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# Development of an IoT-Based Smart Cane with Non-Invasive Health Monitoring for Elderly Care in Batam

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**ABSTRACT**

The rapid growth of the elderly population requires assistive technologies that support mobility, health, and safety. This study presents the development of an IoT-based smart cane designed to enhance elderly independence and health monitoring in Batam, Indonesia. The prototype integrates non-invasive health sensors (MAX30102 for heart rate and $SpO_2$, MLX90614 for temperature, and a non-invasive glucose sensor), a GPS module, a mini-CCTV with two-way audio, and a solar-powered energy system, all controlled by an ESP32 microcontroller connected to the Blynk IoT platform. Ergonomic design was guided by anthropometric data of Indonesian elderly to ensure user comfort and usability. Experimental results demonstrated stable performance of the integrated modules. Heart rate values ranged from 86–103 BPM (mean 89.5 ± 6.2 BPM), blood glucose estimations from 110–112 mg/dL (mean 111 ± 0.9 mg/dL), and body temperature from 36.9–37.1 °C (mean 37.0 ± 0.1 °C), all of which aligned closely with clinical references. Oxygen saturation readings, however, averaged 89 ± 0.8%, slightly below the clinical norm (≥95%), highlighting the need for sensor calibration. Dynamic testing of the GPS module across a 500-meter route achieved positional accuracy within 3–5 meters, while the CCTV system successfully streamed live video but was dependent on WiFi stability.The novelty of this research lies in the unique combination of locally adapted ergonomic design, multi-sensor non-invasive health monitoring, two-way visual and audio communication, GPS tracking, and renewable energy integration within a single portable device. These contributions not only enrich IoT-based healthcare research but also provide practical solutions tailored to elderly care in Indonesia. Future work will focus on clinical-grade validation of sensors, extended field trials, and the integration of predictive analytics using Machine Learning and Fuzzy Logic.



## I. INTRODUCTION

The global demographic shift toward an aging society has led to a significant increase in the elderly population worldwide [1], including in Indonesia [2]. According to the Indonesian Bureau of Statistics, the proportion of elderly citizens has grown from 8.43% in 2015 to 10.82% in 2021 [3], and is projected to reach 28 million people by 2045, or approximately 10.7% of the national population [4]. This demographic change is accompanied by an increase in chronic diseases such as hypertension [5], diabetes mellitus [6], arrhythmia [7], and hypoxemia [8], which are among the primary causes of morbidity and mortality in the elderly population [9], [10]. These health issues not only reduce life expectancy but also significantly impact the independence and quality of life of the elderly.

Batam City, as one of the largest urban centers in the Riau Islands Province, faces considerable challenges in addressing elderly health services [11]. With a population of over 1.24 million in 2023, the proportion of elderly citizens is projected to increase to 13.8% by 2035 [12]. However, limitations in conventional healthcare services—particularly in real-time monitoring of elderly health conditions—pose risks to safety, independence, and timely medical intervention. The lack of effective monitoring tools exacerbates the vulnerability of elderly individuals, especially those living independently.

Several smart cane prototypes have been proposed in prior research [4], [11] . Arduino-based designs have incorporated GPS tracking or haptic feedback for mobility support [13], with triboelectric nanogenerators [14], while other studies focus on technological innovations are aligned with real caregiving needs sensors to monitor basic physiological parameters either with dizziness, and Parkinson's disease [15]–[17], focusing on hip joint loading in patients with late-stage osteoarthritis and lower extremity joint [18], [19]. More recent works have explored the integration of communication modules or energy-harvesting mechanisms. However, most of these designs exhibit limitations, including the absence of two-way audio-visual communication, limited validation of health sensors, and reliance on conventional power sources. Moreover, few studies have considered ergonomic adaptation based on local anthropometric data, which is essential to ensure usability and comfort for elderly users in specific cultural and physical contexts.

To address these gaps, this study develops an IoT-based smart cane that integrates multiple non-invasive health sensors (heart rate, $SpO_2$, temperature, and glucose), GPS mobility tracking, and a mini-CCTV with two-way audio communication, supported by a renewable solar energy system. The ergonomic design is based on anthropometric data of Indonesian elderly to improve comfort and usability. The system employs an ESP32 microcontroller to collect and transmit data in real time via the Blynk IoT platform, enabling caregivers to remotely monitor health status and mobility conditions. The novelty of this research lies in the combination of locally adapted ergonomic design with multi-sensor non-invasive monitoring and renewable energy integration, which has not been comprehensively addressed in previous studies.

The objective of this research is to design, develop, and test an IoT-based smart cane prototype for elderly care in Indonesia. Specifically, the study aims to evaluate the functionality, accuracy, and limitations of the integrated sensors and modules, thereby contributing both theoretical insights to IoT-based healthcare research and practical applications for elderly support in local contexts.

## II. METHOD

The development of the IoT-based smart cane followed an applied research approach consisting of three main stages: data collection, design and integration, and prototype testing.

In the data collection stage, anthropometric measurements of Indonesian elderly were obtained to guide ergonomic design, including body height, grip dimensions, and seat height. At the same time, technical requirements for the IoT modules were identified, covering non-invasive sensors (MAX30102 for heart rate and $SpO_2$, MLX90614 for temperature, and a glucose sensor), the ESP32 microcontroller, GPS module, mini-CCTV with two-way audio, and a solar power system.

The design and integration stage included ergonomic design based on anthropometric data, selection and calibration of health sensors, and assembly of the electronic modules into a functional prototype. The ESP32 was programmed to collect, process, and transmit data to the Blynk IoT platform, allowing caregivers to monitor elderly health conditions in real time.

