Google Maps. It represents multiple roads that a blind person can take from the University of Toulouse to Cathedral Saint-Etienne. We are considering that the blind person is traveling from starting point to the destination point in a very good weather condition (no rain). Furthermore, all routes correspond to the same geometrical area with 155-meter elevation above sea level, presents no slopes, and all the roads present none accessibility for blind persons. Roads can have different lengths and different widths and different types.

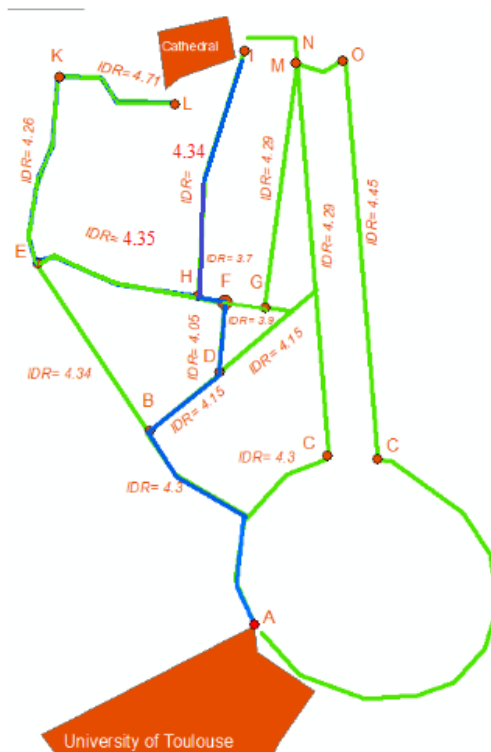


Figure 5.1: Image showing available routes with their IDRs from University of Toulouse to Cathedrale St-Etienne.

All possible intersections are represented by alphabetical letters with A the starting point (University of Toulouse). To start with the blind person has two possible road options AB or AC. Table 5.3 shows the IDR value obtained for each option. On the basis of the IDR values, our navigation system will suggest to the blind person the route with the minimum

## 5.5. SIMULATION OF THE IDENTIFICATION OF THE LEAST STRESSFUL ROUTE 67

value, i.e. AB.

Table 5.3: Calculating the IDR for routes AB and AC

Variable	AC	AB
$x_l$	0.247	0.24
$x_a$	0.75	0.75
$x_s$	0	0
$x_w$	0	0
Total number of obstacles detected	68	70
$x_n$	0.27	0.29
$\sum$ IDO	217	222
IDR	4.32	4.3

When the blind is at point B, he has two possible roads that he can take to achieve his destination: BD or BE. Based on the IDR values shown in Table 5.4, our navigation system will propose for the blind person the road BD which has the minimum IDR.

Table 5.4: Calculating the IDR for routes BD and BE

Variable	BD	BE
$x_l$	0.073	0.205
$x_a$	0.75	0.75
$x_s$	0	0
$x_w$	0	0
Total number of obstacles detected	28	36
$x_n$	0.38	0.17
$\sum$ IDO	88	119
IDR	4.15	4.34

From point D, the blind person will be redirected into DF, because as can be seen on Figure 5.1 the route DF has the lowest IDR value. When the blind is at point F, he has two possible roads that he can take to achieve his destination FH or FG.

Table 5.5 shows that FH has the lowest IDR value and thus it is this road that will be advised to the blind person. Then, starting from point H, the less stressful road according to our approach is HI since, as shown in Table 5.6, it has less detected obstacles.

### 5.5.2/ IDENTIFICATION OF THE LEAST STRESSFUL ROUTE IN LEBANON

The experiments were carried out on a road with a total length of 800 meters. The road was divided into three sectors of equal length. Each sector is 265 meter long. Each of the sectors has a well-known start and end point, and can be considered as a single road in itself. Sector 1 is represented with the line that connects A with B, sector 2 is represented by the line that connects B to C, sector 3 is represented by the line that connects C to D, and sector redirection is the sector represented by the line that connects C to E and

Table 5.5: Calculating the IDR for routes FH and FG

Variable	FH	FG
$x_l$	0.014	0.04
$x_a$	0.75	0.75
$x_s$	0	0
$x_w$	0	0
Total number of obstacles detected	5	10
$x_n$	0.36	0.25
$\sum$ IDO	14	30
IDR	3.7	3.9

Table 5.6: Calculating the IDR for routes HI and HE

Variable	HI	HE
$x_l$	0.23	0.18
$x_a$	0.75	0.75
$x_s$	0	0
$x_w$	0	0
Total number of obstacles detected	54	49
$x_n$	0.23	0.27
$\sum$ IDO	175.5	161
IDR	4.34	4.35

can be taken instead of CD to reach the destination. Figure 5.2 shows the experimenting path starting with point A up to two possible destination points D and E.



Figure 5.2: Image showing the experimental path with starting point A and D and E as destination points.

## 5.5.2.1/ IDR CALCULATION FOR THE DIFFERENT SECTORS

Table 5.7 summarizes the values of the different variables for each of the sectors. It can be noticed that the sector redirection is characterized by a low number of obstacles in comparison with the three sectors. Using these values, the IDR can be calculated for the four sectors. The obtained values are shown in Table 5.8. One can see that sector redirection has a higher value than sectors 1 and 2 due to its high slope value. The most stressful sector is sector 3 because it combines high values for the slope value and density of obstacles compared with the other three.

Table 5.7: Values of IDR variables for each sector

Variable	Sector 1	Sector 2	Sector 3	Sector redir.
$x_l$	0.265	0.265	0.265	0.265
$x_a$	0.75	0.75	0.75	0.75
$x_s$	0	10	35	20
$x_w$	0	0	0	0
Total number of obstacles detected	30	49	38	16
$x_n$	0.11	0.18	0.14	0.06
$\sum$ IDO	101	164	128	50

Table 5.8: Calculating the IDR for the different sectors

	Sector 1	Sector 2	Sector 3	Sector redirection
<b>IDR</b>	4.1	5.1	7.6	6

## 5.5.2.2/ ISR CALCULATION FOR EACH SECTOR FOR DIFFERENT EXPERIMENTATION

Five experiments were carried out, each by a different user. Table 5.9 reports for each user the ISR values calculated for the four sectors. One can see that sector 3 appears to be the most stressful for all the users, while sector redirection produces less stress along the way. We can also note that sector 1 is the less stressful and that the difference with sector 2 is very small for user 1 and user 5. The other three users experienced a similar increase in stress when they switched from sector 1 to sector 2.

Table 5.9: ISR values per user for each sector

Experimentation	Sector 1	Sector 2	Sector 3	Sector redirection
User 1	0.17	0.18	0.28	0.23
User 2	0.16	0.25	0.42	0.34
User 3	0.27	0.36	0.49	0.39
User 4	0.19	0.32	0.51	0.38
User 5	0.29	0.31	0.55	0.43



## 5.6/ APPLYING THE CONCEPT TO A REAL NAVIGATION SYSTEM

The proposed navigation system is designed to accomplish two primary tasks.

In the initial stage, the system suggests the least stressful route for blind individuals. Therefore, the user begins by selecting a starting point and a destination, prompting the system to identify all possible routes and recommend the least stressful one.

In a subsequent stage, the system provides real-time navigation for the visually impaired individual. It detects obstacles encountered during navigation and, additionally, offer real-time voice alerts to inform the user about the type of obstacle encountered. Moreover, the system redirects the user along the entire path using voice instructions to ensure a smooth and stress-free navigation experience. The navigation system under consideration will be seamlessly incorporated into a mobile application. Users with visual impairment will have the ability to engage with the system through voice commands, and all communication from the system to the user will be conveyed through voice feedback.

### 5.6.1/ IDENTIFICATION OF THE LEAST STRESSFUL ROUTE

The process starts when the user chooses to navigate from a starting point to a designated destination. After selecting these points, the system analyses all the potential routes linking the two locations and determines the least stressful option. The actual result of this procedure is to recognize and suggest the least stressful route to the user. Currently, this process is being implemented in the form of a web application using .NET and C#. Although the web application developed is user-friendly for visually impaired people, it can pose problems for blind people. In the future, this process will be integrated into a mobile application and used by blind people using voice commands. In the following We will list the different steps of the process lifecycle.

