INTEGRATED NAVIGATION SYSTEM FOR VISUALLY IMPAIRED PEOPLE

BY

PICHAYA PRASERTSUNG

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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A Thesis Presented

By

Pichaya Prasertsung

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Abstract

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Since traditional obstacle detection and navigation system cannot fulfill the needs of blind, multiple electronic travel aids are introduced during past decades. However, most of them are not practical for utilizing in real life due to their size, weight, and complexity.

This research proposes a framework of indoor navigation for visually impaired people by introducing 3 main parts, which are indoor positioning, obstacle detection, and way finding respectively.

For positioning part, a model for differentiates location of user based on smartphone and Wi-Fi is introduced. For obstacle detection part, a prototype of obstacle detection device based on ultrasonic sensor is introduced. For way finding, an application for navigation and vibrating wristband are introduced. The main objective of the framework is to reduce cognitive load during traveling in order to promote independent traveling for blind.

This research mainly focuses on positioning part by proposing a localization method based on Wi-Fi. Four access points are suitable for room level classification with the area size of 10 x 12 meter. Applying Kalman filter to raw RSSI value before generating the model increase classification performance by 6% on the average.

Keywords: Navigation framwork, indoor-positioning, Wi-Fi localization, blinds

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Chapter 1
Introduction

1.1 Introduction and Thoeretical Framework

Sighted people detect obstacle and find a path to traverse by visual perception. Unfortunately, visually impaired people cannot rely on visual perception. To travel, they need a device with these features: obstacle detection and navigation with haptic feedback or auditory feedback. Blind normally rely on canes and guide dogs to travel. However, both of them cannot detect instant obstacles such as moving vehicles or obstacle in head level such as signage.

For past decade, multiple electronics travel aids are introduced for blind navigation. However, most of them are not popular among blind society due to their size, weight, and complexity of the system.

This research proposes a framework of indoor navigation for visually impaired people. The framework consists of 3 main parts, which are indoor positioning, obstacle detection, and way finding respectively. For positioning part, a model for differentiates location of user based on smartphone and Wi-Fi is introduced. For obstacle detection part, a framework and tool for making an obstacle detection device is explained. For way finding part, a prototype of application is introduced. The main objective of the framework is to reduce cognitive load during traveling in order to promote independent traveling for blinds.

1.2 Statement of problem

Visually Impaired people experience difficulty more than sighted people in independent traveling since they are lack of visual perception to detect obstacle. Traditional navigation tool such as cane and guide dog can detect obstacles only in short distance. Electronics travel aids presenting recently neither portable nor convenience which lead to lack usage among blind community. Hence, a navigation framework, which consist of obstacle detection features and navigation features, is crucial in order to promote independent traveling among blinds.

1.3 Purpose of study

The purpose of this study is to introduce an indoor navigation framework for visually impaired people in order to promote safe and independent traveling among blinds. In this study, the main focus is on indoor localization with less additional infrastructure.

1.4 Significance of this study

The system can help visually impaired people mobility. Blinds can travel more safely and independently than using only traditional navigation system such as cane.

Chapter 2
Literature Review

This chapter will introduce technology and assistive devices, which are developed for visually impaired people. The first part of this chapter will explain about traditional obstacle and navigation system for visually impaired people. The next part is a comparison of each assistive technology for visually impaired people. Positioning technology also mention in this chapter. The rest of this chapter discuss about challenges for indoor navigation andw limitation and delimitation of this work.

2.1 Traditional Navigation System for visually impaired people

Traditional navigation systems for visually impaired people are cane and guide dog. Both of them can detect obstacles in short range (Lakde & Prasad 2015). In addition, they cannot detect obstacles until the obstacles are dangerous closed to. Table 2.1 shows features comparison of cane and guide dog.

Table 2.1 Feature comparison of cane and guide dog

	Features	Cane	Guide dog	Comment
1	Affordability	✔	∆	To breed and train a guide dog costs around £42,300
2	Portability	✔	✗	
3	Can be used anywhere	✔	✗	Dogs are not convenience to use in some places such as crowded bus in Thailand.
4	**Obstacle detection**			
	• Detection obstacle at knee level	✔	✔	
	• Detect potentially hazard obstacles at head level	✗	✗	
	• Detect certain obstacles (e.g. a moving vehicle)	✗	✗	
5	Navigation	✗	✔	
6	Life expectancy	-	-	For cane, it depends on usage and material quality. For guide dog, average life expectancy is 6 years

* ✗ = cannot use, ✔ = can use, and ∆ = can / cannot used (depend on a situation)

From table 2.1, both canes and guide dogs have many limitations. They cannot detect obstacles at head level. They cannot detect certain obstacles such as a moving vehicle. Since traditional navigation system cannot fulfill the need for blinds, many researchers explore various solutions to eliminate these limitations. Assistive technology for blinds in term of obstacle detection and navigation is explained in next section.

2.2 Obstacle detection and navigation technology for visually impaired people

Since one of features for vision loss people travelling is to avoid objects during travel, obstacle detection and obstacle warning are important in order to avoid hazardous. This section will provide basic information and chart comparison among technologies for obstacle detection, navigation, and positioning respectively.

For obstacle detection, various technologies are applied in order to detect obstacles. There are 2 types of technologies, which are vision based and non-vision based obstacle detection. For vision based obstacle detection, this technology relies on camera such as web-cam camera or depth camera like Kinect (Wang et al. 2014). Another type relies on sensor such as ultrasonic sensor and infrared sensor. Table 2.2 shows comparison results for each technology.

Table 2.2 Feature comparison for obstacle detection technology

Features	Technology Name		
	Smart cane	iSonar	Navigation System for the Visually Impaired Individuals with the Kinect and Vibrotactile Belt
1) Portability	✔	✔	✗
2) Obstacle detection			
Head level	✗	✔	✔
Leg level	✔	✗	✔
3) Technology	Ultrasonic	Ultrasonic	RGB-D Camera (Kinect)

Figure 2.1 smart cane (Singh et al. 2010)

Smart cane is a cane with ultrasonic sensor that help user to detect obstacle in both leg level and head level. User will get a haptic feedback from the cane when the obstacles nearby. Special training is required for using this device to help translate the meaning of each vibration pattern (Singh et al. 2010).

The same technology is applied to iSonar(Vorapatratorn 2013). It is an obstacle detection device based on ultrasonic sensor. It helps blinds avoid obstacles in head level. However, this technology has a disadvantage on noise in crowded environment. When user is in crowed environment, the system will detect obstacle all the time.

Figure 2.2 iSonar device (Vorapatratorn 2013)

For navigation, blinds need an appropriate user interface in order to fulfill their need. Since, they cannot read the text on the application, haptic feedback and auditory feedback are crucial. For haptic feedback, the common technology is to attach vibration motors in wearable devices and provide feedbacks by various vibration patterns. For example, a vibrotactile belt that can vibrate in different patterns based on commands (Wang et al. 2014). It helps users to avoid obstacles. The vibrotactile belts consist of 8×2 vibration motors array. Each of the vibration motor is connected to a PWM pin, which is used to change the frequency of the motor.