Prototype testing was carried out in three parts. Laboratory testing validated each sensor module individually under controlled conditions. Dynamic testing was conducted by moving the cane across a 500-meter route to evaluate GPS accuracy in mobility scenarios. In addition, preliminary usability observation was performed with elderly participants to assess comfort, handling, and acceptance of the smart cane in short-term use.

The methodological flow is summarized in the revised flowchart (Fig. 1), which illustrates the input–process–output sequence: literature review and data collection as inputs, design and integration as the process, and prototype performance and identified limitations as outputs.

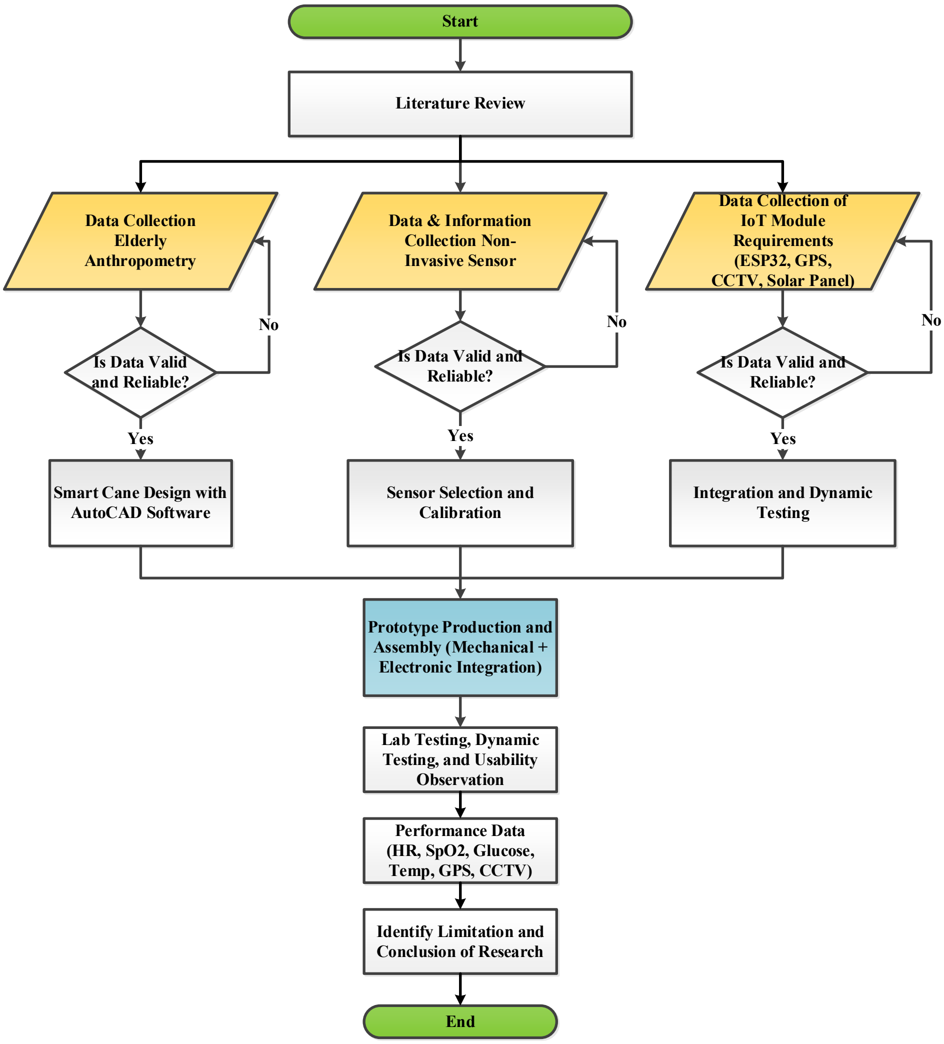



Figure. 1. Research flowchart of IoT-based smart walking cane development.

## A. Ergonomic Design

The ergonomic design process was guided anthropometric data [20], [21] of elderly individuals, ensuring that the smart walking cane accommodates their physical characteristics and daily mobility needs. The grip was designed with a total height of approximately 118 cm and a handle length of 16 cm, tailored to elderly hand dimensions for stability and comfort. Additionally, a foldable seat was integrated, with a height of about 50 cm from the ground, corresponding to the average popliteal height of Indonesian elderly users [22], [23]. allowing them to sit and stand without difficulty.

The structural design considered weight distribution, ensuring balance and safety when both walking and resting. Material selection, including lightweight hollow steel [24] and rubber grips, further enhanced durability and usability [25]. These ergonomic adjustments aimed to reduce fatigue [26], improve user comfort [27], and enhance overall independence during daily activities [28]. Visual result of 3D smart cane is shown in Figure 2

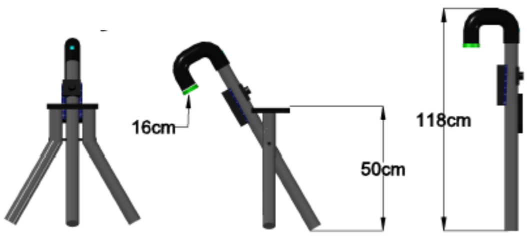



Figure 2. Smart Cane 3D Design

## B. IoT System Integration

The integration of the IoT system in the smart walking cane was designed to ensure real-time monitoring of elderly health and safety. The architecture, as illustrated in the block diagram (Figure 3), consists of several key components connected through a central controller, the ESP32 microcontroller.

