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Building Optimized Wireless Pedestrian Counting Sensors Combining Passive and Active Technologies

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Abstract—Pedestrian flow monitoring plays a vital role in urban planning, transportation management, and smart city or tourism applications. However, monitoring is often needed in challenging scenarios with spatial constraints, low traffic, no power supply, and poor network connectivity, such as birdwatching observatories or open-air heritage sites.

This paper presents a cost-effective, energy-efficient pedestrian counting system tailored for such isolated locations. The system uses two pairs of active infrared (AIR) sensors to count individuals and determine movement direction. To reduce energy consumption, passive infrared (PIR) sensors are used to trigger both the AIR detectors and an IoT board that handles local processing and communication. Depending on local conditions, LoRaWAN or Wi-Fi is used for uplink communication, allowing flexible deployment.

The architecture is built with open-source software and off-the-shelf hardware, supporting low-cost real-world implementation. A comparative analysis of several AIR detectors was conducted, assessing power consumption, detection accuracy, susceptibility to interference, and horizontal beam angle. This fills a gap in the literature regarding the systematic evaluation of AIR sensors. Results highlight the effectiveness of the proposed system in achieving both accuracy and energy efficiency, supporting non-intrusive pedestrian monitoring in various smart city and tourism contexts. The system is currently being deployed and evaluated in the Tagus Estuary Bird Observation and Conservation Area (EVOA).

Index Terms—Infrared Sensor Comparison, Pedestrian Counting, Low-Power Sensor Networks

I. INTRODUCTION

Pedestrian counting and flow monitoring are critical elements in urban planning, transportation systems and smart

city/tourism applications. A relevant scenario is one of natural reserves and environments that require careful management to balance human activity and environmental preservation [1].

To address the above challenges, this paper proposes a pedestrian detection system consisting of two pairs of active infrared detectors (AIRs) arranged in parallel and two passive infrared detectors (PIRs), one on each side of the walking path. PIRs have lower power consumption than AIRs but lack precision. To get the best of both worlds, the PIRs are always on and only turn on the more accurate and power-hungry AIRs and associated processing when a human presence is detected, maximizing energy efficiency, a critical feature in off-grid areas where batteries must be used, while not compromising the accuracy in detecting the number of pedestrians, their speed and direction of movement achieved by analyzing the AIR activation sequence.

In summary, the main objective of this project is to develop a precise sensor-based system that provides real-time pedestrian flow data while maintaining energy efficiency and minimizing cost-effectiveness by employing open-source solutions and low-cost hardware. Additionally, the system's adaptability to different deployment scenarios, enabled by WiFi and LoRaWAN connectivity, ensures its wide-ranging applicability in various environments.

This paper presents a system architecture for deployment in a real-world scenario. It also compares various AIRs, evaluating their power requirements, detection precision, susceptibility to interference, and horizontal beam angle. This is imperative because product specifications often lack critical details and are measured under controlled conditions that do not fully reflect real-world performance, affecting the detector's accuracy and reliability. Consequently, this study developed an experimental setup that independently evaluates multiple AIRs owing to the necessity of a comparative analysis. This evaluation aimed to identify the most suitable components for accurate and efficient pedestrian detection in diverse real-world conditions.

The current system is a follow-up of a proposed crowd sensor to monitor overtourism in critical hotspots, based on

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the activity of mobile devices, by detecting trace elements of wireless technologies, mitigating the effect of MAC address randomization [2] [3]. This development aimed to build better tourism services, improve efficiency and sustainability, and reduce the overwhelming feeling of pressure. The system proposed herein contrasts with the crowd sensor, which is designed to monitor pedestrians who remain within a designated area. Instead, it prioritizes pedestrians' passage along specific pathways. By focusing the detection of passage events over stationary presence, this system enables precise monitoring of pedestrian flow, movement patterns and directionality, suitable when a fine-grained tracking approach is required.

This paper presents a cost-effective, energy-efficient pedestrian detection sensor system that integrates active infrared (AIR) detectors for accurate counting and movement tracking, complemented by passive infrared (PIR) detectors. To conserve energy, the system activates AIR sensing, data processing, and communication only when motion is detected, achieving at least a tenfold increase in autonomy compared to continuously powered AIR-based systems.

A comparative evaluation of multiple AIR sensors is conducted, assessing power efficiency, detection accuracy, interference resilience, and horizontal beam angle. The system's adaptable architecture, which supports WiFi and LoRaWAN connectivity, ensures flexible and seamless deployment in diverse operational environments.

