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Investigating an IoT-Integrated Cane System for Accurate Gait Analysis and Fall Detection

***Abstract**. Thailand has a population of 67 million, and the country has entered an aging society. According to the World Health Organization (WHO) statistics, 10% of the population is elderly (over 60 years old). For this reason, the IoT-Integrated Cane System is researched and implemented to enhance elderly mobility and safety. This research investigates the potential of an IoT-based cane system integrated with the GY-521 module and NB-IoT wireless communication device for gait analysis and fall detection among the elderly. The proposed smart IoT cane brings the concept of a 3-axis accelerometer with a range of -10 to +10 g average. The three orthogonal parts of the acceleration caused by gravity are measured. Namely, By collecting and analyzing sensor data in diverse scenarios – walking on flat, stair, and sloped surfaces and during a walk-fall-walk test – the study evaluates the sensor's ability to discern movement patterns. Statistical analysis, including Coefficient of Variation (CV) calculation, validates the sensor's accuracy in detecting and differentiating various scenarios. Visual representations enhance our understanding of the sensor's responses. The outcomes endorse its utility in gait analysis, fall detection, and activity recognition, yielding insights for improving the safety and well-being of the elderly.*

***Streszczenie.** Tajlandia liczy 67 milionów mieszkańców, a kraj ten wkroczył w starzejące się społeczeństwo. Według statystyk Światowej Organizacji Zdrowia (WHO) 10% populacji to osoby starsze (powyżej 60 roku życia). Z tego powodu system IoT-Integrated Cane jest badany i wdrażany w celu zwiększenia mobilności i bezpieczeństwa osób starszych. Badania te badają potencjał systemu laski opartego na IoT zintegrowanego z modułem GY-521 i bezprzewodowym urządzeniem komunikacyjnym NB-IoT do analizy chodu i wykrywania upadków wśród osób starszych. Proponowana inteligentna laska IoT wprowadza koncepcję 3-osiowego akcelerometru o średnim zakresie od -10 do +10 g. Mierzone są trzy prostopadłe części przyspieszenia spowodowanego grawitacją. Mianowicie, poprzez gromadzenie i analizowanie danych z czujników w różnych scenariuszach – chodzenie po płaskich, schodowych i pochyłych powierzchniach oraz podczas testu chodu, upadku i chodzenia – badanie ocenia zdolność czujnika do rozpoznawania wzorców ruchu. Analiza statystyczna, w tym obliczenie współczynnika zmienności (CV), potwierdza dokładność czujnika w wykrywaniu i rozróżnianiu różnych scenariuszy. Reprezentacje wizualne poprawiają nasze zrozumienie reakcji czujnika. Wyniki potwierdzają jego przydatność w analizie chodu, wykrywaniu upadków i rozpoznawaniu aktywności, dając wgląd w poprawę bezpieczeństwa i dobrego samopoczucia osób starszych. (**Badanie systemu laski zintegrowanego z IoT w celu dokładnej analizy chodu i wykrywania upadków**)*

Keywords: IoT-based cane system, gaiit analysis, fall detection, elderly mobility, sensor integration.
Słowa kluczowe: System laski oparty na IoT, analiza chodu, wykrywanie upadków, mobilność osób starszych, integracja czujników.

Introduction

At present and soon, our global society is experiencing an increasing rate of aging population in many countries [1-2]. As a result, the elderly are still walking for various activities. Important social by traveling to various places. However, the environment in which these trips, such as indoor or outdoor corridors, is [3]. There may be obstacles that do not contribute to the safety of walking smoothly. This concern of the elderly community is that they can use walking sticks that help them move with extra care. Therefore, in dealing with these challenges, the future smart cane of the elderly should be developed to respond to this global context. These modern walking sticks can not only facilitate movement. However, it also has an intelligent feature that can detect possible falls. This intelligent system can notify close caregivers promptly.

In the context of this research, many studies have applied the fall detection device with the GY-521 sensor, which easily recognizes the direction of movement to identify changes in the sensor's X, Y, and Z axis. In addition, the Internet of Things (IoT) system is integrated with such a sensor system, which can be connected to the cloud, such as Wi-Fi. However, this approach is also suitable for indoor areas with Wi-Fi signals [7-9]. The cellular system is a communication system that supports mobility in all areas and can promote eliminating such problems. However, the drawback of cellular systems is the high-power technology. In contrast, in current research, Low Power Wide Area Network (LPWAN) technology has been used to solve such problems, especially wireless communication systems with NB-IoT. These emerging LPWAN technologies have the potential to connect communications by addressing existing energy efficiency challenges. [10].

