Development of Fuzzy Algorithm as Mobility Aid for Blind Person Using Two Sensor Points

Visual Aid for Blind Person

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Abstract: White canes are an ideal choice for blind person to do independent mobility because of its relatively cheap price. However, whitecane has the disadvantage of only being able to identify objects in front of it when they have been touched and cannot provide a choice of direction. This study developed a prototype whitecane with a feature that can provide a choice of direction based on the results of identifying the distance of the object to its user. This prototype was designed and implemented using two ultrasonic sensors installed on the stick as a replacement for the spatial sensing system. Both distance data from the sensors are processed in the Arduino Nano microcontroller to carry out the Fuzzy process stages. Fuzzy input process, rule-based Fuzzy inference, and Defuzzification for decision output. The results of the decision are translated into voice information to the user. Experiments with three scenarios showed that the utilization of the system with constant contact O&M technique showed a success rate of 100% while the other two techniques were only 33.3%. So the constant contact O&M technique can support effective mobility for the use of assistive aids and can be developed into a new technique.

Keywords: Sensor, Fuzzy, Mobility, O&M, voice information.

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Introduction

World Heatlh Organization (WHO) data in 2022 shows that visual impairment affects around 2.2 billion people worldwide. The good news is, around 1 billion of them can be cured or managed through appropriate medical intervention. However, the rest require additional aids such as white canes, animals, or sighted companions to be able to carry out independent mobility activities (Bhatlawande et al., 2024; Tian et al., 2021; World Health Organization, 2023; Zhang et al., 2023). Therefore, this study is expected to provide new contributions by identifying factors that influence the success of white cane innovation and its impact on the blind, as well as providing insight into appropriate O&M techniques that can make humans independent.

The use of a white cane for independent mobility is the most appropriate because in addition to its relatively cheap price, it can be combined with the Orientation & Mobility (O&M) technique. However, the combination of the use of a white cane and the O&M technique has disadvantages. The use of a white cane must first touch the object in order to provide information to its users. And the possibility of the touched object will be damaged and also dangerous for its users (health, cleanliness, injury, radiation, etc.). The use of animals such as dogs to assist independent mobility is considered inappropriate because in addition to its relatively expensive price, the social and environmental conditions of an area are not necessarily appropriate. Meanwhile, the use of humans as companions does not provide a solution for blind people to become independent (Chundury et al., 2022; Lahav et al., 2013; Madake et al., 2023; Montanha et al., 2016; Santos et al., 2021; Sanz et al., 2018).

Previous research has developed a smart whitecane that can help blind people with independent mobility. This smart whitecane is equipped with various sophisticated sensors such as cameras, ultrasonic sonar, laser, GPS-GSM, and others. These sensors work together to detect the surrounding environment, such as shape, obstacles, distance, and location. The information captured by the sensors is then processed by a small computer in the smart whitecane and translated into sound or braille text that is sent to the headset worn by the user. The camera is used to take pictures of the surrounding environment and then processed by the computer using artificial intelligence techniques with the YOLO dataset (Li et al., 2020) and tensorflow to recognize objects such as people, cars, or traffic signs (Jivrajani et al., 2023; Masud et al., 2022; Setiadi, 2020; Zhang et al., 2023). The ultrasonic sonar sensor emits sound waves and reflects echoes to measure the distance to surrounding objects. Meanwhile, the servo motor is used to move the sensor automatically (Cardillo et al., 2022; Meshram et al., 2019). The Inertial Measurement Unit (IMU) sensor is used to detect movement (Li et al., 2020), such as when the user rotates or swings the cane. This movement information can be used to provide directions to the user (Tanabe et al., 2023). GPS is used to determine the user's position. The Haversine algorithm is used to calculate the distance between the user's current position and a predetermined destination. This distance information is then conveyed to the user via voice or braille text (Ahmed et al., 2022; B et al., 2022; Guerrero et al., 2018; Meshram et al., 2019). Visible Light Communication (VLC) technology allows data to be sent via visible light. In this study, VLC was used to detect zebra crossings. The LED lights on the zebra crossing emit light signals that can be captured by the sensor on the stick. And if there is an object that blocks it will be considered as noise to be fixed by the fiber filter. This signal is then converted into sound information and sent to the headset. These signals are then converted into voice information and sent to the headset (Almajdoub & Siddiqui, 2024; Audomphon & Apavatjrut, 2020).

