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Original Article

Assisted Pedestrian Crossing System for Visually Impaired People Through Machine Vision Recognition and LoRa Communication

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Abstract ***-*** *This article presents the design and implementation of a pedestrian crossing system focused on people with visual impairments. The proposed solution combines artificial vision using a customized YOLOv5 model with wireless communication between the system and a smart cane based on LoRa technology. It begins with a crossing request when the user approaches a traffic light equipped with the system within a set range. Upon receiving this request, an ESP32-CAM module captures an image and communicates with a PC running the YOLOv5 program to detect the presence of people with the following characteristics: a person with a cane that integrates a LoRa-compatible device and dark glasses. Communication between the ESP32 microcontroller and the PC is carried out via the UART port, ensuring low-latency interaction. The system offers a cost-effective, scalable, and inclusive solution for smart city environments, improving the mobility and autonomy of people with visual impairments. After implementation, a 60% reduction in incidents at high-risk intersections and urban accessibility is estimated.*

Keywords ***-*** *Smart cane, LoRa communication, Visual impairment, YOLOv5 object detection, Intelligent pedestrian crossing.*

1. Introduction

Urban accessibility continues to be a key challenge for modern cities, especially with regard to the safe mobility of people with different disabilities. In this case, the study focuses on visual impairment. According to reports from entities such as INEI, the national road safety observatory, and urban mobility studies in Peru, a considerable proportion of pedestrian accidents occur at crossings that lack adapted signage, which exacerbates the vulnerability of these citizens. Despite advances in road infrastructure and smart traffic lights, most existing solutions do not consider low-cost inclusive technologies or integrate personalized user detection or audible alerts that allow for easy interaction between citizens. This article presents an innovative and integrated solution that uses Internet of Things (IoT) technologies, Artificial Vision (AI), and long-range wireless communication. The proposed system allows a visually impaired person to autonomously activate a safe pedestrian crossing using a smart cane equipped with a LoRa module. Upon reaching a crossing area, the system recognizes the user through computer vision based on a customized YOLOv5 model that identifies specific characteristics such as a cane, glasses, and the prior activation of the LoRa communication module integrated into the cane. Once verified, the traffic light and an audible countdown signal are activated, ensuring a guided and efficient crossing. This architecture guarantees low latency and high reliability, adapting to urban environments with limited infrastructure. The project seeks to integrate itself into smart city strategies in Peru, offering a scalable, economical, and inclusive solution that significantly improves the mobility and autonomy of people with visual impairments. This proposal seeks to significantly reduce related traffic incidents and improve urban inclusion through a scalable, replicable architecture that can be adapted to different smart city scenarios. Projected improvements have been quantified based on studies and tabulated data from relevant entities, resulting in a 60% reduction in incidents and a substantial improvement in response times. This validates its potential impact on society and new technologies for urban benefit. The improvement could be implemented for other disabilities, such as crutches or wheelchairs.

2. Related Works

Over the last decade, the development of smart cities has driven the adoption of new technologies to improve road safety and urban traffic efficiency. In this context, studies have been developed to ensure safe and continuous traffic flow for both pedestrians and vehicles, and [1] presents a simple but effective location system designed specifically to detect and track pedestrians in crossing areas. This system uses IoT transceivers that pedestrians carry with them or that are integrated into personal devices, emitting signals periodically when crossing a pedestrian. These signals are received by a central system equipped with Angle of Arrival (AoA) estimation, which allows the pedestrian's direction of movement to be calculated. To improve location accuracy, a One-Dimensional (1D) particle filter is used to combine the estimated direction with characteristics of the crossing environment. The proposed solution has been implemented and evaluated experimentally in the smart zone of the city of Antwerp, showing promising results. It is concluded that the system provides an accurate, cost-effective, and non-invasive solution to improve pedestrian safety without compromising their privacy.

Also in [2], where it integrates sensors that monitor the presence and speed of vehicles in real time, allowing for dynamic management of the crossing and ensuring safe traffic flow. This solution focuses especially on vulnerable groups, such as children, older adults, and people with disabilities. In addition, the model helps reduce traffic congestion, improve traffic flow, and optimize public transportation efficiency, which has a positive impact on environmental and public health issues. In addition to improving pedestrian safety, this solution seeks to reduce traffic congestion at busy intersections, optimize public transportation efficiency, and reduce environmental impact by promoting greater traffic flow. Preliminary analyses indicate that the system could significantly reduce waiting and travel times for pedestrians, while ensuring compliance with traffic signals through automated coordination. With the aim of providing greater independence and confidence during travel, an intelligent assistance system has been proposed that combines perception, planning, and real-time control technologies [3]. The system integrates a LiDAR sensor for obstacle detection and two omnidirectional wheels coupled to DC motors that allow precise movements in any direction, eliminating the need to lift the cane during navigation.

