MOBILE X-RAY TRACKING AND MONITORING SYSTEM USING THE INTERNET OF THINGS (IoT) TECHNOLOGY

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ABSTRACT

The objective of this research was to develop an indoor mobile asset tracking system with low cost, to assist in conveniently tracking and monitoring hospital mobile x-ray machines with higher efficiency and accurate services. The system was developed to be able to display the location and search for mobile x-ray machines in real-time and to report the usage history of the machines. The systems used modern IoT technology consisting of MCU nodes with WiFi sets, various sensor modules and wireless communication modules and comprised two parts: a program for sending and receiving data from the nRF24L01 wireless communication at 2.4 GHz, and an application for configuration and reporting results. The results of the performance of two developed systems tested in a short period at Songkhla Hospital, Songkhla Province indicated that the efficiency of the correctness in location identification fell at average values of 88.13 per cent and 90.63 per cent, that both were not at a significantly different level of 0.05. Furthermore, the system's quality had been tested by the radiologists at Songkhla Hospital who showed satisfaction for its all aspects.

KEYWORDS: indoor tracking, monitoring, mobile x-ray, Internet of Things

1. Introduction

1.1 Background and importance of the problem

Nowadays, digital technology has been playing an important role in life, and it is an important aid in improving the quality of life or business. One technology that is currently popular is technology for locating or tracking assets or important resources via smart devices.

Current asset tracking systems can be categorized into two types which are outdoor and indoor tracks. Monitoring assets within the building is currently receiving more and more attention, but there are problems that need to be improved in terms of accuracy and suitability for use and economy.

Mobile X-ray (MBX) tracking and monitoring systems is a system developed to facilitate tracking and observation of mobile medical device services in the building more efficiently. In addition, it is useful to solve problems in providing services that are convenient, fast, and worthwhile. It can also evaluate statistical data for decision-making in asset management in order to analyse Break-even point costs and to consider repairing, maintenance, and purchasing more efficiently.

1.2 Related works

For an indoor asset tracking and monitoring system, there have been various research works applying various technologies which are advantageous, disadvantageous, or possibly practical. All related research works for this study on the indoor asset tracking and monitoring system in hospitals are.

Ultra Wideband Technology (UWB) is used to track assets in hospital environments. UWB technology has been very popular for the indoor asset tracking and monitoring system in hospitals and applied in various works. For example, according to Kuhn et al. [1] they applied UWB technology was employed to cover all hospital areas by Multi-Tag to send data in real time. As a result, its correctness was at a high level with a small number of errors (in millimetres) in stable environments, but it needed to be tested in dynamic environments in the future. However, mobile assets are actually moved in indoor and outdoor areas, especially patients who need to be tracked and monitored. Therefore, Jiang et al. [2] developed a mobile asset tracking system in indoor and outdoor areas by the advantages of UWB and GPS technologies with seamless. The results were satisfied at the primary step of the study. Nevertheless, the system needed to be improved in the adventurous aspects, namely the reliability of WiFi data, the slow data update, low accuracy of GPS tracking, as well as the high cost of UWB sensor network installation to cover all the areas. In order to figure out the high cost issue, some researchers applied RFID technology to track and monitor assets. According to Rahman et al. [3] has proposed a mobile asset tracking and monitoring system was developed to test in public hospitals in Malaysia, and the systems used in the country and other countries such as China were compared. RFID technology was also applied to the mobile tracking and monitoring system for assets and medical instruments. The test of the system was done to find out a way to manage the hospital assets such as asset borrow and return, location inspection, or losses. When the system using RFID technology was compared to the old system, Barcode technology, the results of RFID were better. However, the system was suggested to further improve, and the issue of the public hospital policies-safety and cost reduction-were found and these policies needed to be part of factors in order to be more applicable.

2. Materials and methods.

2.1 The distance with an increment encoder.

Figure 1-2 shows a wheel of an MBX machine. There is only one wheel encoder installed, and each encoder will have two readers installed with the difference angle of 90°, which is responsible for checking the direction of forwarding or backward movements. The advantage of using the encoder is high resolution. When the wheels of the MBX machine move 360°, it generates 64 pulse signals. The reception of this pulse will calculate the distance according to the circumference of the main wheels of the machine by using equation (1) [4-5].

