ไม้เท้าอัจฉริยะสำหรับช่วยเหลือผู้พิการทางสายตา และคนตาบอด

SMART CANE FOR ASSISTING
VISUALLY IMPAIRED PEOPLE AND THE BLIND

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บทคัดย่อ

ข้อจำกัดด้านเคลื่อนไหวสำหรับผู้พิการทางสายตา และคนตาบอดทำให้กิจวัตรประจำวันมีความยากมากขึ้น ทั้งในแง่ของการหลีกเลี่ยงสิ่งกีดขวาง การเดินทาง การข้ามถนน รวมทั้งการเผชิญกับเหตุการณ์ฉุกเฉินต่างๆ ซึ่งในปัจจุบันได้มีการศึกษา และพัฒนาอย่างแข็งขันเกี่ยวกับอุปกรณ์ และเทคโนโลยีต่างๆ ที่ช่วยเพิ่มความคล่องแคล่วในชีวิตประจำวัน รวมถึงการเดินทางโดยอิสระสำหรับผู้พิการทางสายตา และคนตาบอดเกิดขึ้นมากมาย โดยในวิทยานิพนธ์ฉบับนี้เราได้ทำการรวบรวมคุณสมบัติที่จำเป็นต่างๆ เข้าด้วยกันอุปกรณ์เดียว ประกอบไปด้วยคุณสมบัติการตรวจจับสิ่งกีดขวาง การนำทาง และโทรฉุกเฉิน รวมถึงการแนะนำการข้ามถนน และอ่านหมายเลขรถประจำทาง เพื่อเพิ่มความปลอดภัย และความคล่องตัวในการเดินทางของผู้พิการทางสายตาและคนตาบอด ทั้งนี้ผลการทดลองในห้องปฏิบัติการสำหรับคุณสมบัติที่กล่าวมาข้างต้นนั้นประสบผลสำเร็จตามวัตถุประสงค์ที่กำหนดไว้ และอุปกรณ์สามารถแจ้งเตือนผู้ใช้งานด้วยเสียง และการสั่น ตรวจจับทางม้าลาย และอ่านหมายเลขรถประจำทางได้อีกด้วย

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ABSTRACT

The limited mobility of the visually impaired and blind makes daily activities such as avoiding obstacles, traveling, crossing the street, and dealing with an emergency difficult. Currently, there are active studies and developments about devices and technologies that increase deftness daily and travel independently. In this thesis, we combine various functions into one device consisting of obstacle detection, navigation and emergency calls, and crossing a road and reading a bus number guidance to increase the safety and travel mobility of visually impaired people and the blind. The laboratory experiment results of whole functions were successful, the device can alert the user with sound and vibration, detect a crosswalk, and read a bus number.

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Chapter 1

INTRODUCTION

1.1 Background

Limited mobility is major trouble for visually impaired people and the blind, which decreases travel efficiency and safety. Therefore, devices and technologies are required to increase travel efficiency, independently and safety, such as the long white cane, which is a widely used, A guided dog, which uses a special dog to be trained for navigation, A navigation tool [1], a cane assisting blind travelers to navigate among obstacles, A crosswalk guidance system [2] uses programmed glasses to detect crosswalk signals and plan a path across the street. Most developed devices and technologies would be a specific single function per device. A device that is a combination of all the essential functions used for travel by visually impaired people and the blind in one device to increase the safety and travel mobility of visually impaired people and the blind is proposed in this thesis. Our device using for obstacle detection with an ultrasonic system, and if found obstacle, it will alert the user via sound and vibration, and using for navigation and emergency calls by connecting the phone via an app inventor designed for receiving commands and alerting the user via verbal cues, as well as provides guidance to the user by detecting a crosswalk and reading a bus number using an Android app designed on the phone. We also developed this prototype of the device to be friendly to the user and low-cost.

1.2 Objectives

1.2.1 To increase safety and travel mobility of visually impaired people and the blind.

1.2.2 To develop the navigator tool for visually impaired people and the blind to friendly to the user and low cost.

1.3 Research Hypothesis

1.3.1 Devices and technologies that decrease the limited mobility and increase the safety of visually impaired people and the blind.

1.3.2 Devices and technologies that consist of essential functions used for travel by visually impaired people and the blind must be friendly to the user and low cost, so that the user can afford them.

1.4 Scope

A prototype of the device for navigation by visually impaired people and the blind.

1.5 Stage of Study

1.5.1 Study the literature review research and the principles and methods to relate in devices and technologies for visually impaired people and the blind.

1.5.2 Design the working systems and test functions that consist of obstacle detection, navigation and emergency calls, crossing a road and reading a bus number guidance.

1.5.3 Combine the functions and design the prototype smart cane device.

1.5.4 Reviewing and improving the usage and writing a report.

Chapter 2

LITERATURE REVIEW AND REQUIREMENTS

2.1 Literature Review

2.1.1 A Navigation Tool for Blind People [1]

A device can help blind travelers navigate safely and quickly among obstacles and other hazards faced by blind pedestrians by using the Electronic Travel Aid (ETA) principle, which involves a control system using a microcontroller with speech output and an obstacle detection system using ultrasonic sensors and vibrators that attach to the cane and shoulders.

The experiment results from the first field trial of the route of 100 meters along roads showed that the aircraft navigation technique has reduced errors in measuring the distance traveled.

However, they still found limits due to the characteristics of the ultrasound reflections.

2.1.2 Crosswalk Guidance System for the Blind [2]

A device can detect crosswalk signals, plan a path across the street, and provide verbal guiding cues with real-time semantic features to keep the user on the correct path by using algorithms, which have two main tasks consisting of detection and classification of crosswalk signals and guiding users to their destination (across the target crosswalk).

The experiment results from the indoor testing of an 8.87 meter simulated crosswalk in a conference room and the outdoor testing of a 14.87 meters in length with a real crosswalk showed the crosswalk navigation system was able to guide blind users safely at a crosswalk.

However, the proper aiming of the camera was difficult due to magnified camera settings and a lack of visual feedback in the visually impaired test subject.

2.2 Hardware and Software Requirements

According to the whole working system of functions in our research, we must select and develop hardware and software that is user-friendly and easy to access for the visually impaired and the blind.

2.2.1 Obstacle Detection

For the obstacle detection function, we would like to detect obstacles in front of the user within a range of 1 meter and can alert the user in real-time or approximately via sound and vibration.

2.2.1.1 Detection Sensor

The detection sensor is a device to use to detect any objects as we require and respond with a signal to the user by using object sensing technology. We can then use the signal results for processing and developing new technology to use for our purposes. We currently have many different types of detection sensors for various purposes, and each type uses different input detection sensors for many different purposes. The most common types of detection sensors are the following:

2.2.1.1.1 Electro-Mechanical or Precision mechanical sensors

The most basic sensor is an electromechanical limit switch. The Electro-Mechanical or Precision mechanical sensors contain a sensitive microswitch that changes state when a mechanical actuator is displaced by the detected object and transforms mechanical stimulus into electrical signals. Physical contact with the target object is not always desirable or possible. This sensor is highly accurate as a micrometer; common applications for the high precision include precision manufacturing machines to reference stops for X/Y tables on processing machines, quality control to check workpiece thicknesses, detection of the tiniest movements, etc.

2.2.1.1.2 Pneumatic sensor

The most common type is a magnetic proximity sensor. The sensors utilize compressed air and a sensitive diaphragm valve to detect the objects, which produces the output of an electrical control signal. The pneumatic sensors have common applications as explosion-proof sensors or are used in extremely dirty environments, detect the position of a pneumatic cylinder during its operation by means of proximity switches, measuring airflow and pressure, etc.

2.2.1.1.3 Magnetic proximity sensors

The two most common operating principles for magnetic sensors are reed contact and Hall effect transducer, for which a magnetic field produces a change of state in an electrical signal. Reed and Hall effect sensors are often used to detect an air cylinder's internal piston. The failure rate of reed switches is relatively high, so many engineers specify Hall effect sensors when possible. Magnetic sensors are actuated by the presence of a permanent magnet within their sensing range, and some magnetic proximity switches are omni-polar, meaning both the North and South poles are being detected. The distinctive point of the magnetic sensors is their large sensing distance of millimeters; they can detect magnetic fields through metal walls and have very robust and long service times due to their non-contact sensing technology, which is wear-free as well as reliable even in high-dynamic processes for switching frequencies up to 5 kHz; common applications include monitoring the final positions of telescopic outriggers, stroke limitation in hydraulic cylinders, liquid level detection using a float-carried magnet, etc.

2.2.1.1.4 Inductive proximity sensors

The most common sensors used in automation and process equipment are characterized by their high reserve capacities, are impervious to material adhesion such as metal chips on the sensing face, operate on non-contact sensing, are free from wear, are capable of high switching frequencies at high switching accuracy, are very reliable, and are cost effective. These sensors come in different shapes and sizes. The inductive proximity sensors can only be used to detect metallic objects within just a few millimeters that cause a disruption in the electromagnetic field emanating from the body of the sensor, and this disruption indicates the presence of an object depending on the type of metal and also the amount of metal within the sensor's range; common applications for detection of a machine component and objects in process include ultra-precise referencing of the zero position of a moving machine component, detection of different positions, counting metal objects, rotary speed measurement on a metal gear wheel, etc.

2.2.1.1.5 Capacitive proximity sensors

The capacitive sensor basically functions like an open capacitor. An electrical field is formed between the measuring electrode and the GND electrode, and the capacity of the field increases depending on the dielectric constant of this material difference as air enters the electrical field. The generated signal is conditioned during subsequent signal processing and causes output switching at a corresponding magnitude. Their operation is similar to that of inductive sensors, but instead of detecting a change in an electromagnetic field, they utilize an electrostatic field. Hence, the capacitive sensors can detect non-metallic objects made from a wide variety of materials, such as plastic, paper, wood, fabric, liquid, etc. The distinctive point of the capacitive sensors is their large sensing distance of millimeters, reliable detection of many different object materials independent of color, gloss, or surface properties, and non-contact detection of liquid as well as solid objects and bulk solids; common applications include the detection of plastic boxes, wafer detection in solar cell manufacturing facilities, detection regardless of the transparency or brightness of the objects, granulate bulk goods detection in injection molding plants independent of surface properties, etc.

2.2.1.1.6 Photoelectric sensors

The common characteristic of photoelectric sensors is that they all send out a beam of light and then detect a change in the amount of light received back. The light sources used—visible, infrared, LED, or laser—will affect the sensing distance and use different technologies that address a variety of diverse application configurations. The most popular sensors are diffuse, reflective, and through-beam. The diffuse sensors can detect both with background suppression by using the triangulation principle to detect objects by evaluation of the angle of incidence of the light as well as in the detection regardless of the object color, surface, or background, and with intensity difference by using light re-emitted from the target object to trigger the sensor as well as in the detection, which is dependent on object color, surface, and degree of gloss. Both types have a transmitter and receiver in one device. The reflective sensors can detect objects by using beam interruption between the sensor and the reflector. They have a transmitter and receiver in one device and can detect objects regardless of their color or surface.

The through-beam sensors can detect objects by using beam interruption between the transmitter and the receiver. They have a transmitter and receiver located opposite each other in separate housings and can detect objects over long distances. Common applications include detection of objects through the smallest opening and across large distances, even with transparent, uneven, punctured, or rough surfaces; checking of objects in processes independent of the specific object position; extremely fast and precise position detection; counting the objects; and recognizing different object materials, colors, contrasts, etc.

2.2.1.1.7 Ultrasonic sensors

The ultrasonic sensors typically transmit a short burst of ultrasonic sound by emitting high-frequency sound waves toward a target, which reflects the sound back to the sensor, which confirms the object detection. The type of object detected—solid, liquid, granular, or in powder form—is based on the measured propagation time of the ultrasonic signal. The sound wave is well reflected by almost all dense materials, such as metal, wood, plastic, glass, and liquid, and is not affected by color or by transparent or shiny objects, and the foam-like materials that absorb sound waves would not be a reliable application of this sensor type. The distinctive point of the ultrasonic sensors is to detect objects regardless of material, color, transparency, and gloss, as well as surface properties and immunity to dust, moisture, or ambient light; they are not affected by dust, light, or moisture. Common applications include determining the level of liquids in processing tanks, etc., and they are widely used in the packaging industry, the electronics industry, feeding technology, etc.

Based on the distance requirement for detection of obstacles within 1 meter and high-speed feedback for the information when obstacles are found.

We selected the ultrasonic sensor to use in this research because it can detect obstacles at a typical distance of 0.02 to 4 meters and provide high-speed feedback for the information due to using the radio wave as a carrier for transmission the pulse signal at 40kHz from a microcontroller unit (MCU) via the trigger or transmit pin. When found the obstacles, the signal will reflect the echo or receive pin and then transmit this signal to the MCU, see Fig. 1.

We selected the low power consumption HCSR04+ module shown in Fig. 2 to detect the obstacles.

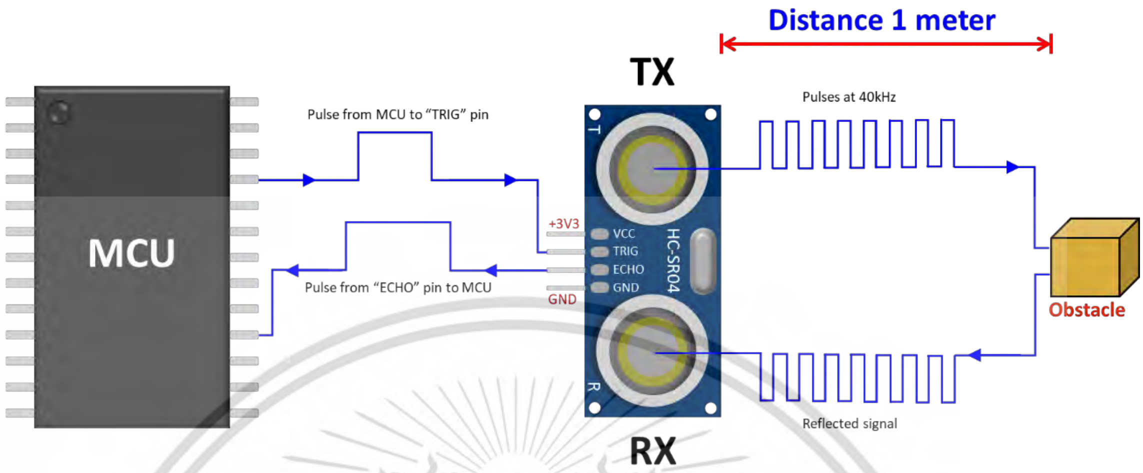


Fig. 1 The principle of ultrasonic system

Fig. 2 The HC-SR04+ module

2.2.1.2 Vibration Module

In [6], Bharadwaj et. al. introduced the tactile method, which is an effective method for the blind in ambient noise environments. They tested it with 12 blind people under the direction of the tactile belt and conventional auditory with ambient and silent simulated street sounds and measured time completion and errors. The results showed the tactile belt was worse than the auditory device in a silent environment and showed almost no difference between the tactile belt and the auditory device in ambient simulated street sounds. In [7], Khusro et. al. introduced tactile feedback and vibration patterns as useful in noisy environments.

They tested it with 24 blind people under 10 different vibration patterns in an indoor test, and the result showed the vibration patterns are easy to recognize. Hence, we considered these theories and selected the vibration method for the alerting system.

The vibration module is attached to the cane, and it will vibrate to alert the user when it receives PWM from the microcontroller unit (MCU).

We selected the vibration motor module (Catalex) as shown in Fig. 3 to use in our research because it gives more vibration, and it has low power consumption.

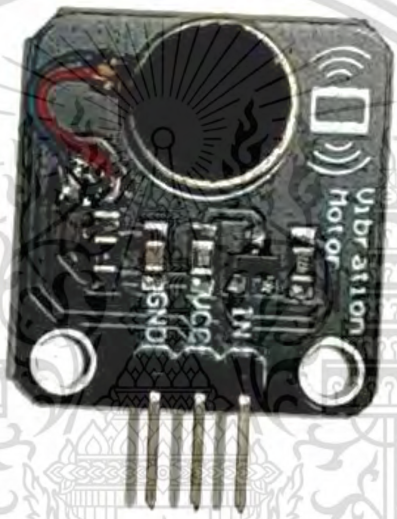


Fig. 3 The vibration motor module (Catalex)

2.2.1.3 Communication

In [8], Mlynski et. al. used auditory stimuli as an alert system for people with visual impairments and the blind. They tested it on 20 visually impaired people with 35 initially proposed sounds, and the results showed that sound information is important for visually impaired people. In [9], Zhang et. al. used 24 sound environments in urban spaces to test perceptions and usage requirements for various urban spaces on 26 people with visual impairments, and the results showed the visually impaired people have different perceptions—both positive and negative—in different urban spaces. Hence, we considered this theory and selected the sound method in the alerting system.

Bluetooth is a wireless technology standard that enables wireless data transfer between different devices over short distances, as well as streaming high-quality audio, sending messages between thousands of nodes in a building automation solution, etc. with the Bluetooth Low Energy (LE) and Bluetooth Classic radios. The Bluetooth Classic, or Basic Rate, or Enhanced Data Rate (BR/EDR) radio, is a low-power radio that streams data over 79 one-MHz channels with adaptive frequency hopping in the 2.4-GHz (2.402–2.480 GHz) unlicensed industrial, scientific, and medical (ISM) frequency band at 1 Mb/s, 2 Mb/s, and 3 Mb/s of bit rates. It is mainly used for audio streaming, such as with wireless speakers, headphones, in-car entertainment systems, etc., and data transfer applications, such as mobile printing, etc., because it supports point-to-point device communication. The Bluetooth Low Energy (LE) radio is designed for very low power operation, transmitting data over 40 two-MHz channels with adaptive frequency hopping in the 2.4-GHz (2.402–2.480 GHz) unlicensed ISM frequency band at 125 Kb/s, 500 Kb/s, 1 Mb/s, and 2 Mb/s of bit rates. It is mainly used for audio streaming, data transfer, location services, device networks, etc., because it supports point-to-point, broadcast, and mesh device communication as well as the device position that enables one device to determine the presence (advertising), distance (RSSI, HADM), and direction (direction finding, AoA/AoD) of another device with high accuracy for indoor location services.

In addition, Bluetooth technology has a standard to define the specifications of the devices to be connected and the communication between them; that standard is called "Bluetooth Profile" and the communication on Bluetooth technology requires the devices connected to have the same Bluetooth Profile.
The Bluetooth Profile list is shown in Table 1.