For autonomous perception and navigation indoors, algorithms from the Robot Operating System (ROS) environment were implemented, including Hector SLAM for real-time mapping, A* for optimal route planning, and differential steering control. The control architecture is based on a master-slave scheme consisting of a Raspberry Pi 3B+ (responsible for decision-making and SLAM processing) and an Arduino Mega 2560 (responsible for low-level control and manoeuvrability). The system was experimentally validated with a user in two indoor environments, achieving efficient, safe, and fully autonomous navigation. The results demonstrate that this approach can function as a mobile assistance robot, allowing visually impaired people to navigate complex indoor spaces without external assistance, significantly improving the user's autonomy and perception of safety. Similarly, vision loss affects more than 940 million people worldwide, mainly those over 50 years of age, according to the WHO [4]. Faced with this challenge, smart canes have emerged as key devices for improving the mobility, safety, and autonomy of people with visual impairments. These canes integrate technologies such as ultrasonic sensors, embedded processing, and even artificial intelligence, enabling obstacle detection and active mobility assistance. However, recent studies identify significant limitations, such as high energy consumption, high costs, and low social acceptance. Likewise, a recent study evaluated the safety of interactions between pedestrians and cyclists on three pedestrian streets in Montreal, using 80 hours of video analyzed during the summer of 2021 [5]. Through automatic tracking and classification of users (pedestrian or cyclist), key indicators such as speed, acceleration, minimum distance, and Time To Collision (TTC) were calculated. The results showed that TTC increases when the cyclist's acceleration is high and the distance from the pedestrian is greater, while high pedestrian density decreases TTC, increasing the risk of incidents.

Additionally, high cyclist speeds were associated with shorter distances and lower TTC values, increasing the risk in heavily trafficked environments. These findings show that even in pedestrian areas, the interaction between active modes of transport can generate conflicts, highlighting the need for smart solutions for dynamic intersection management and urban environment monitoring. Future improvements in embedded AI and energy efficiency are projected to boost their adoption and effectiveness, consolidating them as key tools in the technological assistance ecosystem for accessible urban mobility. Similar to the study, the use of Surrogate Safety Measures (SSM) has gained prominence in the analysis of road behavior, driven by advances in computer vision and object detection models. In this context, an integrated framework for tracking pedestrians and vehicles in complex urban environments has been proposed, based on behavior analysis according to traffic light status and the calculation of Time To Collision (TTC) [6].

The system uses YOLOv8 and ResNet-50 for pedestrian and traffic light detection, integrating techniques such as Kalman filtering, homography transformations, and object re-identification to improve accuracy in real-world environments. The data was captured on roads in central Athens using mobile phone cameras, demonstrating the feasibility of implementation without specialized hardware. The results show an accuracy of 50-70% in traffic light detection and a 23% difference between illegal crossings detected manually and by computer vision, revealing patterns of pedestrian non-compliance, especially during green phases. For industrial use, the increase in logistics activity has led to a higher incidence of accidents in warehouse environments, prompting the development of intelligent systems for detecting and preventing occupational hazards. A recent approach proposes a Comprehensive Anomaly Control System to predict dangerous interactions between pedestrians and mobile equipment using computer vision [7]. This system incorporates detection (YOLOv7) and tracking (Deep SORT) models to identify and track both pedestrians and vehicles in real time, assessing collision risks by analyzing the intersection of 3D bounding boxes, movement vectors, speeds, and relative distances. In addition, it integrates an action classification stage to generate alert levels (encounter, near-accident, emergency), contributing to a proactive response in occupational safety. The system achieves a dynamic understanding of the warehouse environment, classifying anomalous behavior patterns and providing a solid basis for automated real-time alerts. This approach demonstrates how computer vision and deep learning can be key in protecting vulnerable users in high-risk environments, with applications that can be extrapolated to urban contexts such as smart pedestrian crossings. Effective direction recognition in real-world scenarios faces challenges such as a lack of annotated data, partial occlusions, body posture variations, and adverse lighting conditions.

To address these issues, a framework called Origin-End-Point Incremental Clustering (OEIC) [8] was proposed, which identifies pedestrian movement trajectories by analyzing origin and destination points. The system uses YOLOv5 for pedestrian detection and a custom tracking algorithm to track their trajectories. It then uses measures such as entropy and Q-measure to dynamically adjust clustering parameters such as the optimal radius and minimum number of lines to form robust clusters. Compared to traditional methods such as DBSCAN and trajectory clustering models, OEIC demonstrated greater efficiency in trajectory clustering and accuracy in movement direction inference. This approach is particularly relevant for applications where anticipating pedestrian intent can improve safety at smart crossings and assisted traffic lights, such as those proposed in this work.