The remainder of this paper is organized as follows. Section II presents a comprehensive literature review discussing various pedestrian detection techniques and their advantages and limitations. Section III details the proposed system architecture, including the technologies adopted and the implementation considerations. Section IV provides a comparative analysis of different AIRs, evaluating key factors such as power consumption, detection precision, susceptibility to interference and horizontal beam angle. Then, section V details the practical implementation of the system in a real-world setting, explicitly highlighting its application in pedestrian monitoring environments. Finally, section VI summarizes the key findings and discusses future research directions.

II. LITERATURE REVIEW

Pedestrian detection systems have been the subject of extensive research in transportation engineering [4] and smart city applications [5], [6]. Various approaches have already been investigated, incorporating camera-based techniques and sensor-driven solutions. Each of these approaches offers distinct advantages and challenges [7], [8].

Camera-based systems employ video and image processing techniques to obtain information regarding objects in images. However, such systems give rise to privacy concerns, high power consumption and the requirement of computational resources [7]. Moreover, these systems are often susceptible to difficulties in low-light conditions.

Alternatively, using time-of-flight (ToF) or LiDAR (Light Detection and Ranging) technology holds considerable potential. These methods employ laser or infrared pulses, facilitating

precise distance measurement and 3D movement detection with high accuracy and allowing operation in all lighting conditions [7], [8]. However, these systems also incur higher costs, power consumption, and increased complexity.

Another option is PIRs, which can detect changes in infrared radiation emitted by warm objects, such as human bodies. A heat signature difference is detected upon detection of a person within the detector's vicinity, and consequently, an event is triggered. This approach is characterized by its low power consumption and cost-effectiveness [7], [8]. However, PIRs for pedestrian counting have limitations in accuracy due to their inability to detect direction, susceptibility to environmental factors, and reduced precision in open or high-traffic areas with overlapping movement.

The final option under consideration is AIRs. These detectors emit an infrared beam and detect interruptions when an object passes through, making them highly suitable for pedestrian counting. They exhibit substantially reduced energy consumption compared to camera-based systems and LiDAR, making them more suitable for battery-powered applications. However, their consumption remains higher than that of PIRs [7], [8]. Furthermore, they are small and affordable, and since they do not capture images or personal data, they do not infringe on privacy regulations.

AIRs also have limitations, particularly in scenarios with groups of pedestrians. In addressing these limitations, research efforts have been directed toward reducing the discrepancy between the ground truth and the detector counts. The tendency of sensors, supported by AIRs, to underestimate the number of pedestrians, a phenomenon particularly pronounced when individuals walk side by side or in groups, was analyzed in [9]. The authors proposed a non-parametric statistical calibration method that utilizes bivariate bootstrap sampling to address this issue. This approach seeks to adjust the raw detector data to more accurately reflect the actual number of pedestrians, thereby enhancing the data quality.

The enhancement of counting precision by analyzing time-continuous data from AIRs is discussed in [10]. The authors developed a people-counting model based on Support Vector Machine (SVM) algorithms. This model effectively distinguished individual pedestrians, even when multiple people simultaneously passed through the detector's detection area, improving counting accuracy compared to previous approaches.

Given the trade-offs identified in the literature, an optimal pedestrian counting solution should harness the high accuracy of AIRs while addressing the significant energy demands associated with the processing and communication overhead of any sensor-driven system. Although PIRs are less precise, they provide the option of activating the sensor system only when movement is detected, thereby supporting low-power design objectives. Building on this rationale, the present research proposes an architecture in which a PIR triggers a pair of AIRs, processing, and communication, coupled with a flexible network deployment for uplink communication [3], as described in the following section.

III. ARCHITECTURE

A. Proposed System Architecture

Building on the literature insights, the proposed architecture uses PIRs to activate the sensor solely when movement is detected, thereby reducing unnecessary energy consumption. This design proves especially advantageous in low-traffic scenarios, where extended sensor sleep times can further optimize battery usage. Lastly, integrating a flexible communication approach, previously validated by this research team [3], ensures robust data transmission and system scalability, making the solution energy-efficient and practical for various smart-city or remote applications.

The proposed architecture is detailed in Figure 1, where the sensor is configured to record the number of pedestrians that traverse the sensor in each direction and periodically report the information to a cloud server.