#### 5.6.1.1/ CHOOSING A NAVIGATION PATH

In the first step the user should decide on a navigation path. We will consider as an example that the user has chosen to navigate between the University of Toulouse and the Cathedral of Saint-Etienne in Toulouse, France. After choosing the navigation path a user can choose either to automatically get all possible roads to take between the starting point (the University) and the destination point (the Cathedral), or to manually precise each intersection that possibly could be taken in the chosen navigation path.

To get automatically all possible roads that can be taken between two points, the user must first be redirected to the automated system view, after redirecting the user should indicate by clicking on the displayed Google Maps in the view the starting point and des-

tionation point as shown in Figure 5.3. After indicating the starting and destination points the user clicks on the GetRoutes button displayed above the map, see Figure 5.4.

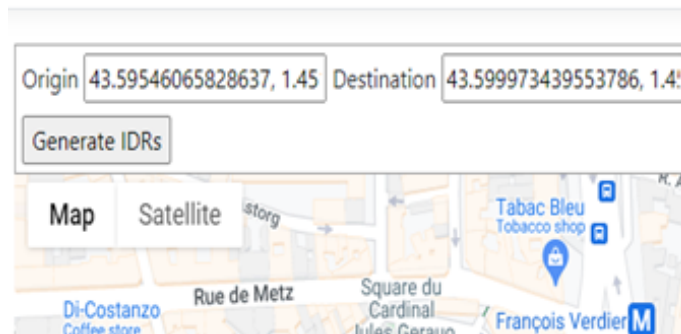


Figure 5.3: Image showing coordinates of origin and destination points chosen by the user.

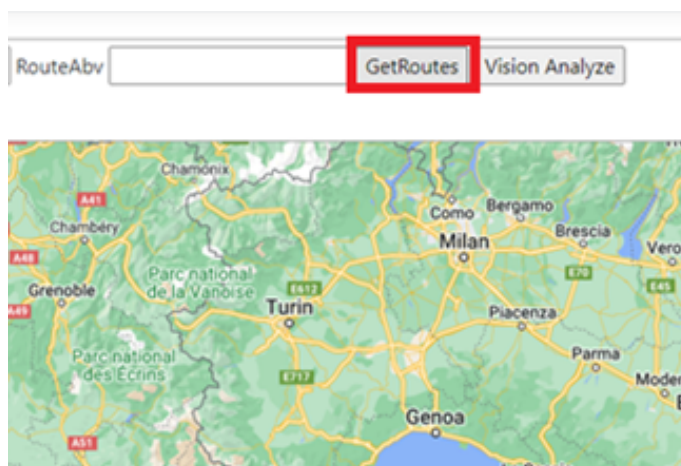


Figure 5.4: Image showing GetRoutes button that user clicks after choosing the start and destination points.

Possible roads that can be taken will be displayed on Google Maps. Figure 5.5 shows three possible routes to take between the University of Toulouse and the Cathedral Saint-Etienne. Furthermore, each possible road will be indexed and saved to an SQL database along with all longitude and latitude points that reside on this route. Tables 5.10 and 5.11 show, respectively, how the three possible routes are and the GPS coordinates of the points defining route with Id 27.

Table 5.10: Possible routes saved into database

Id	Route
27	Tone-0
28	Tone-1
29	Tone-2

A user can also choose to manually indicate on the Google Maps displayed the routes

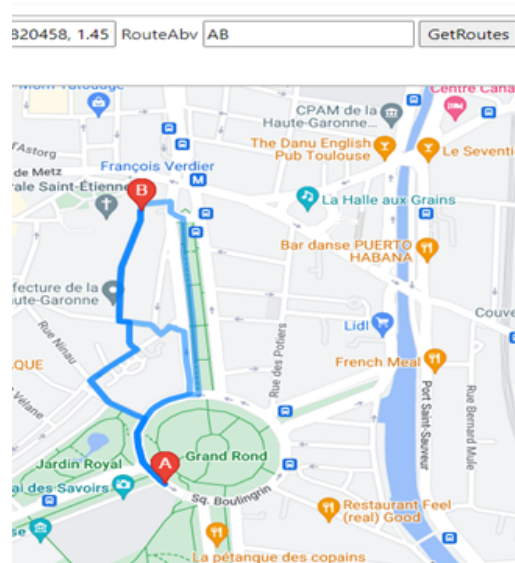


Figure 5.5: Image showing all possible routes displayed in Google Maps after clicking on GetRoutes button.

Table 5.11: Geographical points for a route saved into database

<b>Id</b>	<b>Longitude</b>	<b>Latitude</b>	<b>Route</b>
507	1.45124	43.59539	27
508	1.45139	43.59538	27
509	1.45125	43.59552	27
510	1.45116	43.59579	27
511	1.45114	43.59602	27
512	1.45128	43.59628	27
513	1.45141	43.59643	27
514	1.45166	43.59657	27
515	1.45211	43.59669	27
516	1.45231	43.59669	27
517	1.45231	43.59674	27
518	1.45221	43.59790	27
519	1.45204	43.59934	27
520	1.45201	43.59971	27
521	1.45201	43.59978	27
522	1.45196	43.59980	27
523	1.45189	43.59983	27
524	1.45178	43.59989	27
525	1.45179	43.59992	27

he wish to take from among the possible routes that exist on the chosen navigation path. He can choose to indicate on the map all possible two points that can be possibly taken for the same intersection. Each possible road for each intersection will be saved to SQL database along with all the longitude and latitude points that reside on this road. Figures 5.6 and 5.7 presents two possible routes manually selected by the user.

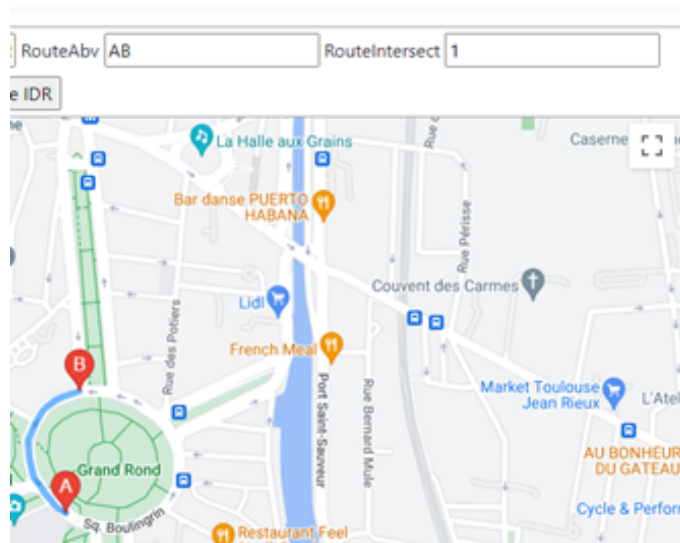


Figure 5.6: Image showing a manually selected route by the user.

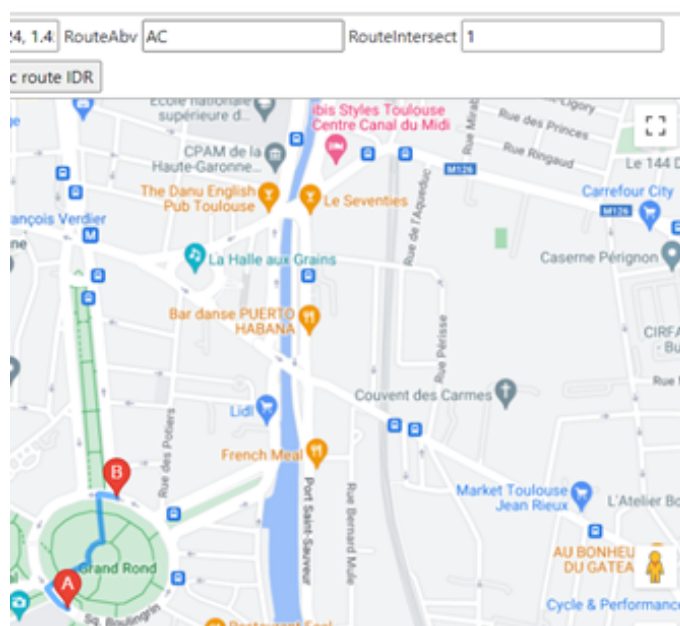


Figure 5.7: Image showing a manually selected possible route for the same intersection in picture above by the user.