This study proposes innovation in visual aids by adding electronic features. This feature uses distance calculations from two sensors to inform the presence of objects in front of it without having to be touched. Furthermore, using the Fuzzy algorithm, the distance data is processed into voice signal information related to the decision of the direction of choice as a command that can be followed by the user.

Research Method

This research innovates by combining simulation and experimental technology to develop a navigation system for the visually impaired. This system utilizes ultrasonic sensors and Fuzzy algorithms to provide accurate and real-time feedback to users. The development process includes the design of hardware and software Fuzzy algorithms for data processing.

Hardware

The system hardware consists of two, namely mechanical and electronic hardware. Mechanical hardware is in the form of a box for placing electronic components. While electronic hardware consists of a combination of sensor components, data processors, and voice signal actuators.

Mechanics

This box is digitally designed using Autodesk Fusion 360 software. Its design is modular, allowing manual assembly without additional tools. This box, in addition to being used to place electronic components, can be mounted on a standard whitecane. The box design details are shown in Figure 1.

The box is ergonomically designed and easy to use. Consisting of four main components as shown in Figure 1(a), the box is equipped with special grips for the index finger on both sides, making it suitable for both left- and right-handed users. These grips help users better control the whitecane when performing O&M movements. In addition, the box is also equipped with a detachable sensor holder for easy installation and replacement of sensors. The control buttons on the box are designed in different shapes, such as a hole for charging, a circle for volume settings, a protrusion for the ON/OFF switch, and a sliding hole for locking the whitecane. This design makes the operation of the box more intuitive and easy to assemble by hand.

The overall design of the box, as shown in Figure 1(b), has been designed in accordance with the standards set by WHO. These standards cover aspects of weight, main function, and product identity. As a result, the box has a very light weight, which is only 78 grams without electronic components, far below the threshold of 295 grams. Although attached to the top of the white cane, this box does not reduce the function or characteristics of the white cane as an assistive device, and still maintains the identity of its user.