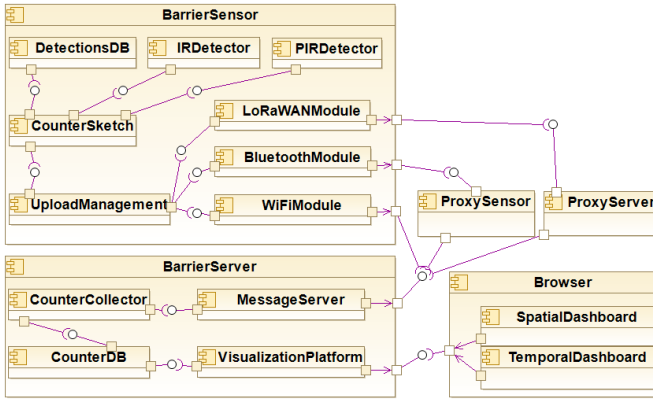


Fig. 1: UML component diagram of the proposed system

The realization of the proposed system is dependent on two components: *PIRDetector* and *IRDetector*. These components are to be used together to provide the low power consumption of PIR detectors and the accuracy of AIR detectors. The sensor has been developed to transmit collected data using multiple communication protocols, including WiFi, LoRaWAN (Long Range Wide Area Network) and Bluetooth. This is possible through the *UploadManagement* component, which determines the currently available options for uploading the data. This multi-channel capability enhances the system's adaptability to various deployment environments, ensuring reliable data transmission even in areas with limited connectivity options. The transmission of data, which consists of simple pedestrian counts and movement patterns, operates with a low data payload, eliminating the necessity for high-bandwidth communication. This feature enables the system to operate efficiently with low-power, long-range protocols such as LoRaWAN, making it suitable for remote or off-grid locations where traditional connectivity solutions such as WiFi are not available. Thus, potential deployment locations are expanded.

The cloud server facilitates visualization of temporal and geographic data, thereby enabling a comprehensive understand-

ing of pedestrian movements. The components that enable this functionality are the *CounterCollector* and *MessageServer*. The latter is the single entry point for all messages in the cloud server, regardless of the communication protocol used to upload the pedestrian information, ensuring transparency.

B. Adopted Technologies

This system uses open-source software technologies and off-the-shelf, low-cost hardware components. Figure 2 presents the UML deployment diagram that details the integration of all technologies employed in the proposed system.

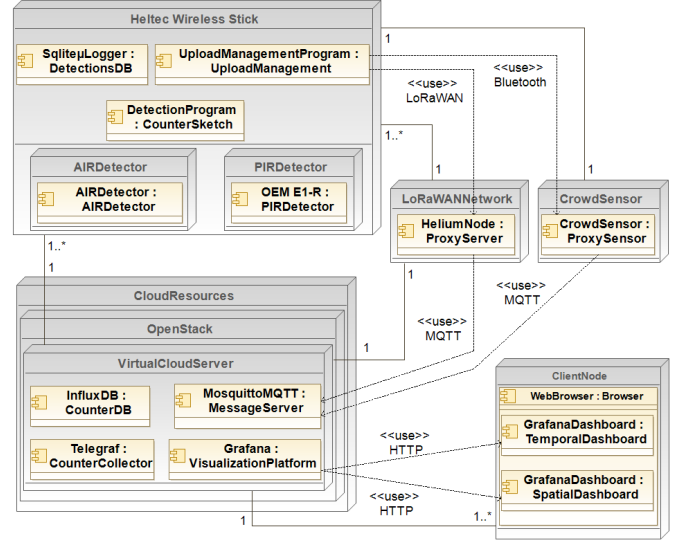


Fig. 2: UML deployment diagram of proposed system

For the computing unit of our sensors, we have opted for the [Heltec Wireless Stick](#), which has available WiFi, LoraWAN and Bluetooth capabilities. The local database utilizes an [SQLite \$\mu\$ Logger](#), which can log data into SQLite databases, even when the SRAM (Static random-access memory) is as low as 2 kilobytes.

For receiving all messages, our cloud server uses the [Mosquitto](#) MQTT server, a lightweight message broker that implements the MQTT protocol. For the data ingestion of sensors data, we chose [InfluxDB](#) a time-series database focused on IoT applications. For the *CounterCollector*, responsible for pushing all messages received in the *MessageServer* via MQTT protocol to the *CounterDB* in the appropriate format, we chose [Telegraf](#), an open-source plugin-driven server agent for collecting and reporting metrics from devices.

Finally, for data visualization, we chose [Grafana](#), an open-source analytics and monitoring tool compatible with several databases, including InfluxDB. This framework can create custom dashboards with graphs and panels for viewing crowding information with different spatiotemporal granularity levels.