#### 5.6.1.2/ ANALYZING THE ROUTES

Having stored the routes and the geographical points associated with each route in the SQL database, it's now time to analyse these routes. The aim of this analysis is to detect obstacles in order to calculate the IDOs for each route. It consists of two steps.

First, we calculate the total distance in meters for each route. To calculate the total distance for each route, we use the Google Maps API. The total distance for each route is the sum of the distances between two consecutive geographical points on that route.

Second, for each route, we identify the obstacles that a blind person may encounter along the way. To identify the obstacles related to each route, we use three APIs: Google Maps, Google Vision, and Mapillary.

The Google Maps static API returns an image (either GIF, PNG, or JPEG) in response to an HTTP request via a URL. For each request, we can specify the location of the map, the size of the image, the zoom level, the type of map, and the placement of optional markers at locations on the map. The Google Vision API offers powerful pre-trained machine learning models through REST and RPC API. It allows to assign labels to images and quickly classify them into millions of predefined categories. It detects objects, read printed and handwritten text, and build valuable metadata into an image catalog. The Mapillary API allows image extraction with object detection in bounding boxes.

Using the Google Maps API and Mapillary, we extract the images associated with each geographical point on a route, knowing its longitude and latitude values. Using Google Vision and Mapillary, we identify the labels and objects for each image associated with a point on a route. Finally, each object or label extracted is identified and stored in the database and associated with an IDO. Table 5.12 shows the IDO for different objects or labels encountered in the route indexed as Tone-0.

### 5.6.1.3/ GENERATING IDR

After storing the routes in the database along with their geographical points and after extracting and identifying objects associated with each route using Google Maps, Google Vision, and Mapillary, it is time now to generate for each route an IDR value. Therefore, we use the different equations introduced previously: Eq. (5.1), (5.2), (5.3), and (5.4).

The system will be able to count the number of objects and labels associated with each route by retrieving from the database the labels and objects related to a route Id. The system will also calculate the total sum of IDOs associated with each object or labelled related to a route Id. The total length of each road is calculated by Google Maps API as stated before. After applying the IDR formula for each route, the system suggests the route with the lowest IDR on the map.

Table 5.13 reports the IDR and length for each of the three routes. It can be seen that the route with Id 27 is the one that our system will propose to the user. Figure 5.8 displays the corresponding route.

### 5.6.2/ REAL-TIME NAVIGATION

This process comes after identifying the least stressful route. After proposing the least stressful route the blind user should begin to navigate into the proposed route. This

Table 5.12: Detected objects or labels with their IDO in the route indexed as Tone-0

Name	Route	ApiUsed	IDO
Car	Tone-0	Google Vision	2.16
Building	Tone-0	Google Vision	3.66
Car	Tone-0	Google Vision	2.16
Car	Tone-0	Google Vision	3.66
Wheel	Tone-0	Google Vision	2.16
Wheel	Tone-0	Google Vision	3.66
Car	Tone-0	Google Vision	2.16
Wheel	Tone-0	Google Vision	2.16
Car	Tone-0	Google Vision	2.16
Car	Tone-0	Google Vision	2.16
Person	Tone-0	Google Vision	0
Van	Tone-0	Google Vision	0
Bus	Tone-0	Google Vision	2.16
Bus	Tone-0	Google Vision	2.16
Bus	Tone-0	Google Vision	2.16
Bus	Tone-0	Google Vision	2.16
Building	Tone-0	Google Vision	3.66
Door	Tone-0	Google Vision	0
Car	Tone-0	Google Vision	2.16
Car	Tone-0	Google Vision	2.16
Building	Tone-0	Google Vision	3.66
Building	Tone-0	Google Vision	3.66
Furniture	Tone-0	Google Vision	0
Stop sign	Tone-0	Google Vision	0
Building	Tone-0	Google Vision	3.66
Person	Tone-0	Google Vision	0
Car	Tone-0	Google Vision	2.16

Table 5.13: Calculated IDR and length for each of the three routes

Id	Route	IDR	Length
27	Tone-0	3.363	613
28	Tone-1	3.381	631
29	Tone-2	4.438	688

process will be integrated later on within the mobile application and will allow the user to navigate safely by getting directions via voice commands along the path and by identifying and detecting in real-time the obstacles that can be encountered along the path. We will use Google Maps to provide the blind user with real-time directions while navigating the path. Users will be directed by voice via the mobile application.

We have already used the mobile's built-in camera, image processing and machine learning techniques to identify and detect obstacles that may be encountered along the way. However, we are continuing our research in this area in order to implement the best technique that will enable us to detect and identify the majority of obstacles that a blind person

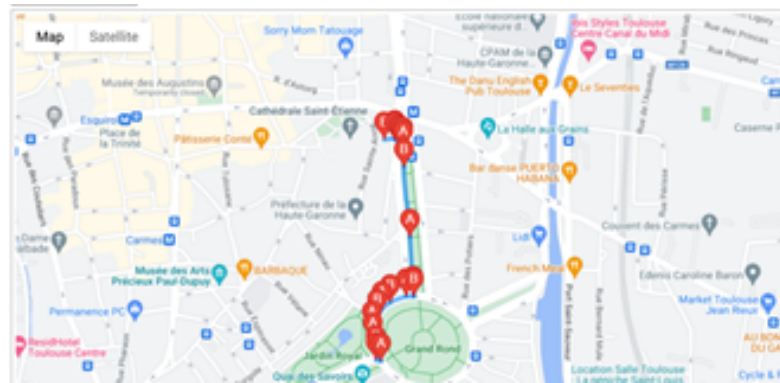


Figure 5.8: Image showing the generated route that has the minimum IDR value 3.363.

may encounter when navigating along a route.

As for now we have been able to implement Single Shot Detection (SSD) [94] real time object detection with real time video capturing within a mobile application. SSD is an object detector released in 2017, which is designed for mobile and embedded vision applications. This architecture uses proven depth-wise separable convolutions to build lightweight deep neural networks. The mobile application uses TensorFlow Lite [95] implementation along with our embedded custom SSD trained model.

Our custom SSD model was trained on Google Colab [96] to be able to identify between two object classes: chairs and tables. Images for these two classes were extracted from different sources from the internet in order to acquire a big image set and be able to split the set into train and test sets in order to train the model accurately. The custom model works well for the two classes chairs (see Figure 5.9) and tables, but can identify only these two classes. To be able to identify more obstacles, it has to be trained on different classes, which means that for each new class to be detected images related to that class have to be acquired and, in addition, a large number of images have to be acquired, which takes time but can be done if there is no other option available. Using a default detection model is possible, but default models can only detect between 70 and 90 classes. In addition, they will not be able to detect the majority of obstacles that a blind person may encounter when navigating (holes, pavements, etc.).

Given all these limitations and as previously indicated, our research continues to implement the most accurate technique capable of identifying the majority of critical obstacles that may be encountered in navigation paths by blind individuals.

## 5.7/ EVALUATION

The evaluation of our navigation system is a critical step in validating its functionality. This part is devoted to evaluating and testing the navigation system to make sure it satisfies



Figure 5.9: Image showing a detected chair with the custom SSD model.

user needs and intended goals. This section will outline the assessment procedure that was used, from collecting data sets to talking about the findings and conclusions. By doing a comprehensive analysis, we are able to see any possible problems, get useful input, and make informed decisions that will improve the prototype's usability and efficacy. Our ultimate objective is to improve and optimize the prototype in order to better meet user requirements and project objectives.