The primary objective of this research is to comprehensively investigate the efficacy of an IoT-based cane system equipped with the GY-521 module and NB-IoT wireless communication device for gait analysis and fall detection among the elderly population. By meticulously collecting and analyzing sensor data across various scenarios, including walking in flat, stair, and slope areas, as well as during a walk-fall-walk test, this study aims to assess the sensor's response to distinct movement patterns. Through statistical analysis, including calculating the Coefficient of Variation (CV), this research seeks to establish the system's ability to differentiate between different movement scenarios and accurately detect critical events. The findings of this study contribute to advancing the understanding of wearable IoT technology in enhancing the safety and well-being of elderly individuals in different mobility situations.

Hardware Description

The hardware configuration includes a cane, Arduino microcontroller, GY-521 sensor, and NB-IoT wireless communication device. This amalgamation forms a cohesive solution for enhancing elderly mobility and safety. The cane offers physical support while seamlessly housing embedded technology. The microcontroller acts as the central processing unit, coordinating interactions. The GY-521 breakout board, coupled with Arduino's software, measures acceleration and angular velocity. With a 3-axis accelerometer and gyroscope, it facilitates comprehensive data collection for versatile applications. This setup empowers holistic support, fostering improved daily mobility and safety for the elderly. The NB-IoT communication is facilitated through AIS, a prominent company, utilizing open libraries compatible with the Quectel BC95 and Quectel BC95-G modules. These modules operate within the Band 8 frequency range (900MHz) and employ the UDP and CoAP protocol stack for seamless and efficient communication. The hardware shows in Figure 1.

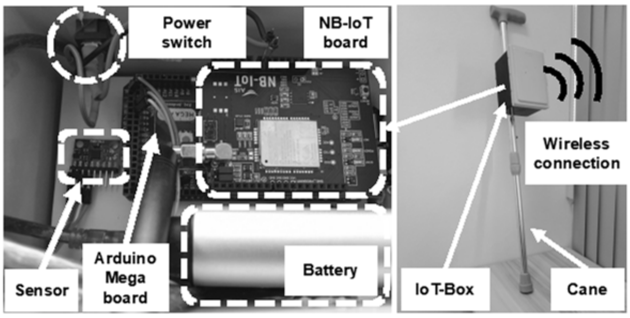

Fig.1. Hardware configuration.

Firmware Description

In our system, the GY-521 module takes on the pivotal role of fall detection, with an exclusive focus on the "Ay" variable for analysis. This specific variable, which captures vertical acceleration data, serves as the linchpin in identifying potential falls. The flowchart shows in Figure 2.

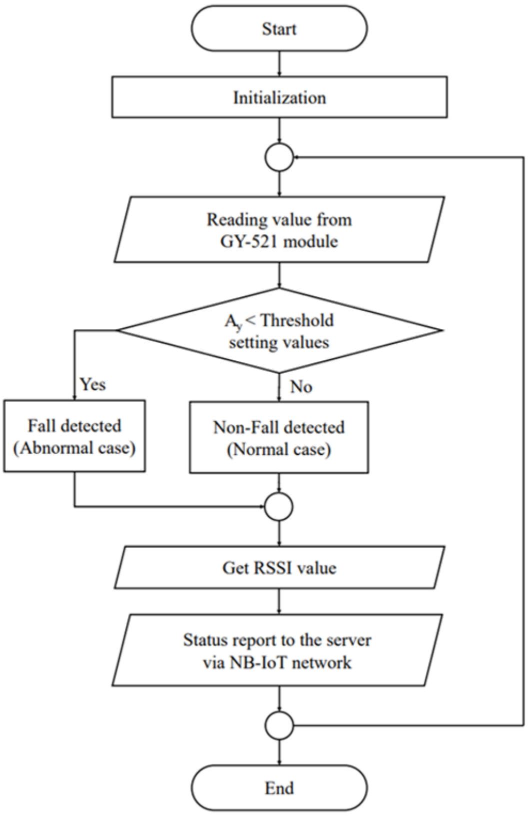

Fig.2. The flowchart of the proposed method.