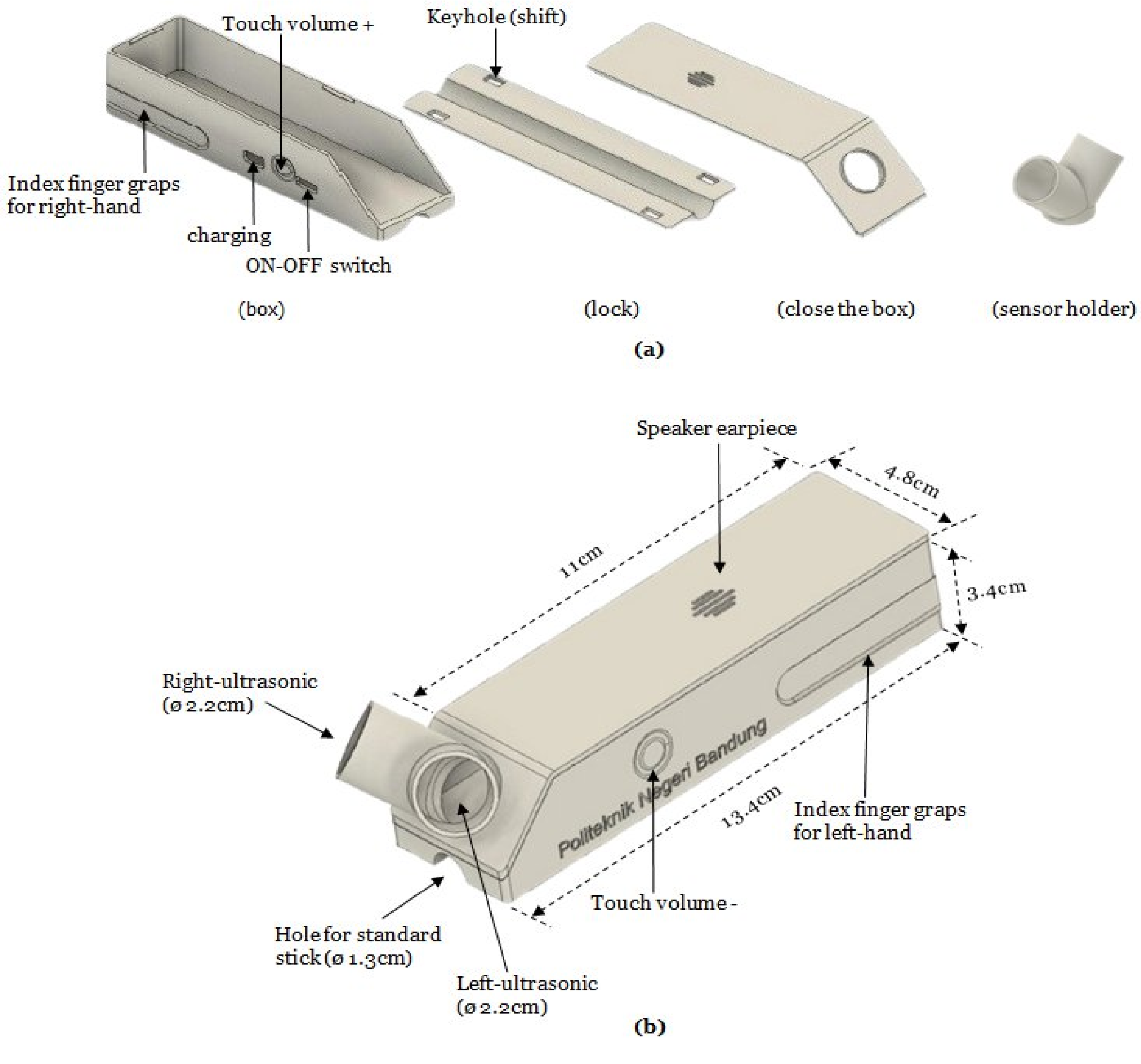

Figure 1. Box Design (a). Modular (b). Combination

Electronic

This electronic hardware is designed to help the visually impaired in their daily activities. Broadly speaking, this device consists of three main parts: input, process, and output as shown in Figure 2. The input part functions to collect information from the surrounding environment, such as the distance to the object in front of it, through the two installed sensors. In addition, there is a setting button that the user uses to operate the device. The process part uses a microcontroller (MCU) from the Arduino Nano platform to process the collected data. Finally, the output part will provide information to the user through voice signals.