Figure 2.3 The overview of the Navigation System for visually impaired people with kinect and Vibrotactile belt (Wang et al. 2014).

Apart from belt, some researcher proposed a wearable tactile harness-vest display (Velázquez 2010). A set of 6 vibrating motors generates tactile messages such as forward, back, left, right, speed up, and slow down to guide the users through an environment.

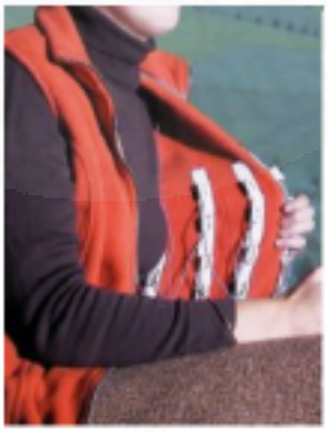

Figure 2.4 A vibrating vest (Velázquez 2010).

Gelmuda Wojciech and Kos Andrzej propose a vibrating wristband for conveying navigation information (Gelmuda & Kos 2012). The wristband generates different vibration patterns to guide users and avoid obstacles.

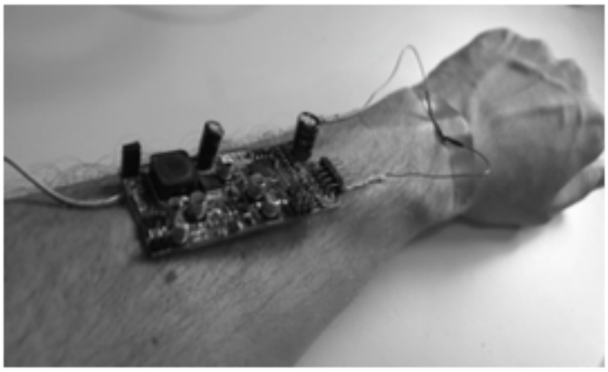

Figure 2.5 A prototype of vibrating bracelet interface (Gelmuda & Kos 2012)

Another group of research proposes refreshable braille display map (Zeng & Weber 2016). The map information is converted into dot matrix display. Blinds can feel surrounded environment by touching on refreshable Braille display screen. When the user moves, the map is changed based on the user's position. Additionally, user can zoom in, zoom out, translates the map using a Wii-remote. Pros and cons of interface technologies mention above are shown in table 2.3.

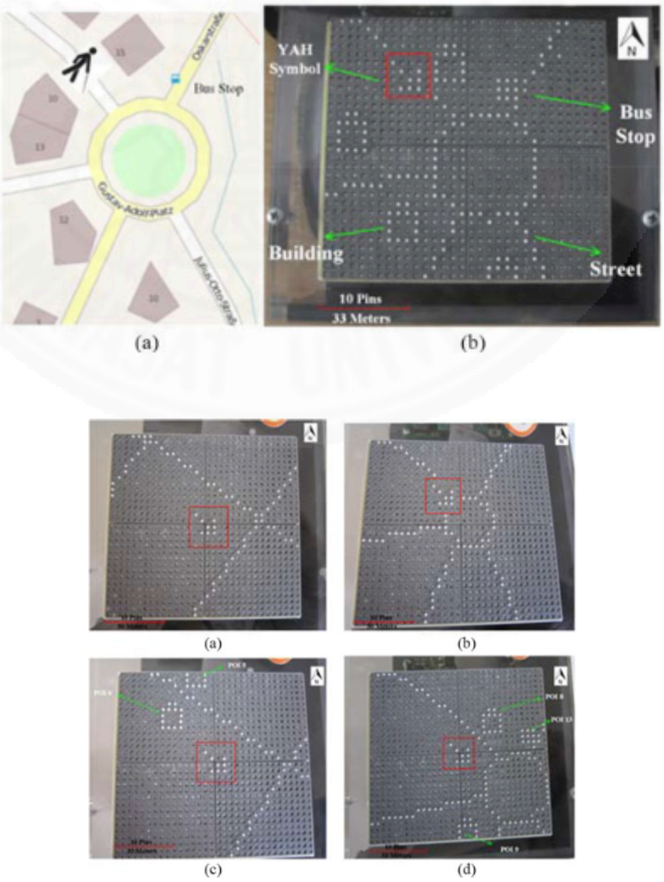

Figure 2.6 A refreshable braille display map (Zeng & Weber 2016)

Table 2.3 Feature comparison of each interface technology

Technology		Information	
	Portable & Convenient	Require special training	Allow surrounding scenario perception
1) Vibrating vest	✔	✔	✗
2) Vibrotactile belt	✗	✔	✗
3) Wristband	✔	✔	✗
4) Refreshable braille display map	✗	✔	✔

Based on table 2.3, vibrating wristband is suitable in term of portability while refreshable braille display map is suitable for surround scenario perception. There are lots of rooms to improve for obstacle detection and navigation in order to fulfill the need of visually impaired people in both user interface and system portability.

For localization and navigation, global positioning systems (GPS), performs well in outdoor environment. However, GPS is not efficient in indoor environment due to attenuated and scattered of signal. For indoor environment, researchers used sensor such as RFID, Beacon, and Wi-Fi in order to locate the position of users. Researchers can implement the system that let users travel inside the building efficiently. Fernandes, Hugo, et al. proposes method using radio-frequency identification (RFID) for navigation (Fernandes et al. 2013). User can use cane with RFID reader to communicate with each RFID installed along the path in order to travel.

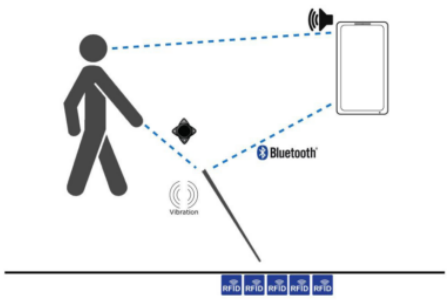

Figure 2.7 System overview of location-based services for blinds supported by RFID technology

Beacon is one of popular technologies that used for positioning. Martin et al. proposes a localization method based on iBeacon (Martin et al. 2014). A system provides an average position estimation error of 0.53 meter. Localization based on Wi-Fi also gains interest due to low cost and wide popularization (Li et al. 2015). Magnetic positioning is also in the area of interest. This method measures location using disturbances of the Earth's magnetic field caused by structural steel elements in a building (Chung et al. 2011). Each technology has its pros and cons as shown in table 2.4.

Table 2.4 A comparison chart between each technology

Features	Outdoor	Indoor	Additional hardware required	Accuracy	Comment
1) RFID (Mengin et al. 2016)	∆	✔	✔	< 1 m	Accuracy depends on type of RFID.
2) Bluetooth / Beacons (Mengin et al. 2016)	✗	✔	✔	1 -3 m	Application is required for client-based solution.
3) Wi-Fi (Mengin et al. 2016)	✔	✔	✗	5 – 15 m	Application is required.
4) Magnetic Field (Chung et al. 2011)	✗	✔	✗	< 1 m	The chance of error increases with the size of the fingerprint map.
5) VLC (Mengin et al. 2016)	✗	✔	✔	< 8 m	Low flexibility when installing the lamp.