Each sensor contains a microcontroller that processes the signals from the sensors and uploads the data to a cloud server via WiFi, LoRaWAN or Bluetooth. In addition, each barrier sensor is equipped with two PIRs, which activate the system.

These detectors effectively transition the microcontroller from a low-power state and activate a pair of AIRs. A 12-volt battery powers all components and requires DC power-down converters since the microcontroller uses 5 volts, including on its general-purpose input/output (GPIO) pins. The corresponding breadboard and schematic diagrams are shown in Figures 3 and 4, respectively.

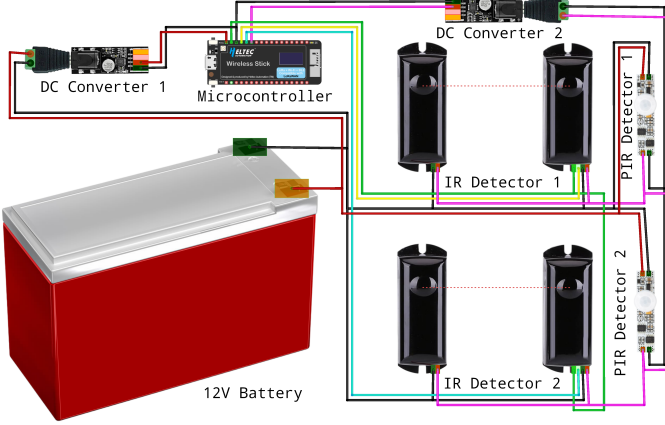


Fig. 3: Breadboard diagram of Sensors

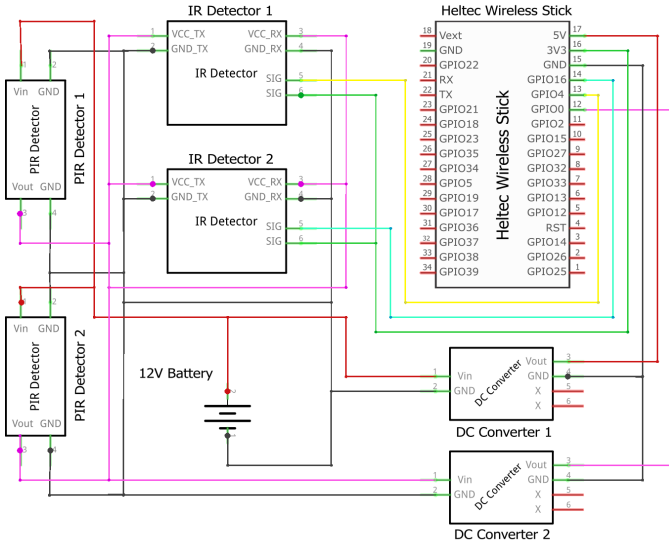


Fig. 4: Schematic diagram of Sensors

IV. DETECTOR SELECTION AND EVALUATION

The architecture of the proposed optimized wireless pedestrian counting sensor integrates active infrared detection (AIR), processing, and communication, with activation triggered by a low-power, resource-efficient, but less accurate, passive infrared detector (PIR). AIRs are essential for achieving high detection accuracy; however, it comes at the cost of increased power consumption. As such, selecting the most appropriate detector is crucial to balance performance and energy efficiency. Six candidate detectors were shortlisted in this context, as detailed in Table I.

The initial selection was guided by key criteria: cost-effectiveness to support scalable deployment, commercial availability to facilitate procurement, and hardware compatibility to enable seamless integration into the system architecture.

TABLE I: Active Infrared Detectors

ID	Detector	Type	Cost [€]
1	Single Beam AIR Detector - ABO-20F	Thru-Beam	11.10
2	Single Beam AIR Detector - ABO-20L	Thru-Beam	12.30
3	Acogedor E3Z-T61	Thru-Beam	27.90
4	STBTECH E3Z-R61	Retroreflective	16.25
5	DFRobot SEN0523	Thru-Beam	14.70
6	Irfora E3F-20C1	Thru-Beam	18.19

It is important to note that manufacturer-provided detector specifications, when available, are typically obtained under differing test conditions, which may not reflect the operational context of the target system. Therefore, conducting a comparative analysis under uniform and application-relevant conditions is essential to ensure a fair and reliable assessment of detector performance. For instance, power consumption is critical in battery-powered systems, as it directly impacts operational autonomy. Additionally, high detection accuracy and resistance to signal interference are equally important, given that the system relies on paired, parallel detector configurations to determine the direction of pedestrian movement. In such arrangements, signal overlap between adjacent detectors can result in false detections and compromise overall sensor reliability. Moreover, variations in the horizontal beam angle caused by detector misalignment or installation inconsistencies can further affect detection performance.