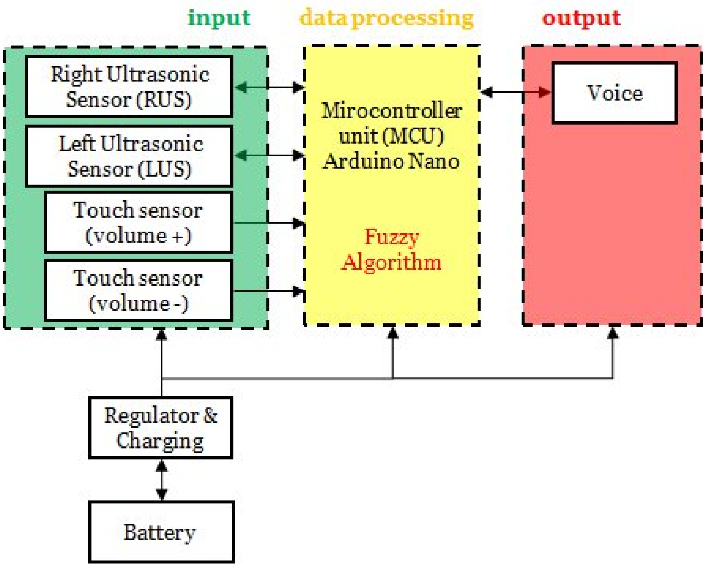

Figure 2. Electronic Hardware Block Diagram

The setting buttons consist of two, namely to increase the volume (volume +) and decrease the volume (volume -), both of which use touch sensors. The sound level is 1 to 30, the higher the value indicates the louder. When the slide switch is in the ON position, the system's sound output is automatically at the default. The sound volume mode is set to 4, namely default (15), normal (20), loud (25), and very loud (30).

The power supply system as the system's electronics source comes from 2xbatteries (3.7Vdc/600mAh). Before being distributed to the system, the battery current is passed through the ON-OFF switch. The battery, to be used by the sensor, touch, MCU, and voice components of the DF-mini player, must first have its voltage increased to 5 Vdc through the regulator. In addition, the regulator functions as a battery charger with its output set to 4.2Vdc. The charger can use a head and cable for Android smartphones.

The brain of this system is an MCU. This MCU is tasked with processing various data, such as the distance generated from measurements by the two ultrasonic sensors and the volume settings selected by the user. In addition, the MCU also determines when and how the information should be conveyed to the user via voice output. All connections between the electronic components in this system are as shown in Table 1.

Table 1 Electronic Components Configuration

No	MCU Pins	Components	Pins
1	D7	Right Ultrasonic Sensor	TRIG
	D8		ECHO
2	D9	Left Ultrasonic Sensor	TRIG
	D10		ECHO
3	D5	Volume +	I/O
4	D4	Volume -	I/O
5	D3	Voice DF-mini Player	Rx
	D2		Tx

Note: all Vcc, gnd pins for MCU and components are connected to the regulator output (Out+, Out-) which is first passed through the ON-OFF switch.

The audio signal output uses the voice DF-mini player component. The voice DF-mini player functions to read signal files stored on the mini SD-Card (mp3 format). The writing of the file sequence is as shown in Table 2.

Table 2 Sound File

No	Files	Voice	Symbol Information
1	0001.mp3	a Little to the Left	LL
2	0002.mp3	Left	L
3	0003.mp3	a little to the Right	LR
4	0004,mp3	Right	R
5	0005.mp3	beep	ALARM

Software

The software data processing method in this study uses the Fuzzy Sugeno algorithm with a Weighted Average (WA) output. The Fuzzy algorithm functions to process input data from both ultrasonic sensors (LUS & RUS) before finally producing an output signal to the user through an output component in the form of a sound signal. In its implementation, the Fuzzy algorithm has three steps for the decision-making process (fuzzification, inference, defuzzification). Details of the detection process to decision making are shown in Figure 3.