#### 5.7.1/ OVERVIEW OF THE NAVIGATION SYSTEM USED IN THE EXPERIMENTATION

The navigation system discussed earlier, has been integrated into a mobile application to enhance accessibility for blind users. The original web application was not ergonomically suited for blind individuals, making the mobile adaptation necessary. This mobile application will primarily perform the functions outlined and described earlier.

First, the application will enable blind users to interact using voice commands to select their starting location and destination. Next, it will calculate the least stressful route. The application will then provide real-time voice-guided navigation and detect obstacles along the route. Additionally, biosignals related to stress will be continuously monitored and recorded in a Google Firebase database throughout the navigation process.



### 5.7.2/ EXPERIMENTATION PROTOCOL

The experiment involved navigating a route from a residential area to the municipality's public building in the center of the town of Jezzine (the same starting point and destination as for contributions 1 and 2).

The route's infrastructure is not accessible and is not user-friendly for blind users. Six blindfolded people conducted the experiment using the navigation system. Most of the users were between 20 and 35 years old. The users were all active, healthy, physically fit, and able to walk a path on their legs, not to mention that none of the users had a heart condition. The experiments were conducted in daylight and in cool weather. For all the experiments, all the users were in a resting state before the start of the test. The preparation time before the start of the test was recorded as was the duration of the entire test for each user. The average time for a user to complete the path and the entire test was around 25 minutes.

The least stressful route among all possible routes from the starting to destination point in the experimentation was chosen by the navigation system for all the users. The least stressful route chosen, show in Figure 5.10, was then divided into three sectors. Bio signals data gathered for each user were then grouped by sectors. Furthermore, each user has been asked to note his stress level within a range from 0 (no stress) to 10 (the most stressed) in each sector three times: at the beginning of each sector, in the center of the sector and at the end.



Figure 5.10: Image showing the least stressful route chosen by the navigation system.

For each user, data stored in the Firebase database are initially extracted in JSON format. Subsequently, this JSON data is converted to CSV format using Python. This conversion

facilitates proper manipulation, visualization, and analysis of the data. Each user's CSV dataset may contain over 1000 records, with the number of records varying based on the total duration, in seconds, that the user spent walking the experimental path. The total number of records collected for all 6 users is 7892. The data samples, partitioned by sectors, are distributed as follows:

- Sector 1: 1497
- Sector 2: 3566
- Sector 3: 2829

### 5.7.3/ DISCUSSION

The heart rate, skin conductance and muscle activity values of all users were added together and filtered by sector. Then the mean for each of the measures was calculated for each sector. The obtained values are shown in Tables 5.14, 5.15, and 5.16.

Table 5.14: Mean heart beats per minute for each sector.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Heart Beats (Means)</b>	93	97	99

Table 5.15: Mean skin conductance values for each sector.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Skin Conductance (Means)</b>	303.5	348.1	358.1

Table 5.16: Mean muscle activity values for each sector.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Muscle Activity (Means)</b>	447.3	485.5	485.47

A notable difference exists between the sectors concerning the heart beat, skin conductance, and muscle activity values, where we can notice that the lower means are in Sector 1, then in Sector 2 and the higher values in Sector 3. Additionally, as stated before, each user has auto-reported his stress level at the beginning, the center and the end of each sector. For each sector and for each user the highest values of stress reported was taken and added together. Next, the stress level was averaged for each sector, resulting in the values shown in Table 5.17. Clearly, the evolution of heart beat, skin conductance and muscle activity values are linked to the stress level. Both can accurately reflect the level of stress induced by the navigation path.

In our experiment with the full navigation system, we analyzed a route selected by the system as the least stressful, which was divided into three sectors. By incorporating self-

Table 5.17: Average stress levels for each sector

	Stress level (mean)
Sector 1	1.3
Sector 2	3.57
Sector 3	4.5

reported stress levels from each user, we observed that all physiological measures (heart rate, skin conductivity, and muscle activity) were influenced by the distance to obstacles. This finding corroborates the results from our previous experiments described in Chapter 4. If we consider the Tables 5.18 up to 5.21 and the corresponding Figures 5.11 up to 5.14, the following observations can be made. Specifically, users exhibited the lowest values for all biosignal measures and reported the least stress in Sector 1. Both biosignal measures and self-reported stress levels increased progressively from Sector 1 to Sector 2 and from Sector 2 to Sector 3.

Notably, despite the sectors being of equal distance, Sector 1 was traversed the fastest by all users. The variations in physiological measures, self-reported stress levels, and travel times were associated with the sector characteristics, such as obstacle density and traffic level. The path was relatively short, approximately 800 meters in length. Sectors 1 and 2 were straight, while Sector 3 was a slope that required minimal physical effort. Additionally, four out of the six users were between 20 and 30 years old.

Compared to the results from the experiment described in Chapter 4, and considering that users traveled from the same starting point to the same destination, this experiment shows the lowest mean values for all stress-related physiological signals and the lowest reported stress levels across all three sectors. This indicates that the navigation system was effective in reducing stress for blind individuals during navigation from the starting point to the destination point.

Table 5.18: Comparison of heart beats means across sectors.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Using Navigation System</b>	93	97	99
<b>Using Prototype in Contribution 2</b>	99	101	102

Table 5.19: Comparison of skin conductance means across sectors.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Using Navigation System</b>	303.5	348.1	358.1
<b>Using Prototype in Contribution 2</b>	325.3	364.7	378.8

Table 5.20: Comparison of muscle activity means across sectors.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Using Navigation System</b>	447.3	485.5	485.47
<b>Using Prototype in Contribution 2</b>	510.8	510.9	510.8

Table 5.21: Comparison of self-reported stress means across sectors.

	<b>Sector 1</b>	<b>Sector 2</b>	<b>Sector 3</b>
<b>Using Navigation System</b>	1.3	3.57	4.5
<b>Using Prototype in Contribution 2</b>	1.8	4	5.6

## 5.8/ CONCLUSION

We have proposed a navigation system to help blind individuals to navigate safely and with less stress. Our navigation system performs two main tasks. Firstly, the navigation system suggests to the blind person the least stressful route to choose from the many possible routes between two points. Secondly, using image processing and machine learning techniques, the system detects in real time any obstacles that the blind person may encounter while navigating the route. In addition, the system provides real-time guidance to the blind person as he navigates the route.

The first process or task for the proposed system was implemented as a web application later on integrated in a mobile application. The proposed system can identify flawlessly any possible routes to take between two points and then propose for the user the route with the minimum IDR (least stressful route). Furthermore, and for future works blind users' feedback will be taken into consideration while identifying the least stressful route.

The second process, real-time object detection, was also implemented in a mobile application. We developed and trained our custom SSD model and tested it for two types of obstacle (a chair and a table). The custom model was able to accurately detect both classes. Our research continues into the second process, with the aim of building a model capable of detecting the majority of obstacles that a user may encounter.

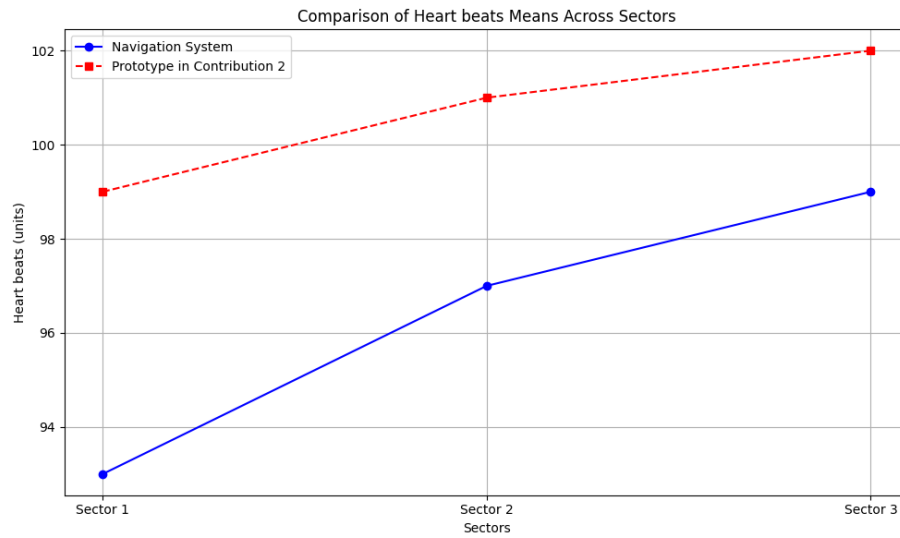


Figure 5.11: Comparison of heart beats means across sectors.