As such, a rigorous evaluation of the candidates was conducted to identify the most suitable detectors for integration. This process involved a systematic analysis of critical parameters influencing detector performance and reliability within the intended application domain, with a particular focus on four key metrics: power consumption (A), detection accuracy (B), mutual interference under close-proximity conditions (C), and susceptibility to variations in horizontal beam angle (D). Accordingly, a structured comparison of these factors is presented in the following subsections:

A. Power Consumption Analysis and Optimization Strategy

In low-power systems, minimizing the energy consumption of the employed components is essential to extending operational lifespan. Table II presents each candidate detector's measured power consumption values.

The results indicate that Detectors 1 and 2 exhibit significantly higher power consumption than the remaining candidates. This elevated energy demand would considerably shorten battery life, making these detectors less suitable for long-term, autonomous deployments. In contrast, Detectors 3, 4, 5, and 6 demonstrate substantially lower power requirements, thereby offering more significant potential for energy-efficient integration and extended system autonomy.

To reflect more realistic usage scenarios, Table II also presents each detector's estimated daily energy consumption

TABLE II: Power consumption of active infrared detectors (AIRs)

Detector ID	Operating Voltage [V]	Power Consumption [mW]				Daily Consumption [Wh/day]		
		Transmitter (Tx)	Receiver (Rx)		Total (Tx + Rx)		1% Time Interrupted	0.1% Time Interrupted
			Uninterrupted	Interrupted	Uninterrupted	Interrupted		
1	12	219.48	77.88	276.00	297.36	495.48	7.18	7.14
2	12	215.52	53.28	255.60	268.80	471.12	6.50	6.46
3	12	32.28	17.40	59.16	49.68	91.44	1.20	1.19
4	12	NA	57.24	97.68	57.24	97.68	1.38	1.37
5	5	65.70	22.45	22.75	88.15	88.45	2.12	2.12
6	12	18.72	13.44	52.08	32.16	70.80	0.78	0.77

NA: Not Available

under intermittent activation, simulating duty cycles of 1% and 0.1%. Under these conditions, Detector 6 emerges as the most energy-efficient option, with an approximately one order of magnitude daily consumption lower than that of the highest-consuming detector. Detectors 3, 4, and 5 also show favorable performance in terms of energy efficiency.

To illustrate the energy impact, the most efficient AIR (Detector 6), operating at a 0.1% duty cycle, consumes approximately 0.77 Wh/day. Meanwhile, the continuously active infrared detector consumes around 1 Wh/day. While these values are similar, the microcontroller alone consumes 8.23 Wh/day when always active, excluding communication costs.

These figures underscore the importance of PIRs to trigger only the AIR and the microcontroller when needed. This strategy significantly reduces the sensor's energy consumption and can extend the system's lifespan by at least a factor of 10 when combined with the most efficient AIR.

B. Detector Accuracy Evaluation

An experimental setup was designed to evaluate the accuracy of the candidate detectors in detecting motion events. The setup consisted of a test rig incorporating a DC motor with an encoder to pull a wheeled cart along a guided rail. The detectors' transmitter and receiver units were mounted 140 cm apart and perpendicular to the track, such that the passing cart interrupted the infrared beam, mimicking pedestrian motion.

The DC motor encoder enabled the cart to move at a controlled and constant speed, ensuring repeatable and precise test conditions. During each trial, the cart's motion at the detector's position was recorded using a high-speed camera configured to capture video at 240 frames/s. This allowed accurate measurement of beam interruption duration as a reference to compare against values registered by each detector.

Tests were conducted at various speeds to assess detector accuracy under realistic conditions, including pedestrian walking speeds reported in [11]. The experimental setup is illustrated in Figure 5.

Figure 6 also presents each detector's average relative error as a speed function. Detector 1 showed the poorest performance, consistently registering an interruption duration of 1.5 seconds, even when the interruption was significantly shorter. Detector 2 exhibited a marked decline in accuracy as speed increased. In contrast, Detectors 3, 4, 5, and 6 produced similar results, with Detector 6 displaying the highest relative error.