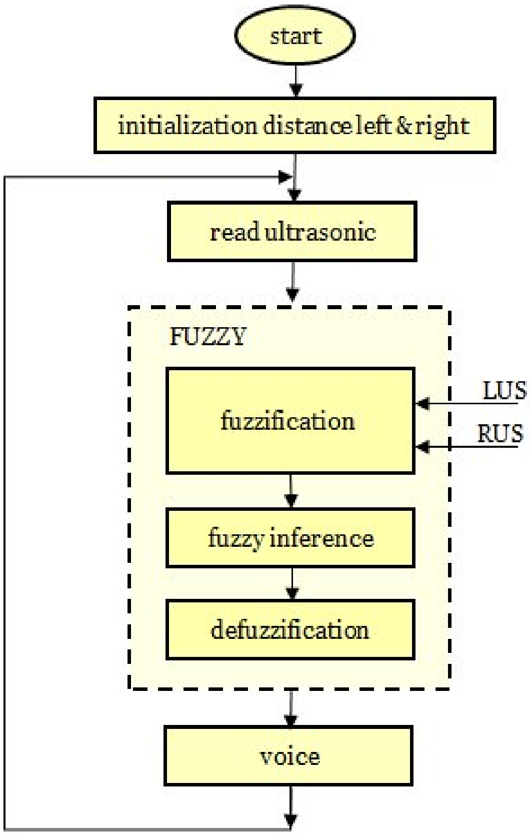

Figure 3. Fuzzy Algorithm Flowchart

The first step, Fuzzification is the transformation of crisp input data into linguistic variables/Fuzzy sets, with a certain degree of membership or can be called Fuzzy input values (Almajdoub & Siddiqui, 2024; Kabir et al., 2021). In this process , the design of the input membership function used will greatly affect the Fuzzy input value. The input membership function in this study consists of two variables. The input variable is the distance reading from the left ultrasonic sensor (LUS) and the right ultrasonic sensor (RUS) with the same logic for each input, as seen in equation (1). Each LUS and RUS input represents the distance (cm) for the linguistic variables NE: near, N: normal, and F: far, as seen in equations (2), (3) and (4) and shown in Figure 4.

$$left\ and\ right\ ultrasonic\ sensor,\ (LUS) = (RUS) = \{NE, N, F\} \tag{1}$$

$$Linguistic\ (NE) = \{0, 0, 80, 200\} \tag{2}$$

$$Linguistic\ (N) = \{80, 200, 230, 250\} \tag{3}$$

$$Linguistic\ (F) = \{230, 250, 400, 400\} \tag{4}$$

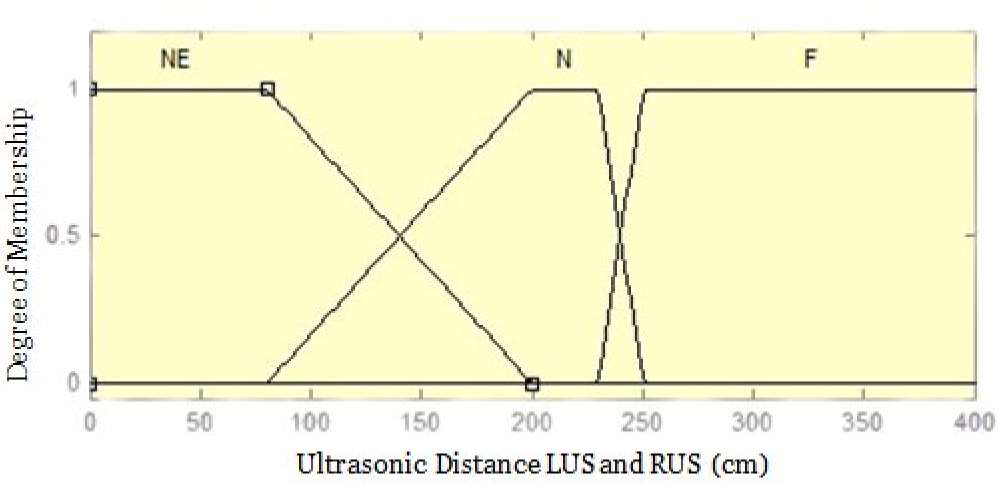

Figure 4 Input Distance Membership Function LUS and RUS

The second step, Inference is reasoning to determine the Fuzzy output value as a form of decision making from input values (Almajdoub & Siddiqui, 2024; Kabir et al., 2021). This inference process combines membership functions and rule bases in determining Fuzzy output. Each rule of the design will be evaluated so that the results of the assessment and decision making are a collection or correlation between rules. In designing this rule base, the author uses the max-min inference method to evaluate each Fuzzy rule. The Fuzzy rule base is designed into nine which are made based on the designer's knowledge and experience in the dynamics of electronic stick movement. While the rules that are set are used to determine the relationship between the input set and the Fuzzy output set. This electronic system stick has linguistic output variables that are used as the basis for Fuzzy rules, namely LL: a little to the left, L: left, LR: a little to the right, R: right, ALARM: alarm (does not allow straight, turn left, or right). Details of the nine Fuzzy rule bases are shown in Table 3.