In the charging method, the demand for smart mobility aids has driven the need for efficient energy management and optimized charging solutions in canes for visually impaired people. In this regard, an optimization model for wireless charging and energy saving in smart canes has been developed, based on Deep Reinforcement Learning (DRL) [9]. The proposed solution implements a Deep Q-Network (DQN) algorithm that makes charging decisions in real time, considering user behavior and dynamic environmental factors. Unlike conventional methods with static programming, this approach allows for adaptive and contextualized management. In addition, an energy-saving strategy was incorporated that regulates the use of key modules such as voice guidance, ultrasonic sensors, audible alerts, a talking clock, and a flashlight, activating them only when necessary. Experimental evaluations showed significant improvements in charging efficiency, battery life, and user experience. This approach demonstrates the potential of integrating reinforcement learning with IoT to maximize the autonomy of assistive devices, providing scalable and practical solutions for the urban mobility of people with visual impairments. Like the system method, a multifunctional smart cane has been developed that combines computer vision, multi-sensory detection, and wireless connectivity [10]. This system integrates an optimised version of the YOLOv5s algorithm for real-time obstacle recognition and complementary technologies such as GPS, auditory feedback, and environmental sensors. The cane provides the user with voice prompts about the condition of the path and advanced detection of potential hazards, improving both safety and autonomy in daily navigation. Field tests demonstrated robust and stable performance, meeting design requirements and providing significant benefits in terms of independent mobility and social participation for blind people. This type of solution is a relevant benchmark for systems such as the one in this study, where the combination of computer vision and guided auditory assistance can enhance urban safety and accessibility for people with visual impairments. Moving in a straight line involves multiple senses that must operate in a coordinated manner.

People with visual impairments face not only the loss of this navigational ability, but also a high risk of accidents. Similar to the cane used, a portable and affordable smart cane with intelligent haptic feedback assistance has been proposed [10]. The device incorporates ultrasonic sensors for obstacle detection, an Inertial Measurement Unit (IMU) with a gyroscope for trajectory tracking, and a real-time haptic feedback system to alert to deviations. Its manufacturing uses 3D printing, which allows for a compact and economical design. Experimental results showed that 70% of deviations were less than 1.2 meters from the target, and that, at an 18-meter crossing, average deviations were up to 2.4 meters. These findings support the development of assistance systems such as the one proposed in this work, where accurate, real-time guidance (whether haptic or auditory) can reduce trajectory errors at pedestrian crossings and increase user safety, especially in high-risk urban environments.

3. Methodology

This article proposes a system for the intelligent activation of pedestrian crossings, which integrates artificial vision and long-range communication using LoRa, with the aim of assisting visually impaired people in urban areas of Peru. The system consists of three main blocks: a cane with LoRa communication, system activation, visualization of people who meet the conditions of having a cane and dark glasses, data processing, and validation using artificial vision based on YOLOv5 [6]. The system has the following characteristics and conditions to be evaluated and activated.

- Integration of the LoRa module into canes for system activation.
- The system is protected with a corresponding serial link between the cane and the Lora module located on the traffic light panel.
- Conditions that validate the use of the system and prevent false activations.

- Detection of recurring individuals and data on daily activations using the system.
- Robust wired communication via USB ports through UART ports.
- Audible alert and guidance for the user when crossing.
- Interlock mode is in the stop state at the traffic light when the user is crossing, and it waits for a restart when the user has crossed.

Table 1. Components to be used

Type	Model	Quantity
Microcontroller	ESP32-CAM	1
Control board	PCB with Lora	1
Lora module	SX1278 - 915Mhz	2
PCB audio alert	DF-PLAYER MINI	1
SD card	2GB	1
DC supply	12VDC 5A	1
CPU	Win 10, 8Gb RAM	1
Cable	USB to UART	1

This system communicates via two USB ports with a UART link between the CPU, control card, and ESP32-CAM. Simulations were carried out in YOLOV5 through the ESP32-CAM camera for object detection in the first instance, using code written in MicroPython for the microcontroller. In addition to adding data regarding the recognition of people with the characteristics required by the system, communication takes place under certain conditions, such as detection by the Lora module of the cane with a unique code or password for automatic connection. Likewise, this PCB will be inside the cane. The design of the cane and the space to be occupied by the PCB inside it was done in AUTOCAD 3D software. After this sketch, simulations of the activation of the DF-PLAYER module were carried out in PROTEUS software to activate the audible alert, in addition to performing the simulated connection via RS232 through the PC. The control PCB or control card was designed using EAGLE 9.6 software, and the dimensions and space occupied by the CPU were also designed using AUTOCAD 3D software.