Through continuous monitoring and sophisticated algorithms, the system discerns changes in the "Ay" values that could indicate a fall event, ensuring precision and reliability in detection. Additionally, our system incorporates the Received Signal Strength Indicator (RSSI) from the NB-IoT wireless communication device. This feature enables ongoing assessment of the wireless signal's strength and quality. By constantly measuring the RSSI value, the system gains insights into the stability of the wireless connection. Should the RSSI value drop below a predefined threshold, the system triggers a user warning mechanism.

RSSI Testing

The RSSI testing phase of our IoT-based Cane system encompassed a thorough evaluation conducted across five distinct areas surrounding the building. These areas were strategically chosen to provide a comprehensive assessment of the wireless signal strength and quality in various scenarios, ensuring the reliability and robustness of our communication infrastructure. The RSSI testing plan shows in Figure 3.

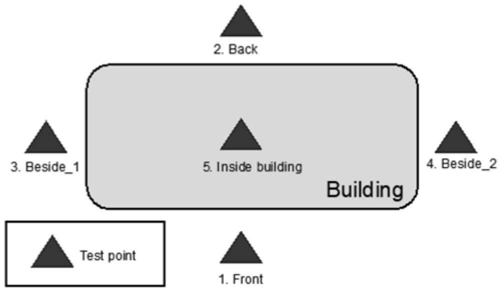

Fig.3. RSSI measurements in Differences Scenarios Within the Building Area.

During the RSSI testing conducted in various areas around the building, we obtained the following signal strength measurements as shown in Table 1.

Table 1: The time-based analysis in the system

Areas in the Building	RSSI (dBm)			
	1	2	3	Average
Front	-57	-57	-57	-57.00
Back	-69	-69	-71	-69.67
Beside_1	-69	-69	-71	-69.67
Beside_2	-55	-55	-55	-55.00
Inside	-73	-75	-75	74.33

The consistent signal strength in the "Front" and "Beside_2" areas suggests reliable connectivity in these locations. However, the weaker signal strengths observed in the "Back" and "Beside_1" areas might indicate potential signal degradation due to obstacles or distance. In the "Inside" area, the higher RSSI values could indicate challenges in signal penetration through building walls, resulting in slightly weaker connectivity. These results will be crucial in optimizing the placement and functionality of the IoT-based Cane system, ensuring that users experience dependable communication across various scenarios and locations.

IoT-Based Cane Sensing Data Analysis

Recording GY-521 data for various scenarios, such as flat walking, stair descent, slope walking, and a fall in a flat area, involves collecting and analyzing acceleration and angular velocity data from the sensor. The overview of data recording for scenarios (see in Figure 4):

The process of data collection and analysis involves a meticulous review of the recorded values for each scenario, which includes identifying variations and patterns within the Ax, Ay, Az, Gx, Gy, and Gz readings. The overarching objective is to assess the degree of alignment between the sensor data and different movement scenarios. As part of the comprehensive methodology, the recorded data is systematically conveyed to the AIS Cloud platform for centralized storage and analysis. This platform ensures secure and efficient data management. The outcomes of this in-depth analysis are meticulously documented and elegantly presented in Table 2 - 5, providing a tangible representation of the sensor's response to distinct movement scenarios. Moreover, the Coefficient of Variation (CV) is calculated for each scenario using the provided data. The CV is determined by dividing the standard deviation by the mean and then multiplying by 100 to obtain a percentage.

$$CV = \frac{\sigma}{\mu} \times 100 \tag{1}$$

(a) (b) (c) (d)

Fig.4. Data collection walking scenarios (a) Flat area (b) Stair area (c). Slope area and (d) Fall scenario in a flat area.

The results discuss the findings of the sensor data collected in various walking scenarios using statistical analysis. Each scenario includes walking in a flat area, stair area, slope area, and the walk-fall-walk test in a flat area.

(a) Walking in Flat Area: The dataset from walking in a flat area demonstrates relatively stable sensor readings. The average values of Ax, Ay, Az, Gx, Gy, and Gz remain consistent, with minimal standard deviations. This suggests that the GY-521 sensor module effectively captures the subtle and consistent body movements associated with walking on a level surface. The CV for these parameters is low, indicating a consistent pattern of motion.

(b) Walking in Stair Area: In the stair area walking dataset, notable variations in vertical acceleration (Ay) are observed, leading to higher standard deviations and CVs. This aligns with the expected vertical movements during stair descent. While angular velocity readings show minor variations, the CVs remain relatively low. These statistics highlight the sensor's sensitivity to vertical motion changes and potential applications in fall detection.