Table 3. Fuzzy Rule Base

Rules	LUS Input	RUS Input	Output
1	NE	NE	ALARM
2	NE	N	R
3	NE	F	R
4	N	NE	L
5	N	N	-
6	N	F	LR
7	F	NE	L
8	F	N	LL
9	F	F	-

The third step, Defuzzification, is the process of changing the Fuzzy output value back into sharp output data or classic output on the control object (Almajdoub & Siddiqui, 2024; Kabir et al., 2021). The defuzzification process in this design uses the WA calculation which is one of Sugeno's methods. The pulse shape is used as the output membership function value with a range of -1 to 1 (LL, L, ALARM, R, LR). This WA calculation method is formulated as shown in equation (5).

$$WA = \frac{\alpha 1z1 + \alpha 2z2 + \dots + \alpha nzn}{\alpha 1 + \alpha 2 + \dots + \alpha n} \quad (5)$$

Explanation of equation (5), αn = value of the nth rule predicate, and zn = index of the nth output value (constant). The voice output signal model is as described in Table 2.

Results and Discussion

Testing in this study combines simulation and real practice approaches. Simulation is used to test the system model virtually, while direct practice at SLBN-A Citeureup Cimahi-West Java-Indonesia aims to validate the simulation results in real-world conditions.

Simulation

Simulations are performed using MATLAB to verify the design and Fuzzy rules before being implemented into the MCU. The number of inputs and outputs of the simulation are in accordance with the software design with the design as shown in Figure 5.

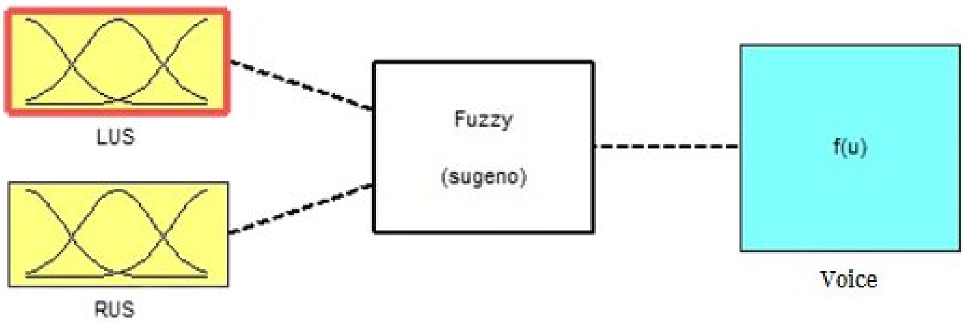

Figure 5 Fuzzy Design – Matlab Simulation

The test was conducted into nine scenarios. With the test scenario representing each design rule base as shown in Table 3. As for the test, sampling was taken for the 2nd rule referring to Table 2. The 2nd rule is a rule base with LUS input: NE, RUS : N and output R. Testing was carried out by giving the values LUS: 123 and RUS: 220 resulting in a sound signal output R: 0.5 as shown in Figure 6.