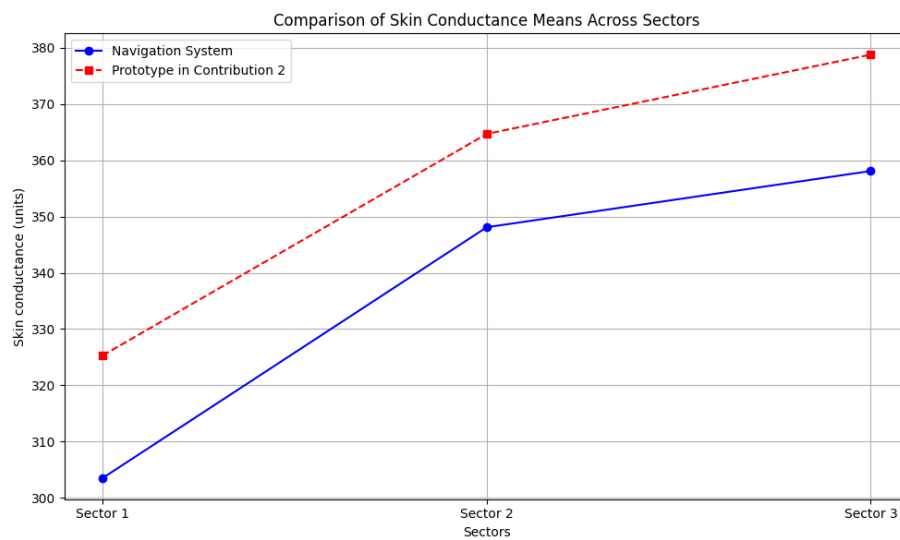


Figure 5.12: Comparison of skin conductance means across sectors.

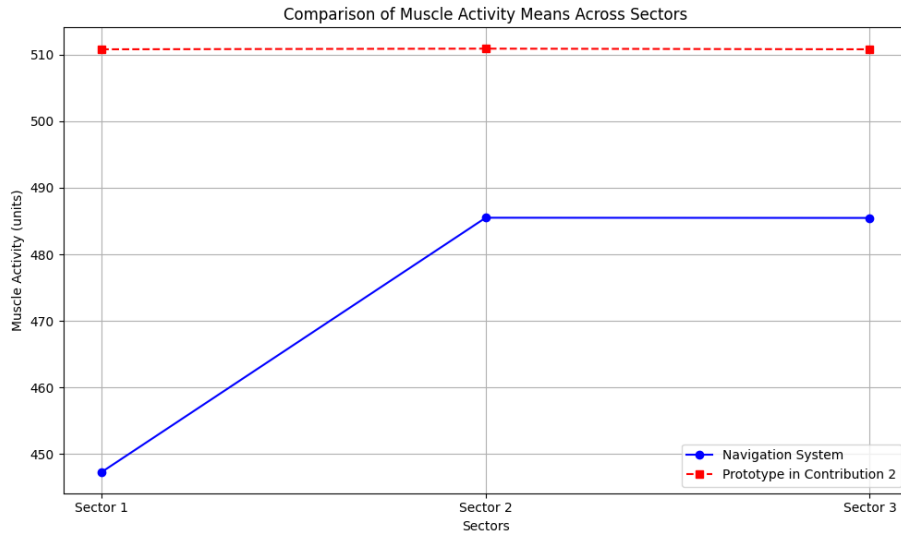


Figure 5.13: Comparison of muscle activity means across sectors.

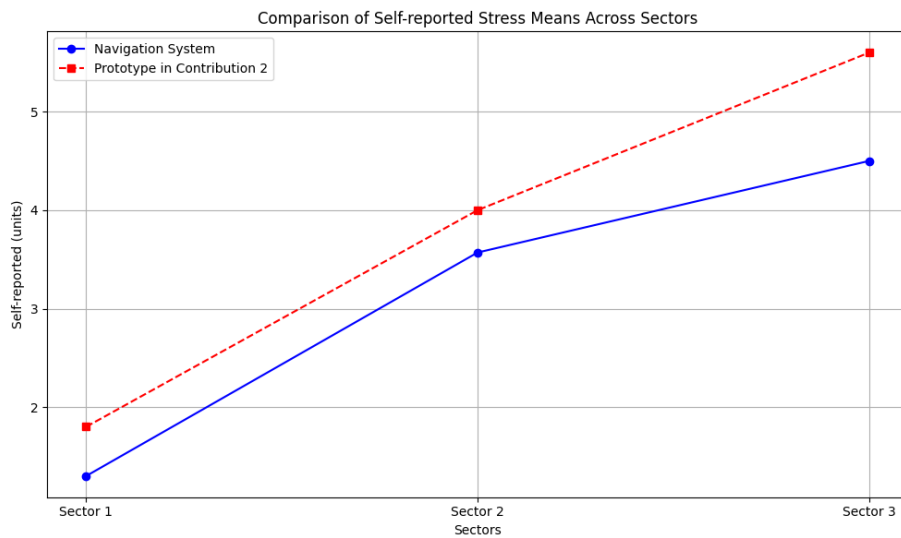


Figure 5.14: Comparison of self-reported stress means across sectors.



## CONTRIBUTION 4: INTRODUCING THE CONCEPT OF A HYBRID NAVIGATION SYSTEM ADAPTED TO BLIND USERS FOR OPTIMAL STRESS-FREE INDOOR AND OUTDOOR MOBILITY

### 6.1/ INTRODUCTION

According to the World Health Organization (WHO), approximately 285 million people worldwide have a severe visual impairment, of which approximately 47 million are visually impaired [1]. Visually impaired people cannot see objects in front of them. However, most of them are able to sense light and shadows only. Hence, navigation is challenging for blind people, especially in situations lacking suitable accessibility elements. When you are in outdoor environments, your digital navigation solution, like Google Maps, is based on satellite imagery, aerial photography and GPS signals. However, these spatial data obviously do not cover the inside of buildings, which means that you need a different service for mapping your venue and facilitating digital navigation indoors.

Blind people need help to detect and avoid physical obstacles in their path, both indoors and outdoors. Many assistive tools have been developed like braille compasses and white canes that help the visually impaired to navigate around in the environment. Moreover, they navigate around, based on their senses and experiences with the aids of guidance canes to detect and avoid obstacles while moving [97]. Technology is a revolutionary force in addressing the challenges faced by people with visual impairments, providing innovative solutions that improve accessibility and independence.



One of the main challenges that blind people encounter in their everyday lives is orientation and mobility in both outdoor and indoor scenarios which impact their social engagement and overall quality of life. This challenge is prevalent in both outdoor and indoor settings. It is particularly noticeable in public places like shopping malls, airports, offices, and other large indoor spaces. Unlike outdoor environments, indoor spaces are not accessible to GPS signals, making reliance on traditional navigation aids impractical. Indoor navigation is challenging due to complex layouts, dynamic obstacles, and unreliable visual cues.

Finding and avoiding obstacles in their path is more challenging when there are no visual cues available. Receiving accurate and up-to-date information becomes more difficult when aiming to arrive at a destination quickly. Because decision-making and continuous spatial awareness demand a higher cognitive load, physical fatigue develops. Also, people get mental tiredness from cognitive fatigue because they are always processing touch and auditory cues to make sense of their environment. Lack of tailored support in unfamiliar indoor spaces worsens challenges, hindering blind individuals' navigation independence and proficiency [98].