Table 1. Bluetooth Profiles

Item	Bluetooth Profile Name	Features
1	A/V Remote Control Profile (AVRCP)	Remote control of A/V equipment
2	Advanced Audio Distribution Profile (A2DP)	Streaming music
3	Basic Imaging Profile (BIP)	Transmission of basic image data
4	Basic Printing Profile (BPP)	Connection between a device (without a printing function) and a printer
5	Dial-up Networking Profile (DUN)	Dial-up internet connection via a mobile phone
6	File Transfer Profile (FTP)	Data transfer between personal computers
7	Hardcopy Cable Replacement Profile (HCRP)	Connection between a device having a printing function and a printer
8	Hands-Free Profile (HFP)	Hands-Free communication
9	Human Interface Device Profile (HID)	Wireless connection of an input device such as a keyboard or mouse
10	Headset Profile (HSP)	Communication with a headset or headphones

Item	Bluetooth Profile Name	Features
11	Object Push Profile (OPP)	Data exchange
12	Personal Area Network Profile (PAN)	Implementation of a small network
13	Phone Book Access Profile (PBAP)	Mobile phone address book reference
14	SIM Access Profile (SAP)	Access to SIM card information
15	Serial Port Profile (SPP)	Using a Bluetooth device as a virtual serial port
16	Attribute Profile (ATT)	A wire application protocol for the Bluetooth Low Energy specification
17	Common ISDN Access Profile (CIP)	Provides unrestricted access to the services, data and signaling that ISDN offers
18	Cordless Telephony Profile (CTP)	Designed for cordless phones to work
19	Device ID Profile (DIP)	Identified above and beyond the limitations of the Device Class already available in Bluetooth
20	Fax Profile (FAX)	Provide a well-defined interface between a mobile phone or fixed-line phone and a PC with Fax software installed
21	Generic A/V Distribution Profile (GAVDP)	Distributing video and audio streams
22	Generic Access Profile (GAP)	Defines how two Bluetooth units discover and establish a connection with each other

Item	Bluetooth Profile Name	Features
23	Generic Attribute Profile (GATT)	Defines how ATT attributes are grouped together into sets to form services
24	Generic Object Exchange Profile (GOEP)	Provides a basis for other data profiles based on OBEX
25	Health Device Profile (HDP)	Transmission and reception of Medical Device data
26	Intercom Profile (ICP)	Allow voice calls between two Bluetooth capable handsets
27	LAN Access Profile (LAP)	Access LAN, WAN or Internet via another device that has a physical connection to the network
28	Message Access Profile (MAP)	Allows exchange of messages between devices
29	OBject Exchange (OBEX)	Exchange of binary objects between devices
30	Proximity Profile (PXP)	Proximity monitoring between two devices
31	Service Discovery Application Profile (SDAP)	Discover services on a remote device
32	SIM Access Profile (SAP, SIM, rSAP)	Allows devices such as car phones with built-in GSM transceivers to connect to a SIM card in a Bluetooth enabled phone
33	Synchronization Profile (SYNCH)	Allows synchronization of Personal Information Manager (PIM) items
34	Synchronisation Mark-up Language Profile (SyncML)	Common data synchronization protocol for open industry
35	Video Distribution Profile (VDP)	Transport of a video stream

Item	Bluetooth Profile Name	Features
36	Wireless Application Protocol Bearer (WAPB)	Carrying Wireless Application Protocol (WAP) over Point-to-Point Protocol

In this research, we selected Bluetooth communication with an Advanced Audio Distribution Profile (A2DP) for transmission of the sound signal from the microcontroller unit (MCU) to the general commercially available Bluetooth earphones.

Advanced Audio Distribution Profile (A2DP) is a wireless transfer of high-quality audio signals between the devices that supply the digital audio stream (source; SRC) and the recipient devices that receive the digital audio stream delivered from the SRC on the same piconet (sink; SNK) and enable the playback of audio data on suitable devices as shown in Fig. 4.

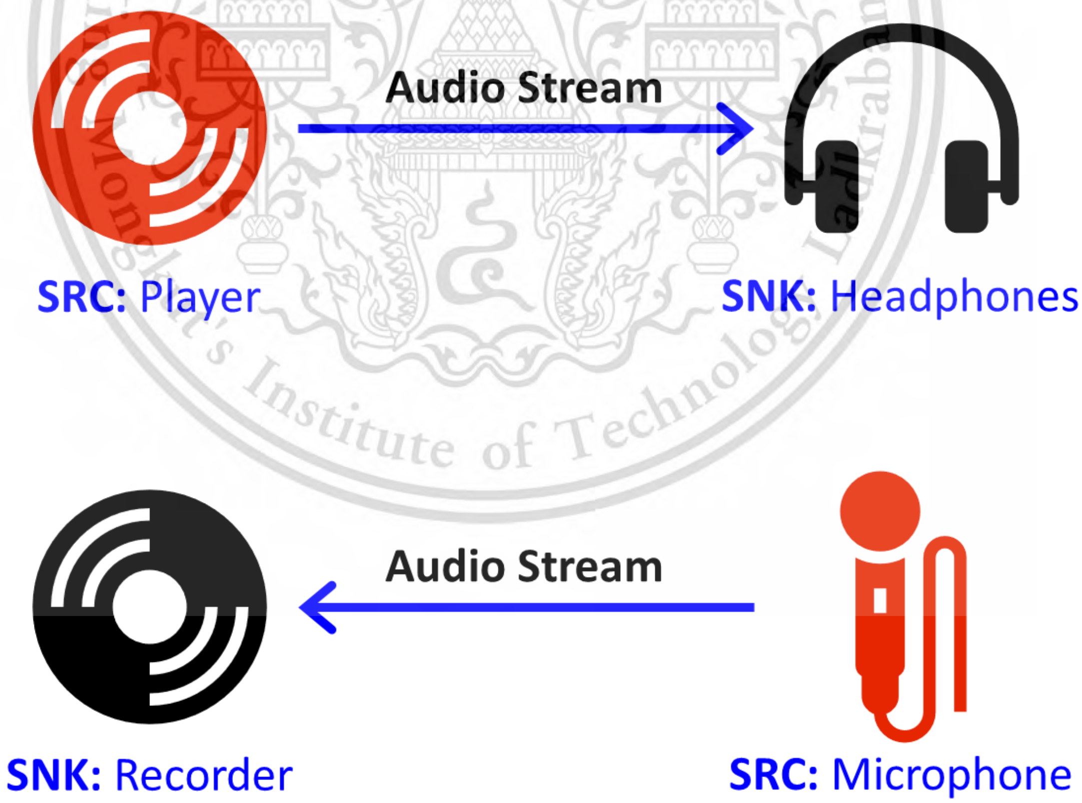


Fig. 4 Source and sink of the A2DP configuration

2.2.1.4 Microcontroller

Regarding the requirements and devices as mentioned above, we would like a microcontroller unit (MCU) that is able to transmit PWM signals to the vibration module and connect Bluetooth to Bluetooth earphones to alert the user via sound and vibration in real-time or approximately.

ESP32 is a series of low-cost, low-power system-on-a-chip microcontrollers with integrated single-2.4 GHz Wi-Fi and Bluetooth, which were created and developed by Espressif Systems, and a combo chip designed with the Taiwan Semiconductor Manufacturing Company Limited's (TSMC) low-power 40 nm technology and use analog power supply in the range 2.3 V–3.6 V. Common features include ultra-low-power features by using a low-power chip for mobile, wearable electronics, and Internet-of-Things (IoT) applications; complete integration features by using CMOS for single-chip fully-integrated radio and baseband for Wi-Fi and Bluetooth IoT applications. ESP32 can be used in a lot of applications in daily life, such as generic low-power IoT sensor hubs and IoT data loggers, cameras for video streaming, over-the-top (OTT) devices, speech and image recognition, mesh networks, home and industrial automation, smart buildings, smart agriculture, audio and health care applications, Wi-Fi-enabled toys, wearable electronics, retail and catering applications, etc. The key features of ESP32 are shown in Table 2.

Table 2. Key Features of ESP32

Part	Key Features
Wi-Fi	- 802.11b/g/n - 802.11n (2.4 GHz), up to 150 Mbps - WMM - TX/RX A-MPDU, RX A-MSDU - Immediate block ACK - Defragmentation - Automatic Beacon monitoring (hardware TSF) - 4 × virtual Wi-Fi interfaces - Simultaneous support for infrastructure Station, SoftAP, and promiscuous modes - Antenna diversity

Part	Key Features
Bluetooth	- Compliant with Bluetooth v4.2 BR/EDR and Bluetooth LE specifications - Class-1, class-2 and class-3 transmitter without external power amplifier - Enhanced power control - +9 dBm transmitting power - NZIF receiver with –94 dBm Bluetooth LE sensitivity - Adaptive Frequency Hopping (AFH) - Standard HCI based on SDIO/SPI/UART - High-speed UART HCI, up to 4 Mbps - Bluetooth 4.2 BR/EDR and Bluetooth LE dual mode controller - Synchronous Connection-Oriented/Extended (SCO/eSCO) - CVSD and SBC for audio codec - Bluetooth piconet and scatternet - Multi-connections in Classic Bluetooth and Bluetooth LE - Simultaneous advertising and scanning
CPU and Memory	- Xtensa® single-/dual-core 32-bit LX6 microprocessor(s) - CoreMark® score: 1 core at 240 MHz: 504.85 CoreMark; 2.10 CoreMark/MHz, 2 cores at 240 MHz: 994.26 CoreMark; 4.14 CoreMark/MHz - 448 KB ROM - 520 KB SRAM - 16 KB SRAM in RTC - QSPI supports multiple flash/SRAM chips
Clocks and Timers	- Internal 8 MHz and RC oscillators with calibration - External 2 MHz ~ 60 MHz crystal oscillator (40 MHz only for Wi-Fi/Bluetooth functionality - External 32 kHz crystal oscillator for RTC with calibration - Two timer groups: 2 × 64-bit timers, 1 × main watchdog in each group - One RTC timer - RTC watchdog

Part	Key Features
Advanced peripheral interface	- 34 × programmable GPIOs - 12-bit SAR ADC 18 channels - 2 × 8-bit DAC - 10 × touch sensors - 4 x SPI - 2 x I2S - 2 x I2C - 3 x UART - 1 host (SD/eMMC/SDIO) - 1 slave (SDIO/SPI) - Ethernet MAC interface with dedicated DMA and IEEE 1588 support - TWAI®, compatible with ISO 11898-1 (CAN Specification 2.0) - RMT (TX/RX) - Motor PWM - LED PWM 16 channels
Security	- Secure boot - Flash encryption - 1024-bit OTP, 768-bit for customers - Cryptographic hardware acceleration: AES, Hash (SHA-2), RSA, ECC, Random Number Generator (RNG)

Therefore, we selected the ESP32 Mini kit module as seen in Fig. 5 because it already embedded a Bluetooth chip on board, high efficiency for processing, low power consumption, and compact.

Fig. 5 The ESP32 Mini kit module

2.2.2 Navigation and Emergency Call

For the navigation and emergency call functions, we would like the user-accessible to the Google Maps and emergency call applications on the phone in less than 5 seconds by pressing command buttons on the cane.

2.2.2.1 Command Buttons

In [6], Bharadwaj et al. introduced the tactile method, which is an effective method for the blind in ambient noise environments. They tested it with 12 blind people under the direction of the tactile belt and conventional auditory with ambient and silent simulated street sounds and measured time completion and errors. The results showed almost no difference between the tactile belt and the auditory device in ambient simulated street sounds; however, the tactile method was a bit more effective in ambient simulated street sounds. In [18], Vinter et al. experimented with blind children of 3–8 years to identify tactile images with textured text from young children's books in natural reading conditions, then compared the correct semantic identification score between previously reported and after the experiment; the results showed that the score after the experiment was higher than previously reported and was positively impacted by haptic practice. Hence, we considered this theory and selected the tactile method in our system to send the commands from the cane by the user to a microcontroller unit (MCU).

The tactile switch is one type of switch that is a momentary action device whose operation is perceptible by the user's touch to control an electrical circuit. By default, when the button on the switch is released, it is a normal closed (NC) circuit and will turn off the electrical circuit; when the button on the switch is pressed, it will turn on the electrical circuit. There are 2 major types of tactile switches: the tactile switch (or standard tactile switch) and the sealed tactile switch, which typically contain 4 pins with 2 sets of internal wiring connections, with the top 2 pins always connected and the low 2 pins always connected, but the top and low pins will connect when the user presses the button, as shown in Fig. 6. The specifications of the tactile switched to we should to consider when selected to use on our circuit designed including voltage rating which indicates the maximum voltage that switch can resist when internal circuit turn on or when user pressed switch, current rating which indicates the maximum current that switch can resist before damage, operating force (or activation force) which indicates the pressure force that switch needed to move an actuator on a switch in gram force or gf, deflection (or actuator travel) which indicates the overall travel distance of depressed switch, contact force which indicates the pressure force that switch needed to connect the terminals and cause power to flow in gram, actuator height which indicates the actuator's height above the body of a switch, lifecycle range which indicates the expected lifetime of the switch under normal operating conditions, temperature range which indicates temperatures within which the switch will operate to specification, mounting style which indicates method used to mount the switch on the printed circuit board (PCB) such as through-hole technology (THT) or surface-mount technology (SMT), and IP rating which indicates an international standard to classify the degrees of protection of switches against dust and liquids. Common applications include keyboards and keypads, remote controls, game controllers, phones, toys, musical instruments, notebook computers, appliances, security electronics, industrial controls, electrical and electronic instruments, portable equipment, medical equipment, etc.

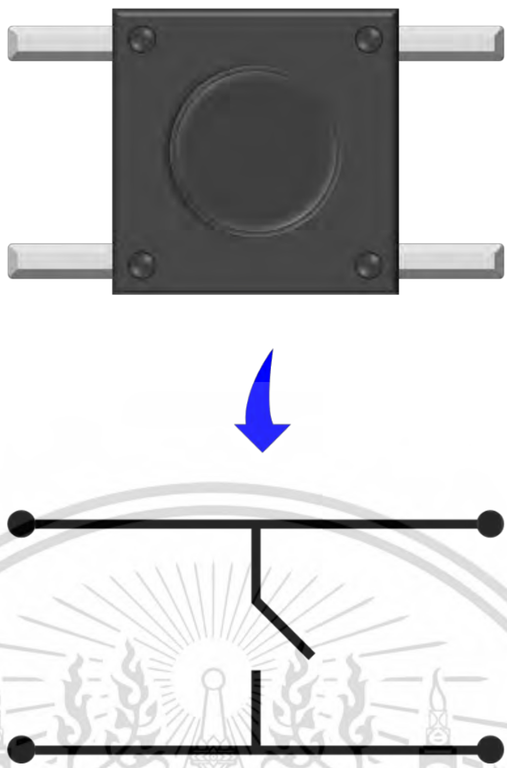
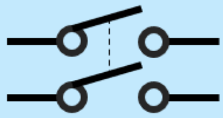
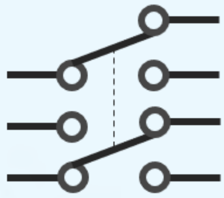


Fig. 6 Typical tactile switch pin configuration

The pole of a switch refers to the number of circuits that a switch can control in its operation, such as single-pole switches that control one circuit and double-pole switches that control two circuits in the same switch with two single-pole switches. Single-pole features are more common in residential settings, while double-pole features are more common in industrial settings. The throw of a switch refers to the number of contact points; the common types are single-throw and double-throw. The main four types of switches are shown in Fig. 7.

Type	Description	Symbol
Single-Pole, Single-Throw (SPST)	One circuit (NO or NC contacts)	
Single-Pole, Double-Throw (SPDT)	One circuit (Changeover contacts)	
Double-Pole, Single-Throw (DPST)	One circuit (NO or NC contacts)	
Double-Pole, Double-Throw (DPDT)	One circuit (Changeover contacts)	

NO = Normal Open
NC = Normal Close

Fig. 7 Types of switch configuration

Braille is a tactile system of raised dots that represent the letters of the alphabet that allows visually impaired people and the blind to access literacy by reading and writing. Braille is used by thousands of people all over the world in their native languages and was developed by Louis Braille in France in the 1820s. It continues to have a huge impact on the lives of visually impaired people and the blind 200 years later, and the main code for Braille is the Unified English Braille (UEB) code. People read braille by moving one hand or both hands from left to right along each line, and the index fingers generally do the reading, which has an average reading speed of about 125 words per minute. Braille symbols are formed within units of space, or Braille cells; the full Braille cell consists of six raised dots arranged in two parallel vertical columns of three dots, and the dot positions are identified by the numbers 1 to 6. The possible combinations of these six dots are 64. It also has contracted braille, which represents specific groups of letters or whole words by using cells individually or in combination with others to form a variety of contractions, such as GD = GOOD, LL = LITTLE, etc., that help to speed up reading as well as being used most often for books and publications. Braille can be written on paper using a Perkins Brailler™ which produces embossed braille directly onto a page.

It has six keys and a space bar for writing, as well as electronic braille notetakers that serve as braille word processors and also possess the functionality of a smartphone or tablet.

In our research, we selected the tactile switch with Single Pole Single Throw (SPST). The command buttons are installed on the cane with Braille [24] for the convenience of the user, including three buttons with the Braille numbers for navigation function as shown in Fig. 8 (a) – (c) and another button with the Braille alphabet for emergency call function shown in Fig. 8 (d).

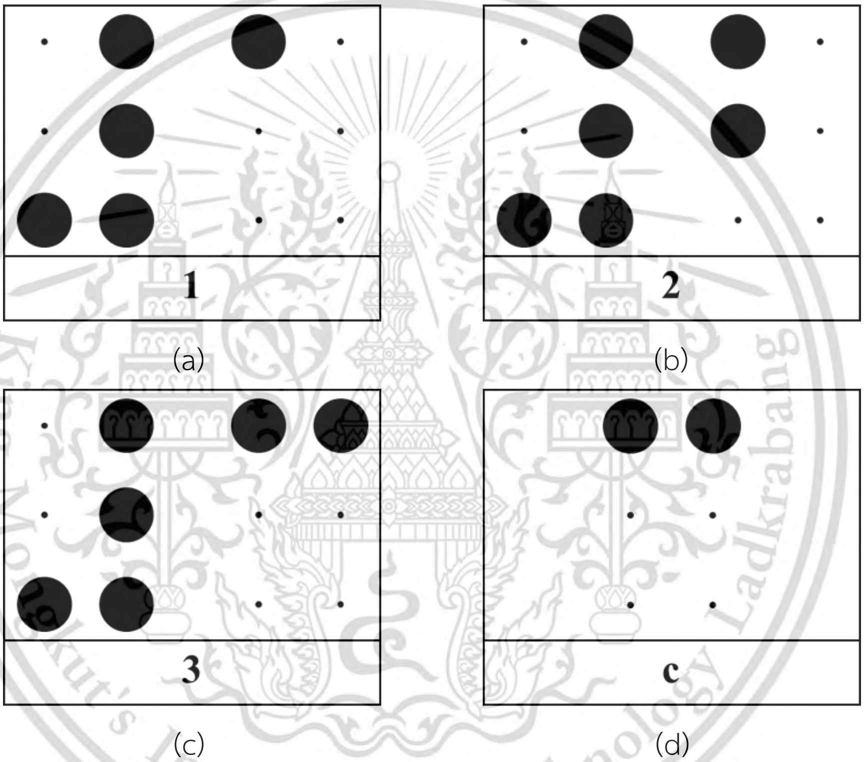


Fig. 8 Braille on the command buttons. (a) The Braille number 1.
(b) The Braille number 2. (c) The Braille number 3. (d) The Braille alphabet c

2.2.2.2 App Inventor

Low-code Internet of Things (IoT) platforms are designed for everyone, even newcomers to computer programming, to easily create and manage IoT apps and dashboards without advanced coding skills. It can also be utilized by product developers that are looking for a low-cost, high-quality IoT app. There are many low-code IoT platforms in the market that are trending, such as MIT App Inventor, Blynk, Kodular, Tractian, Sematext Cloud, zzBots, PubNub, PRTG Network Monitor, DATOMS, The Asset, Guardian (TAG), Fracttal, AppDynamics, Cedalo, ClickUp, N-AOS, OneBlink, Kianda, WEM, Carrd, Magento, TrackVia, Joomla, etc.

App Inventor is used to develop applications for Android phones by using a web browser and either a connected phone or emulator. The App Inventor servers also store your work and help you keep track of your projects. App Inventor has almost two parts for creating and developing an app: (i) the App Invertor Designer, in which the user selects the components and creates the dashboard for your app; and (ii) the App Invertor Block Editor, in which the user assembles programs visually, fitting pieces together to create commands for your app. When you are finished creating your app, you can use the Android emulator software to simulate running it on your computer, then package your app and produce a stand-alone application to install on your Android phone, as shown in Fig. 9. The App Inventor development environment is supported for Mac OS X, GNU/Linux, and Windows operating systems, and several popular Android phone models.