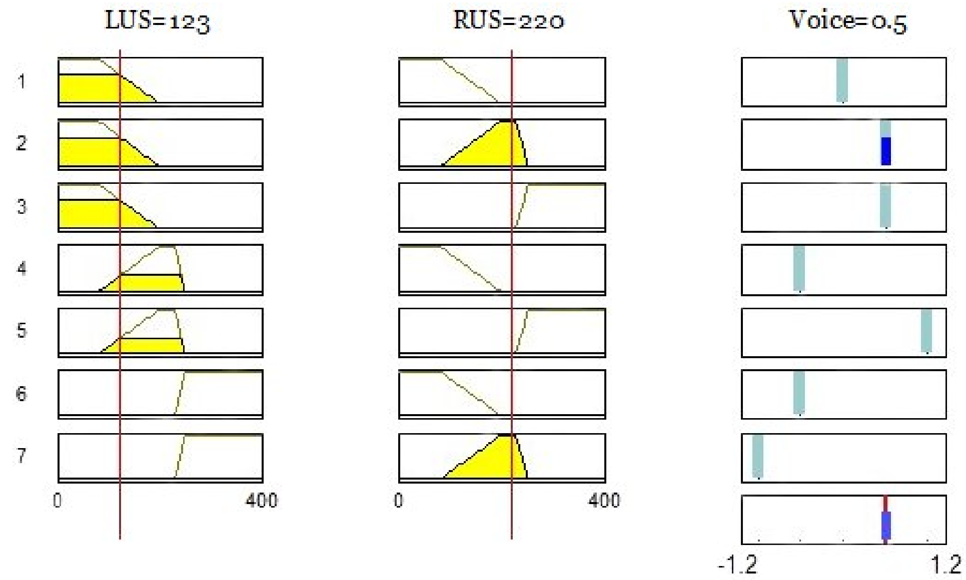

Figure 6 Sample Results of NE-N Rule-2 Base Simulation

Practice

The prototype system testing process was carried out to ensure that the Fuzzy rule base design embedded in the MCU worked well according to the perception and simulation results. The testing was carried out in three scenarios, tested by visually impaired users who are instructors at SLBN-A Citeureup Cimahi as shown in Figure 7.

Figure 7 Live Testing of Electronic System Prototypes by Blind Person

The purpose of the test is more focused on seeing the benefits of using the prototype by educated users with their O&M technique skills. The O&M technique scenarios used as a reference for testing consist of three, namely sweeping, constant contact, and two-point touch techniques. The sweeping technique uses the wrist to sweep the stick horizontally from left to right and vice versa. This technique can provide a complete picture of information about what is in front, as well as what is slightly to the side. The constant contact technique is to drag the tip of the stick lightly along the surface while keeping the stick on the ground at all times. This technique provides a continuous and complete picture of information about the terrain ahead and helps reduce tension on the wrist. The two-point touch technique is a combination of sweeping-constant contact. This technique is done by tapping both sides of the left-right, right-left stick sweep and keeping the tip of the stick just above the ground between taps. This technique allows users to walk faster.

Tables 4 and 5 show the test results with three O&M technique scenarios. Each scenario was tested nine times with an obstacle object in the form of a chair with dimensions of 40 cm wide and 82 cm high. Each test was set with a predetermined distance and pattern of obstacle object placement, as shown in Figure 8. The initial position of the object for each test before the system was ON was in front of the user, with a distance as shown in Table. The speed of testing the use of the white cane was set to be slow at around 0.5 m/s.