* ✗ = cannot use, ✔ = can use, and ∆ = can / cannot used (depend on a situation)

Various Algorithm and techniques can be applied in order to improve accuracy of positioning such as fusing with sensors in smartphones (Link et al. 2011). Additionally, there is a platform for visually impaired people called HULOP (Human-scale Localization Platform). This platform is developed for creating engaging experience for visually impaired people. An application called NavCog is a part of this project. Navcog is an application that help navigate blinds in unfamiliar environment based on BLE Beacons with a localization algorithm that work for both indoors and outdoors.

2.3 Wi-Fi Indoor Positioning Technology

Indoor positioning technology can be divided into 2 types which are image-based and non-imaged based indoor positioning system. For image based indoor positioning, this can be done by capturing images and matching with the corresponding image in the database in order to get the location (Zhang & Kosecka 2006). For non-imaged based positioning system, measuring radio frequency signal is a popular method. There are various technologies such as Bluetooth, magnetic field, and Wi-Fi as mention in section 2.2.

Wi-Fi positioning technology can be classified to 3 techniques as follows (Prasertsung & Horanont 2017)

1. Wi-Fi RSSI measurements
2. Channel state information (CSI)
3. WiFi probe requests and responses

Measuring Wi-Fi signal strength can infer the position of the user. The advantage of this technique is no additional hardware install. The common techniques which applied in order to obtain positions of users from Wi-Fi signal are trilateration, approximate perception, and scene analysis.(Xia et al. 2017)

There are many challenges for indoor positioning technology. Maghdid, Halgurd S., et al. state that technology for seamless positioning should providing unconstrained and/or infrastructureless localization solutions to reduce the cost and size.(Maghdid et al. 2016) Since Wi-Fi are available in the building. Indoor positioning using Wi-Fi is suitable for implement.

Chapter 3
Methodology

We study about a navigation framework for visually impaired people, which mainly focus on localization part. Indoor localization based on Wi-Fi and smartphone is presented in this chapter. Overall framework is displayed in Figure 3.1

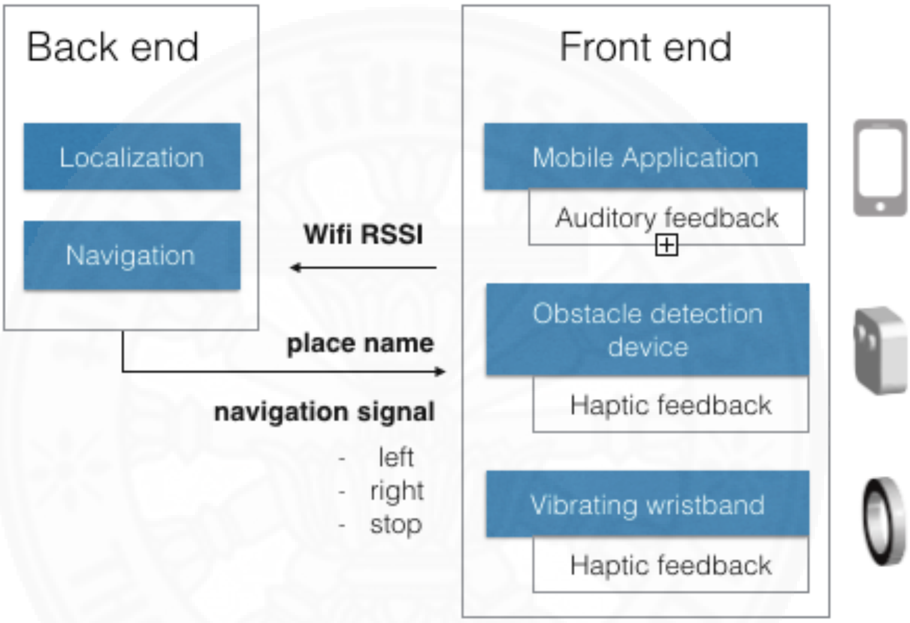

Figure 3.1 System overview

For this work, there are 3 steps to accomplish the task as follows.

1. Indoor map construction
2. Localization method and Model selection
3. Navigation prototype implementation

3.1 Indoor map construction

3.1.1 Map digitizing

In order to generate the floor plan, we digitize the map and divided map into grid with 1-meter width and 1-meter height as shown in Figure 3.2

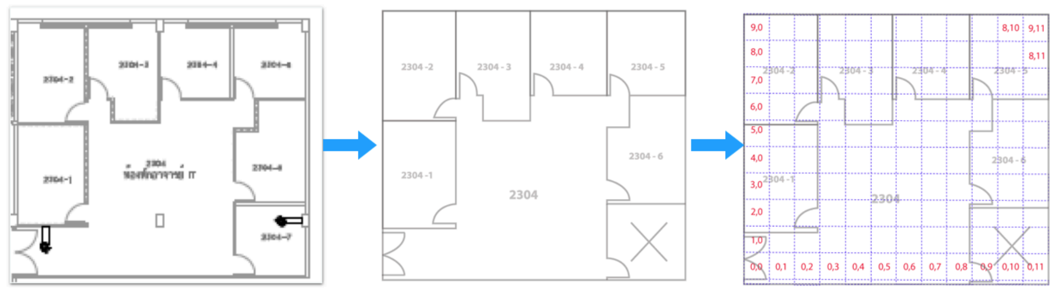

Figure 3.2 Map digitizing

3.1.2 Fingerprint construction

In this state, we collect RSSI fingerprinting for each grid. There are 3 cases that we consider

(1) Non – filtered available APs

(2) Filtered available APs

(3) Self calibrate APs

A smartphone, LENOVO Vibe X3 is used as a device to collect RSSI from different APs in each grid.

3.1.2.1 Non – filter available access points

In this state, all detected access points in experiment area are used. There are more than 20 access points found in this areas.

3.1.2.2 Filtered available access points

In this case, we filter only significant APs in the experiment area. The strategy is to select strongest received signal strength with known position.

3.1.2.3 Self calibrate access points

Raspberry PIs are used as access points. We manually put access points in different locations in order to find which position will provide the best localization performance.

3.1.3 Localization methods and Model Selection

Signal fingerprint is the method that we used for localization. We collect a set of RSSIs of different access points at the curtain time. Room's name and grid id are labeled while scanning during a training phrase. Figure 3.3 shows data format that we collect during training phrase at each grid.

```
{ Grid   : [x,y]
  Room  : xx,
  RSSI  :
  {
     AP_i      : n_i,
     AP_{i+1}  : n_{i+1},
     ...
     AP_{i+n}  : n_{i+n},
  }
}
```

Figure 3.3 Data format from survey phrase

Gird refers to grid id. Room refers to room name. RSSI refers to RSSI value of different access points (APs). In order to get position of the user, we rely on 3 machine-learning models, which are Naïve Bayes, Support vector machine, and Random forest. A set of RSSI of different APs is used as a training data as display in table 3.1