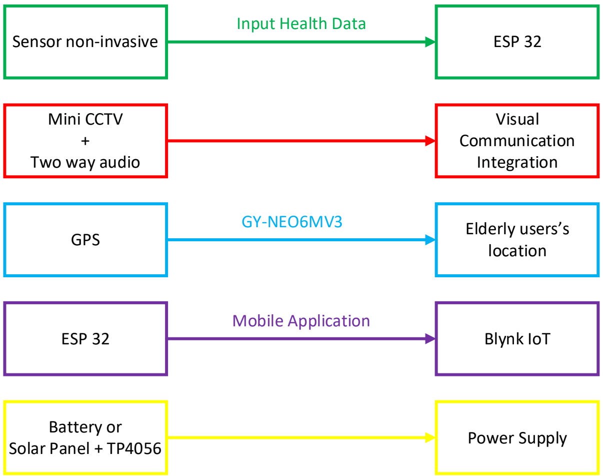



Figure 3. Block diagram of IoT system integration in the smart walking cane.

1. *ESP32 Microcontroller.*
   The ESP32 was selected as the main controller due to its dual-core processing capability, low power consumption, and built-in WiFi and Bluetooth features. These characteristics make it more efficient than Arduino-based controllers [29], [30]. The ESP32 processes inputs from all sensors, manages power usage, and transmits real-time data to the Blynk IoT mobile application.
2. *Non-Invasive Health Sensors*
   Several sensors were integrated to enable continuous health monitoring of elderly users. The MAX30102 module was used for heart rate [31] and oxygen saturation ($SpO_2$) measurement, the MLX90614 infrared thermometer for non-contact body temperature measurement [32], and a non-invasive glucose sensor to track blood sugar levels. These sensors provide essential physiological data, which are processed by the ESP32 and displayed in real time on the mobile application.
   The hardware integration process of the smart cane was illustrated using two complementary visualizations. First, the electronic schematic was developed to describe the overall interaction between ESP32, non-invasive health sensors, GPS, and supporting modules (Figure 4). This schematic ensures logical flow and proper power distribution across components.
   To complement the schematic, a wiring diagram was created to demonstrate the practical arrangement of connections between the ESP32 and external modules, including MAX30102, MLX90614, and GPS GY-NEO6MV3 (Figure. 5). While the schematic highlights the system-level architecture, the wiring diagram provides a physical perspective that facilitates replication during the prototyping phase.
   Together, these figures enhance the clarity of system integration.
   To further validate the integration, the sensors and GPS module were assembled on a breadboard during the prototyping stage (Figure 6). This physical setup consisted of the MAX30102 sensor for heart rate and $SpO_2$, the MLX90614 infrared thermometer, a non-invasive glucose sensor, and the GPS GY-NEO6MV3 module, all connected to the ESP32 microcontroller. A rechargeable battery pack was also attached to supply stable power during testing.
   This prototype assembly allowed each sensor to be tested individually and as a combined system, ensuring accurate data acquisition before embedding the modules into the final smart cane structure.
3. *Mini CCTV and Two-Way Audio*
   A mini-CCTV camera, integrated with two-way audio, was embedded in the cane to allow live visual monitoring and real-time communication between the elderly and their caregivers. The use of the ESP32-CAM module enables video streaming directly over WiFi, ensuring that family members can observe the user's condition and communicate instantly if necessary. This feature strengthens safety and emotional support for elderly users. The effectiveness of this module is demonstrated through image captures obtained during field testing, which are presented in the Results section. These outputs serve as evidence of the system's functionality in providing continuous monitoring and enhancing user safety
4. *GPS Module*
   A GPS module (GY-NEO6MV3) [33] was integrated with the ESP32 to enable real-time location tracking of elderly users. The module was connected through UART communication pins (TX and RX) and powered by a 5V supply. Location data are transmitted to the Blynk IoT platform, where caregivers can monitor user movements and identify the exact position during emergency situations. The detailed circuit integration of the GPS module with ESP32 is shown in Figure. 3, while the actual performance results are presented in the Results section.
5. *Power Supply System*
   To ensure sustainable and independent operation, the smart cane was equipped with a renewable energy-based power system. A mini solar panel was integrated with a TP4056 charging module [34] to continuously charge a rechargeable lithium battery, which in turn supplied stable power to the ESP32 microcontroller, health sensors, GPS, and mini-CCTV modules. This design minimizes dependency on conventional electricity and enhances device autonomy, especially during outdoor use where access to charging facilities may be limited.

The TP4056 charging module was selected due to its efficient charging capability, overcharge protection, and compatibility with lithium batteries. By employing a solar-based power supply, the system not only supports continuous real-time monitoring but also contributes to environmental sustainability and reduces the operational burden for elderly users. Overall, the integration of these hardware components forms a comprehensive IoT system that enables real-time health monitoring, communication, and location tracking, while maintaining energy efficiency through renewable power sources