C. Detector Arrangement and Interference Assessment

The system requires two infrared detectors arranged in parallel to determine the direction of pedestrian movement. Two possible configurations are considered:

- *Opposed configuration* – Each detector's transmitter and receiver are placed on opposite sides of the passageway (Figure 7a).
- *Crossed Configuration* – Each side of the passage is equipped with a transmitter and receiver from different detectors (Figure 7b).

Both configurations are susceptible to interference, though the sources differ. In the opposed configuration, interference may occur due to the wide reception angle of the detectors, which can lead a receiver to unintentionally capture signals from the adjacent transmitter (Figure 7a). In the crossed configuration, interference may arise from signal reflections off the body of a pedestrian, causing the receiver to detect unintended signals from the other transmitter (Figure 7b).

The minimum allowable distance between detector pairs was experimentally determined to evaluate and compare interference between configurations. A smaller distance between detectors offers multiple advantages, including improved detection accuracy, better individual separation in group scenarios, and reduced spatial requirements for installation, which is critical in constrained environments.

The procedure to determine the minimum separation distance began by placing the detector pair close enough to induce interference. The distance was then gradually increased in small increments until no further interference was detected. The resulting minimum distances required for reliable operation in both configurations are presented in Table III.

TABLE III: Minimum required distance between detectors

Detector ID	Opposed Configuration [cm]	Crossed Configuration [cm]
1	0	0
2	77	32
3	62	12
4	18	18
5	19	5
6	3.5	2

Results indicate that Detector 1 performs favorably due to its ability to operate at four distinct frequencies, which facilitates

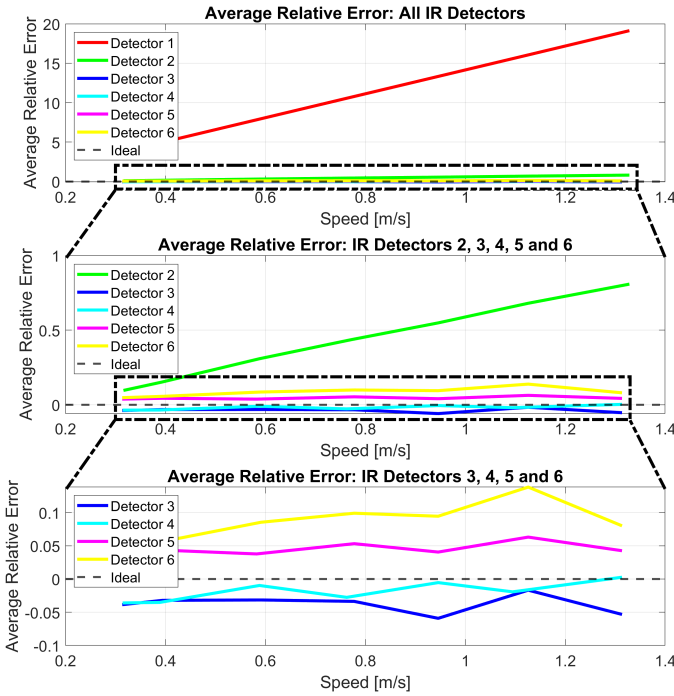


Fig. 6: Detectors' average relative error over speed

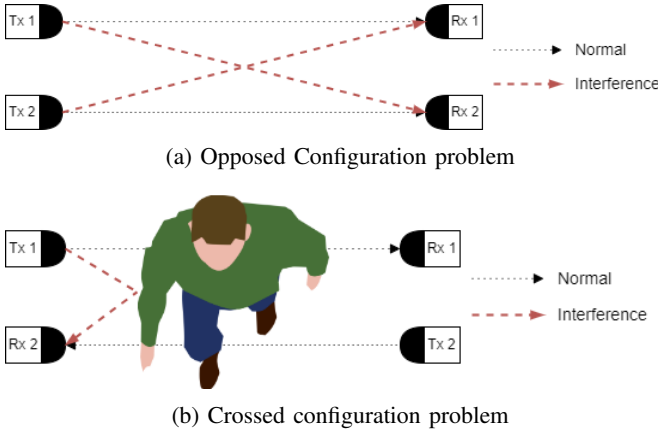


Fig. 7: Top view – Opposed and crossed configurations

fine-tuning and reduces interference. In contrast, Detectors 2 and 3 were unsuitable for the opposed configuration due to the excessive spacing required to eliminate interference. Detector 6, distinguished by its high precision, consistently demonstrated optimal performance in both configurations, making it the most effective option for interference mitigation.