Table 3.1 Features construction for training phrase

AP1	AP2	…	APn	Grid	Room
RSSI_AP1$_1$	RSSI_AP2$_1$	…	RSSI_APn$_i$	x_1,y_1	room_x_y
RSSI_AP1$_2$	RSSI_AP2$_2$	…	RSSI_APn$_2$	x_2,y_2	room_x_y$_2$
…	…	…	…	…	…
RSSI_AP1$_n$	RSSI_AP2$_n$	…	RSSI_APn$_n$	x_n,y_n	room_x_y$_n$

Data from a survey is split into a training set and testing set at a ratio of 70:30. To avoid over fitting, 10-fold Cross Validation is applied for each model. The overall process is displayed in Figure 3.4

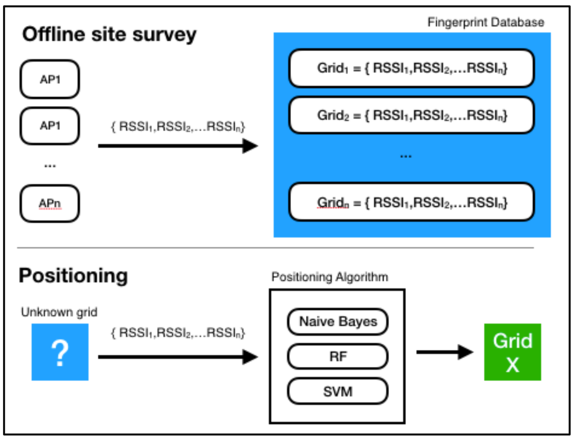

Figure 3.4 Overall Wi-Fi positioning processes

3.2 Mathematical Formula

3.2.1 Signal Strength Percentage to dBm Values

The IEEE 802.11 standard defines a mechanism by which RF energy is to be measured by the circuitry on a wireless NIC. For RSSI, this numeric value is an integer with an allowable range of 0-255 (a 1-byte value) (Bardwell 2007). The formula to convert quality percentage to the RSSI value in dBm (decibel milliwatts) unit is as follows.

$$dBm = \frac{Quality}{2} - 100$$

3.2.2 Kalman Filter

In order to deal with sudden changes of signal value, Kalman filter is applied to raw signal data. Kalman filter is a state estimator that makes an estimate of some unobserved variable. The sudden changes of signal value can be estimate based on previous signal values (Sung 2016). The formulas are shown below (Faragher 2012).

3.2.2.1 The standard Kalman filter equations for the prediction stage

$$\hat{X}_{t\,|\,t-1} = F_t \hat{x}_{t-1\,|\,t-1} + B_t u_t$$

Where $\hat{X}_{t\,|\,t-1}$ = Estimated State (current state),
F_t = State transition matrix at time t
u_t = A control variable at time t
$\hat{X}_{t-1\,|\,t-1}$ = Previous state,
B_t = Control input matrix at time t

$$P_{t\,|\,t-1} = F_t P_{t-1\,|\,t-1} F_t^T + Q_t$$

Where P_t = The covariance matrix,
F_t = State transition matrix at time t,
Q_t = The process noise covariance

3.2.2.2 The measurement update equations

$$\hat{X}_{t\,|\,t} = \hat{X}_{t\,|\,t-1} + K_t(z_t - H_t + \hat{X}_{t\,|\,t-1})$$

$$P_{t\,|\,t} = P_{t\,|\,t-1} + K_t H_t P_{t\,|\,t-1}$$

Where $K_t = P_{t\,|\,t-1} H_t^T (H_t P_{t\,|\,t-1} H_t^T + R_t)^{-1}$

3.3 Navigation prototype implementation

In order to validate the concept of this framework, we develop the first prototype integrate software and hardware. We propose an application that can navigate users in indoor environment and the vibrating wristband that can send haptic feedback to users. Tools for developing this prototype are as follows.

3.3.1 A navigation application prototype

This application helps locate a position of user inside the building and help guide the user from starting point to destination point. The early state of this prototype is not yet support verbal input. Figure 3.5 displays the system overview of this application.

3.3.1.1 Tools & Technique

(1) Android studio

(2) Java Open Street Map (JOSM)

(3) Leaflet Javascript Library

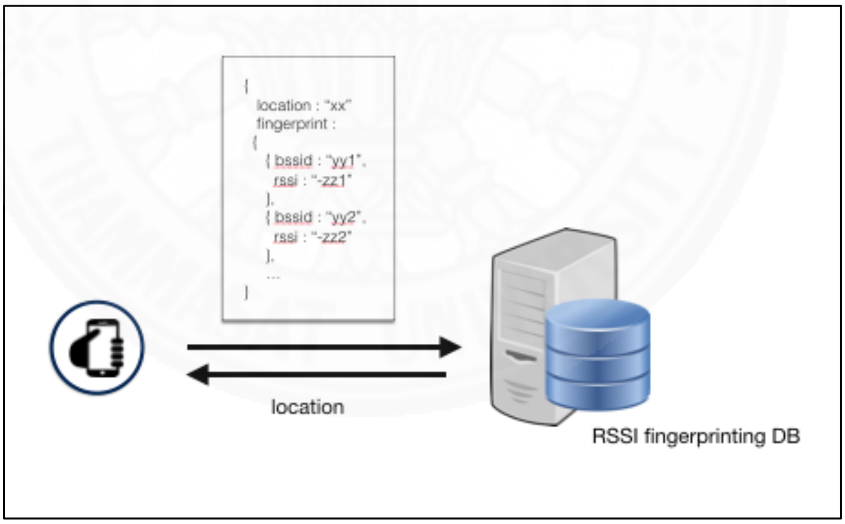

Figure 3.5 System overview of navigation application prototype

3.3.2 An obstacle detection device

Figure 3.6 illustrates the system architecture diagram of the obstacle detection device. Two ultrasonic sensors are used to find the obstacle distance for both head level and leg level. The required elements for implementing this device are listed as follows.

3.3.2.1 **Tools & Techniques**

(1) Ultrasonic sensors

(2) Transistor

(3) Vibration motor

(4) Microcontroller

(5) Speaker

(6) DC plug charger

(7) Printed Circuit Board (PCB)

(8) Arduino DUE (for testing)

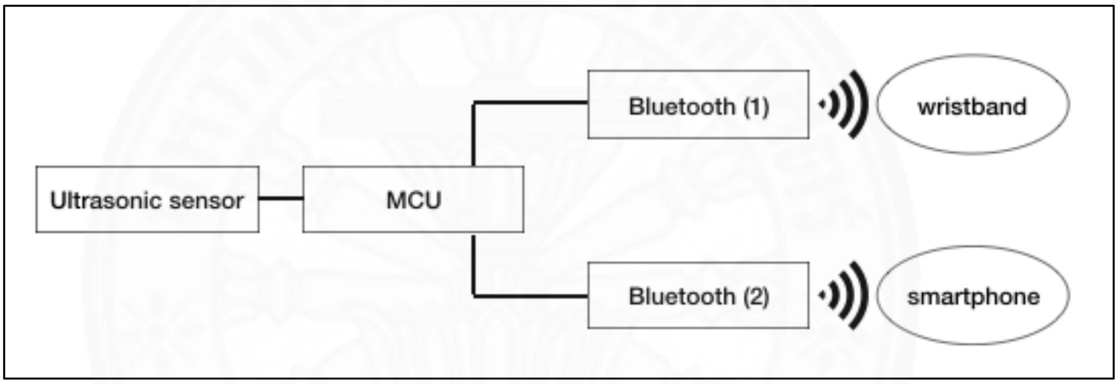

Figure 3.6 The system architecture diagram of the obstacle detection device

3.3.3 A vibrating wristband prototype

This vibrating wristband helps translate information to vibration pattern to inform users. Figure 3.7 displays the system diagram of vibrating wristband.