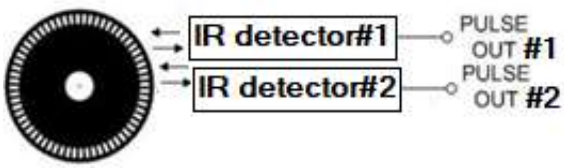


Figure 1 Working principle of rotation encoder.

Figure 2 Infrared detector for rotation encoder.

$$D = \frac{W \times C}{P} \quad (1)$$

Where D is the distance value
W is a wheel circumference
C is the number of pulses
P is the pulses per round

2.2 The direction with an electronic compass

An electronic compass is a detector that obtains its heading (azimuth) degree from the magnetic field direction. The type of electronic compass used in this research is HMC5983 as shown in Figure 3. The heading accuracy of this electronic compass is $\pm(1^{o}\text{-}2^{o})$ [6]. The error negligible values can be ignored for calculations. Thus, the orientation calculation using HMC5983 is simple, cheap and accurate enough [4].

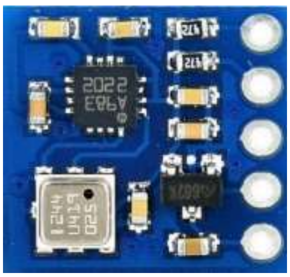


Figure 3 Module electronic compass (HMC5983)

2.3 Estimation of distances and directions with vector methods.

The distance finding technology with the rotary encoder is combined with the direction reading by electronic compass, resulted in a vector. When vectors are used, each stored path is stored in a database and connected to each other to find the distance and direction from the origin [7-8]. This result can be applied to the current research. It can be used to indicate the location of MBX by using the principle of vectors as shown in Figure 4; as an example, the method of calculations based on this formula is given as follows:

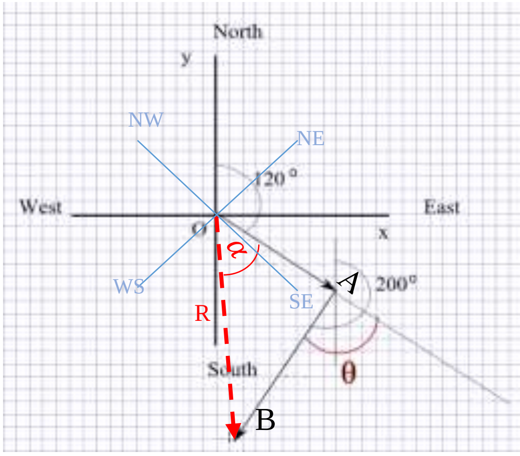


Figure 4 The distance from the origin.

Distance R is given by the magnitude of vector relationship is shown by equation (2). And the direction of the result vector is given by (3). When there are multiple paths, all of the vectors are cumulative with by Head-to-Tail method given by (4).

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta} \quad (2)$$

$$\alpha = \tan^{-1}\frac{B\sin\theta}{A + B\cos\theta} \quad (3)$$

$$\vec{R} = \vec{A} + \vec{B} + \cdots + \vec{N} \quad (4)$$

Where R is a result of final vector

A is a sub-vector

B is a sub-vector

θ is the angle of vector A and vector B

α is the angle of the result vector.

2.4 Estimation altitude with a digital pressure sensor.

A digital barometer was used to measure air pressure and altitude. The BMP280 digital pneumatic sensor as shown in Figure 5. It was used as the measuring sensor which is great for all sorts of weather sensing and can even be used in both I^2C and SPI. This precision sensor is the best low-cost, precision-sensing solution for measuring barometric pressure with ±1 hPa absolute accuracy, and temperature with ±1.0°C accuracy.

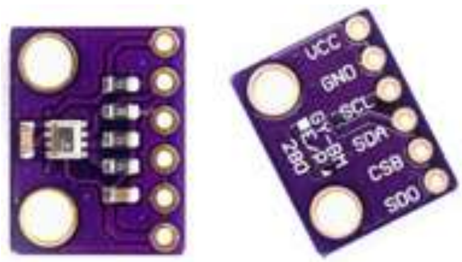


Figure 5 BM280 pressure sensor for measuring altitude

The BMP280, the initialization program of BMP280, and the conversion program of pressure and altitude were written and debugged. The pressure data was processed. The experimental system was also set up. Furthermore, the pressure altitude of different floors of the hospital building was measured several times at different temperatures. The actual height per floor is 4.5 m. It was shown by [9] that there is a relationship between pressure and altitude. As the equation shown in the following (5).

$$h = (1013.25 - \frac{p}{100}) \times 9 \quad (5)$$

Where h is the altitude in m

p is the pressure in Pa.