Finally, in order to understand the implementation of this system, a flow chart of the process was developed in six functional phases (see Figure 1), beginning with the acquisition of the request by the user, who uses the cane that integrates the PCB module with Lora incorporated, detecting the proximity of an intersection and traffic light that will have artificial vision. Once validation is complete, the next phase verifies proximity and authentication. The system checks whether the ID is included in its list or data and whether the signal's RSSI is above the threshold. Only in that case does it proceed to capture images of the environment, validating the cane and glasses, whereby only users with this visual impairment can initiate the alert and assisted crossing process. As a third phase, artificial intelligence verifies the user with the sole objective of detecting three types of conditions, such as cane, glasses, and authentication validation. The next phase is activating the traffic light, which energizes the system's signaling system, advancing the countdown and starting with the amber light and ending with the red light. Along with this, the DF PLAYER mini module provides assisted audio guidance until the user has finished crossing. The final phase involves the registration, security, and validation of the system, which stores data such as the user ID, system activation time, request time, detection result, and final condition upon completion of the crossing.

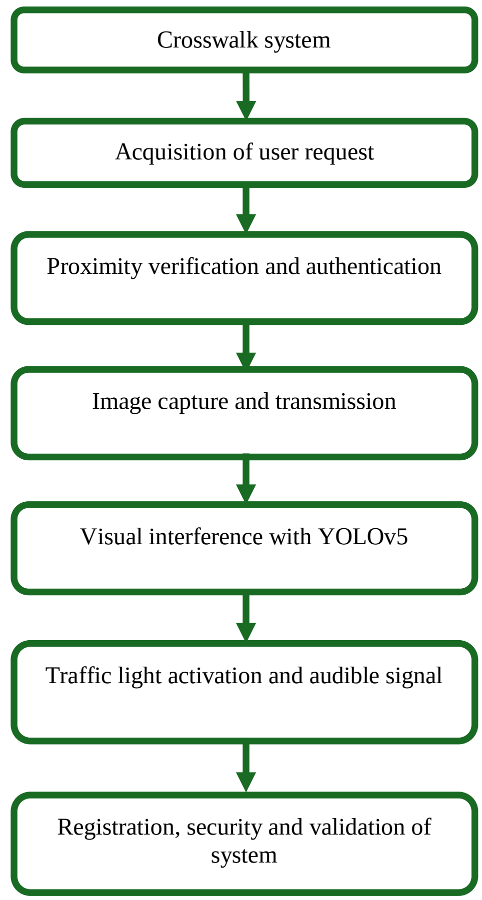


Fig. 1 System flowchart

4. Developed System

The developed system consists of an architecture that integrates electronics, wireless communication, and artificial vision to enable a smart pedestrian crossing for people with visual impairments. The system is modular and consists of three main subsystems: the cane, the traffic light with the integrated system, and the vision processing unit see Figure 2. The system operates via the cane, which acts as a mobile activation interface. It is equipped with an ESP32 microcontroller for control logic, the SX1278 Lora module for wireless transmission of requests, slight vibration of the cane when it is within the optimal range for authentication and confirmation with a push button, and a portable power supply with a rechargeable battery and integrated charging circuit.

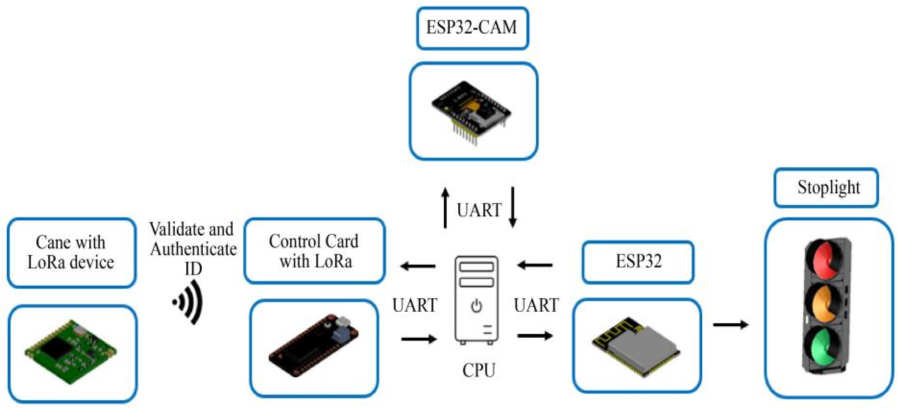


Fig. 2 Subsystems by modules

The mode of operation consists of pressing the built-in button after receiving the vibration for authentication, which confirms proximity to the traffic light by means of an RSSI value.