3.3.3.1 Tools & Technique

(1) Coin cell battery

(2) Printed Circuit Board

(3) Transistor

(4) Diode

(5) Bluetooth low energy module

(6) Wristband

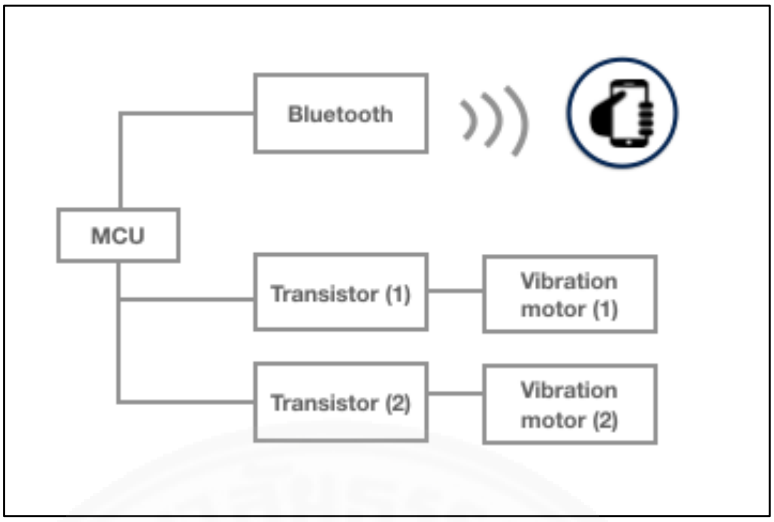

Figure 3.7 System Diagram of vibrating wristband

Based on interviewing 8 visually impaired people, all of them agreed that haptic feedback is help for navigation in real environment. Auditory feedback is important. However, using a headphone during traveling decrease perception of the sound of surrounded environment. Therefore haptic feedback can complement in this point. Understanding the meaning of the vibration pattern helps user travel effectively.

Chapter 4
Results and Discussion

This section focuses on the model that we used for localization. As mentioned in chapter 3 that 3 cases are considered for localization. From the experiment, using all detected access points is not efficient because too many detected access points cause multipath effect. Therefore, APs selection is considered.

In order to find out which position provide better accuracy, we selected access points with known location. The position of selected access points is shown in Figure 4.1. Circles refer to the position of APs. There are 3 APs considered in this case.

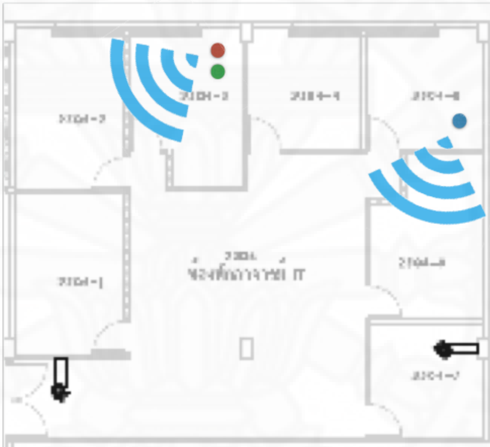

Figure 4.1 Access points location

A confusion matrix from the experiment is displayed below. The overall accuracy is 96.81%. Kappa is 95.64%.

Table 4.1 A confusion matrix for training data from filtered available APs

Prediction	2304-1	2304-2	2304-6	2304-5	2304	2304-3	2304-4
2304-1	**54**	13	0	0	1	0	0
2304-2	19	**399**	0	0	0	3	1
2304-6	6	0	**491**	0	0	0	0
2304-5	0	0	0	**111**	0	0	0
2304	13	2	0	1	**78**	7	0
2304-3	0	4	0	0	0	**53**	1
2304-4	0	0	0	0	0	0	**60**

The overall accuracy is high. However, the problem is the misclassification in room 2304-1 as shown in the confusion matrix.

In order to decrease a misclassification between classes, we explore the suitable position of access points. Since available APs inside a building is not movable, raspberry PIs versions 3 are used as access points instead. Then, we start experimenting by manually put Raspberry Pi in different positions as explained in section 4.3: Result from Self calibrate access points.

4.3 Result from Self calibrate access points

We explore the appropriate location that will provide better accuracy by manually put access points in different positions. Circles refer to position of APs. Each AP has different colors and names as label in figure 4.2.

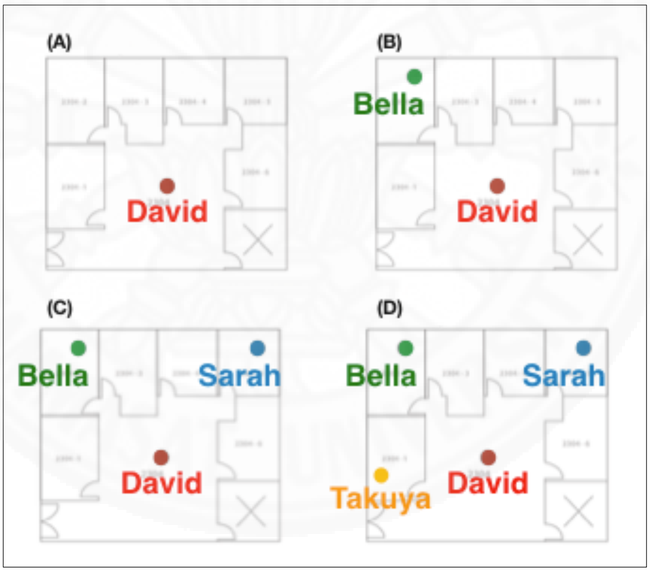

Figure 4.2 APs' position (Raspberry PI)

From (A) in figure 4.2, we put only one AP in the middle of the room. Then we collect the RSSI of each room. The same method is repeated for (B), (C), and (D).

Using only 1 AP gives poor performance. The overall accuracy is less than 60% in classification. 2 APs as in (B) provide better result, but they still misclassify between each room as shown in a figure 4.3. In figure 4.3, the color represents to each room. From the graph, there are lots of misclassification in each class.