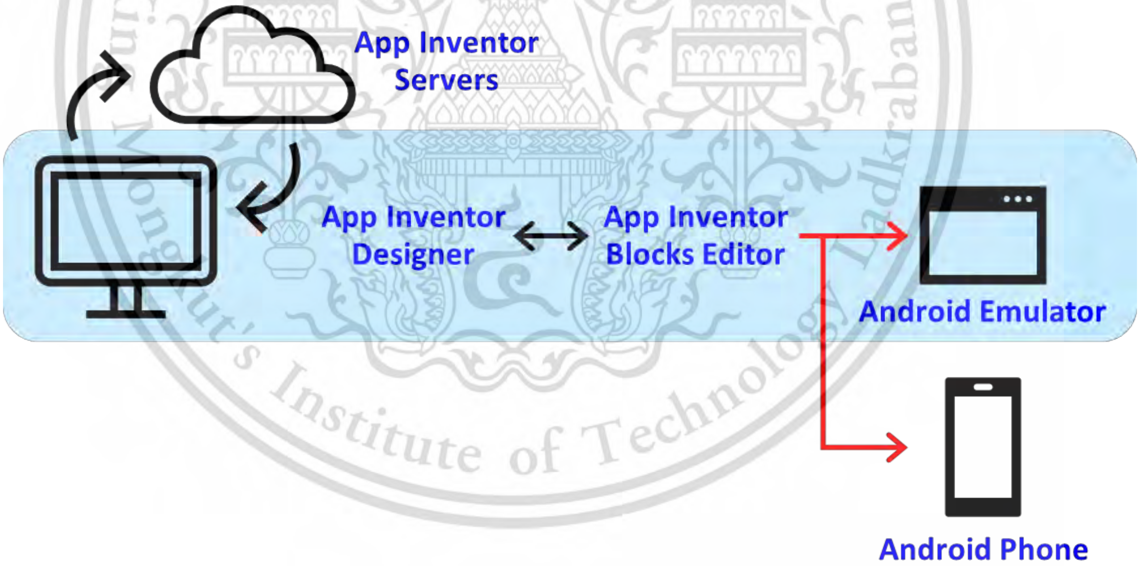


Fig. 9 App Inventor system

We designed an app inventor with MIT App Inventor that is installed on the phone to receive commands from the microcontroller unit (MCU) to access Google Maps and emergency calls on the phone as well as alert the user via verbal cues via Bluetooth communication with earphones.

MIT App Inventor is an intuitive, visual programming environment with free and open-source software originally provided by Google and now maintained by the Massachusetts Institute of Technology (MIT) that allows everyone to build fully functional apps for Android phones, iPhones, and Android and iOS tablets.

2.2.2.3 Communication

As we mentioned above, Bluetooth is a wireless technology standard that enables wireless data transfer between different devices over short distances, as well as streaming high-quality audio, sending messages between thousands of nodes in a building automation solution, etc. with the Bluetooth Low Energy (LE) and Bluetooth Classic radios. And has many Bluetooth Profiles to use that are connected and communicated between devices with the same Bluetooth Profile.

The transmission of information via the command button to the app inventor on the phone must be fast, especially in the emergency call function. Therefore, we selected Bluetooth communication with a Serial Port Profile (SPP) to transmit the commands from the microcontroller unit (MCU) to the MIT App Inventor on the phone.

Serial Port Profile (SPP) defines the protocols and procedures that shall be used by devices using Bluetooth as a cable replacement through a virtual serial port (TX/RX) abstraction for RS232 or UART serial cable emulation. It is great for sending bursts of data between two devices, as shown in Fig. 10.

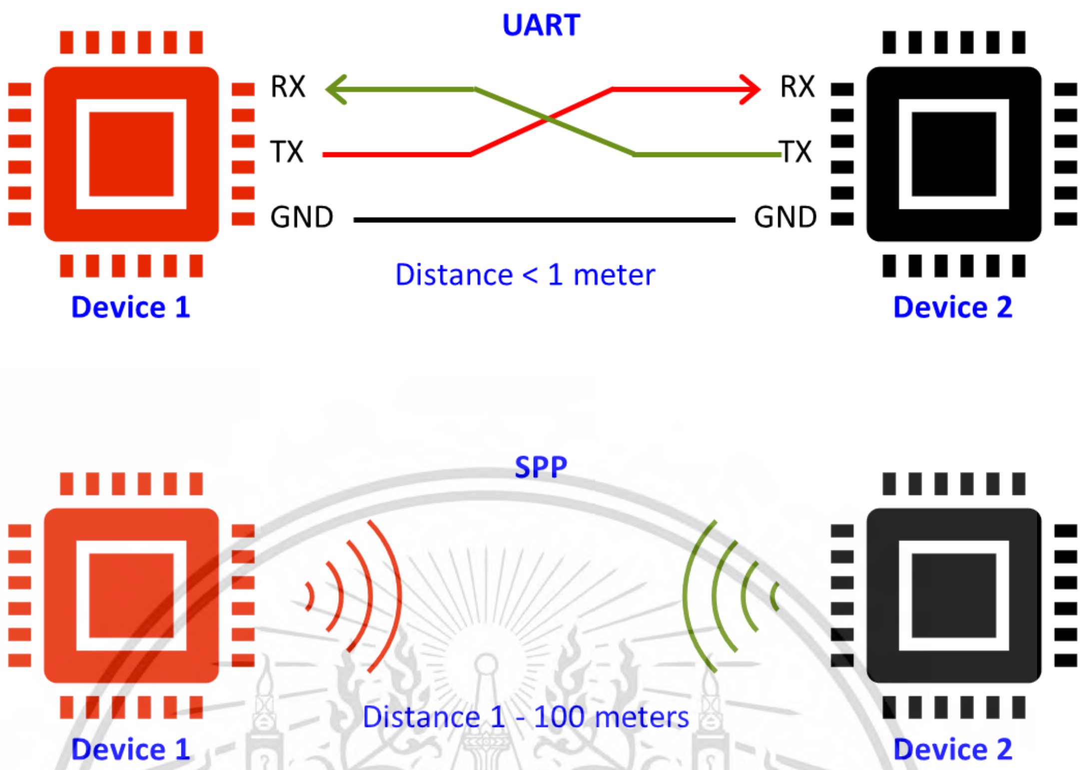


Fig. 10 UART and SPP connections

2.2.2.4 Microcontroller

The microcontroller must be able to receive a signal from command buttons and connecting Bluetooth to the app inventor on the phone.

Due to Bluetooth communication being unable to communicate an Advanced Audio Distribution Profile (A2DP) and a Serial Port Profile (SPP) at the same time, it is then unable to use the ESP32 Mini kit module with an obstacle detection function.

Therefore, we selected the ESP32 Mini kit module as seen in Fig. 5 because it already embedded a Bluetooth chip on board, high efficiency for processing, low power consumption, and compact.

2.2.3 Crossing a Road and Reading a Bus Number Guidance

For the crossing a road and reading a bus number guidance functions, we would like to have detection and classification of crosswalks and bus numbers by using a neural network with high accuracy and real-time performance or approximately, as well as the ability to guide the user when crossing a road and reading a bus number via verbal cues.

2.2.3.1 Software Library

Machine learning (ML) is a branch of artificial intelligence (AI) and computer science that uses methods that leverage data to improve computer performance on some set of tasks to imitate the way that humans learn. Machine learning is a rapidly growing field that has numerous applications in various industries, and it has the tools for processing in learning programming. The most commonly used is a machine learning library that provides specific functionalities with a collection of pre-written codes, pre-defined methods, and classes that can be used in a program to perform a specific task or set of tasks. It includes functions, class definitions, important constants, etc. Machine learning libraries are software libraries that provide tools and functions for building and implementing machine learning models, as well as a range of capabilities that enable developers and data scientists to easily build, train, and deploy machine learning models. Currently, there are many machine learning libraries available, and each has its own unique set of features and capabilities, such as TensorFlow, NumPy, Matplotlib, pandas, Scikit-learn, PyTorch, Keras, SciPy, Armadillo, Mlpack, PyCaret, OpenCV, Transformers, OpenNN, FANN, SpaCy, Weka, KNIME, Colab, Apache Mahout, Accors, Shogun, Rapid Miner, etc.

TensorFlow is an end-to-end open source platform for machine learning, and it is a rich system for managing all aspects of a machine learning system. TensorFlow Lite is TensorFlow's light-weight solution with a set of tools that enable on-device machine learning and is specifically designed for the mobile platform, embedded devices, and edge devices. TensorFlow is used to build or train the model, and TensorFlow Lite is used to provide the ability to perform predictions on a trained model and can optionally include metadata that has a human-readable model description and machine-readable data for the automatic generation of pre- and post-processing pipelines during on-device inference, as shown in Fig. 11.

Regarding the objects we would like to detect (a crosswalk and bus numbers), they are not complex enough for machine learning, which will make it easier to develop the function in the future. We selected TensorFlow Lite 2.8.2 for the object detection module because it is an open-source software library that makes it easy to build and deploy machine learning models, as well as a framework for running lightweight machine learning models on low-power devices.

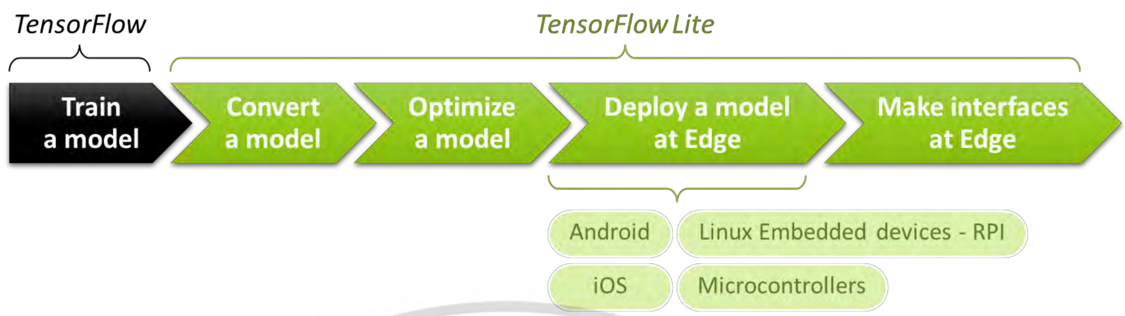


Fig. 11 TensorFlow and TensorFlow Lite deployment

2.2.3.2 Hardware Accelerator

A central processing unit (CPU) is a processor consisting of logic gates that processes the basic instructions in a computer system, such as arithmetic, logical functions, and I/O operations, and allocates commands to other components and subsystems running in a computer because it is considered the brain of a computer's integrated circuitry and interprets and executes most of the computer's hardware and software instructions. CPUs are typically a small but powerful chip integrated into the computer's motherboard with one or more cores (multi-core), cache, memory management unit (MMU), and the CPU clock and control unit. A graphics processing unit (GPU) is a computer processor that performs rapid calculations to render intensive high-resolution images and graphics. It is designed for rendering 2D and 3D images, videos, and animations as well as big analytics, machine learning, and deep learning on a computer by using parallel processing to speed up their operations, dividing tasks into smaller subtasks, and distributing them among multiple processor cores. The standard components of a GPU contain similar components to those of a CPU, including cores, cache, memory, etc.

Machine learning requires the input of large, continuous data sets to improve the accuracy of the algorithm and requires a lot of computational power. CPUs can perform complex mathematical calculations quickly, as long as they process one problem at a time, but when performing multiple tasks simultaneously, performance begins to slow down. It is proper to process algorithm-intensive tasks, such as real-time inference and machine learning (ML) algorithms that don't parallelize easily, recurrent neural networks relying on sequential data, inference and training recommender systems with high memory requirements for embedding layers, models using large-scale data samples, such as 3D data for inference and training, etc. GPUs proper for parallel processing and training data sets continue to grow larger, requiring increasingly massive parallelism to enable the efficient performance of tasks such as neural networks, accelerated AI and deep learning operations with massive parallel inputs of data, traditional AI inference and training algorithms, etc. While CPUs can process many general tasks in a fast, sequential manner, GPUs use parallel computing to break down massively complex problems into multiple smaller, simultaneous calculations.

For improving the training efficiency of a machine learning model, we selected training on the Google Colab with a graphics processing unit (GPU) due to its ease of development for future coding.

Colaboratory, or Colab, is a product from Google Research that allows everyone to write and execute arbitrary Python code through the browser, and the host service is a Jupyter notebook that provides free access to computing resources, including GPUs. It is appropriate for machine learning and data analysis.

2.2.3.3 Detection Model

Based on the model zoo, which is Google's collection of pre-trained object detection models, they show the level of speed and accuracy for each model; the fast model means that it uses less processing power, but this comes at the trade-off of having lower accuracy. The TensorFlow 2 detection model zoo provides a collection of detection models pre-trained on the COCO 2017 dataset, which is a large-scale object detection, segmentation, and captioning dataset, and these models, including CenterNet HourGlass104, CenterNet Resnet50, CenterNet MobileNet, EfficientDet, SSD MobileNet, SSD ResNet50, SSD ResNet101, SSD ResNet152, Faster R-CNN ResNet50, Faster R-CNN ResNet101, Faster R-CNN ResNet152, Faster R-CNN Inception ResNet, and Mask R-CNN Inception ResNet, are supported by Colab.

The CenterNet model is an anchorless object detection architecture that replaces the classical NMS (Non Maximum Suppression) at the post-process, which is natural to the CNN flow and enables much faster inference by a deep detection architecture that removes the need for anchors and the computationally heavy NMS based on the insight that box predictions can be sorted for relevance based on the location of their centers rather than their overlap with the object by training to predict the confidence heat map and predict regression values for box dimensions and offsets, as shown in Fig. 12.

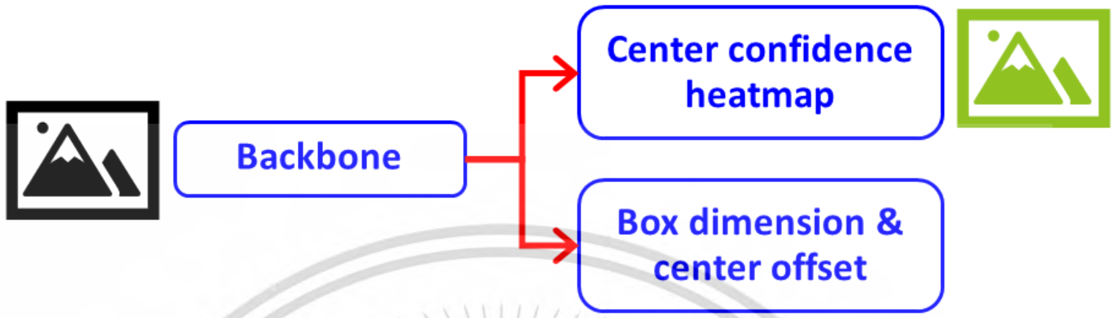


Fig. 12 CenterNet model

The EfficientDet model is an object detection model for real-time object detection with a highly scalable architecture that has a backbone and a custom detection and classification network, as well as the smallest EfficientDet-D0, which has 4 million weight parameters and infers in 30 milliseconds in this distribution, as shown in Fig. 13, and is considered to be able to be stored with only 17 megabytes of storage.

Fig. 13 EfficientDet model

The SSD model is a single-shot detector for real-time object detection that speeds up the process from the faster R-CNN model by eliminating the need for the region proposal network as well as improving multi-scale features and default boxes to recover the accuracy drop. These improvements allow SSD to match the faster R-CNN's accuracy using lower resolution images, which further pushes the speed higher. SSD uses VGG16 to extract feature maps, then detects objects by using the Conv4_3 layer, and each cell or location makes 4 object predictions as well as reserves a class "0" to indicate it has no objects, as shown in Fig. 14. It has no delegated region proposal network and predicts the boundary boxes and the classes directly from feature maps in one single pass.

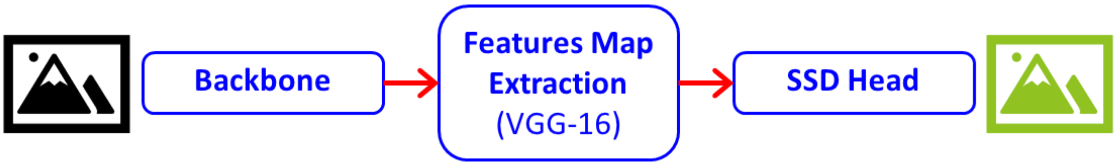


Fig. 14 SSD model

The R-CNN model is a two-stage detection algorithm that consists of (i) identifying a subset of regions in an image that might contain an object by generating region proposals using an algorithm such as edge boxes, then cropping and resizing regions, and then refined bounding boxes by a support vector machine (SVM) that is trained using CNN features, and (ii) classifying the object in each region using extracted features. The fast R-CNN model also uses an algorithm like edge boxes to generate region proposals, but it processes the entire image for crops and resizes region proposals. The fast R-CNN is also more efficient than R-CNN because the computations for overlapping regions are shared. The faster R-CNN model adds a region proposal network (RPN), which uses anchor boxes for object detection to generate region proposals directly in the network instead of using an external algorithm like edge boxes, which makes generating region proposals in the network faster and better tuned to your data, as shown in Fig. 15.

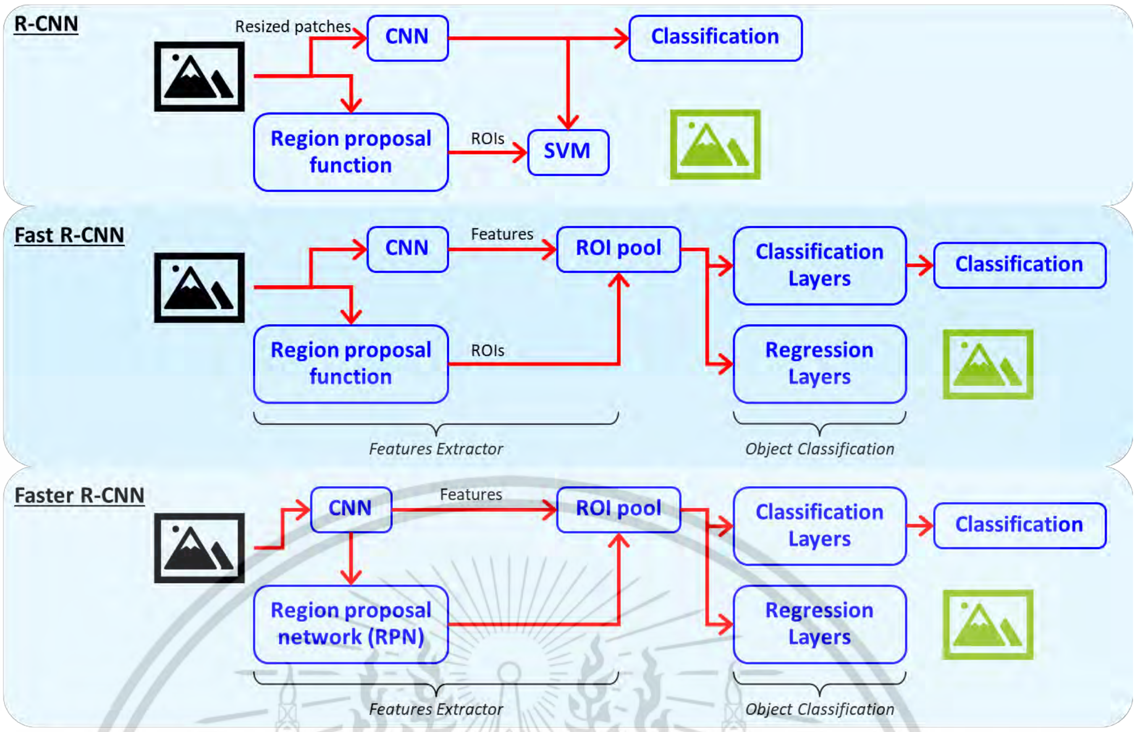


Fig. 15 R-CNN, Fast R-CNN, and Faster R-CNN model

Regarding our requirement to use to detect bus numbers, in real life the buses are moving fast. Hence, we selected the SSD MoblieNet V2 FPNLite 320x320 model for training because we considered the level of speed to detect in mainly, and it provides the level of speed of 22 milliseconds (ms) and the level of accuracy of 22.2 mean Average Precision (mAP), as shown in Fig. 16, as well as a simple training pattern that is appropriate for our requirements. Unfortunately, when we tested training with the SSD MobileNet V2 FPNLite 640x640 model, we found the limitation on the Google Colab's RAM in the standard version, as well as when we tried to train on CenterNet Resnet50 V1 FPN 512x512 and CenterNet Resnet101 V1 FPN 512x512 models, which is a complex setting for our training, so it is not proper for our requirements.