In practice, detectors requiring a minimum spacing of less than 20 centimeters are considered suitable for both the opposed and crossed configurations, as they offer a practical balance between reliable performance and ease of installation.

D. Detector Beam Angle Analysis

The horizontal beam angle of infrared detectors is a critical factor influencing accuracy, particularly in environments subject to physical disturbances. Detectors with narrow beam angles are more sensitive to slight misalignments, which may result from unintentional physical disturbances, such as bumps, handling during maintenance, or vibrations from nearby activity. Such deviations can potentially lead to signal loss and potential system malfunction. Conversely, detectors with wider horizontal beam angles exhibit reduced directionality, which may compromise detection accuracy. A broader beam increases the likelihood of registering motion from unintended directions, raising the risk of false positives and erroneous detection.

To assess this characteristic, the maximum horizontal beam angle was measured by independently rotating the transmitter and receiver until the receiver no longer detected the transmitted signal. The angular deviations in each direction were then summed to determine the total beam angle, with results presented in Table IV.

TABLE IV: Horizontal beam angle of detectors

Detector ID	Horizontal beam angle [°]	
	Transmitter (Tx)	Receiver (Rx)
1	185	172
2	207	205
3	25	42
4	48	8
5	17	22
6	2	89

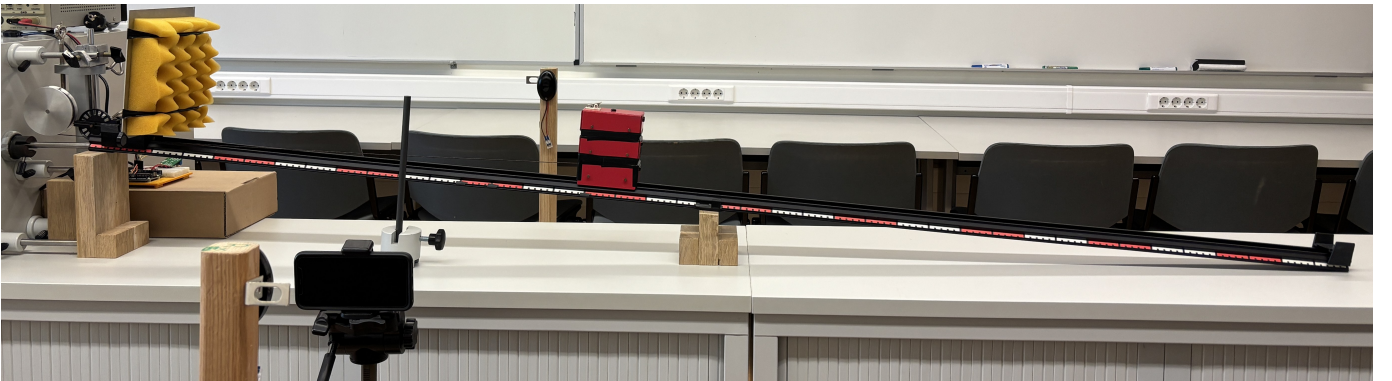


Fig. 5: Experimental setup to test detectors' precision

The measurements indicate that Detectors 1 and 2 possess the widest horizontal beam angles, making them more susceptible to directionality-related interference. Detector 6, while more directional, exhibited the lowest transmitter angle among all candidates. While this can enhance precision, it also increases vulnerability to slight displacements that may misalign the beam. The remaining detectors displayed moderate beam angles, representing a more favorable balance between directional accuracy and operational stability.

E. Comparative Summary

The four key metrics - power consumption (A), detection accuracy (B), interference mitigation (C), and beam angle (D) - underline significant trade-offs in detector selection. A qualitative assessment in Table V highlights that Detectors 3, 4, 5, and 6 generally outperform detectors 1 and 2.

TABLE V: Qualitative Assessment of detectors

Detector ID	Metrics				
	A	B	C		D
			Opposed	Crossed	
1	—	—	—	+	—
2	—	—	—	—	—
3	+	+	—	+	+
4	+	+	—	+	+
5	+	+	+	+	+
6	+	+	+	+	+

In summary, Detector 6 consistently emerges as the most balanced candidate, combining low power consumption, reasonable detection accuracy, minimal interference under close spacing, and a well-defined directional beam. Detectors 3, 4, and 5 also offer viable alternatives depending on specific design and deployment constraints. In contrast, Detectors 1 and 2 exhibit limitations across multiple metrics, reducing their suitability for compact, low-power, direction-sensitive pedestrian detection systems.