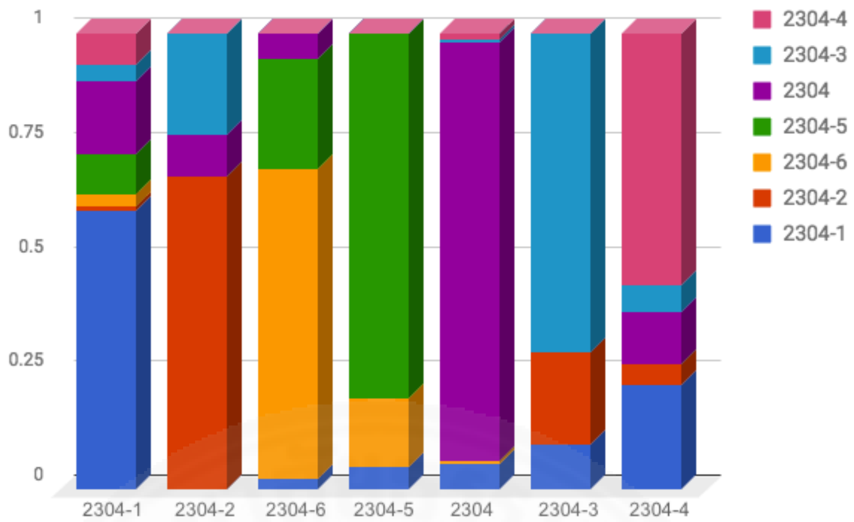

Figure 4.3 A classification result from a confusion matrix (2 APs)

Three APs as in (C) have difficulty in classification between room 2304 – 1 and room 2304. Finally, 4 APs as in (D) provide the highest performance. The overall accuracy for each number of APs is shown in table 4.2

Table 4.2 Overall accuracy from different experiment.

Model	1 AP accuracy	2 APs accuracy	3 APs accuracy	4 APs accuracy
Naive Bayes	57.29%	76.81%	88.85%	90.35%
SVM	58.88%	75.75%	85.29%	90.26%
Random forest	55.32%	75.08%	90.63%	**93.76%**

From the table above, 4 APs provide best accuracy as display in figure 4.4

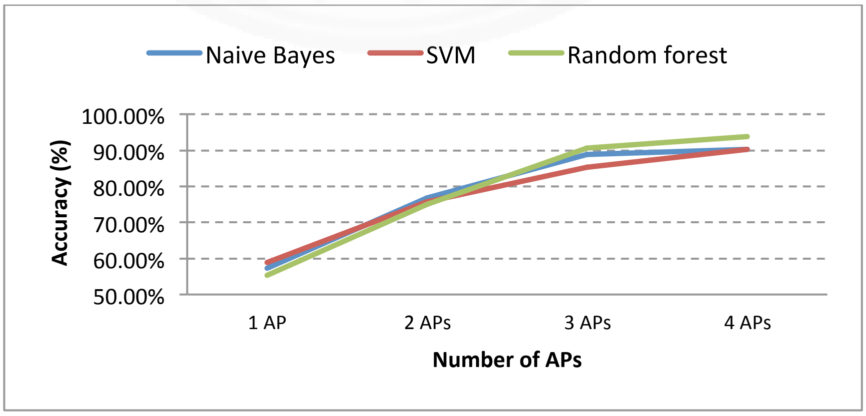

Figure 4.4 Accuracy VS the number of APs

Four APs help classify increase classification between room 2304 and room 2304-1 as shown in confusion matrix in table 4.3

Table 4.3 A confusion matrix from testing dataset (Random Forest model)

Prediction	2304-1	2304-2	2304-6	2304-5	2304	2304-3	2304-4
2304-1	**104**	1	0	0	10	0	0
2304-2	0	**127**	0	0	5	7	0
2304-6	0	0	**72**	1	1	0	0
2304-5	0	0	0	**62**	1	0	0
2304	20	1	1	0	**514**	7	1
2304-3	0	1	0	0	6	**46**	0
2304-4	0	0	0	0	6	0	**63**

4.4 Model Evaluation

We test the performance of models by splitting dataset into 70:30. 70% of the dataset is used as a training data. The remaining dataset is used for testing data. 10 cross-validation are applied in order to avoid over fitting. There are 3 models that we considered as display in table 4.4. ACC in the table refer to overall accuracy. KP refers to Kappa. AVG stands for average value.

Table 4.4 Overall accuracy and Kappa for training data and testing data

#	Naive Bayes				SVM				Random Forest			
	Trainset		Testset		Trainset		Testset		Trainset		Testset	
	ACC (%)	KP (%)	ACC (%)	KP (%)	ACC (%)	KP (%)	ACC (%)	KP (%)	ACC (%)	KP (%)	ACC (%)	KP (%)
1	91.20	87.76	93.19	90.37	89.74	85.50	92.43	89.18	99.96	99.94	99.94	92.59
2	92.46	89.56	90.35	86.11	90.75	87.08	90.26	85.88	92.46	89.56	93.76	90.96
3	92.09	89.07	91.77	88.19	90.59	86.80	90.35	85.95	99.96	99.94	93.85	91.08
4	92.09	88.90	91.58	88.41	90.75	86.83	90.35	86.64	99.96	99.94	93.76	91.38
5	91.93	88.66	91.96	88.88	90.75	86.91	90.44	86.69	99.92	99.89	95.18	93.29
AVG	**91.95**	**88.79**	**91.77**	**88.39**	**90.52**	**86.62**	**90.77**	**86.87**	**98.45**	**97.85**	**95.30**	**91.86**

We randomly split dataset into training data and testing data as mentioned above. By repeating split data for 5 times, Random Forest provides the best accuracy among other models as shown in figure 4.5

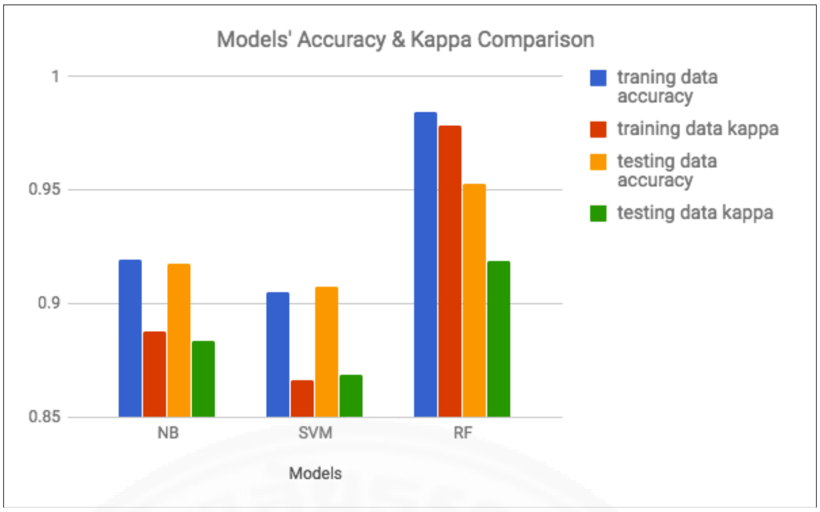

Figure 4.5 Accuracy and Kappa comparison of each model

Then we classify in grid level to explore the accuracy. Testing data is used as an input data. The accuracy drops from about 90% to 60% for Naïve Bayes and SVM, which is about 33.33%. For random forest, the accuracy drops from about 90% to 70%, which is 22.22%. Figure 4.6 shows the accuracy comparison between room level and grid level.