Model name	Speed (ms)	COCO mAP
CenterNet HourGlass104 512x512	70	41.9
CenterNet HourGlass104 1024x1024	197	44.5
CenterNet Resnet50 V1 FPN 512x512	27	31.2
CenterNet Resnet101 V1 FPN 512x512	34	34.2
SSD MobileNet v2 320x320	19	20.2
SSD MobileNet V1 FPN 640x640	48	29.1
SSD MobileNet V2 FPNLite 320x320	22	22.2
SSD MobileNet V2 FPNLite 640x640	39	28.2
SSD ResNet50 V1 FPN 640x640 (RetinaNet50)	46	34.3
SSD ResNet50 V1 FPN 1024x1024 (RetinaNet50)	87	38.3
SSD ResNet101 V1 FPN 640x640 (RetinaNet101)	57	35.6
SSD ResNet101 V1 FPN 1024x1024 (RetinaNet101)	104	39.5
Faster R-CNN ResNet50 V1 640x640	53	29.3

https://github.com/tensorflow2/models

Fig. 16 TensorFlow 2 detection model zoo

2.2.3.4 Microprocessor

In the present mobile phone there is a high-efficiency microprocessor that is enough for using in machine learning processing crosswalks and bus numbers, and there is a high-resolution camera in itself that does not require more equipment for installation to use for detection of crosswalks and bus numbers.

Android Studio is the official Integrated Development Environment (IDE) for Android app development, which offers more features such as a flexible Gradle-based build system, a fast and feature-rich emulator, a unified environment where you can develop for all Android devices, live Edit to update composables in emulators and physical devices in real time, code templates and GitHub integration to help you build common app features and import sample code, extensive testing tools and frameworks, lint tools to catch performance, usability, version compatibility, and other problems, C++ and NDK support, and built-in support for Google Cloud Platform. In terms of project structure in Android Studio, it contains one or more modules with source code files and resource files, including Android app modules, library modules, and Google App Engine modules. The default displays your project file in the Android project view and all build files are visible at the top level, under Gradle Scripts.

We selected to build the Android apps with Android Studio by referring to TensorFlow's Running TF2 Detection API Models on Mobile and a blog post's suggestion to [45], Build an Android app for custom object detection (TensorFlow 2.x), and then install the object detection app on the phone and use it to detect crosswalks and bus numbers.

2.2.4 Specification of the Smart Cane

For our smart cane, we would like to design it based on the specifications of the white cane standard, which the visually impaired people and the blind use worldwide because it has to do with familiarity and usage in their daily lives.

2.2.4.1 Cane Types

In [46], the World Health Organization (WHO) described a functional requirement in each type of white cane by referring to technical details and other specific functionality to describe a product variation for the typical user, specific characteristics of the product, and the standard configuration of the product, such as range of body weight, suitability for indoor or outdoor environments, etc. There are three basic types of general features:

2.2.4.1.1 Straight white cane

The specific characteristics of straight white can is straight tubing and roller tip, which the straight tubing should be made of aluminum, fiberglass or carbon fiber tubing with about 12 millimeters outer diameter to maintain light weight and straight tubing, and the roller tip should be made of durable material such as nylon with about 2 – 3 centimeters thick to flexible to roller in 360 degrees as well as the length varies depends on the typical user including length of 145 centimeters for tall adults, length of 140 centimeters for adults, and the length of 70 centimeters for children, and in the last part of the straight white cane is handgrip, it should be made of durable material such as plastic, rubber, etc. with about 20 centimeters of length and 2.5 centimeters of diameter. The typical users of the straight white cane are visually impaired people, particularly those with severe vision loss and blindness.

Fig. 17 Straight white cane

2.2.4.1.2 Angular white cane

The specific characteristics of angular white can is straight tubing with handgrip bent 150 degrees and roller tip, which the straight tubing should be made of aluminum, fiberglass or carbon fiber tubing with about 12 millimeters outer diameter to maintain light weight and straight tubing, and the roller tip should be made of durable material such as nylon with about 2 – 3 centimeters thick to flexible to roller in 360 degrees as well as the length varies depends on the typical user including length of 145 centimeters for tall adults, length of 140 centimeters for adults, and the length of 70 centimeters for children, and in the last part of the angular white cane is handgrip, it should be bent at 150 degrees from the main body of the cane and it should be made of durable material such as plastic, rubber, etc. with about 20 centimeters of length and 2.5 centimeters of diameter. The typical users of the straight white cane are visually impaired people, particularly those with severe vision loss and blindness.

Fig. 18 Angular white cane

2.2.4.1.3 Folding white cane

The specific characteristics of folding white can is foldable tubing and roller tip, which the foldable tubing can have 4 or 5 folds and it should be made of aluminum, fiberglass or carbon fiber tubing with about 12 millimeters outer diameter to maintain light weight, and the roller tip should be made of durable material such as nylon with about 2 – 3 centimeters thick to flexible to roller in 360 degrees as well as the length of the folding white cane after connecting the joints should be 140 centimeters for adults, and in the last part of the folding white cane is handgrip, it should be made of durable material such as plastic, rubber, etc. with about 20 centimeters of length and 2.5 centimeters of diameter. The typical users of the straight white cane are visually impaired people, particularly those with severe vision loss and blindness.

Fig. 19 Folding white cane

2.2.4.2 Cane Categories

In [24], the Royal National Institute of Blind People (RNIB) described categories of the white cane that support and are useful for visually impaired people and the blind. There are four basic types of general categories:

2.2.4.2.1 Symbol cane

The symbol cane is a short cane that does not usually touch the ground and can be folded for easy storage. The symbol cane is suitable for low but useful vision people, and it can also help alert other people to sight and/or hearing loss, but it cannot be used as a walking stick, a support aid, or to detect obstacles on the ground.

2.2.4.2.2 Guide cane

The guide cane can help the user find obstacles, kerbs, or steps in front of them by holding the cane diagonally across their body. The guide cane is suitable for people with visual impairments.

2.2.4.2.3 Long cane

The long cane is rolled or tapped from side to side as the user walks. To find a way and avoid obstacles, it has a rigid or folding design. The guide cane is suitable for people with restricted or no vision.

2.2.4.2.4 Red and white banded cane

All types of cane are also available with red and white banding, which indicates that you have a hearing impairment as well as sight loss.

2.2.4.3 Cane Tips

There are many different types of cane tips available on the market, each with a different application. For example, a pencil tip is a thin and straight tip that is mostly used to identify obstacles but does not provide surface feedback; a mushroom tip is shaped like a mushroom with a small rounded bottom of the tip and provides surface feedback; a rolling marshmallow tip is shaped like a marshmallow and rotates to 360 degrees to maintain constant contact with the ground and provide surface feedback; a metal glide is a thin and flat metal disk at the bottom of a guiding cane that is mostly used by completely blind people because it easily goes to any surface and provides audio feedback when it touches the surface. Omni-sense tip is an omni-wheel technology allowing fluid, 360-degree movement across a range or surface to move in all directions and maintain constant touch with the ground, as well as better providing auditory and sensory feedback.

Chapter 3

RESEARCH METHODOLOGY

3.1 Working System

The concept of the smart cane, which combines obstacle detection, navigation, and emergency call functions, must design an uncomplicated and user-friendly working system.

3.1.1 Obstacle Detection

The working system of the obstacle detection shown in Fig. 20 and Fig. 21 consists of three main parts, a sensor to detect the obstacles or detection sensor, a microcontroller unit (MCU), and the alert system. In [6], Bharadwaj et. al. introduced the tactile method, which is an effective method for the blind in ambient noise environments. They tested it with 12 blind people under the direction of the tactile belt and conventional auditory with ambient and silent simulated street sounds and measured time completion and errors. The results showed the tactile belt was worse than the auditory device in a silent environment and showed almost no difference between the tactile belt and the auditory device in ambient simulated street sounds. In [8], Mlynski et. al. used auditory stimuli as an alert system for people with visual impairments and the blind. They tested it on 20 visually impaired people with 35 initially proposed sounds, and the results showed that sound information is important for visually impaired people. Our system combined both sound and vibration methods in the alerting system.

The detection sensor, as we use the HCSR04+ module, is an ultrasonic sensor as shown in Fig. 2. It will detect the obstacles in front of the user by transmitting the pulse signal at 40 kHz from a microcontroller unit (MCU), as we use the ESP32 Mini kit module as shown in Fig. 5, via the trigger or transmit pin of the HCSR04+ module, and when the HCSR04+ module detects the obstacles within a specified range, in the research we specified at 1 meter, the signal will high-speed feedback the information to the echo or receive pin, then transmit this signal to the ESP32 Mini kit module. After the ESP32 Mini kit module receives these signals, it will process and transmit a pulse width modulation (PWM) signal to the vibration module attached to the cane. The cane will vibrate, and the user will be aware of obstacles in front of them. The ESP32 Mini kit module will also transmit a sound signal to the Bluetooth earphone via Bluetooth communication with the Advanced Audio Distribution Profile (A2DP) profile, which will also alert the user by sound at the same time.

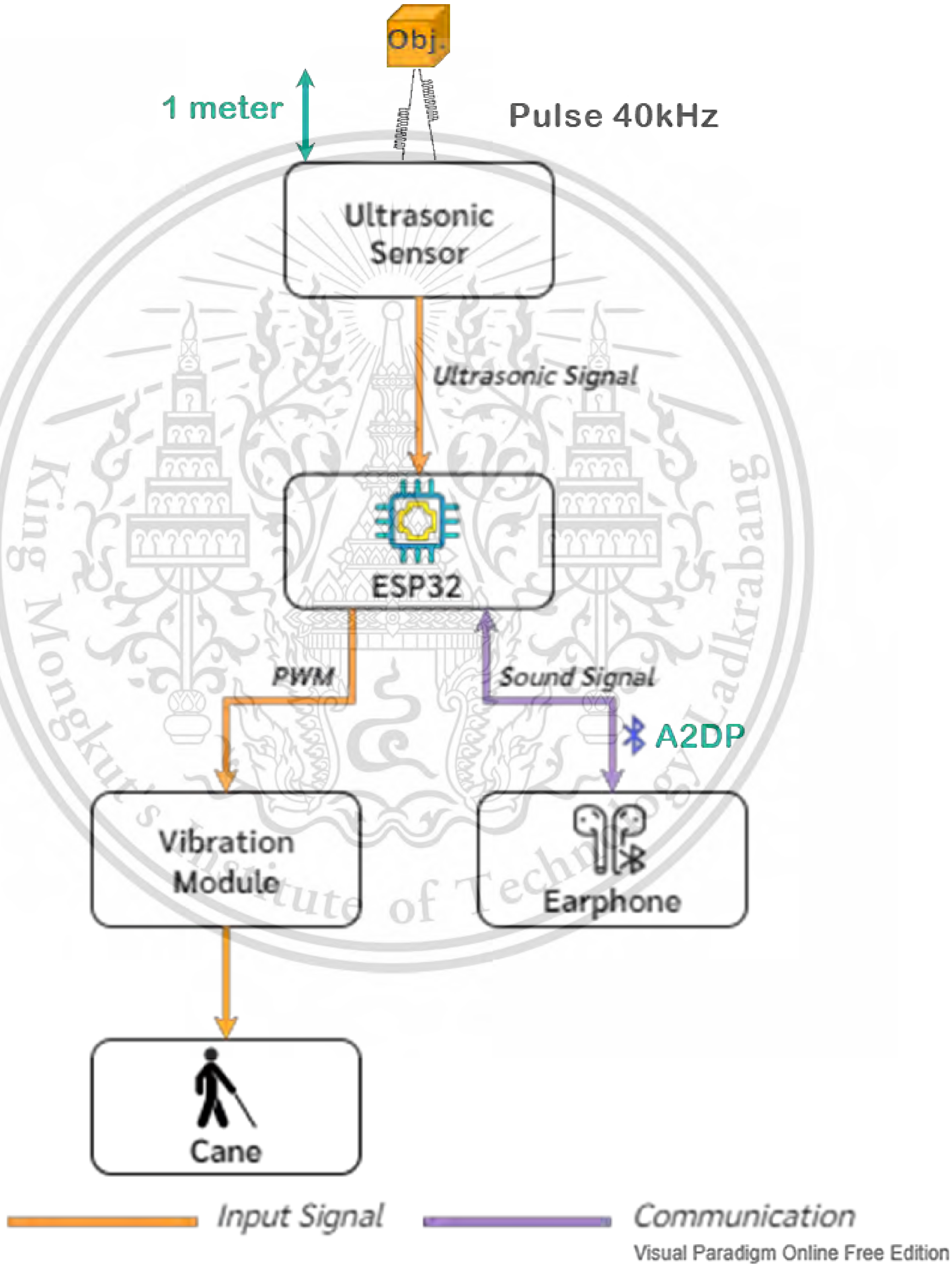


Fig. 20 The obstacle detection working diagram

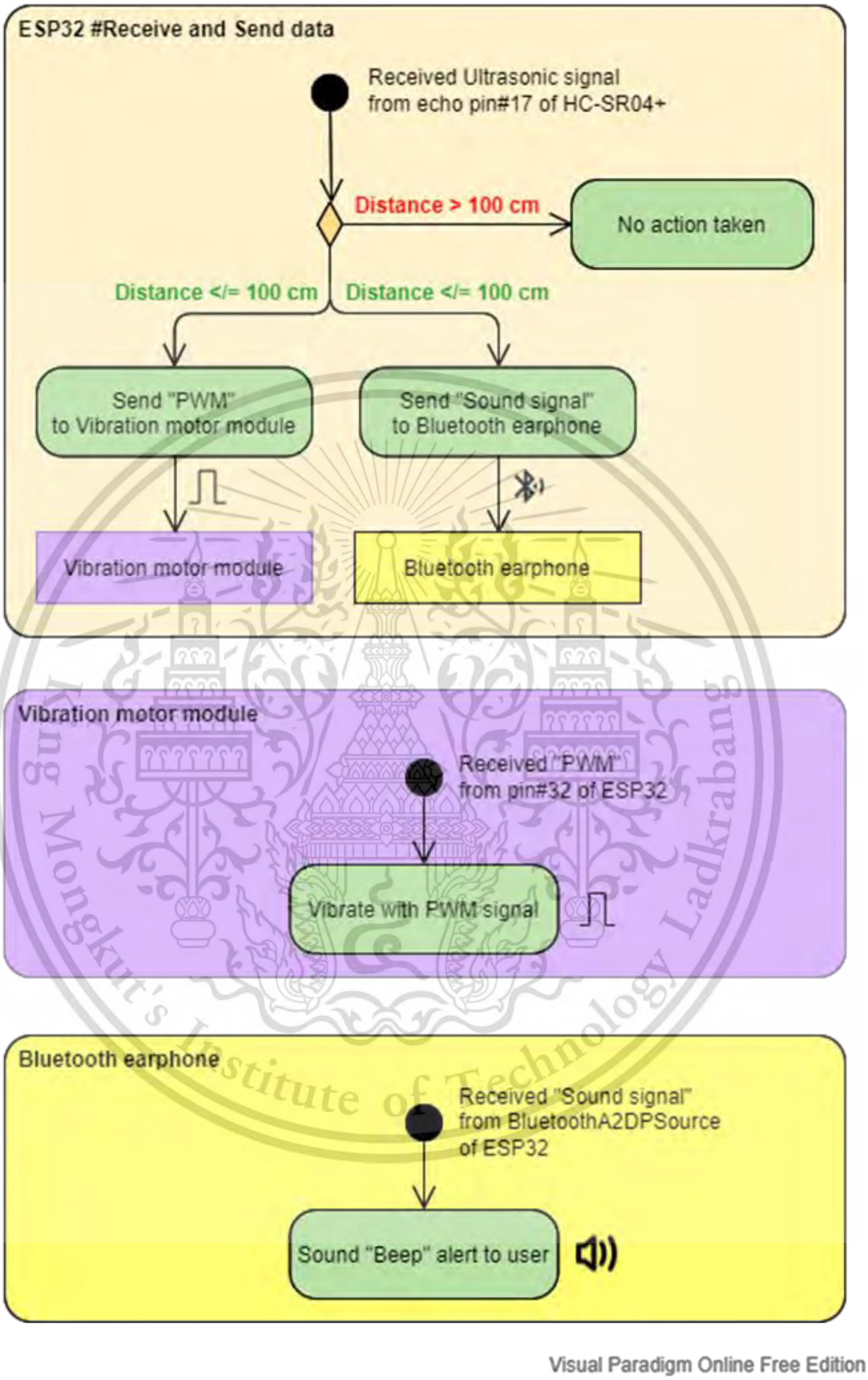


Fig. 21 The obstacle detection working system

3.1.2 Navigation and Emergency Call

The working system of the navigation and emergency call shown in Fig. 22 and Fig. 23 consists of three main parts, including (i) command buttons as numeric and call to installed on the cane, (ii) the microcontroller unit (MCU), and (iii) the Google Maps and call applications accessing on the phone.

When the user would like to travel to their favorite places, they can press the numeric buttons on the cane, as we use the tactile switch with Single Pole Single Throw (SPST), which is installed on the cane and connected with the Braille numbers 1 - 3 as shown in Fig. 8 (a) – (c). Each button defines different coordinates of a place according to the programed destination set by the user. After a microcontroller unit (MCU), as we use the ESP32 Mini kit module as shown in Fig. 5, has received the command signal, it then processes and transmits the data to the phone via an app inventor on the phone, as we designed with MIT App Inventor with the name "Smart Cane", via Bluetooth communication with a Serial Port Profile (SPP) to be accessible to the Google Maps app and start navigation as well as alert the user via verbal cues at the same time.

The user can press the call button on the cane, as we use the tactile switch with Single Pole Single Throw (SPST), which is installed on the cane and connected with the Braille alphabet c shown in Fig. 8 (d) for connecting emergency calls on the phone, according to the phone number programmed by the user. After a microcontroller unit (MCU), as we use the ESP32 Mini kit module as shown in Fig. 5, has received the command signal, it then processes and transmits the data to the phone via an app inventor on the phone, as we designed with MIT App Inventor with the name "Smart Cane", via Bluetooth communication with a Serial Port Profile (SPP) to be accessible to the emergency call app and immediate calls as well as alert the user via verbal cues at the same time.