The cane transmits this request to start the next subsystem with the control module installed in the traffic light. The traffic light physically installed at a crossing point includes a PCB or control card with an SX1278 LoRa module, which receives the link request, as well as an ESP32-CAM, which captures images after validation by the first subsystem, changing the traffic light status from amber to red for visual signaling to pedestrians, advancing the countdown. It will have an audio system through a DF-PLAYER mini and a speaker to emit guidance sound and begin assisted crossing, as well as the remaining time to cross every 10 seconds. The artificial vision processing is implemented on a PC [5], which receives images via UART connection from the ESP32-CAM, executing the inference and verifying the three specific conditions of the citizen, such as black glasses and the cane with the integrated Lora device. Images will be captured approximately every three seconds to prevent the system from generating delays or operational delays.

Table 2. System stages

Stage	Description	Estimated time
LoRa transmission	The baton sends the request to the traffic light node	30 - 100ms
Validation of ID and RSSI	The traffic light verifies the valid ID and is at	20ms
Image capture	ESP32-CAM takes and encodes the image	250-400ms
UART sending	Image transmission of 25kB by UART to 115200	1.75-2.2s
PC processing (YOLOv5s)	Image inference and object detection	100-300 ms
Decision and command	If everything is valid, an activation command is sent	20ms
LED activation	Turn on the traffic lights	Immediate (hardware)

Then the value of approximately 3 seconds is calculated based on this respective data, obtaining a value within the desired range:

Lora module SX1276: 60ms
RSSI validation: 20ms
Image capture: 300ms
UART at 115200 baud:

$25KB = 204800\ bits$

$\frac{204800}{115200} = 1.78s$

YOLOv5 processing on PC: 200ms
Decision and response: 20ms

$Total\ time = 0.06 + 0.02 + 0.3 + 1.78 + 0.2 + 0.02$

$Total\ time = 2.4\ seconds$

The countdown is advanced to the amber signal from the confirmation of the visually impaired user, in order not to make untimely stops in vehicles when there is a free transit, the traffic light emits the respective acoustic signals of counting and assistance to the user until the end of his journey, At the end of the subsystems, a local register of users is made by means of their IDs, the time of activation, result and final conditions at the end of the crossing (See Figure 3). Each subsystem is detailed based on the selected process to be executed and supplied. The description begins with the cane, which incorporates the LoRa SX1278 module controlled by an ESP32 microcontroller, a logic system that operates with a 3.3V power supply, regulated from a 3.7V lithium battery as nominal voltage and with 4.2V charge, which is rechargeable through a charging circuit implemented in the internal PCB (See Figure 4).