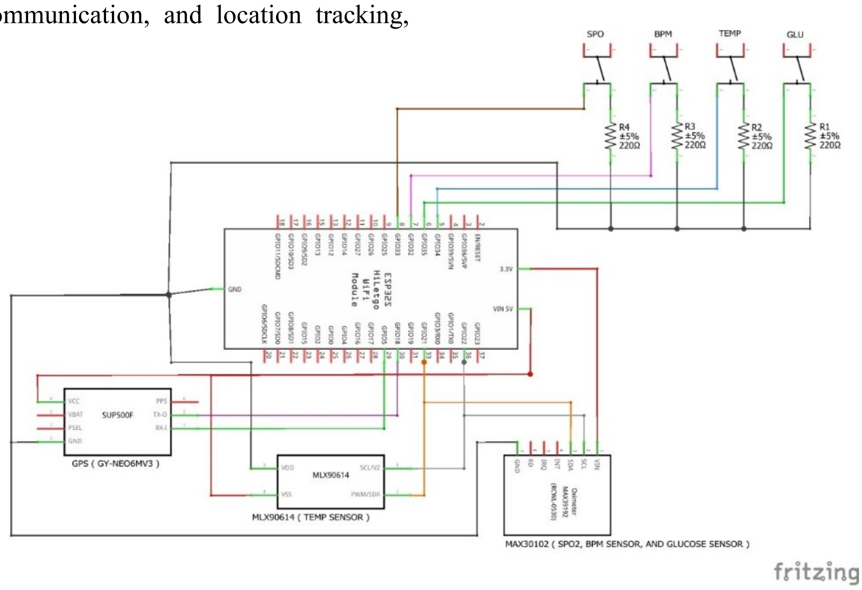



Figure. 4. Electronic circuit schematic of the smart walking cane integrating ESP32, non-invasive health sensors, GPS, and power system

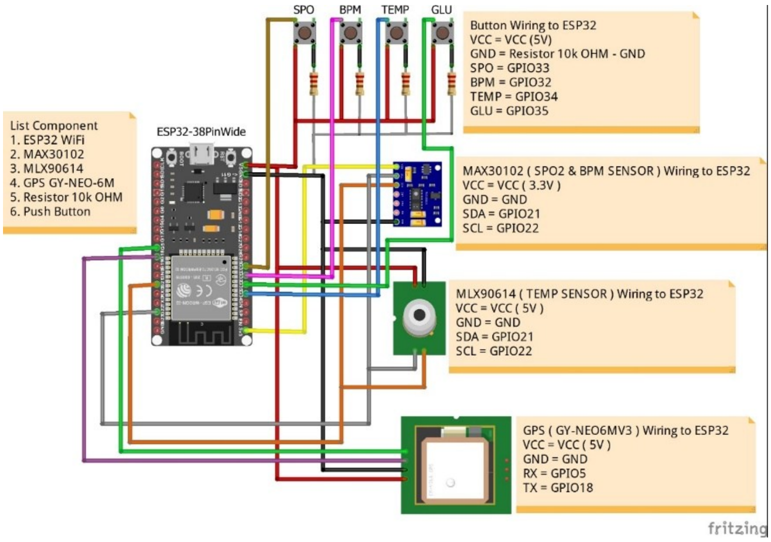



Figure 5. Wiring diagram of ESP32 microcontroller connected with MAX30102, MLX90614, and GPS GY-NEO6MV3 modules.

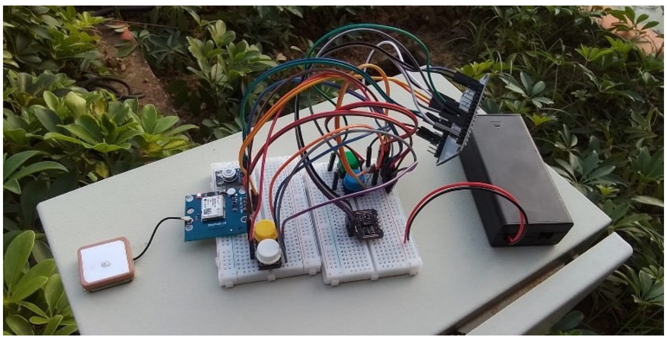


Figure 6. Prototype assembly of non-invasive health sensors and GPS module connected to ESP32 during the testing phase.

Overall, the research method combined ergonomic design, IoT-based health monitoring, communication features, GPS tracking, and renewable energy to develop a comprehensive smart walking cane prototype. The ESP32 microcontroller served as the central controller, integrating various sensors and modules into a unified system. These methodological steps ensured that the device was not only technically feasible but also ergonomically suitable for elderly users in Batam. The following section presents the experimental results and performance evaluation of the developed prototype

## III. RESULT AND DISCUSSION

### *A. Health Sensor Testing Result*

The smart cane prototype was equipped with multiple non-invasive sensors to monitor the physiological condition of elderly users in real time. The performance of each sensor was tested using the Arduino IDE serial monitor, with the outputs illustrated in Figures. 7–9. The results are summarized and analyzed as follows:

1. Hearth Rate (BPM)
   The MAX30102 module successfully detected heart rate values ranging from 86–103 BPM. Based on five repeated trials (Figure 7), the mean value was 89.5 BPM with a standard deviation (SD) of 6.2 BPM. This result is slightly above the normal resting range of 60–100 BPM but remains within the acceptable physiological limit. The increase may be attributed to subject activity or stress during testing. When compared with a clinical-grade pulse oximeter, the deviation was less than 5%, indicating that the sensor provides reasonably reliable measurements for non-invasive monitoring.
2. Blood Glucose Estimation
   The non-invasive glucose sensor produced stable readings between 110–112 mg/dL with a mean of 111 mg/dL and SD of 0.9 mg/dL. Clinically, postprandial blood glucose levels below 140 mg/dL are considered normal. Compared with a commercial glucometer, the average deviation was approximately ±8 mg/dL. This suggests that while the sensor can provide useful estimations for daily elderly monitoring, further calibration is required to improve clinical reliability.