(c) Walking in Slope Area: Walking on a slope area elicits distinct changes in the dataset's statistics. Vertical acceleration (Ay) variations are more pronounced, contributing to higher standard deviations and CVs. Additionally, the CVs for Ax and Az may increase, reflecting adjustments to the sloped terrain. Angular velocity readings show subtle changes with low CVs, indicating controlled body orientation changes.

(d) Walk-Fall-Get-up Test in Flat Area: The walk-fall-walk test dataset demonstrates significant statistical shifts during the fall phase. Abrupt changes in acceleration and angular velocity readings lead to higher standard deviations and CVs, indicating substantial deviations from the walking patterns. In contrast, the subsequent walking phases exhibit statistics similar to the initial walking scenario, with low CVs.

In summary, statistical analysis reaffirms the sensor's performance across various walking scenarios. Stable sensor readings in a flat area, pronounced changes during stair descent and slope walking, and the drastic shifts during the fall phase of the test are all reflected in the statistics. These insights highlight the sensor's capability to differentiate movement patterns and detect critical events, demonstrating its potential in gait analysis, fall detection, and activity recognition applications.

Table 2: Data Recorded During Walking in a Flat Area.

No Test.	Ax	Ay	Az	Gx	Gy	Gz
1	0.39	9.87	0.52	-0.04	0.03	0.01
2	0.01	9.76	0.76	0.40	0.09	-0.01
3	1.68	8.81	-0.88	-1.11	0.45	-0.16
4	0.49	9.53	-0.45	0.64	-0.11	0.13
5	-0.33	9.88	1.35	0.14	0.09	0.19
6	1.37	10.12	-0.23	-1.53	-0.07	-0.52
7	0.10	9.57	0.95	-0.12	0.10	-0.07
8	0.65	9.77	-0.32	0.44	-0.59	0.04
9	1.10	9.22	-2.48	-1.05	0.10	-0.25
10	1.04	9.17	-1.16	-1.48	0.35	-0.16
CV (%)	**99**	**4**	**-591**	**-225**	**637**	**-257**

Table 3: Data Recorded During Walking in a Stair Area.

No Test.	Ax	Ay	Az	Gx	Gy	Gz
1	0.48	9.87	0.34	-0.02	-0.12	0.01
2	0.66	9.79	1.43	0.23	0.09	0.14
3	0.47	9.79	0.03	0.01	-0.41	0.10
4	0.50	9.79	-2.48	0.17	-0.49	-0.03
5	0.80	9.25	-0.80	-0.35	0.01	0.09
6	0.07	9.89	-0.29	-0.01	-0.04	0.00
7	-0.09	8.74	-0.67	-0.28	1.15	-0.15
8	0.35	9.88	1.15	0.13	-0.10	0.12
9	0.67	6.76	0.23	-0.36	0.84	-0.08
10	0.62	7.54	-0.78	-0.44	0.06	0.04
CV (%)	**61**	**12**	**-604**	**-266**	**519**	**388**

Table 4: Data Recorded During Walking in a Slope Area.

No Test.	Ax	Ay	Az	Gx	Gy	Gz
1	0.40	9.75	-0.14	-0.78	0.03	-0.20
2	0.43	9.20	0.74	-0.85	-0.11	0.00
3	0.93	9.25	-1.35	-0.87	0.30	-0.31
4	1.57	9.59	-1.58	0.42	-0.20	0.16
5	0.92	9.87	-1.02	-1.29	0.40	-0.24
6	1.91	9.40	-1.54	0.36	0.15	0.08
7	0.80	9.05	0.04	-0.77	0.40	-0.11
8	0.38	9.73	0.32	0.38	-0.19	0.31
9	2.38	9.20	-1.51	0.41	0.26	0.23
10	1.10	9.35	-2.14	-0.94	-0.16	-0.28
CV (%)	**63**	**3**	**-119**	**-176**	**278**	**-623**

Table 5: Data Recorded During 'Walk-Fall-Get Up' Sequence in a Flat Area.