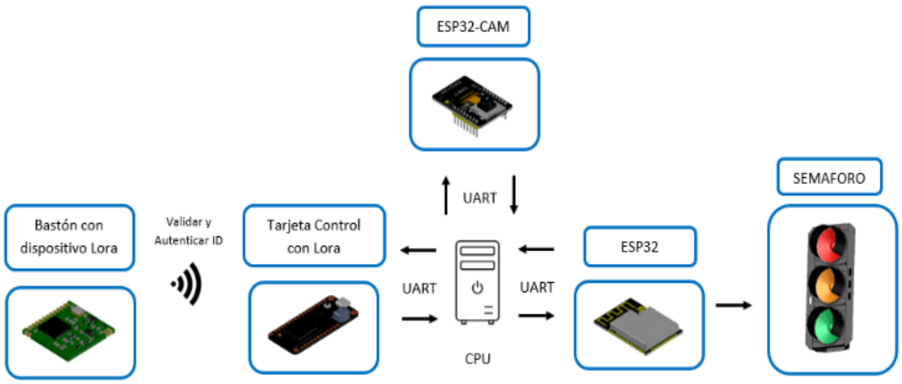


Fig. 3 Operating architecture

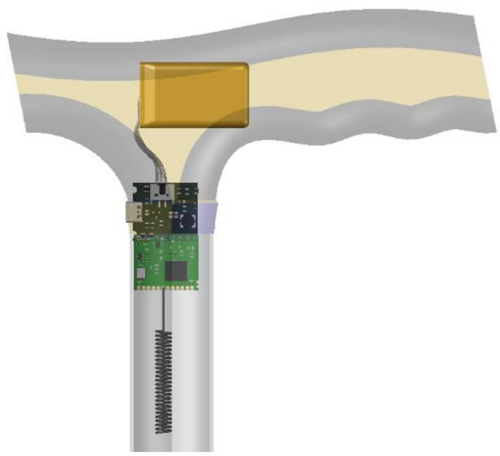


Fig. 4 Cane with Lora SX1278 module

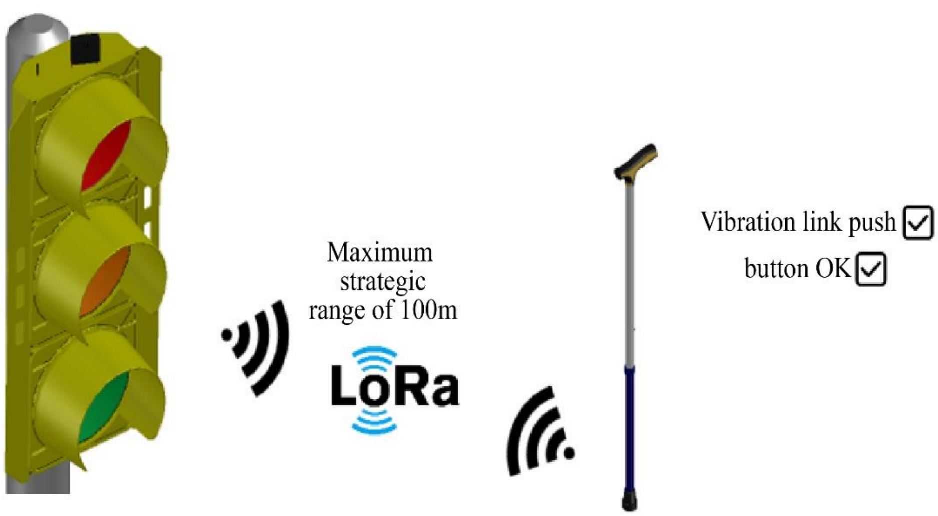


Fig. 5 Range of the module and alert in baton with possible link

The request is made wirelessly, the RSSI signal must be above the acceptance threshold of -66.67dBm at 100 meters so that only in this case the next subsystem can be activated, once this acceptance threshold is obtained the baton will emit a vibration waiting for the confirmation that must be made and confirmed through a push button to move to the next subsystem (See Figure 5). To estimate an adequate RSSI and ensure that the microcontroller could perform this correct reading at a given distance, the following calculations were performed:

Free Space Path Loss o FSPL:

$$FSPL(dB) = 20\log(d) + 20\log(f) + 32.44$$

$$FSPL(dB) = 20\log(0.1) + 20\log(915) + 32.44$$

$$FSPL(dB) = -20 + 59.23 + 32.44 = 71.67dB$$

RSSI estimate received is:

$$RSSI = Ptx + Gtx + Grx - FSPL - losses$$

$$RSSI = 10 - 71.67 - 5 = -66.67dBm$$

In urban conditions, this value can vary between -60 and -70 dBm depending on the height, interference and orientation. According to the results, there is a wide range of reception at this distance, which is limited to just making the link with the user 100m (-66.67dBm) as the maximum configured in the microcontroller. The activation and confirmation of the user through the ID is configured in a list already incorporated in the PC, the validation will be recorded and saves the time that the activation was performed by emitting an audible alert of "waiting for link" note that if there were 2 people with the same visual impairment can only be activated by one and the choice will be randomly between users, the confirmation signal will be received by an ESP32 of the PCB or control card built into the traffic light, through connectors type C to USB allow the UART connection between the ESP32-CAM and the PCB with Lora, to a PC where the artificial vision will be developed, this PC is strategically located on the distribution board of the traffic light, it should be noted that the voltages are 220VAC, the artificial vision will allow the computer or PC to evaluate the logical conditions that will activate the camera of the ESP32-CAM to perform the evaluation of whether one or more users have the cane, dark glasses the respective link ID (See Figure 6).