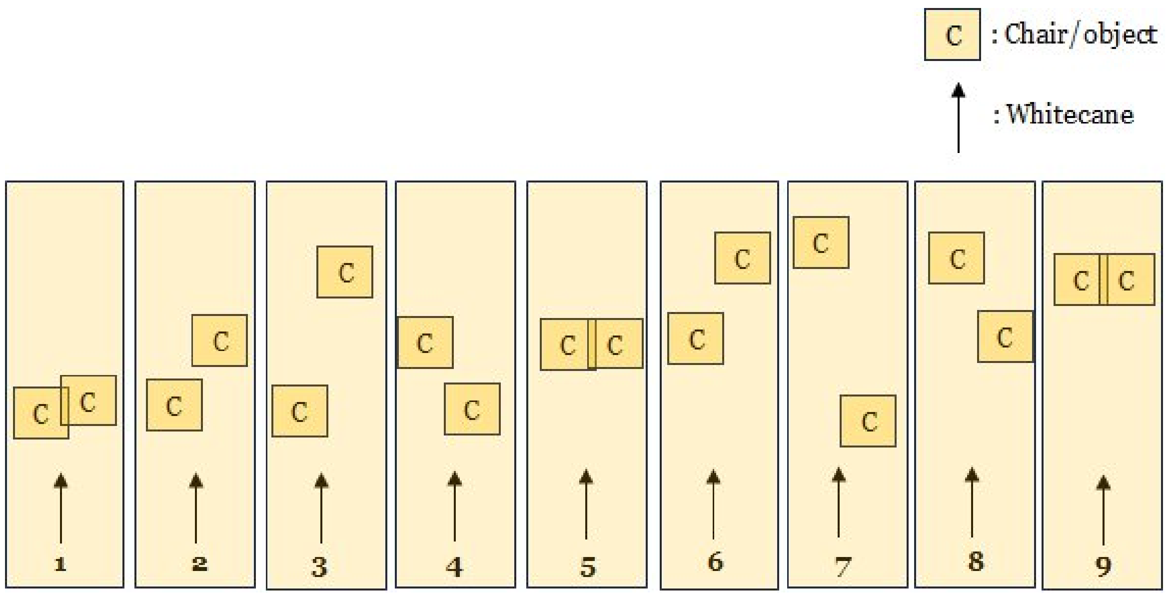

Figure 8 Test Pattern

Table 4 Test Result Data Using Sweep and Two-Point Touch Technique Scenario

No	Estimated Input Distance to Object (cm)		Output	Information
	LUS	RUS		
1	80	100	ALARM	obstacles are detected very near
2	110	205	R/LL	sometimes obstacles are detected on the left/right
3	100	320	R/LL	sometimes obstacles are detected on the left/right
4	220	100	L/R	sometimes obstacles are detected on the right/left
5	220	220	-	no obstacle detection
6	240	350	LR/-/L	sometimes obstacles are detected on the left/not detected/right
7	380	50	L/ALARM/-	sometimes obstacles are detected on the right/near/not detected
8	350	210	LL/R/-	sometimes obstacles are detected on the right/left/not detected
9	300	300	-	no obstacle detection

Table 5 Test Result Data Using Constant Contact Technique Scenario

No	Estimated Input Distance to Object (cm)		Output	Information
	LUS	RUS		
1	80	100	ALARM	obstacles are detected very near
2	110	205	R	obstacles are detected on the left
3	100	320	R	obstacles are detected on the left
4	220	100	L	obstacles are detected on the right
5	220	220	-	no obstacle detection
6	240	350	LR	obstacles are detected very near on the left
7	380	50	L	obstacles are detected on the right
8	350	210	LL	obstacles are detected very near on the right
9	300	300	-	no obstacle detection

The test scenario of the sweep technique and two-point touch produced the same data. Because in principle both techniques move the stick horizontally to the left-right and vice versa as wide as the shoulder (60 cm). The error rate in both techniques is very large due to two factors, namely the movement of the sensor reading and the distance of the object to the sensor. The first factor is the movement of the left-right reading which affects the detection of obstacles to the object that is shifting. The second factor is the distance of the object that is too far. So that when the movement of the reading shifts even a little, it will have an impact on the reading angle which widens (not read by the sensor). The level of accuracy of success of both techniques is 33.3% each as shown from the results of the probability calculation from Table

4, points (1, 5, 9).

Meanwhile, the constant contact technique scenario test resulted in very accurate data success of 100%, as shown in Table 5. This is because it is not influenced by changes in the sensor position to the object (the sensor position remains relatively constant).

Conclusions

The results of the prototype system design experiment can provide voice signal information related to the decision to choose the direction for independent mobility of the visually impaired without having to touch the object in front of it. From the three scenarios that were tested, one technique was obtained that was feasible for the use of this prototype. The scenario of using the constant contact O&M technique is the most appropriate with a success rate and accuracy of 100% which is very good compared to the other two techniques which are only 33.3%. So that with this success, a new constant contact O&M technique can be developed as one of the solutions for navigation. While future developments can be used to update the algorithm or hardware. So that the prototype can be used well in the sweep and two-point touch O&M technique scenarios. The use of the object distance reading identification algorithm can be developed into an area, while the hardware can be developed such as the scanning principle. So that both developments change single input data into two or three-dimensional data.

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