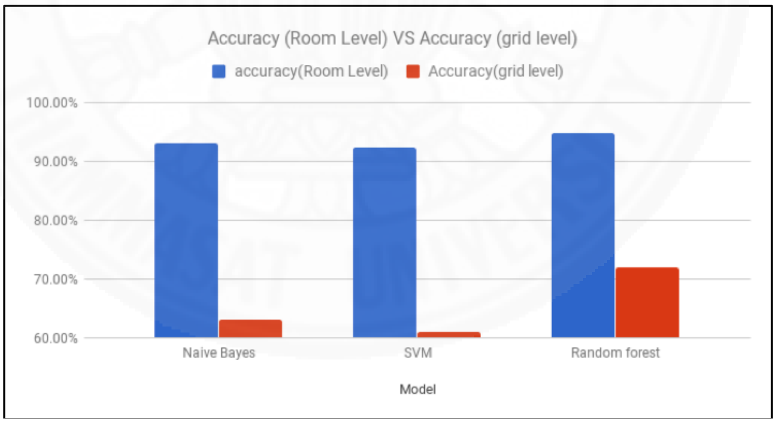

Figure 4.6 Accuracy comparison between room level and grid level

4.5 Result after applied Kalman Filter

Even models mentioned in the previous section provide an acceptable rate of accuracy, there are challenges when implementing the system in a real environment because of uncertainty of signal strength. As reported in Indoor Fingerprint Positioning Based on Wi-Fi : An Overview that the effect of human body and the effect on the multipath cause decline and uncertainty of the signal (Xia et al. 2017).

To tackle this problem, Kalman filter is applied to the signal to avoid rapid change. Figure 4.7 displays the graph that compares raw RSSI values of 3 APs and result after Kalmal filter is applied.

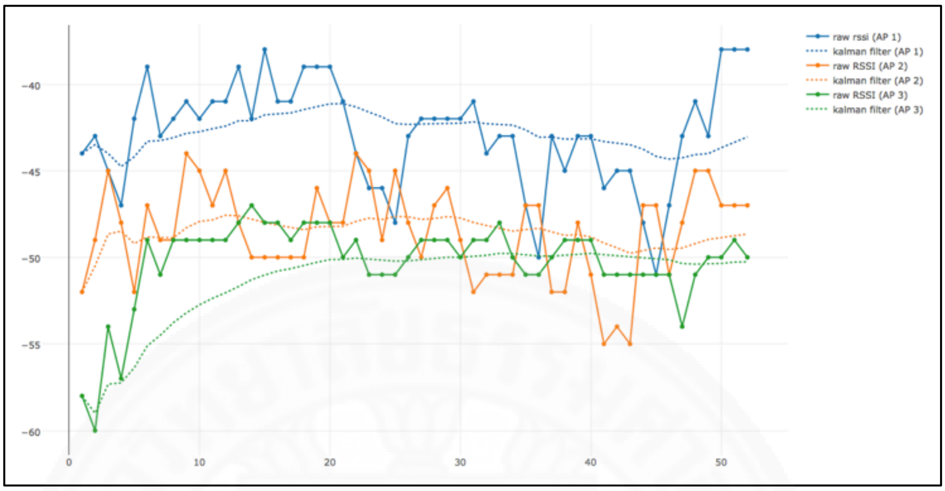

Figure 4.7 Raw RSSI value & Kalman filtered RSSI value for each APs

Y-axis is RSSI value. X-axis is the ordering number. After applying the Kalman filter to the raw data. The signal becomes smoother. Then we regenerate model again using filtered data as an input. The graph below displays the accuracy of RAW RSSI value and Kalman filtered RSSI value of each model (Room level).

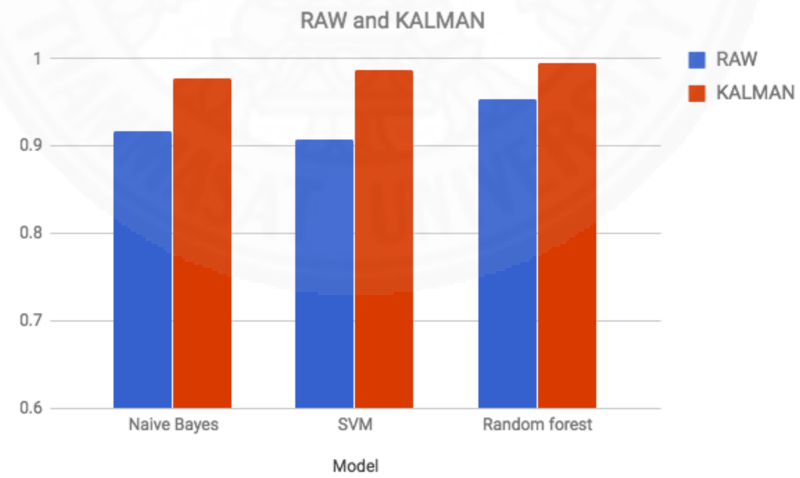

Figure 4.8 Accuracy comparison between each model (Raw RSSI value VS Kalman filtered RSSI value)

Applying Kalman filter helps increase accuracy of the model about 6% on the average for room level. Random forest provides best performance among other models. Additionally, applying Kalman filter to data provide better classification result for grid level classification as shown in Figure 4.9. Noted that size of each grid is 1 x 1 meter.

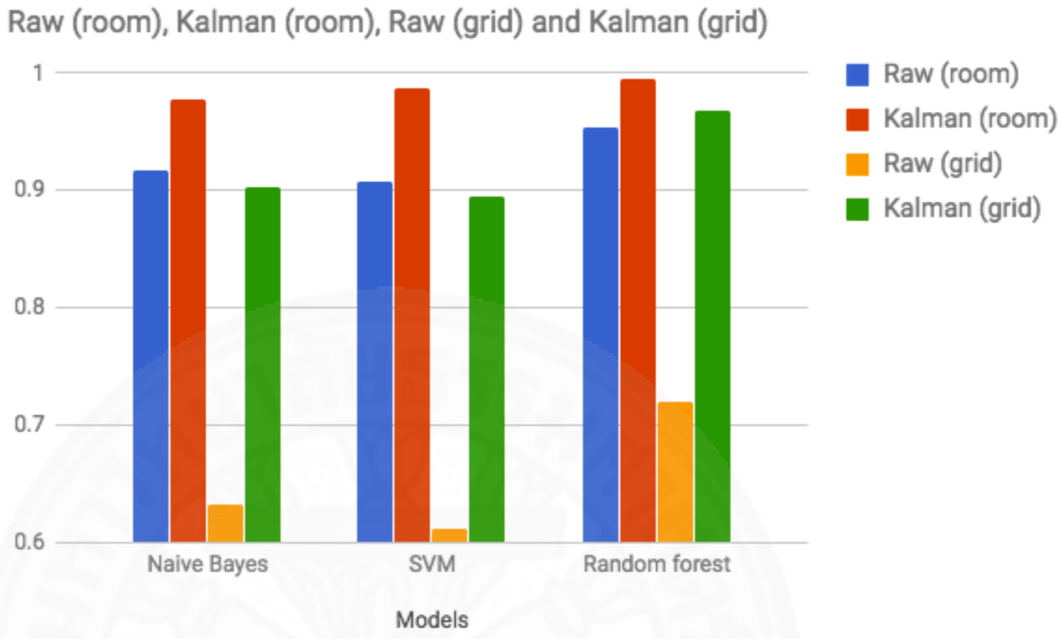

Figure 4.9 Accuracy comparison between room level & grid level (Raw RSSI value VS Kalman filtered RSSI value)

Chapter 5
Conclusions and Recommendations

5.1 Research summary

This research provides overview information for implementing navigation system for visually impaired people. There are 2 main things to consider which are obstacle detection part and user interface part.