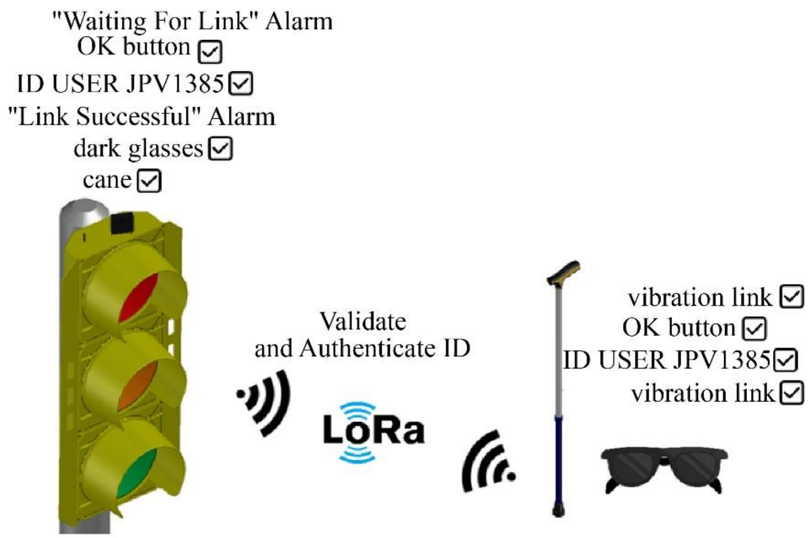


Fig. 6 Artificial vision to validate and authenticate the user ID

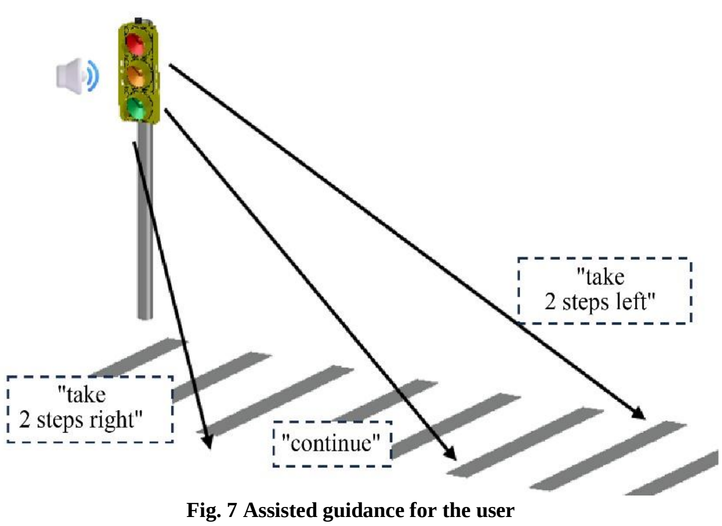


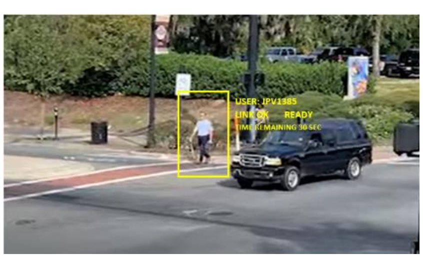
Fig. 7 Assisted guidance for the user

Once the conditions are evaluated and confirmed the system proceeds to issue the corresponding acoustic message of “preferential stop”, which allows the visually impaired user to advance in the respective crosswalk, in addition this system will emit the countdown of the traffic light in an audible manner at an interval of every 10 seconds, "It will also warn the user to advance smoothly by offering an assisted directional guide if he/she is not within the respective zebra lines and corroborate that the user reaches the final crossing point (See Figure 7). The artificial vision occupies a crucial factor for the determination of the user, since it must consider the time to issue the message of “speed up the pace” in the case that the pedestrian crossing is not achieved successfully, the time of 30 seconds maximum will be increased in such a way that there will be a restart missing 5 seconds to the next state that would be green light, with a maximum of 2 repetitive cycles, occupying the second cycle to issue an alert of “pedestrian assistance” to achieve the goal successfully. (See Figure 8).

(a)

(b)

(c)



(d)

Fig. 8 Link and assisted guidance with artificial vision

Tests were carried out with electronic modules designed for this study, but they were not carried out at a real traffic light, as permits are required from the regulatory body MTC (Ministry of Transport and Communications) to make modifications to the timing of traffic lights. For this purpose, a 20-meter-long free space was used to evaluate the quality of vision and recognition of users by the camera, the appropriate timing for a pedestrian with visual impairment, the maximum and minimum range of the Lora module connection between the cane and the traffic light, as well as the respective assisted guidance alerts, comparing the traditional use of a standard 45-second pedestrian crossing system without alarms or respective protections for users with disabilities, achieving efficiency in terms of the accident rate at high-risk crossings and risk-free urban accessibility.

5. Test and Results

The evaluation projected after the implementation in a real traffic light, compared with the physical simulations carried out in a limited space provided a high rate of user protection and a correct transit for visually impaired pedestrians, the comparison is made in terms of the timed time of 30 seconds as a basis for a usual crossing time of 45 to 60 seconds, the comfort in terms of a vibration alert after an optimal approach to the traffic light to cross to alert the user who is in a strategic point or start of zebra lines, in addition to an assisted guide for the user to be fully guided to meet the goal of reaching the next crossing without any problem, then the comparison of each point mentioned evaluating the effectiveness of the system is made.