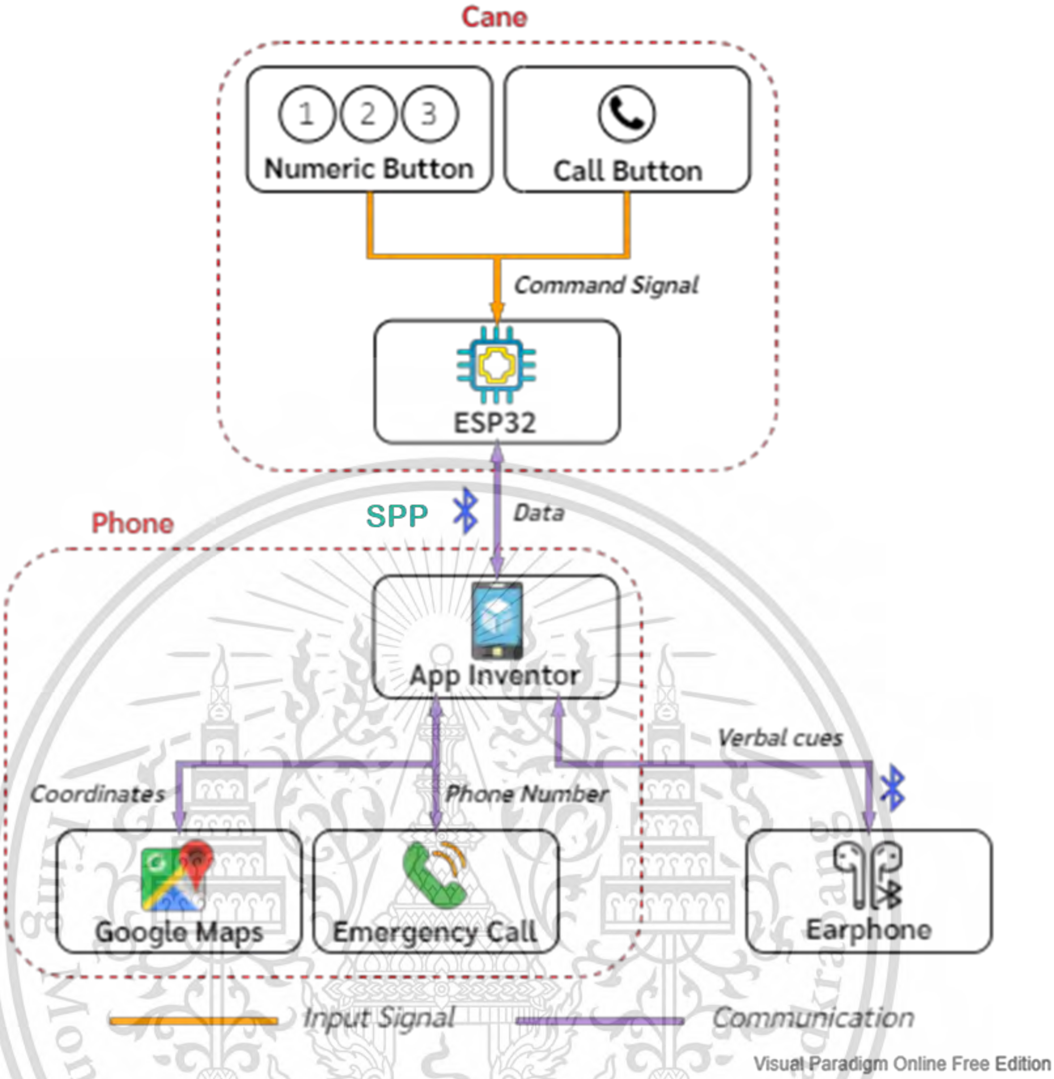


Fig. 22 The navigation and emergency call working diagram

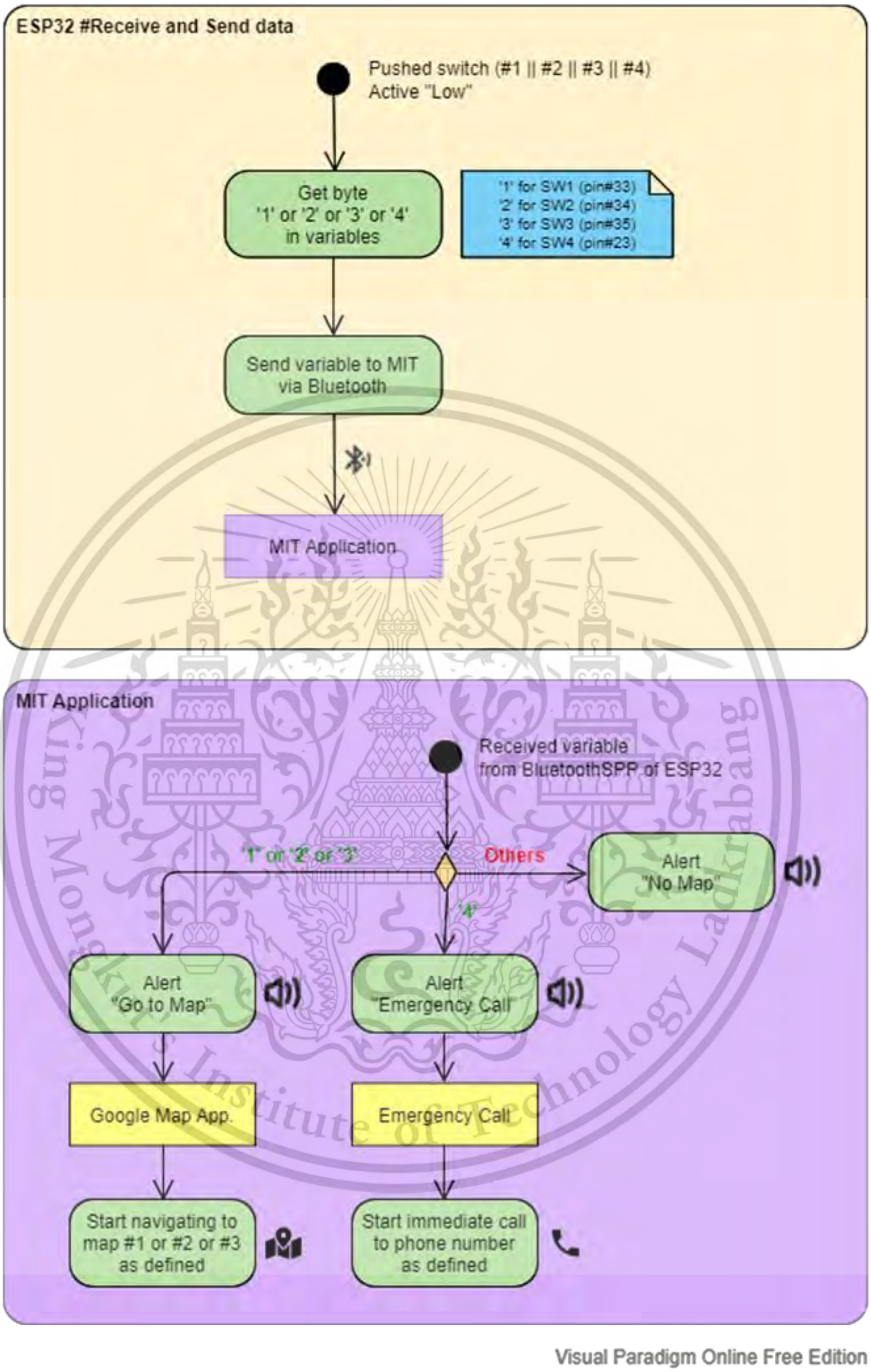


Fig. 23 The navigation and emergency call working system

3.1.3 Crossing a Road and Reading a Bus Number Guidance

The working system of the crossing a road and reading a bus number guidance shown in Fig. 24 and Fig. 25 consists of three main parts, including (i) the camera to get a real-time video frame, (ii) the microprocessor with detection and classification of machine learning, and (iii) the guidance system. In the present mobile phone, there is a high-efficiency microprocessor that is enough for use in machine learning to process crosswalks and bus numbers, and there is a high-resolution camera in itself. Thus, we use the mobile phone for detection of crosswalks and bus numbers in part of the camera to get a real-time video, and the microprocessor with detection and classification of machine learning via TensorFlow Lite apps, named "TFL Detect" on which we have trained the machine learning and then installed it on the mobile phone.

While the user turns on a "TFL Detect" app on the mobile phone, the mobile phone’s camera will get the high-efficiency real-time video frame into the mobile phone, and then the mobile phone will act as a microprocessor to detect region of interest (ROI) and classification via SSD MoblieNet V2 FPNLite 320x320 model. When it detects crosswalks and bus numbers, it will show the results with a region of interest (ROI) frame consisting of crosswalks and bus numbers, totaling 63 group numbers. After that, the guidance system will translate the text as shown on the interface app into verbal cues, whether crosswalk or bus number, and guide the user via Bluetooth communication with earphones. On the other hand, if the system detects other objects that are not crosswalks or bus numbers, it will not show text on the interface app and will not alert the users.

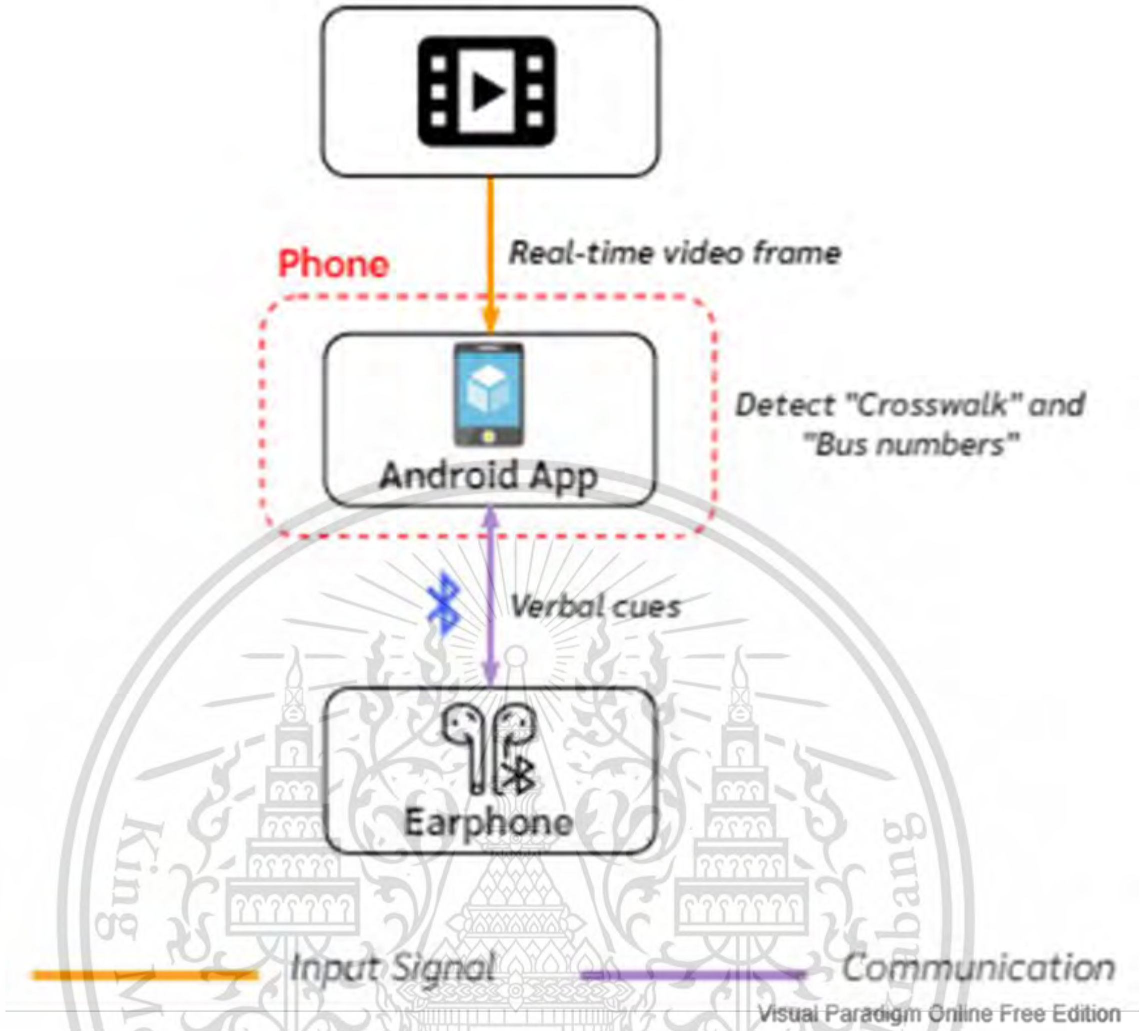


Fig. 24 The crossing a road and reading a bus number guidance working diagram

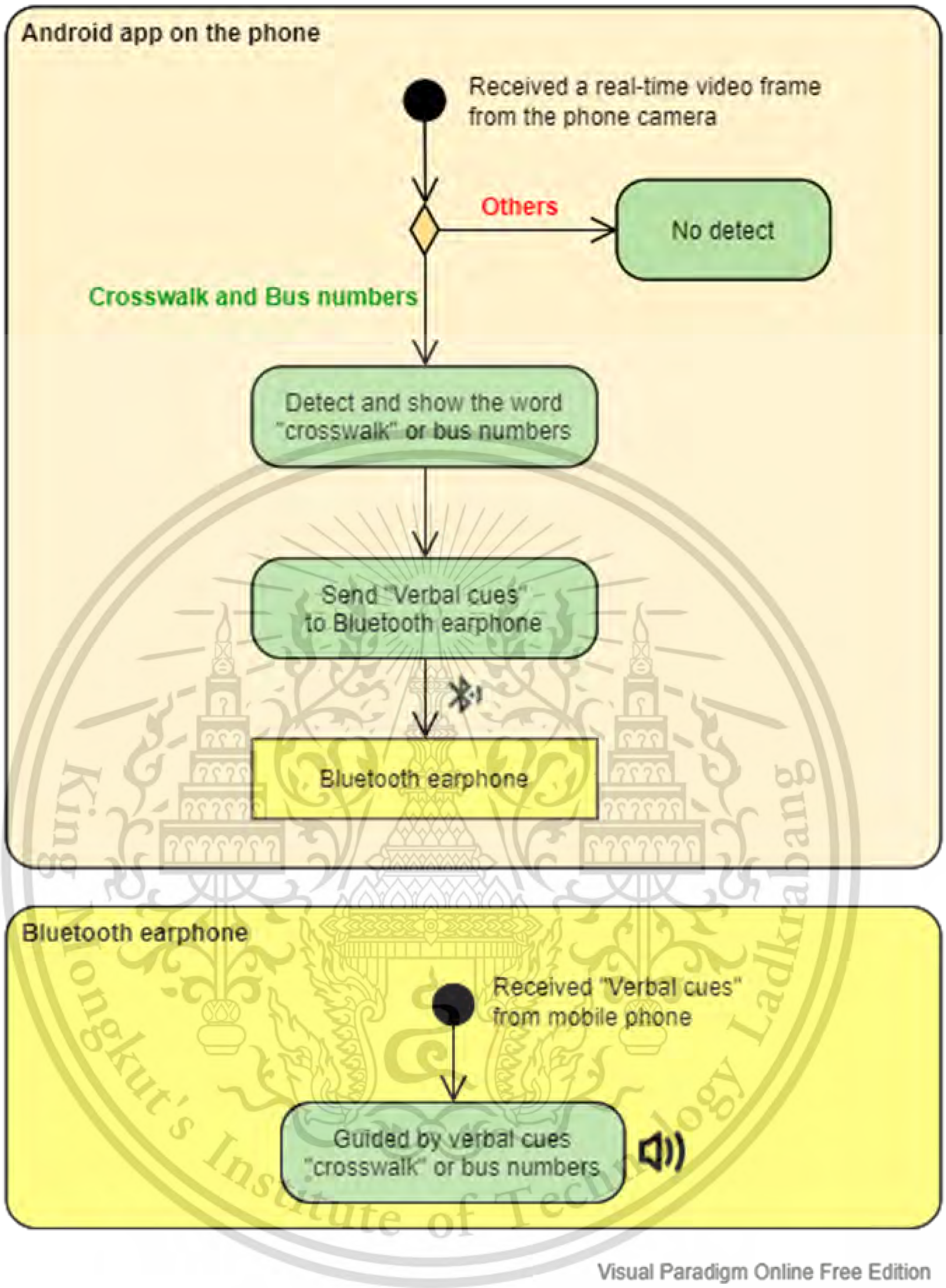


Fig. 25 The crossing a road and reading a bus number guidance working system

3.2 Experiments and Results

For the experiment with our prototype device, it is testing the working system in each function according to concepts and requirements. The whole experiment is tested in the laboratory by the organizer due to the COVID-19 situation.

3.2.1 Obstacle Detection

We connected a HC-SR04+ module as a detection sensor and the vibration motor module (Catalex), following the schematic as we designed on the protoboard as shown in Fig. 26 and Fig. 27, which are located approximately 0.3 meters from the floor, and connected them to an ESP32 Mini kit module as a microcontroller unit (MCU) which is connected to a computer to observe the distance at which the system detects obstacles in real-time via control code in Arduino as shown in Fig. 28, and we modified A2DP source coding (music sender) and converted sound data to hex with C in Arduino for alerts the user to Bluetooth earphones as shown in Fig. 28. The 8 types of obstacles are placed in front of the HC-SR04+ module at a specified distance of 3 ranges: 0.5 meters, 1 meter, and 1.5 meters, as shown in Fig. 29 and Fig. 30.