V. REAL-WORLD DEPLOYMENT

The initial practical application of the system will take place at the EVOA (Tagus Estuary Birdwatching and Conservation Area) in Portugal. Located approximately 30 minutes from Lisbon, EVOA has an environmental interpretation center, several camouflaged bird-watching wooden huts (see Figure 8) and electric buses to circulate among them.

EVOA's primary objectives are to preserve bird diversity, facilitate scientific research, offer visitors a unique experience, foster a lasting connection with nature, and raise awareness of the importance of sustainable water and land management.

The data collected through integrating infrared and crowd sensors, complemented with bird vocalization analysis, presents a significant opportunity to enhance visitor management strategies at EVOA. By identifying specific times, locations, and human activities correlating with measurable changes in bird presence or movement patterns, managers are empowered to make evidence-based decisions. These include



Fig. 8: EVOA map featuring several monitored birdwatching huts in our Grafana dashboard

regulating the timing and routing of school group visits, implementing noise reduction protocols, or adapting programming according to bird abundance. This real-time, non-intrusive monitoring allows a dynamic approach to management, balancing conservation priorities with public engagement [12].

The crowd sensors, referenced in section I, allow determining the congestion of the observation huts to guarantee the quality of visits without compromising the integrity of the birds' habitat. The entrance to the bird observation huts, where the crowd sensors are installed, has a single pedestrian passage, as shown in Figure 9, so a group of pedestrians cannot pass through the sensor simultaneously. Since the most challenging problem for infrared detectors is the passage of groups, this allows infrared detector counts to be highly accurate, allowing both sensors to work together as a validation mechanism.

The data collected from the sensor monitoring the number of individuals entering the observation hut can be utilized for cross-validation. This process entails comparing the data with the count of individuals inside the hut, as recorded by the crowd sensor. Cross-referencing the two data sets enhances the reliability of the collected information.

This data will be used in a future study to measure the impact of human presence on the avian species in EVOA. This objective will be achieved by leveraging parabolic microphones and the eBird Merlin API, a tool developed at the ornithology laboratory at Cornell University in the USA. This API enables the identification of birds by their unique vocalizations. This approach will yield insights into the birds' presence and assist in identifying species that demonstrate a heightened susceptibility to human disturbance.



Fig. 9: Pathway to one of EVOA's birdwatching huts

Beyond informing internal decisions, these technologies can play a key role in increasing visitor awareness and responsibility. Communicating the measurable impact of human presence, such as decreased bird activity linked to noise, encourages more mindful behavior. Infrastructure upgrades, such as improved camouflage and sound barriers near observation huts or along access paths, could be guided by sensor data to minimize disturbance. This scientific feedback loop reinforces the value of visitor participation in conservation and positions EVOA as a model for harmonizing education, ecotourism, and biodiversity protection in sensitive wetland environments [13].

VI. CONCLUSION AND FUTURE WORK

This paper presents a low-cost, energy-efficient pedestrian monitoring system supported by sensors that employ two active infrared (AIR) detectors arranged in parallel, triggered by passive infrared (PIR) detectors, to optimize power usage. By selectively activating the AIR modules and associated processing and communication only when motion is detected, the system sensors achieve more than an order-of-magnitude increase in operational autonomy. Furthermore, flexible up-link communication options, including WiFi and LoRaWAN, facilitate broad adaptability to diverse deployment scenarios.

The proposed system uses open-source technologies and low-cost hardware to detect pedestrians' movement and determine their direction and velocity. It enhances crowd management and safety by enabling real-time monitoring of pedestrian flow, triggering alarms, and providing longitudinal data that can be analyzed in a graphical dashboard.

A comprehensive comparison of AIRs revealed that specific models demonstrate superior power efficiency, accuracy, and resistance to mutual interference. The most suitable AIR was selected based on experimental validation, ensuring optimal performance in real-world deployment.

The system's development is being finalized, with current efforts directed at refining the detection algorithms to ensure high accuracy under dense pedestrian conditions. Deployment has commenced, allowing real-world data collection under various operational conditions. This multi-site deployment strategy ensures that the sensor network is exposed to diverse pedestrian flow patterns, facilitating a comprehensive assessment of its accuracy and autonomy. The insights gained from this validation will guide subsequent optimizations to enhance algorithmic performance and energy efficiency.

The data will support a future study on the impact of human presence on bird species at EVOA. Using parabolic microphones and the eBird Merlin API, bird species will be identified through their vocalizations. This approach will provide insights into species' sensitivity to human disturbance.

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