2.5 Wireless communication technology with radio waves nRF24L01

nRF24L01 is a wireless communication module in the radio frequency range of 2.4 GHz as shown in Figure 6. It can be programmed to be both a receiver and a transmitter. It can be integrated with the microcontroller through the SPI connection standard. nRF24L01 it suitable for Ultra low power wireless. nRF24L01 is also designed for operation in the worldwide ISM (Industrial Science and Medical) frequency band [10]. Its basic physical layer is known for its efficiency and often used in the context of the Internet-of-Thing (IoT) [11]. The nRF24L01 Radio System on a Chip (SoC) enables low-complexity and low-power transmission for wireless networking of consumer devices such as computer peripherals or embedded system [12]. The nRF24L01 second version comes within special RFX2401C chip which integrates the PA, LNA, and transmit-receive switching circuitry. This range extender chip along with a duck-antenna helps the module achieve a significant lager transmission range of about 1000 m. [13], which is sufficient to cover the working area for the Songkhla Hospital building.

Figure 6 nRF24L01 module with antenna and amplifier.

3. Development

The system development is divided into two important parts:

3.1 The development of MBX monitoring and tracking system

The development of MBX monitoring and tracking system was based on the concept of MBX inspection and tracking at a low cost to save energy and a small number of nodes as shown in Figure 7. The tag has a controller (Arduino Uno R3) to receive input data of MBX machine that reads data from the detection device, the distance with the encoder sensor, the direction indicator with the electronic compass detector, and the position of the floor of the building with a pressure sensor as further presented in Figure 8 (a). At the same time, the information is transmitted with nRF24L01 to the reader (Arduino Uno R3 + ESP8266) as in Figure 8 (b). It only one MCU node used to transmit through the wireless network with the WiFi module of MBX on the application to monitor and report results via smartphone.

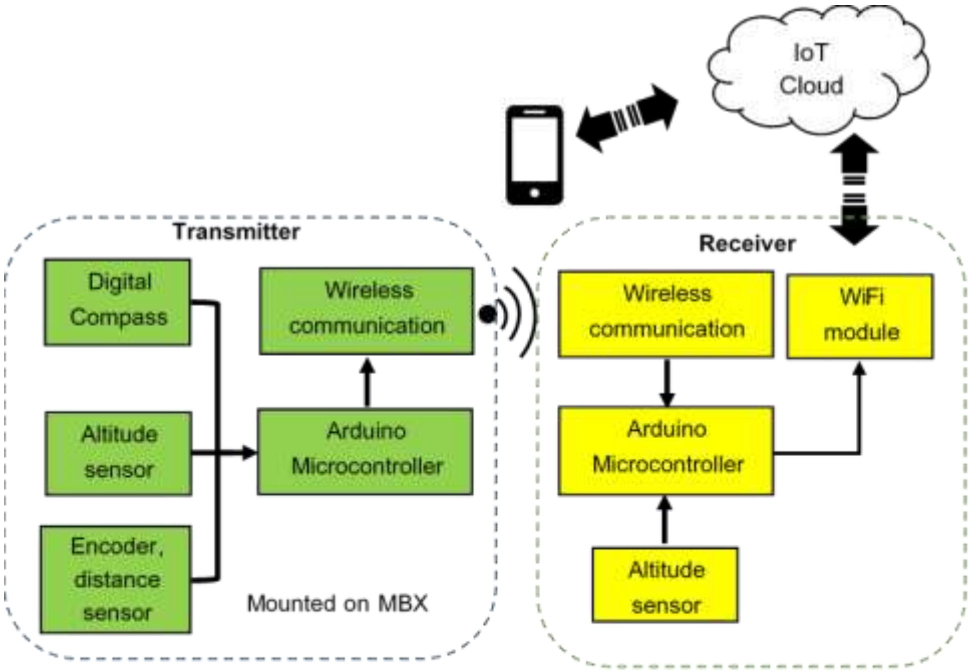


Figure 7 **The block diagram of indoor monitoring and tracking MBX.**

(a) (b)

Figure 8 **The tag (transmitter-receiver) composed of arduino platform and nRF24L01 with attenna Sensor modules (a-b).**

3.2 The development of quality evaluation forms

The development of quality evaluation forms was a questionnaire construction section to assess the quality of the systems, consisting of work satisfaction in accordance with the objectives, information accuracy, and convenience in using. The evaluation form was used by three experts who were radiologists at Songkhla Hospital.