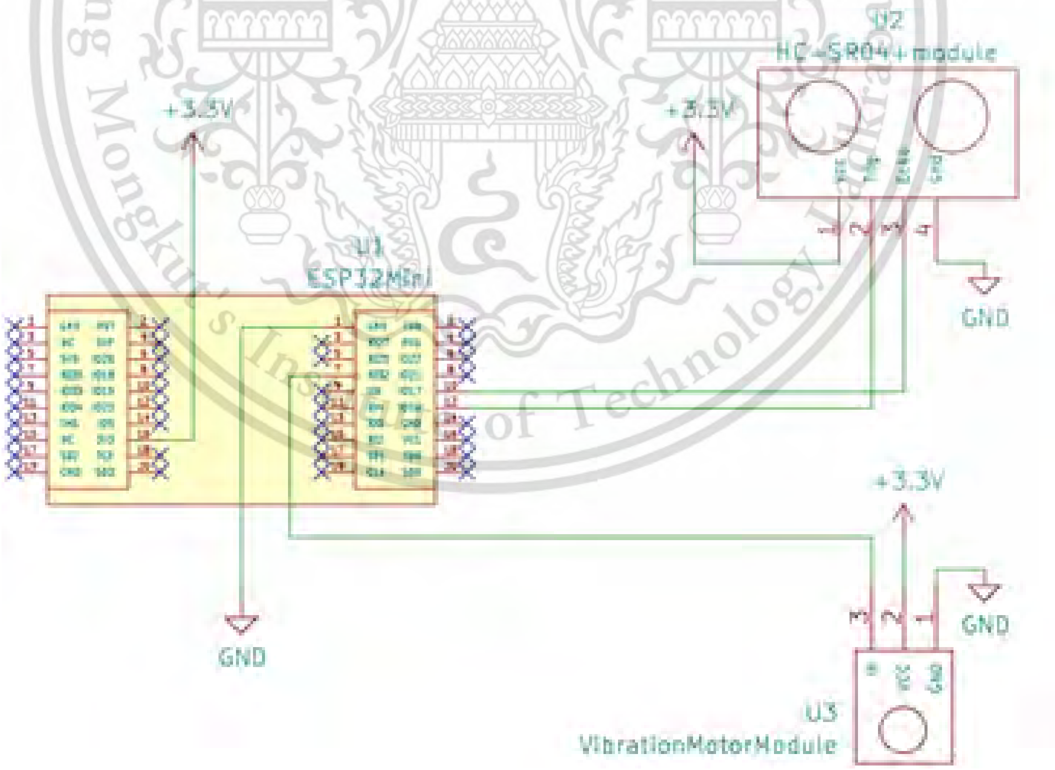


Fig. 26 The obstacle detection schematic

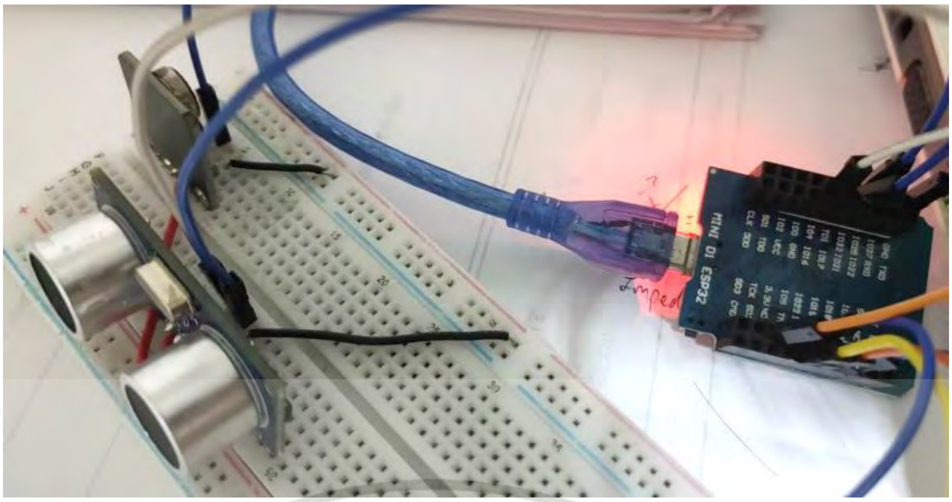


Fig. 27 Connected the obstacle detection devices on the protoboard

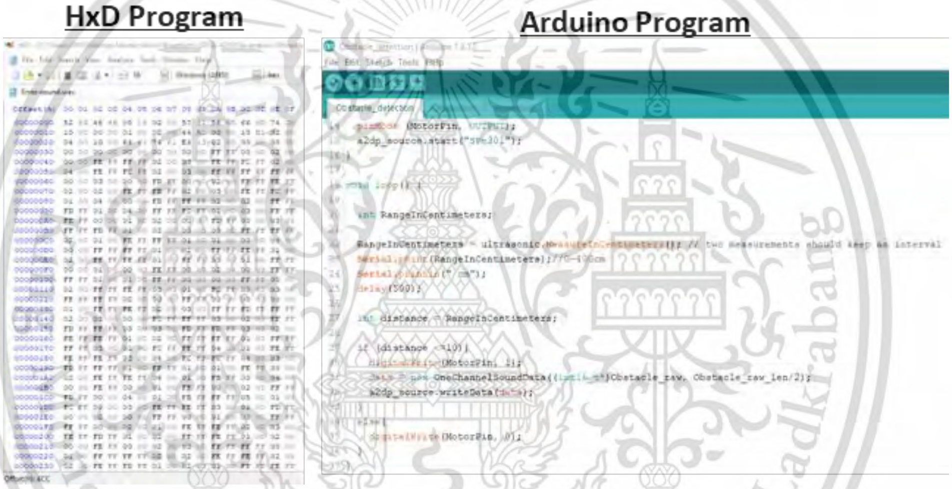


Fig. 28 Converting sound data to hex and control code in Arduino

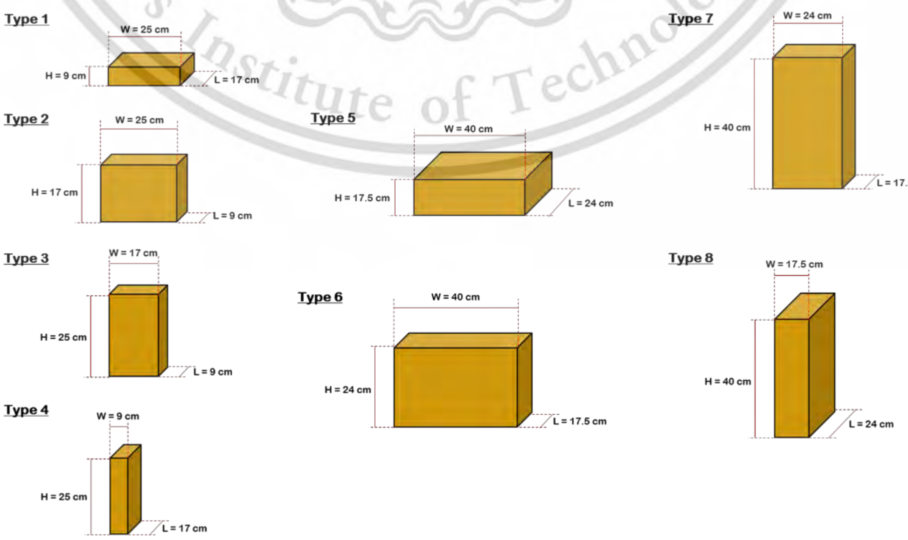


Fig. 29 Size of obstacles of 8 types

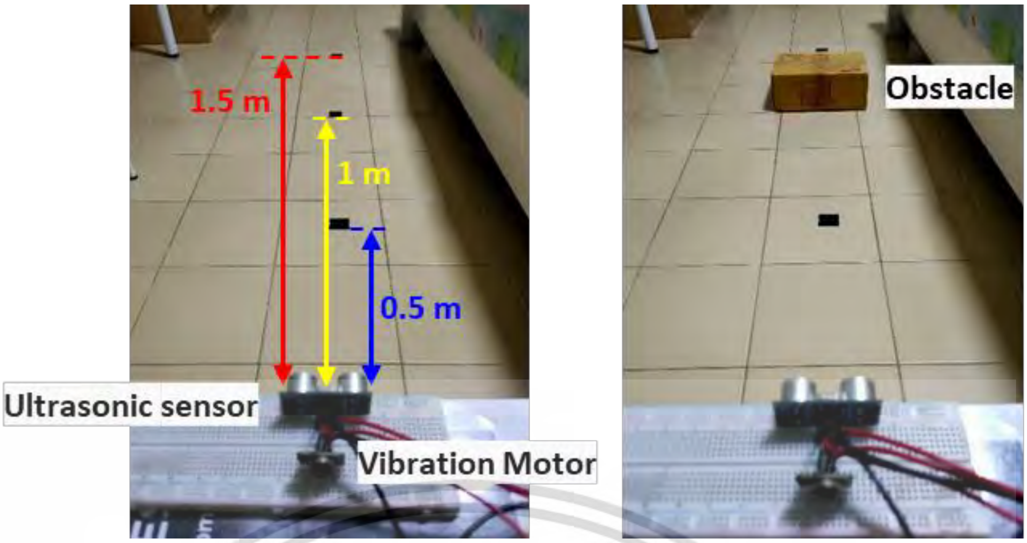


Fig. 30 Test with obstacles of 8 types at a specified distance of 3 ranges

The results show that our system was able to detect the obstacles in real-time, as shown in Fig. 31, and it was able to detect the obstacles at all 3 specified ranges in front of it, as shown in Fig. 32. For a specified distance of 0.5 meters, the highest error is 16.667% for obstacle type 1, which has the lowest height with an average measured distance of 0.583 meters, and the best accuracy is for obstacle type 6, which has the widest with an exactly measured distance of 0.500 meters. For specified distances of 1 meter and 1.5 meters, a small error in measured distance with a maximum error of 0.03 meters is observed.

And when the system found the obstacle in front of the user within a range of 1 meter, the system alerts the user in real-time via vibration from the vibration motor module (Catalex) within an average time of 369.80 milliseconds and sound from Bluetooth earphones with Bluetooth communication within an average time of 432.00 milliseconds, as shown in Fig. 33 and Fig. 34.

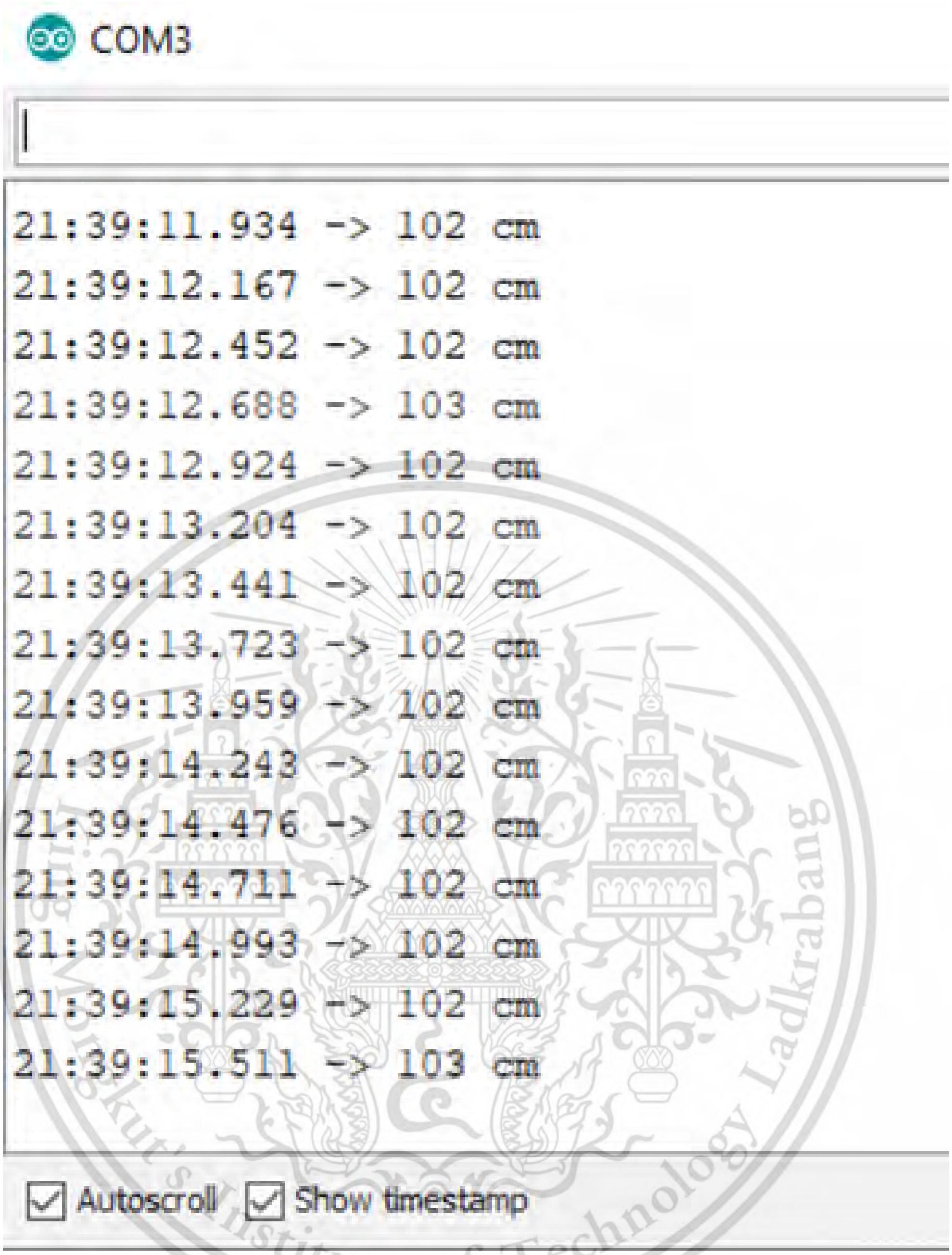


Fig. 31 Real-time measured obstacle distance on serial monitor

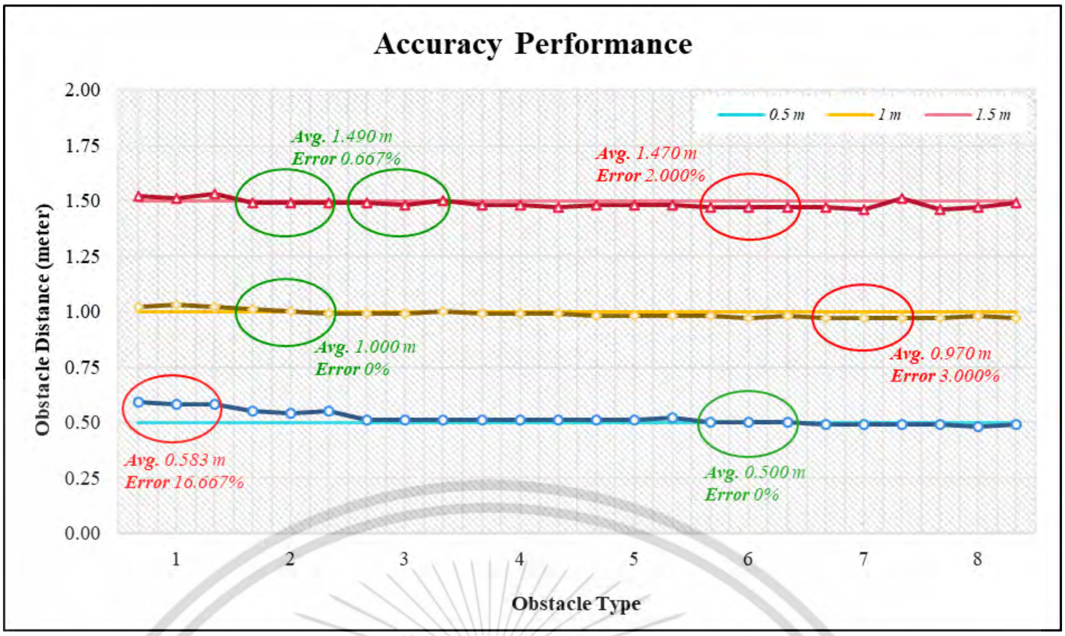


Fig. 32 The graph of the measured obstacle distance accuracy of the system that displays on the serial monitor, which repeated the test 3 times for placing the obstacles of 8 types at a specified distance of 3 ranges of 0.5 meters, 1 meter, and 1.5 meters.

Fig. 33 The simulation results for specified an obstacle distance of 10 centimeter

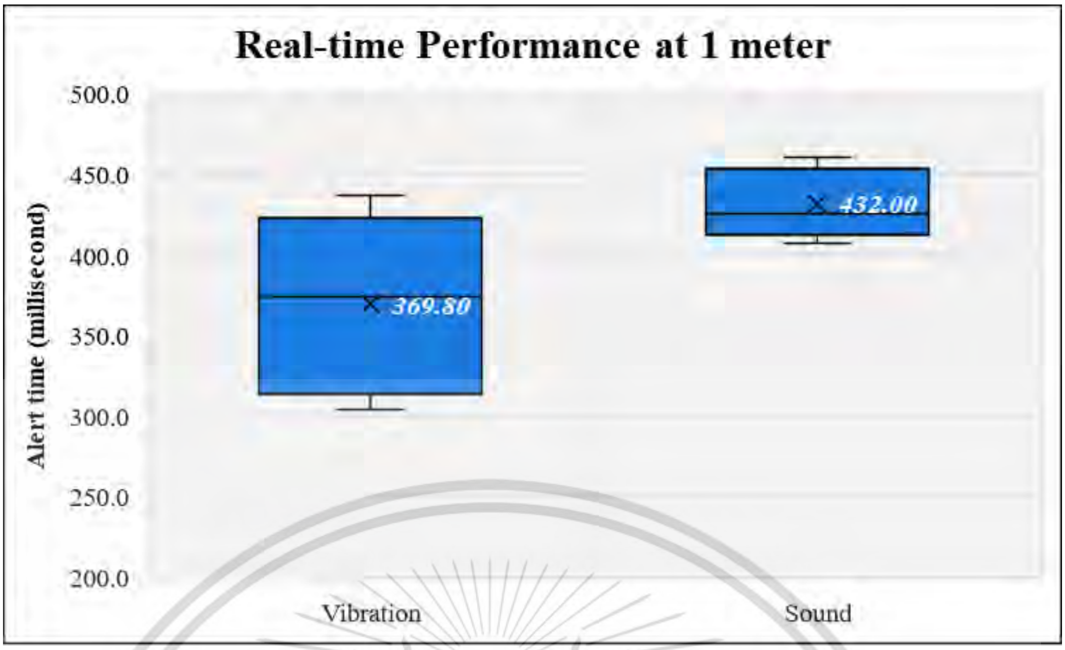


Fig. 34 The Boxplot of time for an alert user via sound and vibration shows that when found the obstacle in front of the user within a range of 1 meter, by manual counting, since immediately the ultrasonic sensor into 1 meter until the vibration module vibrates and the Bluetooth earphones a notification sound, which repeated the test 5 times. The average time of vibration is 369.80 milliseconds, and the sound is 432.00 milliseconds.

3.2.2 Navigation and Emergency Call

We connected a microcontroller unit (MCU) which we use the ESP32 Mini kit module and three numeric and call buttons, which are tactile switches without Braille, following the schematic as we designed on the protoboard as shown in Fig. 35 and Fig. 36, then we programming for control the ESP32 Mini kit module in Arduino to receive commands from the command buttons via Bluetooth connection with Serial Port Profile (SPP) as shown in Fig. 37, and designed app inventor with MIT App Inventor, name "Smart Cane", for receiving the commands from the ESP32 Mini kit module via Bluetooth communications as well as alert the user via verbal cues via Bluetooth communication with earphones and access to Google Maps app and emergency calls on the phone which we have already programmed the coordinates of the place to each numeric button and the phone number to the call button, and then installed it on the phone as shown in Fig. 38.