Table. 3 Comparison of system features

Features	Assisted Intelligent Traffic Light (Proposed)	Traffic light Ordinary Traditional
Customized activation	Yes (LoRa + YOLOv5 vision)	No
Programmed crossing time	30 seconds	45-60 seconds
Auditory guidance	Yes (audible countdown)	No (visual only)
User recognition	Visual detection + LoRa authentication	No
Immediate start on the approach	Yes (<3s from request)	No (random cyclic wait)
Time efficiency	High (only activated when necessary)	Low (constant cycle)
Universal accessibility	High (inclusive design)	Limited

A relative improvement was obtained in terms of dead time for the crosswalk, comparing the ordinary traffic light of 60 seconds maximum after activation and waiting for change of state in 20 seconds after crossing the crosswalk, as well as the time of 30 seconds for crossing and change of state in amber of 3 seconds for the activation of the system:

$$Total\ time\ reduction = \left(\frac{60+20-33}{60+20}\right) = 0.5875$$

$$\approx 58.75\%\ of\ improvement\ in\ total\ time$$

After the simulation was implemented from 20 meters, an increase in time efficiency was achieved due to the adapted activation, while user safety was enhanced through auditory-assisted guidance, which contributed to reduced stress levels and improved spatial orientation, in addition to having a device in the cane that allows him to take precautions by means of a vibration to warn of an upcoming crosswalk.

Table 4. Comparison of system features

Feature	Smart Cane (Proposed)	Cane Ordinary (Traditional)
Pedestrian crossing detection	Yes (via LoRa signal from smart traffic light)	No (requires experience or third-party assistance)
Early warning	Yes (vibration within 10-15m of crossing)	No
Level of sensory assistance	High (direct haptic stimulation to the user)	Null
Automatic interaction with traffic lights	Yes (initiates crossing request when in LoRa range)	No
Early safety	High (anticipates crossing and initiates visual validation)	Low (only personal perception of the environment)
User autonomy	High (alerts, communicates and waits for confirmation)	Limited (requires guidance or assistance)

Table. 5 Cases

Indicator	Reported value	Source
Total traffic accidents in urban areas	92,437	INEI
% of accidents involving pedestrians	26% (~24,033 cases)	ONVSV - MTC
% estimated % of pedestrians with visual impairment	~2.1% of pedestrians involved (~505)	PUCP / WHO
% attributable to crossing without visual or hearing assistance	>65% of cases	UNMSM / Observatorio Vial

In addition to being able to count on a visually assisted guide which serves as an orientation for the user to be able to cross without inconveniences, minimizing the rate of incidents and accidents managed by the corresponding regulatory entities.

It is estimated that a reduction of incidents with the system in high-risk areas, according to data from INEI and the national observatory of road safety, in the year 2023, was recorded in Peru, 92,437 urban traffic accidents, in which 26% involved pedestrians, according to indexes of the PUCP, UNMSM, about 2.1% of these pedestrians have visual impairment:

$$Annual\ cases = 2.1\%\ x\ 24033 \approx 505\ people$$

UNMSM and ONSV studies indicate that at least 65% of incidents involving visually impaired people occur at intersections such as main avenues, markets, schools and hospitals.

$$Incidents\ at\ intersections = 65\%\ x\ 505 = 328\ cases$$

It is estimated that the implementation of the assisted system at crosswalks will reduce the current incidents in these critical areas by at least 60%.

$$Reduction = 60\%\ x\ 328 = 197\ avoidable\ accidents$$

The progressive implementation of the system in areas such as critical crossings could avoid hundreds of accidents annually, in addition to not only reduce the risk but also increase safety, confidence and autonomy of people with visual impairment, these data can justify public policies at municipal or national level aligned with sustainable development objectives, likewise this study can be focused to more people with disabilities such as crutches, wheelchairs, etc. by simply varying the detection system used as the cane in this case, for a wheelchair or crutches.

6. Conclusion

This system offers an innovative and inclusive solution for safe pedestrian crossings for people with visual impairments, integrating IoT technologies such as artificial vision using YOLOv5, LoRa communication, and sequential audio assistance.

The projected results show a significant improvement in urban accessibility, with an estimated 60% reduction in annual incidents in high-risk areas and a 50% decrease in crossing times compared to conventional systems. In addition, audio and assisted guidance improve user orientation and autonomy.

In conclusion, this system demonstrates technical feasibility, scalability, and strong social impact, aligning with inclusive mobility policies. Its implementation can represent a tangible step toward smarter cities that are safer and more accessible for all citizens.

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