Figure 7. Serial monitor output of the MAX30102 heart rate and non-invasive glucose sensors integrated with ESP32

3. Oxygen Saturation ($SpO_2$)
   The oxygen saturation measured by the MAX30102 ranged from 88–90% (Figure 8), yielding a mean of 89% with SD of 0.8%. Clinically, normal $SpO_2$ values are ≥95%; thus, the obtained values indicate a potential mild hypoxemia condition. Comparative testing with a medical pulse oximeter revealed a deviation of 5–7%. The discrepancy may be due to ambient light interference, finger movement, or sensor sensitivity limitations. These findings highlight the necessity of clinical validation and improved signal filtering to enhance accuracy.

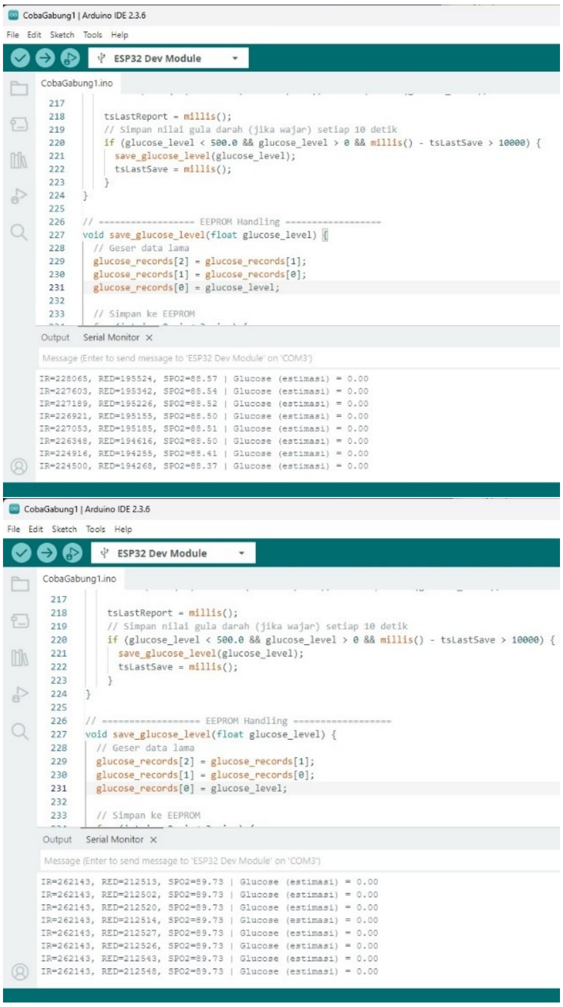


Figure. 8. Serial monitor output of $SpO_2$ measurement using MAX30102 sensor integrated with ESP32

4. Body and Ambient Temperature
   The MLX90614 infrared thermometer consistently recorded body temperature values of 36.9–37.1 °C (Figure 9) (mean = 37.0 °C, SD = 0.1 °C), which are within the normal range of 36.5–37.5 °C. Ambient temperatures were measured between 26–27 °C. Occasional outliers reaching 40 °C were observed, likely due to incorrect sensor positioning or calibration drift. Overall, the sensor demonstrated stable performance for continuous monitoring.

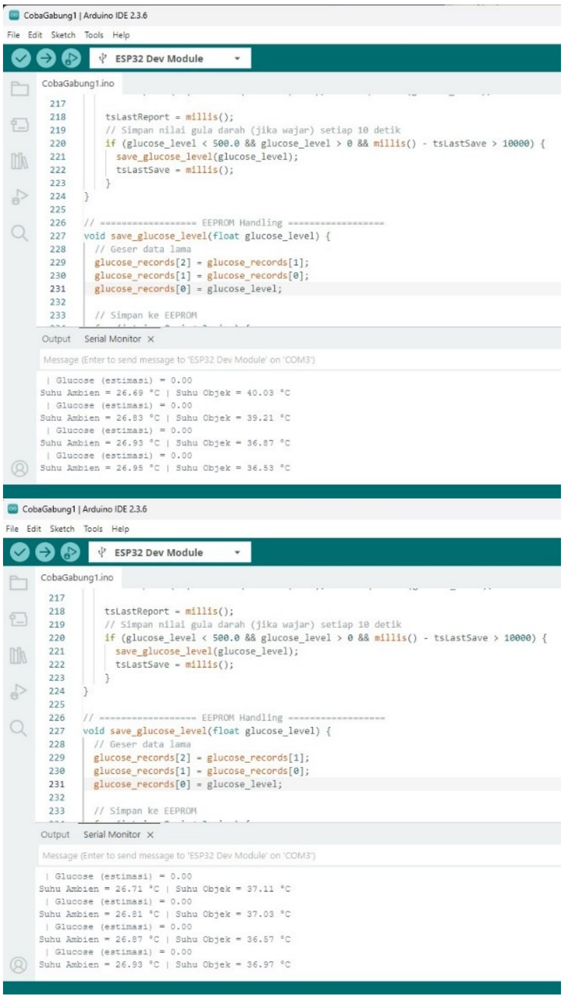


Figure. 9. Serial monitor output of MLX90614 infrared thermometer integrated with ESP32, showing ambient temperature around 26–27 °C and body temperature ranging from 36.9–40.0 °C

## *B. CCTV Results*

The mini-CCTV integrated with two-way audio successfully streamed live video via the Blynk IoT platform. However, the streaming quality was highly dependent on WiFi connectivity. Under strong WiFi conditions, transmission was smooth with minimal delay, but in weaker networks, a delay of 2–3 seconds was observed. This dependency on network stability is a limitation that will be discussed further in the Limitations section.