While several technologies have emerged to assist individuals with visual impairments, they remain insufficient in fully addressing obstacles, overcoming barriers, and ensuring successful arrival at the intended destination. Therefore, we are proposing a concept of an indoor and outdoor navigation system designed to empower visually impaired users. This system will overcome blind users stress in both environments indoor and outdoor when navigating by providing real time navigation and obstacle detection. Note that this contribution was presented at the International Wireless Communications and Mobile Computing Conference, May 2024, Ayia Napa, Cyprus [99].

The remainder of this chapter is organized as follows:

- **First:** Comparative analysis of relevant research for navigation.
- **Second:** Introducing our navigation system concept.
- **Finally:** The conclusion.

## 6.2/ ANALYSIS OF RELEVANT RESEARCH FOR NAVIGATION

As we showed previously in the related work chapter (Chapter 2), various innovative solutions have been proposed to address the indoor navigation challenges faced by visually impaired individuals. These include Wi-Fi-based systems, computer-vision and BLE technologies, Wiimotes with infrared LED systems, Ultra-Wide Band integration, and LED light with geomagnetic sensors. Each approach presents distinct advantages and limitations,

such as accuracy, real-time tracking, user-friendliness, and cost considerations. Additionally, it is noteworthy that some systems lack features like obstacle detection, potentially impacting their overall effectiveness. While certain countries have mandated accessibility aids for the blind in public spaces, the adequacy of these measures poses a crucial question. This emphasizes the need for ongoing assessment and improvement to ensure full support for the visually impaired community.

In what follows, we present tables comparing the different approaches described in the section on related work, taking into account various criteria. First, Table 6.1 focuses on the ability to detect and avoid obstacles, as well as the effectiveness of the different approaches presented. There are few ready-made solutions for obstacle management, and at best, they are only moderately effective. Only CamNav and Wiimote are in that case, whereas the four other solutions cannot deal with obstacle and for BLE and LED light exhibit a low efficiency.

Table 6.1: Comparing obstacle detection and avoidance, as well as the effectiveness of the considered solutions

Existing Solution	Object detection	Object avoidance	Efficiency
Wi-Fi-based	No	No	Medium
BLE	No	No	Low
CamNav	Yes	Yes	Medium
Wiimote	Yes	Yes	Medium
UWB	No	No	Medium
LEDlight	No	No	Low

Table 6.2 allows to identify whether a solution can go from a prototype to a tool used on a large scale by blind people. Regarding feasibility and cost, on the one hand almost all solutions are possible, only CamNav seem to be more difficult to deploy, and on the other hand their respective costs range from low up to high. One can notice that the cost of CamNav is not defined, which is a second drawback in addition to its difficulty of implementation. Finally, Table 6.3 shows that there is no solution without any drawback, each one at least one problem that will affect its performance.

Table 6.2: Comparing feasibility and cost of the solutions

Existing Solution	Feasibility	Cost
Wi-Fi-based	High	Low
BLE	High	Medium
CamNav	Low	N/A
Wiimote	High	Medium
UWB	High	High
LEDlight	Low	High

Table 6.3: Comparing feasibility and cost of the solutions

Existing Solution	Disadvantages or Problems
Wi-Fi-based	Faulty or absent AP Network configuration issues
BLE	Provision of imprecise instructions at junctions
CamNav	Delay Difficulty in maintaining fixed position
Wiimote	No routing from x to y Inapplicable for dynamic locations
UWB	Absence of speech recognition
LED light	Position divergence

### 6.3/ INTRODUCING OUR NAVIGATION SYSTEM CONCEPT

Our goal is to develop a technological solution using sensor, mapping, and artificial advancements for real-time guidance and spatial awareness, reducing stress during navigation indoors and outdoors.

#### 6.3.1/ STRESS DETECTION IN INDOOR AND OUTDOOR ENVIRONMENTS

Our earlier efforts concentrated on identifying and detecting stress experienced by blind users during outdoor navigation. In Chapter 3, which was published as [80], we introduced a prototype comprising a white cane integrated with a network of biosensors for experimentation and the collection of biological data related to stress. The prototype underwent testing with 6 users, revealing a correlation between unexpected situations and signal peaks in various biosignal measures. For example, Figure 3.10 presents the heart rate variability observed among three users, showing that, as expected, the rate changes depending on the situations encountered during navigation.

In [84], which is the contribution presented in Chapter 4, we implemented updates to the prototype to enhance experimental efficiency. Additionally, we restructured the previous experimental path into three sectors, prompting users to assess their stress levels on a scale from 1 to 10 for each sector. These sectors are of roughly equal lengths, with sector 3 presenting the highest density of obstacles, attributed to its location in the city center where our experiments were conducted. The mean values of biosignals, as presented in Table 6.4, indicate an increasing difficulty along the path, corroborated by the average stress levels reported by users across the three sectors and presented in Table 6.5.

The experiments have shown that stress can be detected and is co-related to obstacles detected along the path of blind persons when navigating. For indoor environments, stress detection employs the same approach and features as outdoor settings, which implies using the same white cane integrated with the same network of biosensors used

Table 6.4: Average biosignals values for each sector

Sector	Heart Beats	Muscle Activity	Skin Conductance
Sector 1	99	510.8	325.3
Sector 2	101	510.9	364.7
Sector 3	102	510.8	372.8

Table 6.5: Average stress level for each sector

	Sector 1	Sector 2	Sector 3
Stress Level	1.8	4.0	5.6

in outdoor environment to experiment and collect biological data related to stress while blind users navigate in indoor environments.

### 6.3.2/ NAVIGATION IN INDOOR AND OUTDOOR ENVIRONMENTS

For the outdoor environment, based on the experimentation results, we have built an outdoor navigation system that, in an initial step, can identify the least stressful route among multiple possible routes to take between two points. After identifying the least stressful route, the system redirects the blind person in real time, using voice directions and detects obstacles in real time using machine learning techniques.

For indoor navigation, we offer a solution based on QR codes and the Firebase database. Using a mobile application, users will scan QR codes strategically placed inside a building to enable the system to establish the user's current position and receive a pre-set route from a cloud-based database (Firebase). Without relying on additional infrastructure such as WiFi or BLE beacons, this method allows users to move around freely and easily. With the use of widely accessible technology like cell phones and QR codes, our approach is incredibly scalable, economical, and user-friendly. With auditory assistance, the device provides visually impaired users with improved interior movement by providing clear, sequential directions.

To make it simple for customers to find their precise location, QR codes can be thoughtfully positioned inside the facility. These QR codes should thus be placed in important spots such as:

- Entrances and Exits: Designed to make it simple for people to identify the entrances and exits of the building.
- Hallways and Corridors: QR codes are positioned here to assist users in navigating lengthy corridors and avoiding confusion in locations where there are several branching pathways.

- Important Landmarks: QR codes are used to guarantee that users can locate important locations including conference rooms, bathrooms, and information desks on their own.

Each QR code contains information specific to the building in which it is located. Using the application's built-in camera, users can scan a QR code to determine its precise position using (x,y) coordinates. The application decodes the information. As QR codes require only the user's smartphone and no additional hardware, they are the ideal inland navigation option due to their affordability and ease of use. The application quickly determines the user's current location by scanning these codes and then prepares to direct them to the location of their choice.

Once the user's position is determined by scanning a QR code and choosing the desired destination, the application establishes a connection with Firebase, a cloud-based database that has pre-configured static routes for the building. The most important Firebase functions are as follows:

- Route Retrieval: To obtain the precise route from Firebase, the application determines the user's position via a QR code and uses a specified destination.
- Centralized Storage: Firebase serves as a single point of contact for all relevant navigational data and routes. Building managers can easily update or modify the system's routes as needed, ensuring the navigational data is accurate. The application makes use of Firebase's real-time functionalities to guarantee prompt and dependable retrieval of every route, hence facilitating seamless navigation.

After retrieving the user's path from Firebase, the application switches to audio navigation in real-time. This software feature ensures that visually challenged users may navigate without relying on visual information by providing thorough, step-by-step guidance, through audio cues. Important characteristics consist of:

- Clear Instructions: To ensure that users can follow the itinerary precisely, the application offers simple instructions like "Walk straight for 10 meters" or "Turn left in 5 meters."
- Distance Updates: To keep users informed and focused while they travel, the application provides them with frequent updates on the distance to the next turn or significant landmark.