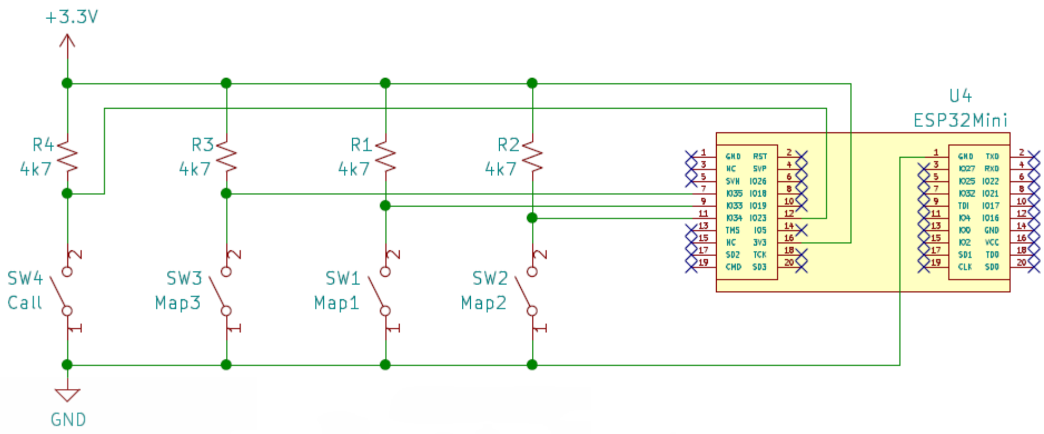


Fig. 35 The navigation and emergency call schematic

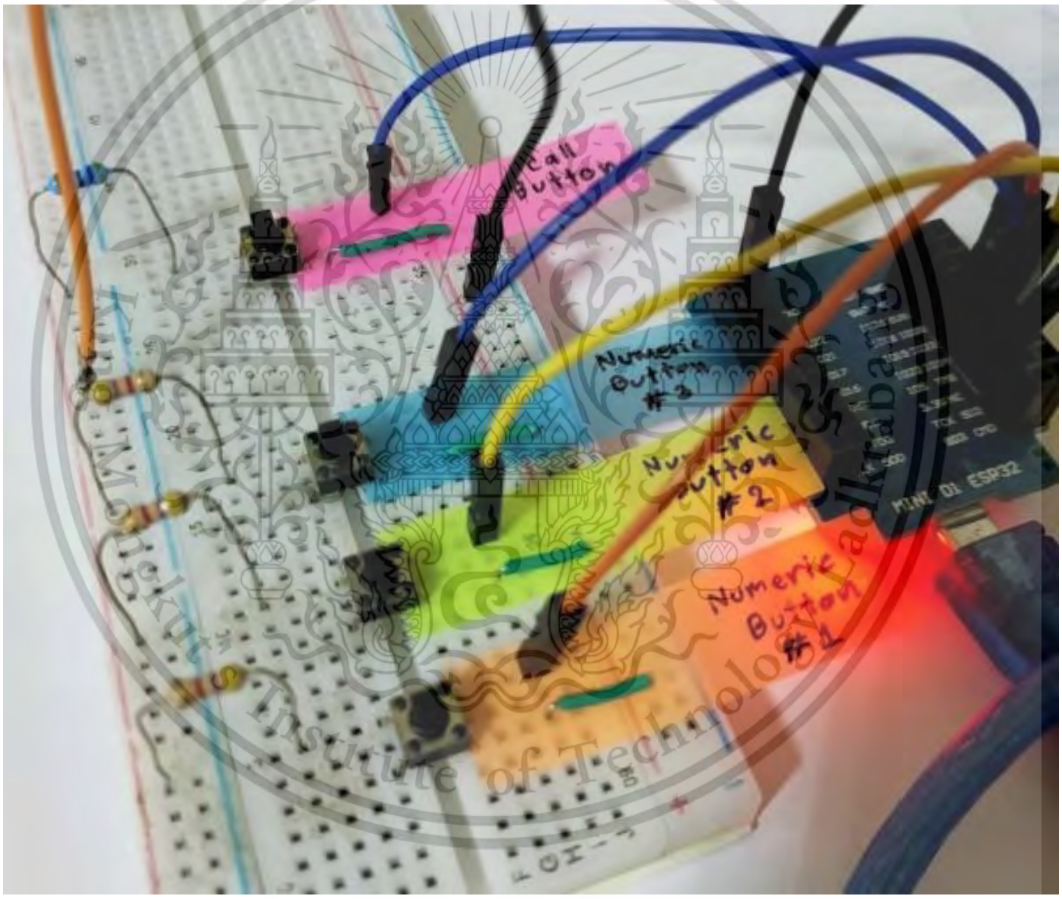


Fig. 36 Connected the navigation and emergency call devices on the protoboard

Fig. 37 Programming for control the ESP32 Mini kit module in Arduino

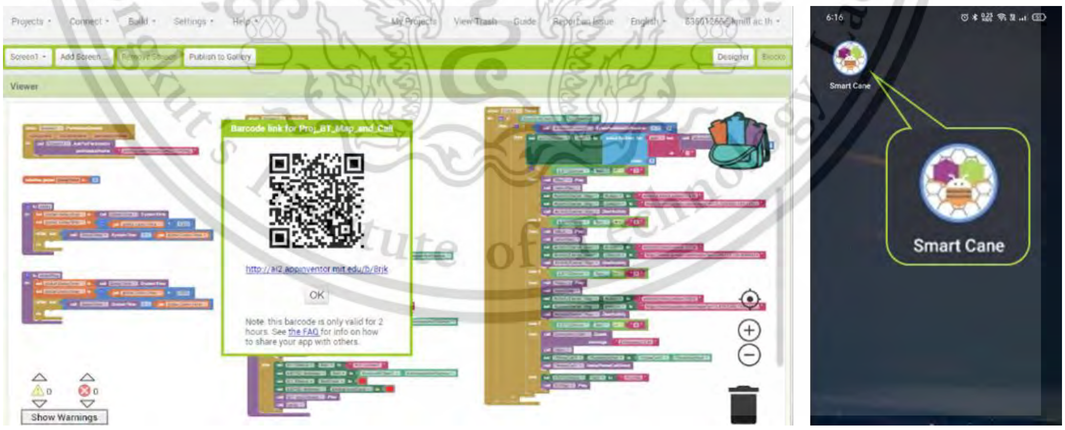
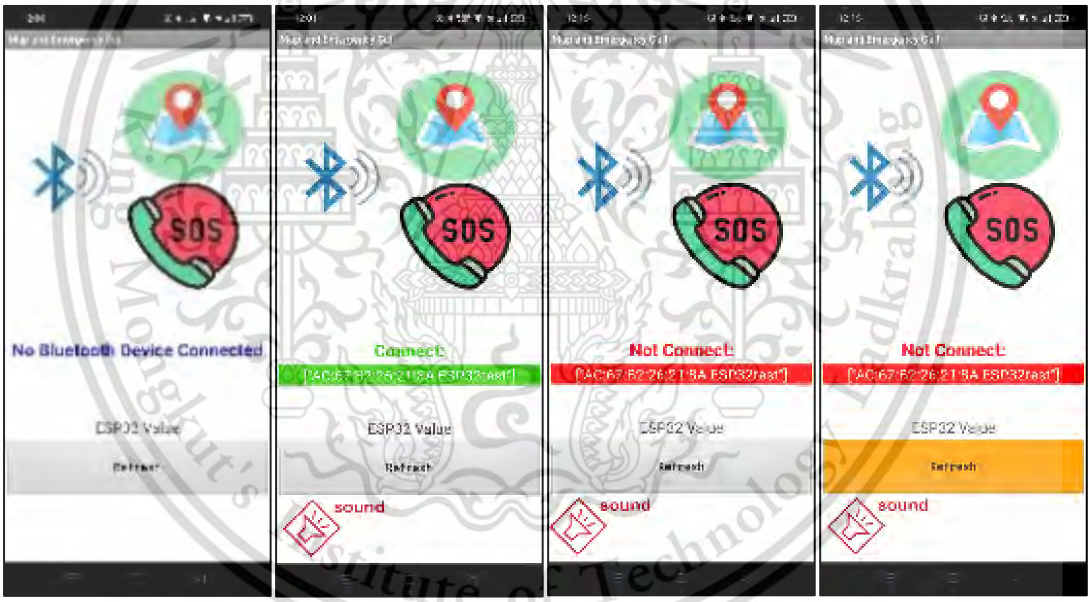


Fig. 38 Design the “Smart Cane” app and install app on the phone

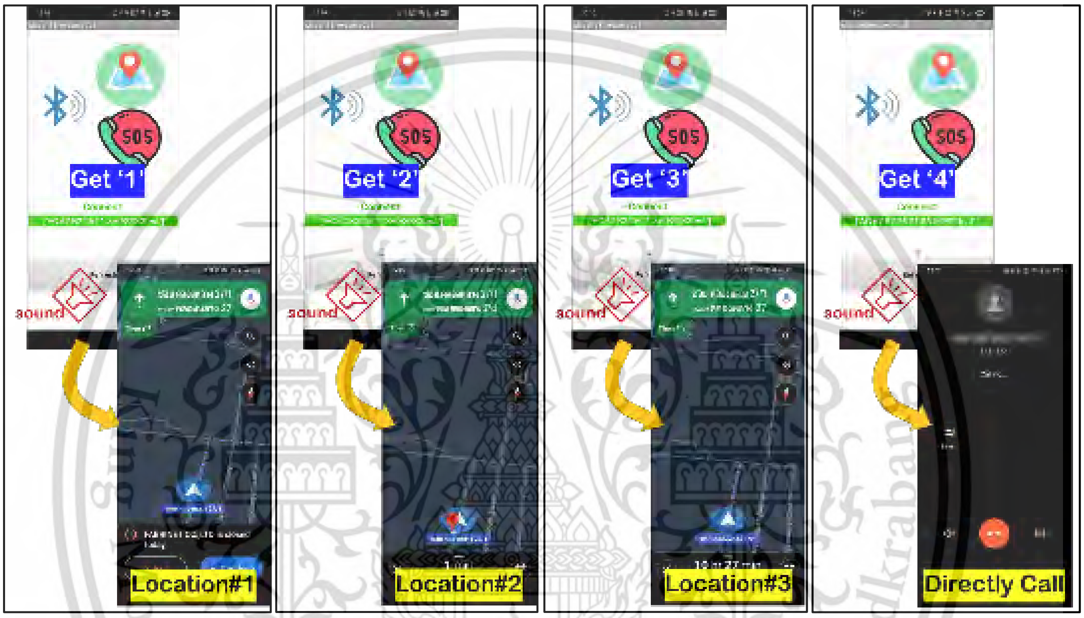
The results show that the App inventor that we designed, named “Smart Cane”, was able to connect Bluetooth to the ESP32 Mini kit module and display Bluetooth connection status and alert the user via verbal cues, as shown in Fig. 39, which the Fig. 39 (a) shown when you activate Smart Cane app, and the app finding the ESP32 Mini kit module’s Bluetooth automatically in 2 second, the Fig. 39 (b) shown the Smart Cane app connected Bluetooth to the ESP32 Mini kit module, and it alert user via verbal cues, the Fig. 39 (c) shown the Smart Cane app unable connected Bluetooth to the ESP32 Mini kit module, and it alert user via verbal cues, and the Fig. 39 (d) shown the Smart Cane app unable to find the ESP32 Mini kit module’s Bluetooth or Bluetooth communication is missing, and it alert user via verbal cues but in this case the user can press the refresh button on the Smart Cane app after that the app will re-connect the Bluetooth to ESP32 Mini kit module and it alert the user via verbal cues.



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

Fig. 39 Bluetooth connection status. (a) Activate App inventor that we designed and finding the Bluetooth of ESP32 Mini kit module. (b) Connected Bluetooth to ESP32 Mini kit module. (c) Not connect Bluetooth to ESP32 Mini kit module. (d) Refresh Bluetooth connection

Our system was able to access the Google Maps application on the phone and navigate to the coordinates of a place according to set with alerts to the user via verbal cues after pressed the numeric buttons as seen in Fig. 40. within an average time of 3.437 seconds with no errors, as shown in Fig. 41. And it was able to access the call on the phone and dial a phone number according to set accurately and with alert the user via verbal cues after pressed the call buttons as seen in Fig. 40 within an average time of 1.477 seconds with no errors, as shown in Fig. 41.



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

Fig. 40 The results after pressing the numeric buttons (a) Navigate to the first destination after pressed the numeric button 1. (b) Navigate to the second destination after pressed the numeric button 2. (c) Navigate to the third destination after pressed the numeric button 3. (d) Emergency call after pressed the call button

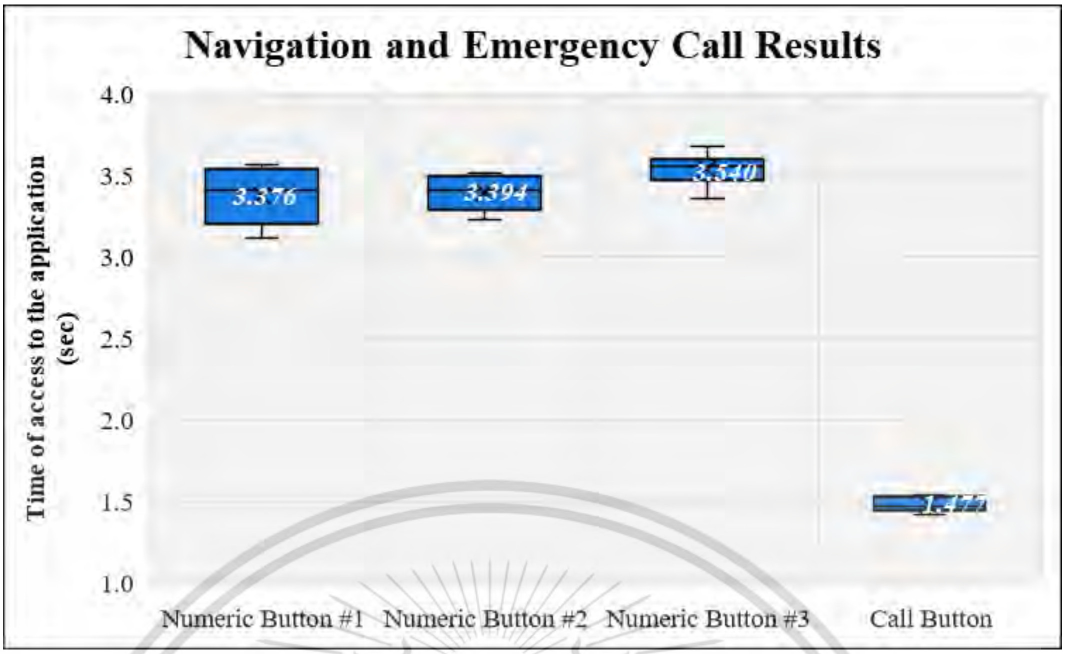


Fig. 41 The Boxplot of time for accessing the Google Maps app and calling on the phone after pressed the numeric and call buttons by counting since immediately after pressed the button until starting to navigate to the coordinates of the place for the navigation function, which includes finding the best route, and until calling out for the emergency call function, which repeated the test 6 times for whole buttons. The average time of the first numeric button is 3.376 seconds, the second button is 3.394 seconds, the third button is 3.540 seconds, and the call button is 1.477 seconds.

3.2.3 Crossing a Road and Reading a Bus Number Guidance

We used machine learning to train the crosswalks and bus numbers with TensorFlow 2.8.2 and the SSD MoblieNet V2 FPNLite 320x320 model on the Google Colab with a graphics processing unit (GPU), as shown in Fig. 42, by referring to [45]. We used 1,159 images of data sets, divided into training data sets totaling 875 images (75%) consisting of 487 images of crosswalks and 388 images with 63 group numbers of bus numbers, and testing data sets totaling 284 images (25%) consisting of 125 images of crosswalks, 119 images of bus numbers, and 40 other images that were not crosswalk or bus numbers. After we stopped training with the classification loss of 0.036, as seen in Fig. 43, by referring to the recommendation for best machine learning results for the SSD model, which states that we should stop the training when the loss is less than 0.1 and the ideal loss should be below 0.05, we exported the interface graph, as shown in Fig. 44, to test our trained object detection model on images.

Then we convert the trained SSD MoblieNet V2 FPNLite 320x320 model with TensorFlow 2.8.2 after testing it to a TensorFlow Lite model with attached metadata, as shown in Fig. 45 and Fig. 46, and then download the model for deployment on the Android app. In the final step, we build an Android app with Android Studio by referring to Running TF2 Detection API Models on Mobile of TensorFlow and [45], then install this object detection app, named "TFL Detect", on the phone as seen in Fig. 47 and test it for detection of crosswalks and bus numbers.