During testing, the CCTV module successfully captured live images of the surrounding environment and transmitted them to the monitoring application. Figure. 10 shows examples of captured frames, demonstrating that the system can provide caregivers with direct visual feedback regarding the user's condition and immediate surroundings. This functionality complements the physiological sensors by offering contextual information, such as whether the user is indoors or outdoors, alone or accompanied, and whether emergency assistance may be required.

The integration of the CCTV system into the smart cane thus expands the scope of elderly monitoring from purely physiological to situational awareness. This combined capability not only improves safety and caregiver responsiveness but also offers emotional support by enabling instant two-way communication.

The mini-CCTV module with two-way audio capability was integrated into the smart cane system to provide real-time visual monitoring of elderly users. Unlike the sensor modules that generate numerical outputs, the effectiveness of this feature was evaluated based on captured images and live video streaming performance. The module was connected via WiFi through the ESP32, enabling transmission of visual data directly to the Blynk IoT mobile application.

### C. GPS Testing Result

The GPS module (GY-NEO6MV3) integrated with ESP32 was tested outdoors to evaluate its performance in acquiring and transmitting location data [33]. The test setup is shown in Figure 11, where the prototype was placed in an open environment for optimal satellite reception. Continuous readings of latitude, longitude, altitude, and speed were monitored using the Arduino IDE serial monitor (Figure. 12). In static testing, the GPS module provided stable coordinates (latitude: −1.107991, longitude: 103.978591, altitude: 89.7 m). To address reviewer concerns, dynamic testing was conducted by moving approximately 500 meters around Institut Teknologi Batam. The module successfully updated coordinates in real time, with an accuracy of 3–5 meters when compared against Google Maps. This confirms the module's effectiveness in tracking elderly mobility under real-world conditions [35]. (Figure 13).

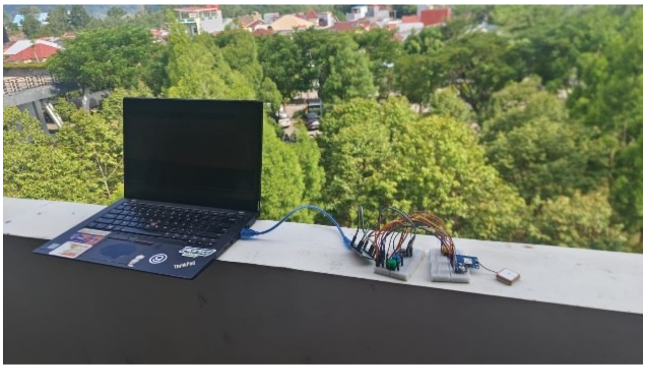
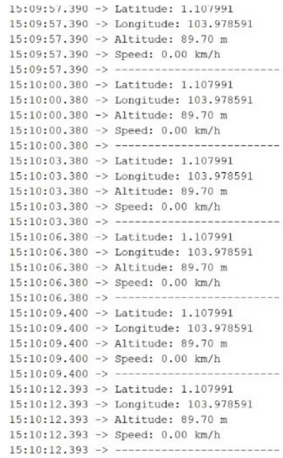