This application allows users to concentrate on moving around the building with confidence, thanks to clear, concise instructions. For additional safety, the application integrates obstacle detection and avoidance via sensors on the user's white cane, providing

verbal warnings when needed. Upon reaching the destination successfully, users are prompted to share their feed back and rate their experience. This valuable input contributes to analyze the stress at each way-point in the route and refining the application route recommendations for future use, ensuring an improved and reliable navigation system for all users. Figure 6.1 represents the schematic of the indoor navigation system.

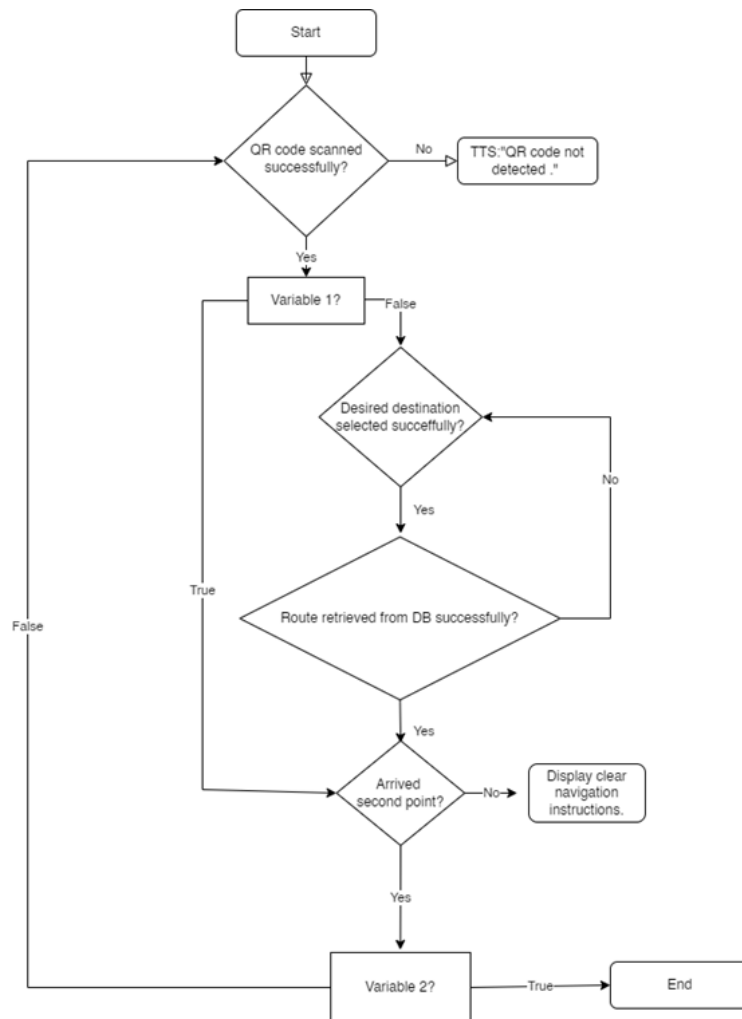


Figure 6.1: Flow diagram of the application's architecture.

## 6.4/ EXPERIMENTS AND RESULTS

Experiments were conducted with three blindfolded participants to evaluate the system's performance in real-time navigation across a university campus. The participants navigated from location D1.1, representing a specific room in building D1, to location C1.1 in building C1. To help them navigate, QR codes were strategically placed at key intersections along the route, while the application provided directional advice based on azimuth navigation and tracked the user's steps using a pedometer. As illustrated in Figure 6.2,

the navigation map highlights the placement of QR codes along the path from D1.1 to C1.1, guiding users effectively through the campus environment.

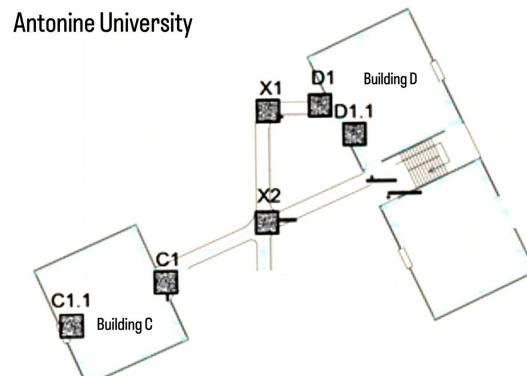


Figure 6.2: Experimental path with QR codes location.

The system demonstrated successful navigation, effectively guiding the users from room D1.1 to room C1.1. Each QR code was accurately scanned at the designated cross-sections (X1, X2), and the pedometer functioned correctly, tracking the users' steps throughout the journey.

Overall, the system performed well in a live environment, guiding users through various checkpoints with a high success rate. The QR code reading function, step tracking and azimuth-based navigation all worked well together, providing a seamless user experience. In tests, the QR code scanner reliably extracted location data, ensuring that users reached the correct checkpoints. The azimuth navigation provided accurate directional information, although it was subject to slight interference from metal objects in the environment. The pedometer tracked users' steps effectively, but its accuracy decreased when there was a sudden change in walking pace.

To wrap up, the system successfully guided participants across the campus by combining QR code scanning, directional assistance, and step tracking. These findings highlight the system's potential to enhance navigation for visually impaired individuals, presenting a low-cost and scalable solution suitable for urban environments. This innovative approach not only addresses navigation challenges, but also fosters greater independence for users in complex settings.

## 6.5/ CONCLUSION

In the contribution presented in Chapter 4, we have identified a relation between stress and obstacles while blind persons navigate outdoor. Afterward, in the contribution described in Chapter 5, we have built an outdoor navigation system capable of identifying the least stressful route between two points, offering real-time navigation directions, and

detecting obstacles. In this final contribution, we have introduced the concept of an indoor and outdoor navigation system. Outdoors, this system will incorporate the existing functions of the already developed outdoor navigation system. This contribution proposes adaptations for indoor navigation coupled with stress detection.





## CONCLUSION AND FUTURE WORK

### 7.1/ CONCLUSION

In this work, we have presented a new navigation system designed to reduce stress during navigation and give a detailed summary of developments in stress detection for blind people. Our literature review showed that current research focuses on discovering physiological markers of stress and circumstances that cause stress in blind users. Based on these findings, we have been working on a machine learning-based strategy that requires a lot of data processing to produce a working stress detection model. To do this, we have developed an intelligent prototype called ICane, which helps to avoid obstacles while collecting essential data for stress research.

Our research demonstrates that blind people experience a lot of stress when taking new routes, mainly due to unforeseen obstacles. We found that tensions could be identified and linked to navigational obstacles through our work with two smart white cane prototypes. We can therefore use machine learning techniques to classify stress scenarios and anticipate stress levels based on our analysis of this data. This allowed us to offer real-time assistance, such as route optimization, stress reduction techniques, and obstacle avoidance assistance.

Our proposal is a dual-function navigation system that will help blind individuals feel less stressed and more secure. The route selection method, which determines the least stressful path between two points, and the real-time obstacle detection capabilities, which makes use of image processing and machine learning techniques, are the two main components integrated by this system. The web application that has been built for the route selection component efficiently finds and recommends the least stressful route. Future improvements will include user input to further improve this procedure. We integrated the real-time obstacle detection feature into a mobile application, where we trained a custom model to recognize particular obstacles, such as tables and chairs. The goal of expanding this model is to identify a wider variety of obstacles.

Once these components are integrated into a single mobile application, blind users will be able to receive voice-guided navigation, real-time obstacle alarms, and stress-reduction help. This system will be tested in both indoor and outdoor conditions, with the results driving future enhancements to improve system accuracy and functionality.

As a whole, our contributions cover a number of important domains, including: establishing a connection between stress and navigational obstacles for visually impaired people; creating a navigation system that provides least-stressful route recommendations and real-time obstacle detection, and putting forth a comprehensive solution for indoor and outdoor navigation. With future work focused on improving the system based on real-world testing and user input to assure its effectiveness and user satisfaction, this technique offers a substantial improvement in navigation technology for blind people.