Fig. 42 Training the crosswalks and bus numbers on the Google Colab

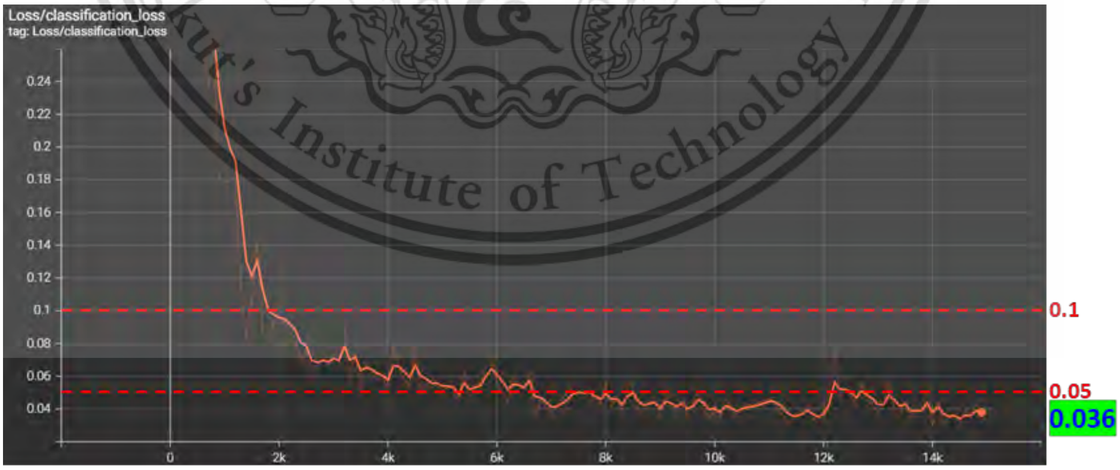


Fig. 43 The classification loss of 0.036 on the TensorBoard

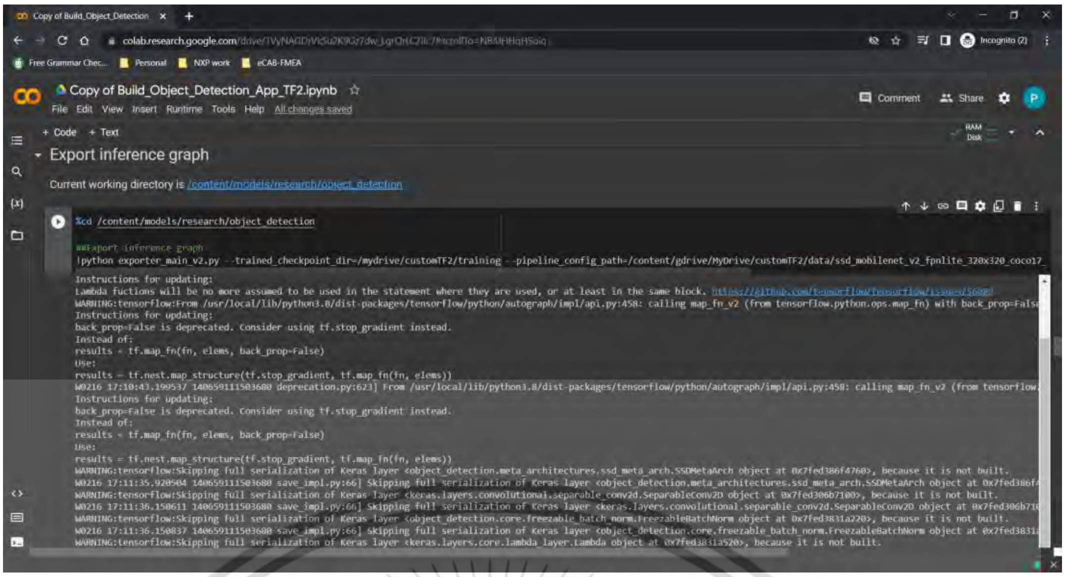


Fig. 44 Export interface graph

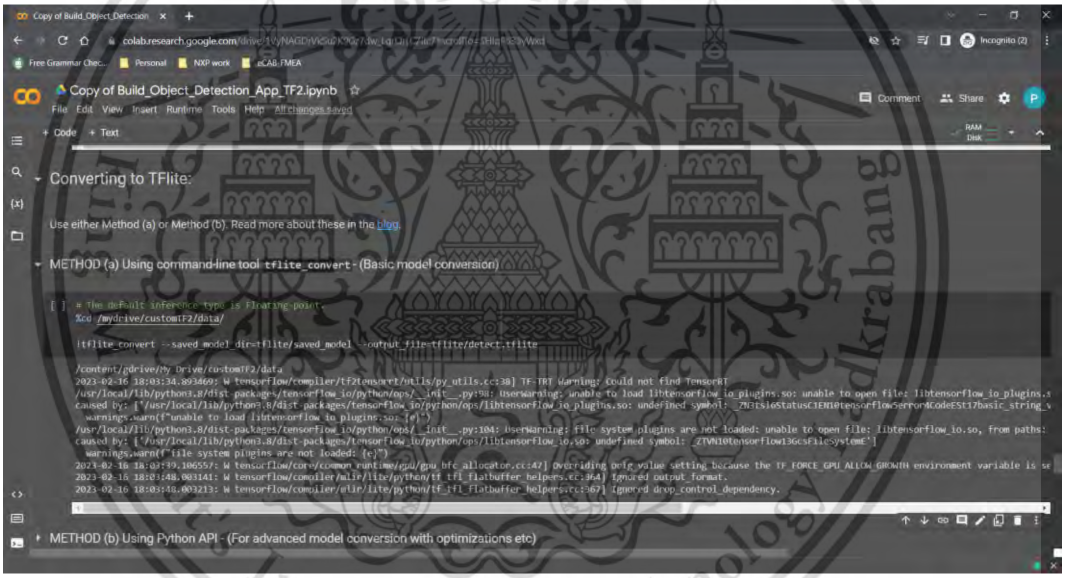


Fig. 45 Converting SSD model with TensorFlow 2.8.2 to TensorFlow Lite

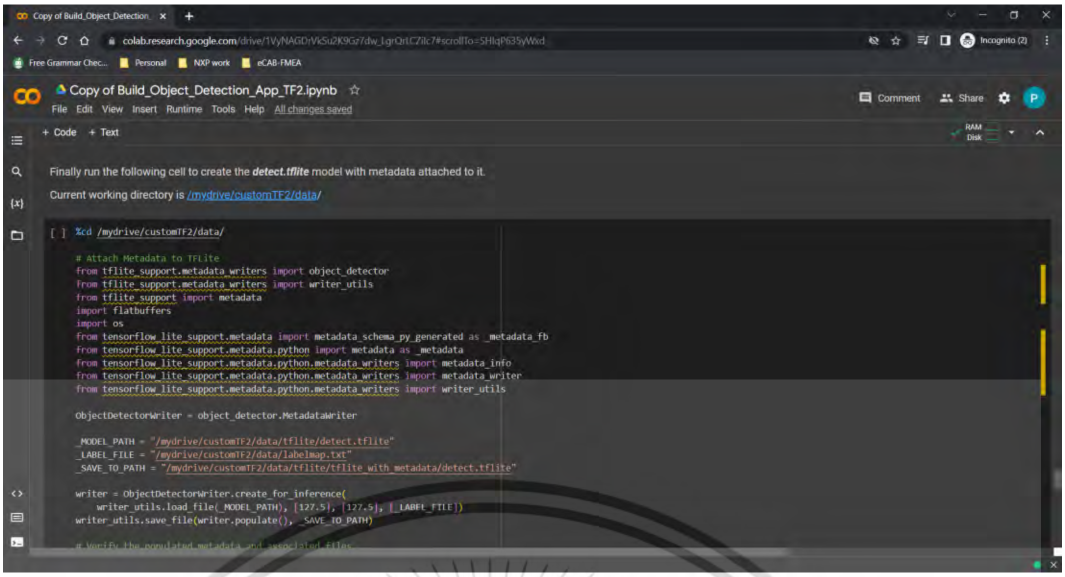


Fig. 46 Attaching metadata to TensorFlow Lite

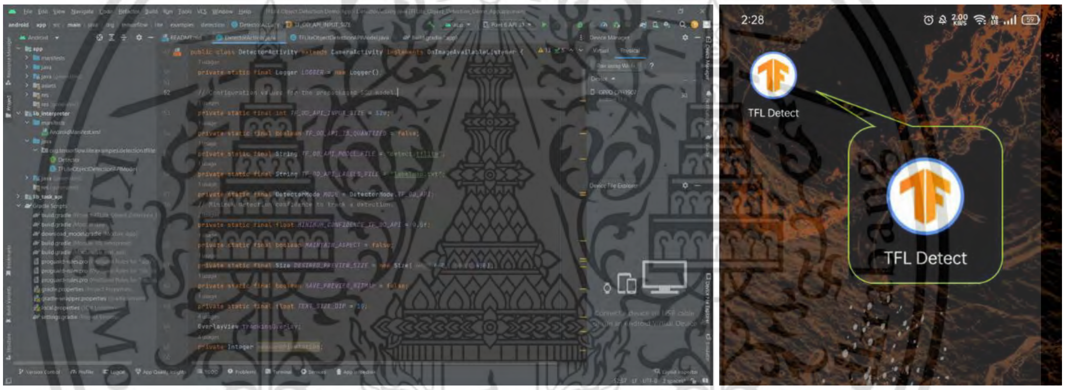


Fig. 47 Build "TFL Detect" app with Android Studio and install app on the phone

The results for testing the model on TensorFlow 2.8.2 show that our trained model was able to detect bus numbers of 81.51% detection and 54.62% correct detection, which is greater than acceptance criteria at 50% and a better result than previous training model results, as shown in Fig. 48 and Fig. 49, and it was able to detect crosswalks of 92.00% detection and 91.20% correct detection, which is greater than acceptance criteria at 80%, as shown in Fig. 50 and Fig. 51, as well as not detect other images that did not have crosswalks or bus numbers of 80.00% correct detection, which is equal to acceptance criteria at 80%, as shown in Fig. 52 and Fig. 53.

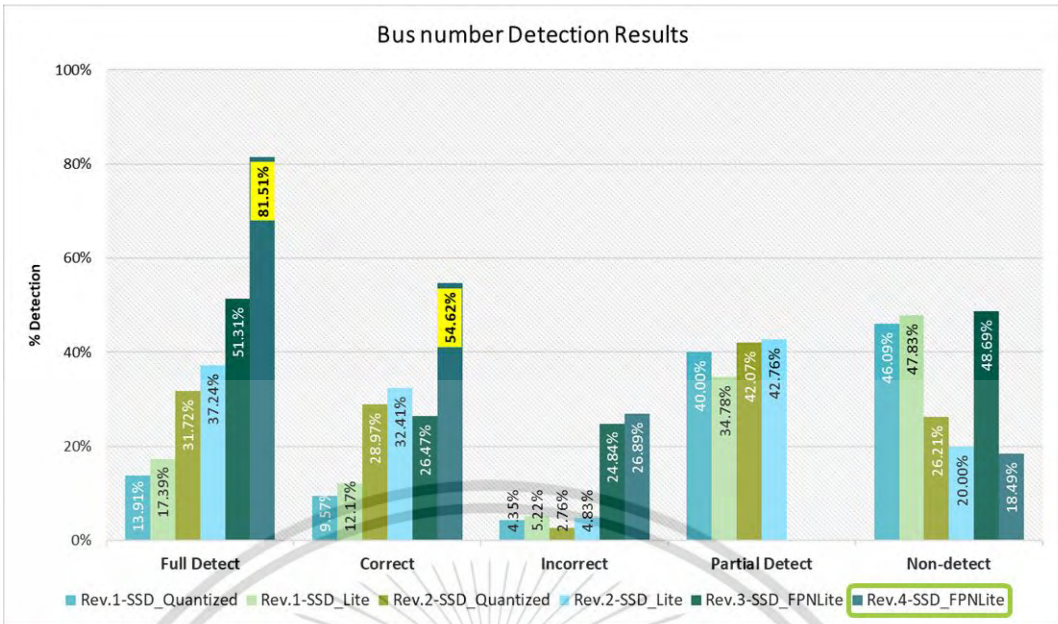


Fig. 48 Bus numbers detection graph results with TensorFlow 2.8.2

(a) (b) (c)

Fig. 49 The bus number detection results with TensorFlow 2.8.2 (a) Our system was able to detect the bus number and make the correct detection. (b) Our system was able to detect the bus number but made the incorrect detection. (c) Our system was unable to detect the bus number.

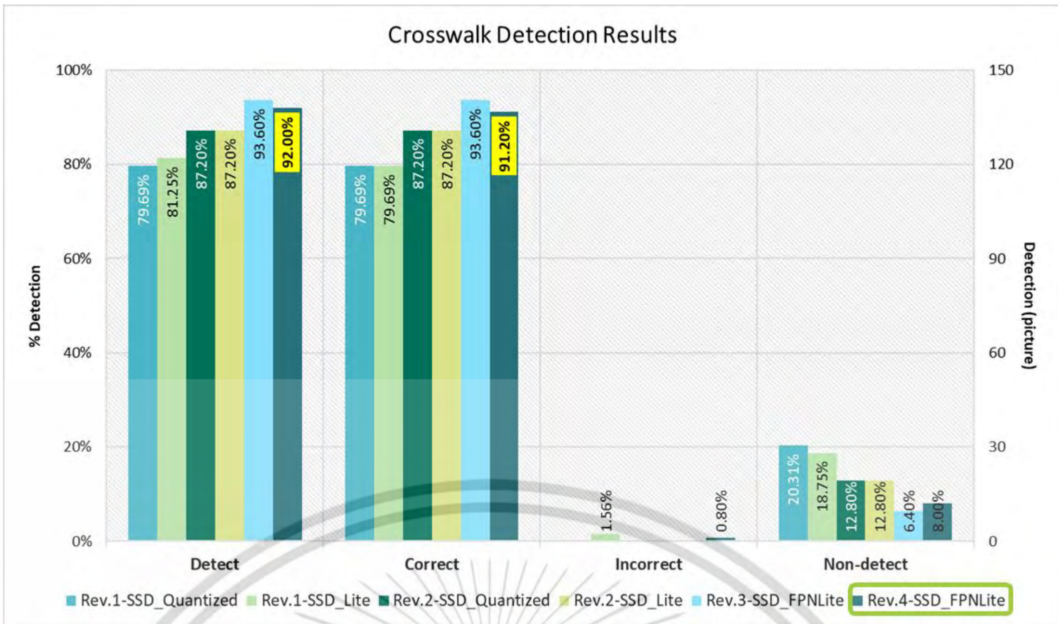
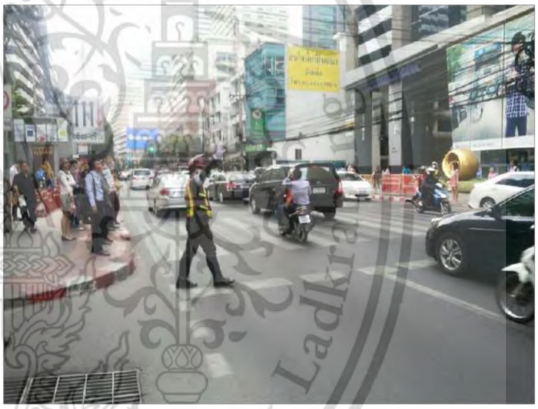


Fig. 50 Crosswalks detection graph results with TensorFlow 2.8.2

(a)



(b)

Fig. 51 The crosswalks detection results with TensorFlow 2.8.2 (a) Our system was able to detect the crosswalks and make the correct detection. (b) Our system was unable to detect the crosswalks.

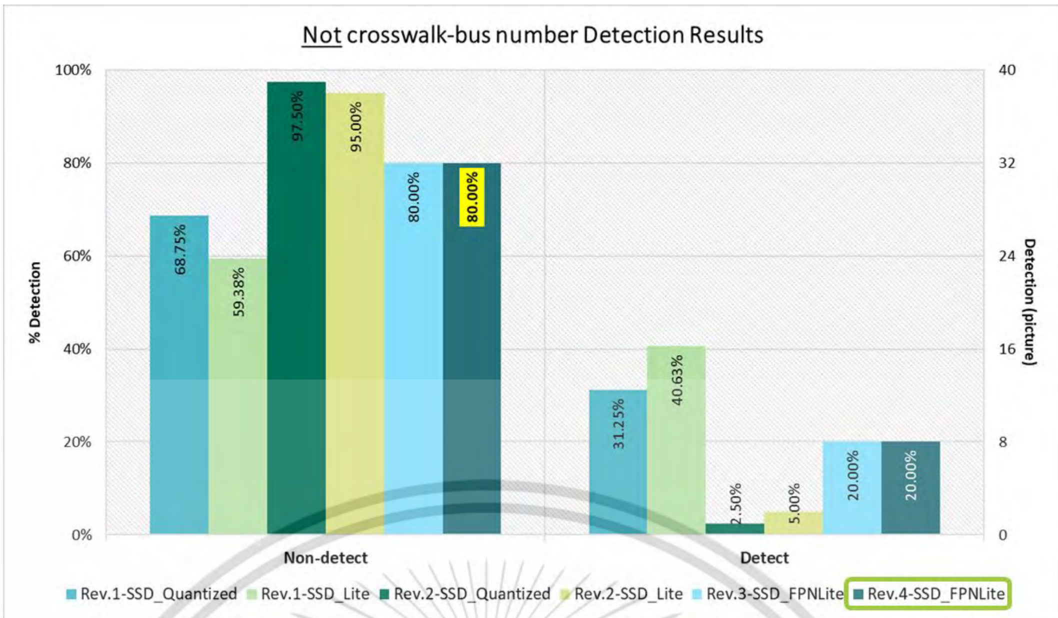


Fig. 52 Other images detection graph results with TensorFlow 2.8.2

(a) (b)

Fig. 53 The other images detection results with TensorFlow 2.8.2 (a) Our system not detect other images that did not have crosswalks or bus numbers and make the correct detection. (b) Our system detect other images that did not have crosswalks or bus numbers but made the incorrect detection.

The results for testing the model on the TFL Detect app with TensorFlow Lite on the phone show that our app was able to detect bus numbers and crosswalks as well as not detect other images that did not have crosswalks or bus numbers. However, there was some error in making the incorrect detection, as shown in Fig. 54 – Fig. 56.

Fig. 54 The crosswalk detection results on the TFL Detect app

Fig. 55 The bus numbers detection results on the TFL Detect app

Fig. 56 The other images detection results on the TFL Detect app

3.3 Design the Smart Cane

Referring to item 2.2.4, the specification of the smart cane, we designed our smart cane shown in Fig. 57, which is able to disassemble into three parts, including (i) the handle and controller, (ii) the cane body, and (iii) the cane tip.

Fig. 57 Smart cane

3.3.1 The handle and controller

The controller consists of the microcontroller unit (MCU), as we use the ESP32 Mini kit module, the vibration module, as we use the vibration motor module (Catalex), and the command buttons, as we use the tactile switch with Single Pole Single Throw (SPST), which are installed inside of the cane handle, which is assembled to the cane body at 150 degrees, and on the outside of the handle, there are 4 command buttons with Braille with standard size and symbols, as shown in Fig. 58, as well as the cane handle cover with nylon, which is 2.5 centimeters of diameter and 20 centimeters of length, as shown in Fig. 59.

3.3.2 The cane body

The cane body is made of aluminum or fiber glass tube with 1.2 centimeters of diameter and 140 centimeters of length in white and 35 centimeters of length in red on the tip of the cane body, and we installed the ultrasonic sensor, as we use the HCSR04+ module, inside the cane body, as shown in Fig. 59.

3.3.3 The cane tip

The cane tip we use is a general commercially available omni-sense tip, roller tip, or wheeling tip for assembly to the cane body because we would like to protect our controller devices from more vibration because it might affect the function of devices and their lifetime, as shown in Fig. 59.

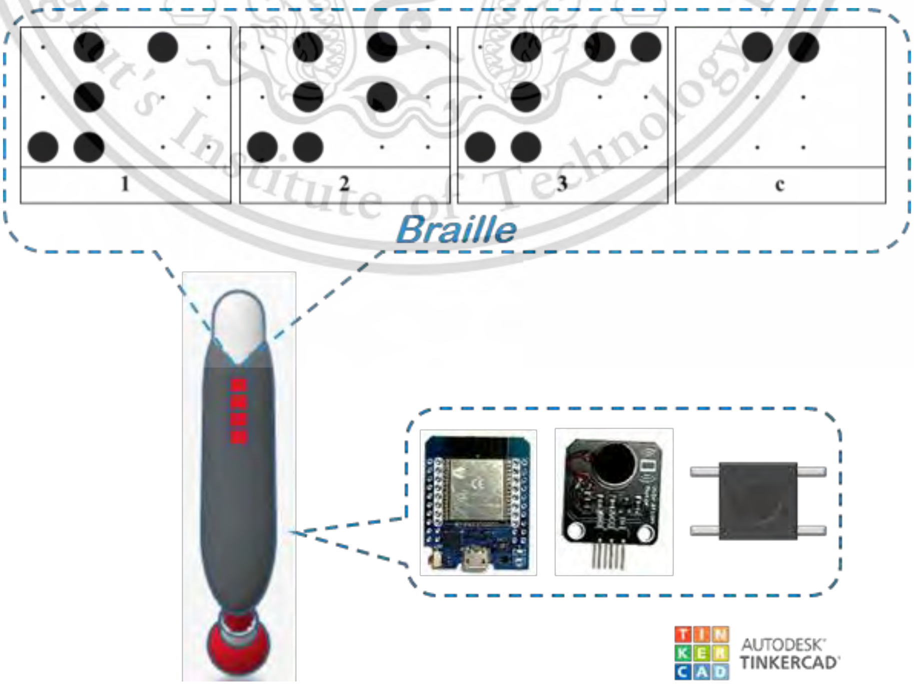


Fig. 58 The handle and controller of smart cane

Fig. 59 Details of smart cane

Chapter 4

DISCUSSION AND CONCLUSION

The smart cane for assisting the visually impaired and the blind was able to detect obstacles in front of the user and alert the user via sound and vibration by using an ultrasonic sensor, an ESP32 Mini kit module, and a vibration module when it found obstacles within 1 meter in real-time and high performance to decrease accidents caused by walking into obstacles and increase travel safety. The height and width of the obstacle as well as the distance of the obstacle from the ultrasonic sensor have a significant effect on the accuracy performance of the system for measuring obstacle distance, which the smaller obstacle and closer the ultrasonic sensor will have more error to be measured the distance. However, the time of alerting the user via sound might depend on the stability of the Bluetooth.

The navigation and emergency call functions was accessible to the Google Maps application on the phone in less than 4 seconds and accessible to calling in less than 2 seconds by using an ESP32 Mini kit module and a Smart Cane app on the phone as an App Inventor after pressing the command buttons by using a tactile switch with Single Pole Single Throw (SPST) with Braille, as well as alert the user via verbal cues with Bluetooth communication with no error. The time for accessing the Google Maps application to navigate to destination places might change depending on the stability of the Bluetooth and phone service as well as the coordinates of the destination place. The graph of the time for accessing the call shows less dispersed data, and the time performance for calling has enough to contact in an emergency, however, might depend on the stability of the Bluetooth and phone service. In the near future, we plan to experiment with the cane that we designed to observe signal absorption.

The crossing a road and reading a bus number guidance functions was able to provide guidance to the user by detecting and classifying crosswalks with more than 90 percent accuracy and real-time performance and reading bus numbers with more than 50 percent accuracy and real-time performance by using a TFL Detect app on the phone as an Android app built by Android Studio and TensorFlow Lite. On the other hand, our system did not detect other images that did not have crosswalks or bus numbers with 80 percent accuracy. However, there was some error in making the incorrect detection and classification crosswalks and bus numbers that might be caused by limitations in the trained results with our data sets on SSD MoblieNet V2 FPNLite 320x320 model and actual real-time video because the images in our data sets are not comprehensive in actual real-time video framing, the resolution of the trained image and actual real-time video framing from the mobile phone camera is different, and the efficiency of the microprocessor of the mobile phone is a bit lacking for processing with actual real-time video framing; additionally, there was a limitation in translating the text displayed on the interface app into verbal cues that remains incomplete successfully. In the near future, we plan to increase travel efficiency, independence, and safety for visually impaired people and the blind by translating the text as shown on the interface app into verbal cues, whether crosswalk or bus number, and guiding the user via Bluetooth communication with earphones via the Smart Cane app as an App Inventor on the phone as we use in the navigation and emergency call functions.

For future development, we will append other functions to increase travel efficiency, independence, and safety for visually impaired people and the blind, and assembly whole functions in our designed cane, then final test the systems before experimenting with visually impaired people and the blind, both indoors with a simulated environment and outdoors with the daily activities of visually impaired people and the blind.

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