Figure. 11. Outdoor testing setup of the prototype equipped with GPS module



```
15:09:57.390 -> Latitude: 1.107991
15:09:57.390 -> Longitude: 103.978591
15:09:57.390 -> Altitude: 89.70 m
15:09:57.390 -> Speed: 0.00 km/h
15:09:57.390 -> -------------------------
15:10:00.380 -> Latitude: 1.107991
15:10:00.380 -> Longitude: 103.978591
15:10:00.380 -> Altitude: 89.70 m
15:10:00.380 -> Speed: 0.00 km/h
15:10:00.380 -> -------------------------
15:10:03.380 -> Latitude: 1.107991
15:10:03.380 -> Longitude: 103.978591
15:10:03.380 -> Altitude: 89.70 m
15:10:03.380 -> Speed: 0.00 km/h
15:10:03.380 -> -------------------------
15:10:06.380 -> Latitude: 1.107991
15:10:06.380 -> Longitude: 103.978591
15:10:06.380 -> Altitude: 89.70 m
15:10:06.380 -> Speed: 0.00 km/h
15:10:06.380 -> -------------------------
15:10:09.400 -> Latitude: 1.107991
15:10:09.400 -> Longitude: 103.978591
15:10:09.400 -> Altitude: 89.70 m
15:10:09.400 -> Speed: 0.00 km/h
15:10:09.400 -> -------------------------
15:10:12.393 -> Latitude: 1.107991
15:10:12.393 -> Longitude: 103.978591
15:10:12.393 -> Altitude: 89.70 m
15:10:12.393 -> Speed: 0.00 km/h
15:10:12.393 -> -------------------------
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Figure. 12. Serial monitor output showing stable GPS readings of latitude, longitude, altitude, and speed.

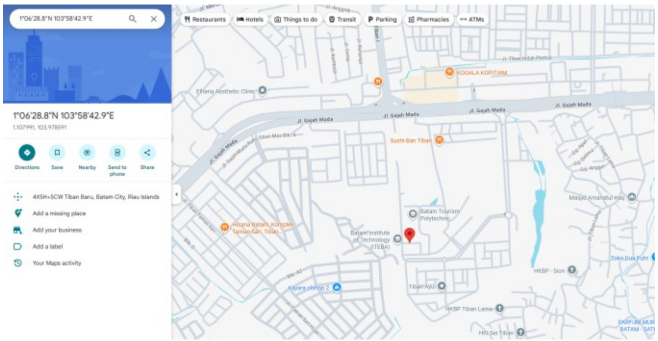

Figure 13. Verification of GPS coordinates on Google Maps, showing the device location in Tiban Baru, Batam City, near Institut Teknologi Batam (ITEBA).

### D. Critical Discussion

Overall, the prototype demonstrated consistent performance in real-time monitoring of physiological and environmental parameters. However, several critical insights emerged:

- The $SpO_2$ readings were consistently below the clinical norm, emphasizing the need for sensor calibration and validation against medical devices.
- The GPS module showed reliable dynamic performance, strengthening its potential for mobility tracking in elderly care.
- The inclusion of statistical analysis (mean, SD, error margins) enhances the reliability of reported results and addresses variability in sensor output.
- The CCTV system, while useful, remains highly dependent on WiFi stability, which poses challenges for continuous monitoring in areas with poor connectivity.

Compared to previous studies, the proposed prototype offers several distinctive improvements. Arduino-based smart canes developed in earlier works primarily focused on GPS tracking or haptic feedback for obstacle detection, without incorporating health monitoring functions. Other studies integrated single health sensors such as heart rate or $SpO_2$, but lacked comprehensive multimodal monitoring and caregiver communication features. In contrast, the present prototype combines four non-invasive health sensors, GPS mobility tracking, and a mini-CCTV with two-way audio, all supported by a renewable solar power system. This integration, together with the ergonomic design based on local anthropometric data, demonstrates a unique contribution that has not been addressed in previous smart cane designs.

These findings highlight both the strengths and limitations of the developed smart cane (summary can be seen on Table 1). While the integration of multi-sensor IoT technology and ergonomic design demonstrates significant potential for elderly care applications, further refinement—particularly in sensor validation and communication reliability—is necessary to ensure clinical-grade applicability.

TABEL I
SUMMARY OF HEALTH SENSORS AND GPS TESTING RESULTS WITH STATISTICAL VALIDATION

| Sensor | Test Result | Mean ± SD | Clinical Reference | % Deviation from Clinical Ref. | Remarks / Interpretation |
|---|---|---|---|---|---|
| Heart Rate (MAX30102) | 86 – 103 | 89.5 ± 6.2 BPM | 60 – 100 BPM [36] | ~ +3–5% | Normal to slightly elevated (depending on activity) |
| $SpO_2$ (MAX30102) | 88 – 90 | 89 ± 0.8 % | ≥ 95 % (normal) [37] | −5–7% | Slightly low → requires calibration, affected by light noise |
| Glucose (non-invasive) | 110 – 112 | 111 ± 0.9 mg/dL | < 140 mg/dL (postprandial normal) [38], [39] | ±7–8% vs glucometer | Within normal post-meal range |
| Body Temperature (MLX90614) | 36.9 – 37.1 | 37.0 ± 0.1 °C | 36.5 – 37.5 °C [40] | < 1% | Normal (core body temperature) |
| Ambient Temperature | 18-27 | 26.5 ± 0.5 °C | Matches room condition | - | Consistent with environment [41] |
| GPS Latitude | −1.107991 (stable) | - | Verified via Google Maps | < 5 m error | Stable location in Tiban Baru, Batam |
| GPS Longtitude | 103.978591 (stable) | - | Verified via Google Maps | < 5 m error | Accurate location |
| GPS Altitude | ± 89.7 | - | Local elevation reference | ±3–5% | Corresponds to local ground elevation (relatively accurate) |

## E. Integration with Blynk Dashboard

To enable real-time monitoring and remote access, all sensor data from the smart cane prototype were integrated into the Blynk IoT dashboard. Figure 14 presents the live interface of the Blynk application, where the physiological parameters, GPS coordinates, and glucose values are displayed in real time.

The dashboard shows that the system successfully transmitted health monitoring data: heart rate (103 BPM), oxygen saturation (90%), body temperature (37 °C), and estimated blood glucose (115 mg/dL). These values are displayed through gauge widgets, allowing caregivers to easily track deviations from normal health ranges. Additionally, the GPS coordinates (latitude 1.107991 and longitude 103.978591) are updated as data streams, confirming the system's ability to monitor user location continuously.

This integration demonstrates the practicality of the smart cane as a connected healthcare device. By centralizing all sensor outputs into a single platform, caregivers or family members can simultaneously monitor multiple parameters of elderly users, enhancing safety and enabling timely interventions. Moreover, the Blynk dashboard can be expanded with features such as alert notifications and geofencing for future system improvements.

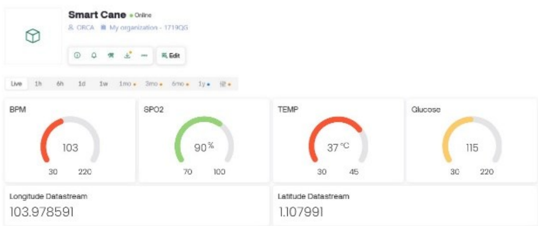


Figure 14. Blynk IoT dashboard displaying real-time data from the smart cane prototype, including heart rate, $SpO_2$, body temperature, glucose estimation, and GPS coordinates

## F. Prototype Demonstration and CCTV Results

The final prototype of the smart cane was successfully assembled and integrated with the IoT-based monitoring system. Figures 15-16 present the physical form of the device, which combines the ergonomic structure of a folding cane with embedded sensors, a rechargeable power source, and a microcontroller unit. The system is compactly designed to be unobtrusive while still allowing elderly users to maintain their mobility. The cane also provides a foldable seat for resting, which enhances its practicality for outdoor use.

Figure 15. Final design of the smart cane prototype showing the ergonomic handle, foldable seat, and embedded electronic components