## 7.2/ FUTURE WORK

In light of our current advancements, several promising avenues for future work emerge to further refine and enhance our navigation system for blind individuals. These directions are crucial for expanding the system's capabilities, improving user experience, and addressing various practical challenges.

### 7.2.1/ EXPANDING OBSTACLE DETECTION CAPABILITIES

- **Broader range of obstacles:** While our custom model currently detects specific obstacles, future research will focus on expanding the model to recognize a wider variety of obstacles, including dynamic objects such as moving pedestrians and environmental features like curbs or uneven surfaces.
- **Improved accuracy and real-time processing:** Enhancing the accuracy of obstacle detection and ensuring real-time processing capabilities are essential. This will involve refining machine learning models and incorporating more advanced image processing techniques to handle diverse and challenging environments.

### 7.2.2/ IMPROVING INDOOR AND OUTDOOR NAVIGATION SYSTEM

- **Seamless transition:** We aim to create a unified system that smoothly integrates indoor and outdoor navigation, allowing users to transition effortlessly between different environments, while maintaining consistent support and functionality.
- **Environmental adaptation:** Implementing features that adapt the navigation system based on varying environmental conditions, such as lighting changes or different

types of indoor and outdoor surfaces.

- Personalized navigation: Enhancing the system's ability to provide personalized navigation support by integrating user preferences and historical data to customize routes and stress-reduction strategies.

### 7.2.3/ STRESS MITIGATION STRATEGIES

- Real-time stress interventions: Creating and evaluating fresh approaches to stress reduction in the moment, including guided breathing exercises or relaxation methods that can start working as soon as stress levels are identified.
- Preemptive stress management: Putting into practice fresh predictive functions that foresee possible stressors and provide proactive measures to stop stress before it starts.

### 7.2.4/ EXTENDED TESTING AND VALIDATION

- Diverse User Testing: Extending the testing process to encompass a wider spectrum of users with diverse visual impairment levels and environmental scenarios in order to verify the resilience and efficacy of the system.
- Long-Term Evaluation: Conducting longitudinal studies to assess the system's long-term impact on users' stress levels, navigation efficiency, and overall quality of life.

### 7.2.5/ INTEGRATION WITH OTHER ASSISTIVE TECHNOLOGIES

- Collaborative systems: Exploring integration with other assistive technologies, such as wearable devices or smart home systems, to create a more cohesive support network for blind individuals.
- Cross-platform compatibility: Ensuring compatibility with various platforms and devices to enhance accessibility and usability.

As we can see, there are many possible extensions for this work. By addressing these future directions, we aim to create a more robust, adaptable, and user-centered navigation system that not only improves the safety and ease of navigation for blind individuals, but also actively supports their well-being by managing stress effectively. Each of these areas represents a step towards a more integrated and intelligent system that meets the diverse needs of its users.



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## JOURNAL PAPERS IN SUBMISSION

- Youssef Keryakos, Youssef Bou Issa, Michel Salomon and Abdallah Makhoul. *“Introducing a Stress Management and avigation System for Blind Individuals”*. **Submitted to Advances in Science, Technology and Engineering Systems Journal, 2024.**

## CONFERENCE PAPERS

- Youssef Keryakos, Youssef Bou Issa, Michel Salomon and Abdallah Makhoul. *“Introducing the Concept of a Hybrid Navigation System Adapted to Blind Users for Optimal Stress-free Indoor and Outdoor Mobility”*. In: **2024 International Wireless Communications & Mobile Computing Conference, IWCMC 2024**, Ayia Napa, Cyprus, May 27-31, 2024, pages: 1129-1134, doi:10.1109/IWCMC61514.2024.10592407.
- Youssef Keryakos, Youssef Bou Issa, Michel Salomon and Abdallah Makhoul. *“Correlation between types of obstacles and stress level of blind people in outdoor navigation”*. In: **2023 International Wireless Communications & Mobile Computing Conference, IWCMC 2023**, Marrakesh, Morocco, June 19-23, 2023, pages: 458-463, doi:10.1109/IWCMC58020.2023.10183030.
- Youssef Keryakos, Youssef Bou Issa, Abdallah Makhoul, Michel Salomon. *“Analyzing stress situations for blind people”*. In: **15th IEEE International Conference on Signal Image Technology & Internet Based System, SITIS 2019**, Sorrento, Italy, November 26-29, 2019, pages: 454-461, doi:10.1109/SITIS.2019.00079.



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**Title:** Detection and management of stressful situations to help the blind persons in their daily lives

**Keywords:** Blind individuals, stress detection, navigation system, physiological signals, white cane sensors, General Adaptation Syndrome, ...

**Abstract:**

Stress affects everyone, but it can be particularly challenging for those who are visually impaired. It manifests as physical or mental tension due to anxiety or frustration, and the body responds through phases outlined by the General Adaptation Syndrome, involving stress hormones like cortisol and adrenaline. For blind individuals, the inability to perceive surroundings heightens stress, especially in unfamiliar environments where traditional navigation tools, like GPS, may not work.

Research shows a direct link between higher stress levels and navigation difficulties, compounded by obstacles. While assistive devices like white canes and braille compasses exist, they often fall short in providing comprehensive support.

To address these challenges, we propose a hybrid navigation system that integrates real-time stress detection with navigation assistance. It uses a smart white cane equipped with biosensors to monitor

stress indicators (heart rate, skin conductance, etc.). By analyzing biosignals, it identifies stressful situations and suggests less stressful routes.

Our solution improves navigation in both indoor and outdoor settings. It uses advanced image processing to detect obstacles and provides verbal guidance, while augmented reality (AR) and a content management system (CMS) create virtual maps for indoor navigation. Users can interact with these maps via a mobile app that scans QR codes within the environment.

This innovative approach combines stress detection and navigation support, aiming to enhance efficiency and reduce stress for blind or visually impaired individuals. Future studies will evaluate its effectiveness, gather user feedback, and refine the technology to ensure optimal performance and satisfaction, ultimately promoting greater independence in navigation.

**Titre :** Detection and management of stressful situations to help the blind persons in their daily lives

**Mots-clés :** Personnes aveugles, détection du stress, système de navigation, signaux physiologiques, capteurs de canne blanche, Syndrome d'Adaptation Générale, ...

**Résumé :**

Le stress, une expérience courante, impacte particulièrement la vie quotidienne des personnes aveugles. Il se manifeste comme une tension physique ou mentale résultant de frustration ou d'anxiété. Le Syndrome d'Adaptation Générale décrit la réponse du corps au stress, impliquant des phases d'alarme, de résistance et d'épuisement, ainsi que la libération d'hormones comme le cortisol. Les personnes mal-voyantes ressentent un stress accru lors de la navigation, surtout dans des environnements complexes où les aides traditionnelles, comme le GPS, sont inefficaces. Nos recherches montrent que la complexité des itinéraires et la présence d'obstacles sont directement liées à des niveaux de stress élevés. Les dispositifs d'assistance existants, tels que les cannes blanches, sont souvent insuffisants.

Pour remédier à cela, nous proposons un système de navigation hybride intégrant détection du stress en temps réel et assistance à l'orientation. Ce

système utilise une canne intelligente dotée de capteurs biologiques pour surveiller des indicateurs de stress. Il identifie les situations stressantes et recommande des itinéraires moins éprouvants.

Notre solution couvre à la fois les environnements intérieurs et extérieurs. Pour l'extérieur, elle génère des indices de difficulté de parcours, tandis que la détection d'obstacles se fait par traitement d'images, avec des indications vocales pour guider les utilisateurs. À l'intérieur, où le GPS est inutilisable, le système utilise la réalité augmentée pour créer des cartes virtuelles accessibles via une application mobile.

Cette innovation améliore l'efficacité et réduit le stress lié à la navigation, visant à rehausser la qualité de vie des personnes malvoyantes. Des études futures évalueront la performance du système et affineront la technologie pour garantir satisfaction et fonctionnalité, favorisant ainsi l'indépendance des utilisateurs.