For obstacle detection, ultrasonic sensors are widely used. However, this technology has limitation on subject sensitivity. Additionally, types and characteristic of obstacle is unknown. Users know that there is an obstacle, but they do not know what it is. To fulfill this limitation, computer vision technique can be used instead. This method helps users to feel surrounded environment and know element around them is. However, this technique requires more computational cost than ultrasonic sensor technique. For user interface part, auditory feedback or haptic feedback is required.

This research also mentions about localization part, which is crucial step for navigation part. Localization based on Wi-Fi is mention due to emerge of the large amount of Wi-Fi in buildings, which are suitable for implementing in real environment. Four access points installed at the corner of the room (area size 10x12 meter), is suitable position in order to get acceptable accuracy at the room level. In order to gain more accuracy, Kalman filtered can be applied to raw RSSI values before generating the model. After applying Kalman Filter, the average accuracy is 6% increase. Additionally, the Random Forest based model provides an acceptable result to classify position in grid level, which is higher than 90%.

The limitation of this technique is time consuming for generating the fingerprint map. Moreover, if the environment is changed, the fingerprinting map needs to be updated.

5.2 Key contribution of this research

This research provides a guideline framework for those who would like to implement an assistive system for visually impaired people. Current researches and technologies about assistive technologies for blinds are introduced. Indoor positioning using Wi-Fi is mentioned.

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Appendices

Appendix A
Navigation Appication & Vibration wristband prototype

Figure A.1 Obstacle detection device prototype

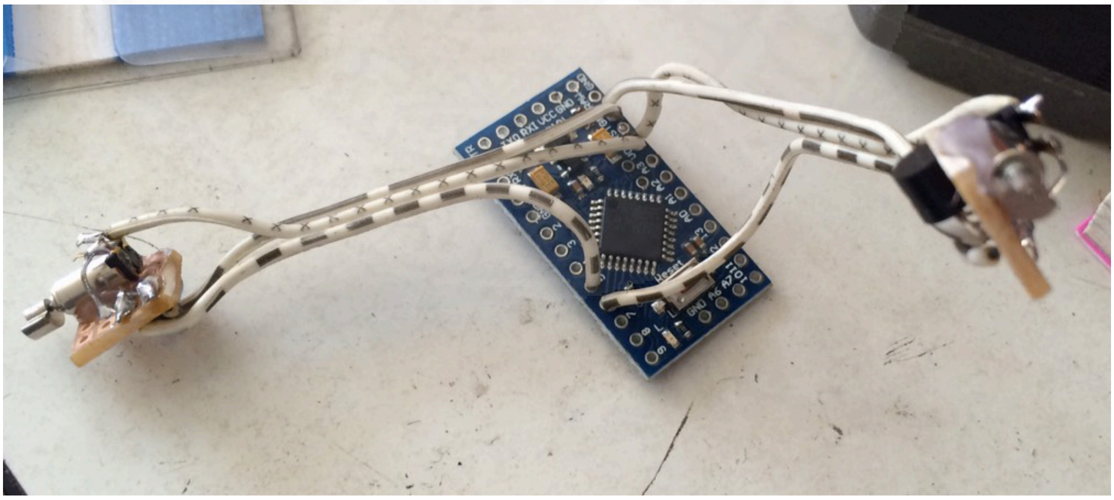

Figure A.2 Vibrating wristband prototype version 1

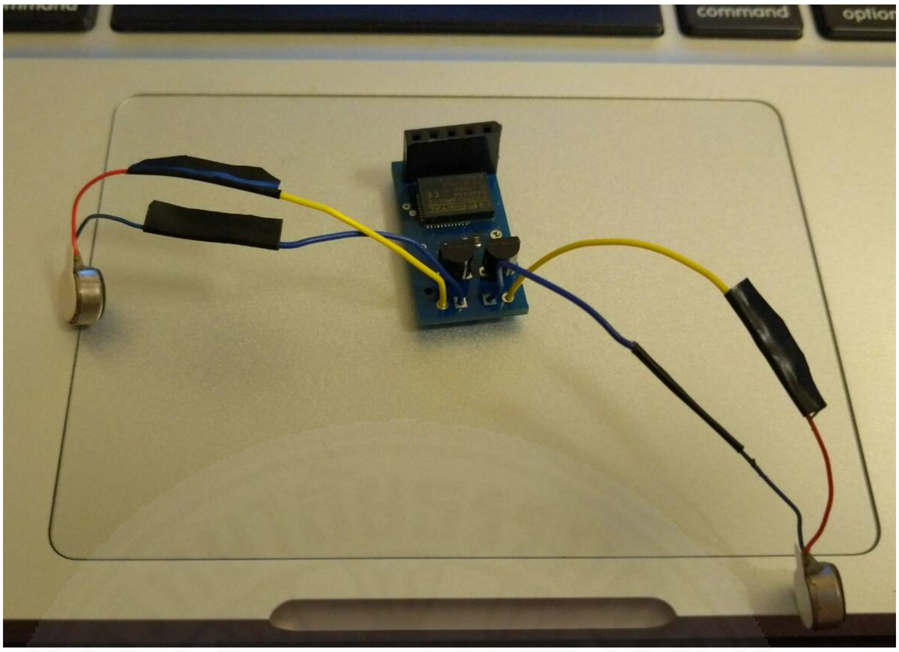

Figure A.3 Vibrating wristband prototype version 2

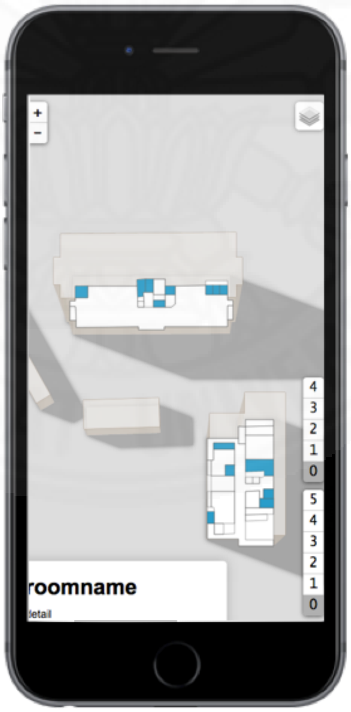

Figure A.4 Navigation Application prototype

Appendix B
List of publications

B.1 International Conference

1. Prasertsung, P. and Horanont, T., 2016, December. A classification of accelerometer data to differentiate pedestrian state. In Computer Science and Engineering Conference (ICSEC), 2016 International (pp. 1-5). IEEE.

2. Prasertsung, P. and Horanont, T., 2017, September. How does coffee shop get crowded?: Using WiFi footprints to deliver insights into the success of promotion. In International workshop on Pervasive and Urban Appication, In conjunction with ACM Ubicomp 2017, ACM.