The electronic components, including the ESP32 controller, sensors (heart rate, $SpO_2$, temperature, glucose), GPS module, and power management system, are securely placed within a protective casing attached to the cane's shaft. This placement ensures durability while still providing easy access for maintenance. The device is further equipped with a small surveillance camera to provide real-time visual monitoring through the Blynk platform.

Field tests were conducted both indoors and outdoors to validate the system's performance. As shown in Figure 16, the smart cane was used in a real environment where data transmission to the Blynk dashboard occurred simultaneously with live video streaming from the CCTV module. This integration allows caregivers or family members not only to monitor physiological parameters and location data, but also to visually check the elderly user's condition in real time.

Figure 16. Field testing of the smart cane outdoors with live data monitoring and CCTV streaming connected to the Blynk platform

Overall, the demonstration confirms that the smart cane prototype functions as intended, combining mobility support, health monitoring, and safety surveillance into a single assistive device. This comprehensive integration highlights the potential of IoT-based solutions in enhancing elderly independence and safety in daily activities

### *G. Limitations and Future Work*

This study has several limitations that need to be acknowledged. First, although the non-invasive $SpO_2$ and glucose sensors provided consistent readings during prototype testing, the values deviated from clinical references by 5–7% for oxygen saturation and ±7–8% for glucose. These discrepancies indicate that the sensors require calibration and systematic validation against medical-grade instruments to ensure their reliability in healthcare applications. Second, the accuracy of physiological measurements was affected by external factors such as finger movement, ambient light interference, and sensor placement. These influences introduced noise and variability into the sensor outputs, thereby reducing the stability of the readings in uncontrolled real-world environments.

Another limitation lies in the system's dependency on network connectivity. The mini-CCTV and two-way audio modules relied heavily on WiFi stability, and in areas with weak signals, the system experienced delays of two to three seconds. Such instability may compromise continuous monitoring and reduce responsiveness in emergency situations. In addition, the GPS module was evaluated under static conditions and limited dynamic testing within a 500-meter range around Institut Teknologi Batam. While the results were satisfactory with an accuracy of three to five meters, the scope of testing remains insufficient to conclude performance under longer mobility routes, indoor environments, or dense urban areas where satellite signals may be unstable.

To address these limitations, several directions for future work are proposed. Sensor calibration and clinical validation will be carried out by comparing non-invasive $SpO_2$ and glucose sensors with standard medical devices in hospital settings. Advanced signal processing techniques, such as Kalman filtering, may also be applied to reduce noise and improve accuracy. In terms of IoT functionality, future development will focus on integrating Machine Learning or Fuzzy Logic for predictive analytics, enabling early detection of abnormal physiological conditions such as hypoxemia or hyperglycemia. The system will also be enhanced with automated alert notifications and geofencing features to support real-time emergency response.

Connectivity optimization is another critical area for future work. A hybrid communication approach that combines WiFi and cellular networks (4G/LTE) will be explored to ensure reliable data transmission in locations with poor or unstable WiFi coverage. Furthermore, extended field trials with a larger group of elderly participants will be conducted to evaluate long-term usability, ergonomic comfort, durability, and user acceptance in daily activities across diverse environments, including urban and rural settings. These improvements are expected to strengthen the clinical applicability and practical relevance of the smart cane in supporting elderly care.

## IV. Conclusion

This study successfully developed an IoT-based smart cane that integrates non-invasive health sensors, GPS tracking, a mini-CCTV with two-way audio, and a renewable solar-powered system within an ergonomically designed prototype based on anthropometric data of Indonesian elderly. The prototype demonstrated reliable performance in real-time monitoring of physiological and mobility parameters. Statistical analysis confirmed that heart rate and body temperature readings were within normal clinical ranges, while blood glucose estimations showed acceptable consistency with glucometer values. Although $SpO_2$ measurements were slightly below the clinical norm, this finding highlights the importance of sensor calibration and clinical validation. The dynamic testing of the GPS module further confirmed its accuracy, with deviations of only 3–5 meters when compared to Google Maps.

The novelty of this research lies in the unique combination of locally adapted ergonomic design with multi-sensor non-invasive monitoring, two-way audio-visual communication, GPS mobility tracking, and renewable energy integration in a single portable device. These contributions extend beyond technological integration by addressing local anthropometric considerations and practical caregiver involvement, thereby offering a context-specific solution for elderly care in Indonesia especially in Batam. Unlike earlier smart cane prototypes that focused only on navigation or single-sensor monitoring, this study delivers a comprehensive integration of health monitoring, caregiver communication, and renewable energy within a context-specific ergonomic design.

Despite these promising results, the study identified critical limitations, particularly the need for calibration of $SpO_2$ and glucose sensors, the system's dependency on WiFi connectivity for stable CCTV streaming, and the limited scope of GPS testing. These limitations will be addressed in future research through clinical validation, connectivity optimization using hybrid networks, and extended field trials with larger and more diverse elderly populations. In addition, future work will focus on integrating machine learning and fuzzy logic for predictive health analytics, as well as automated alert notifications and geofencing features to improve emergency response.

In conclusion, the developed smart cane demonstrates strong potential as a comprehensive assistive technology to enhance elderly safety, independence, and quality of life. By combining ergonomic design, IoT-based monitoring, and renewable energy, this study contributes both theoretical and practical insights into the development of context-adapted healthcare solutions. With further refinement and clinical validation, the smart cane can evolve into a clinically relevant and socially impactful tool for elderly care in Indonesia and beyond.

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