No Test.	Ax	Ay	Az	Gx	Gy	Gz
1	2.37	9.02	-2.63	0.43	0.01	0.19
2	1.15	9.94	-0.64	-0.11	-0.60	0.00
3	1.17	10.85	1.05	0.33	-0.38	0.21
4*	-9.62	1.02	-1.53	-0.04	0.04	0.01
5*	-9.61	1.02	-1.57	-0.04	0.02	0.01
6*	-9.60	1.01	-1.58	-0.04	0.02	0.02
7*	-9.60	1.01	-1.58	-0.04	0.02	0.02
8	1.78	9.38	-2.01	-1.79	-0.33	-0.40
9	2.49	9.45	-0.56	0.35	-0.18	0.24
10	1.18	9.08	0.00	0.32	0.29	0.30
CV (%)	**-207**	**72**	**-97**	**-1018**	**-240**	**330**

The findings from Table 2 to Table 5 are depicted in Figure 5. Observed graph patterns align with numerical results, highlighting the sensor's effectiveness in capturing varied movement scenarios. Stable patterns in flat walking, distinct shifts during stair descent, slope walking, and significant deviations during falls underscore its potential for gait analysis, fall detection, and activity recognition. These visuals deepen our understanding of the sensor's responses to diverse mobility among the elderly.

The accelerometer sensor module performs two main tasks: It functions as an accelerometer, using the Ax, Ay, and Az axes to measure linear acceleration relative to the gravitational constant g. It can ascertain the sensor's inclination. This device serves to assess the magnitude of inertia in a gyroscope. However, this paper primarily concentrates on the application of linear acceleration. The study focuses on the detection of falls using the calculated principle of linear acceleration, which is described as follows [11]:

$$|A| = \sqrt{A_x^2 + A_y^2 + A_z^2} \tag{2}$$

However, the obtained results are shown different acceleration data in various cases, which are the flat area, stair area, slope area, and Walk-Fall-Get up area. These conditions are analyzed, which found that the acceleration data and unit of gravity in the condition of Walk-Fall-Getup are different compared to other tested conditions. Namely, the A_x value is lower down closely to -10 m/s^2. Moreover, the A_y is also reduced closely to 1 m/s^2 significantly.

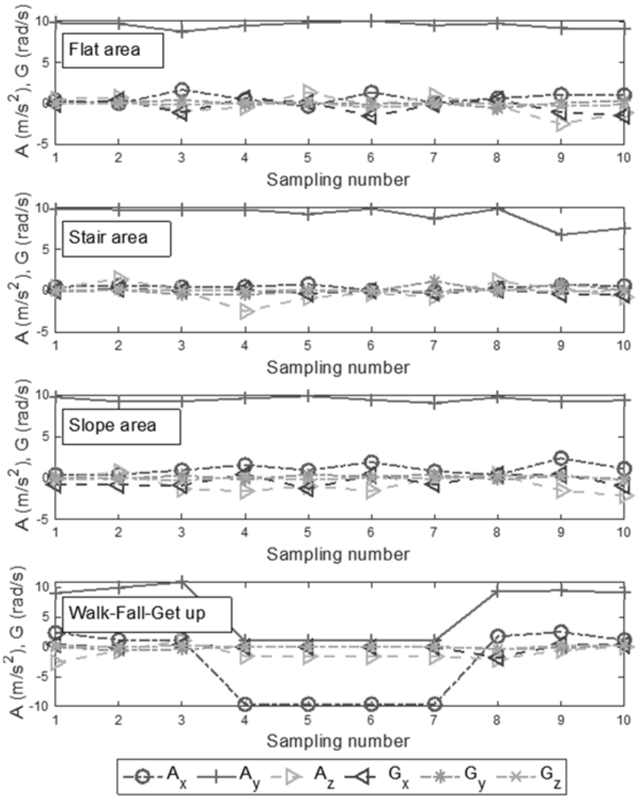

Fig.5. Walking demonstration of the sensor results.

Conclusion

This paper meticulously examined the capabilities of an IoT-based cane system equipped with the GY-521 module and NB-IoT wireless communication device in capturing and analyzing distinct movement scenarios. Through comprehensive data collection and rigorous analysis, the sensor's effectiveness was validated in differentiating patterns during walking in flat, stair, and slope areas, as well as in fall events. The results underscore its potential in gait analysis, fall detection, and activity recognition among the elderly population. Visual representations further enriched our comprehension of the sensor's responses to diverse mobility scenarios. This study contributes valuable insights towards enhancing safety and well-being for the elderly through wearable IoT technology.

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