4. Results

4.1 The trial operation and the installation of the system.

The actual location was used by bringing the sender set which has various detector systems as aforementioned to be installed on the MBX with the least impact on the MBX. That means no piercing or destruction of the body or any connection was used by the method of sticking on the body only as shown in Figure 9. The tag setup was tested to install on two MBX devices. The personal receiver had only one set installed in the center of the building and chosen to place. The elevator page of the first floor consisting of many buildings was tested as shown in Figure 10. Each floor has the layout as shown in Figure 11 (a-d).

Figure 9 Tag setup

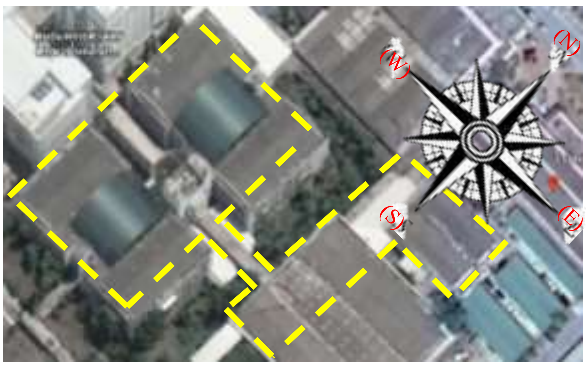
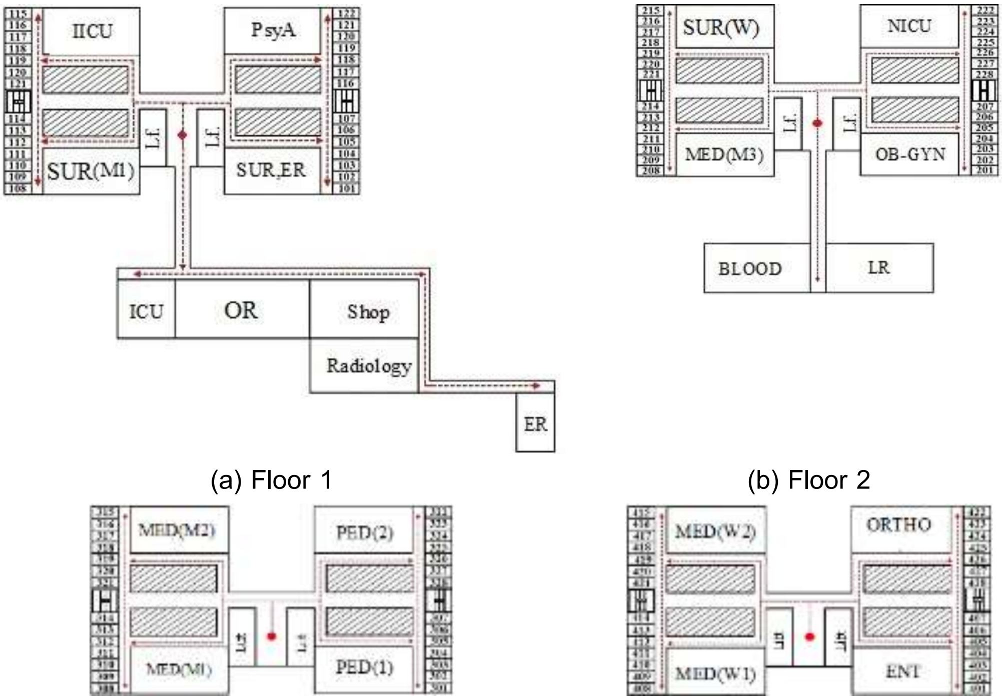


Figure 10 The testing area in Songkhla Hospital.



(a) Floor 1 (b) Floor 2

(c) Floor 3 (d) Floor 4

Figure 11 The indoor layout of Songkhla Hospital building for system testing.

The results can be read from various sensors and transmitted via the 2.4 GHz radio frequency band to the receiver, and the receiver then transmitted the data through the wireless network system to the internet. After that, the user or the administrator opened the application to monitor the position and status of both MBX machines in a timely manner. As the information is shown in Figure 12 (a), the administrator can decide if the MBX service is requested by a device to provide the service by notifying the vehicle staff with walkie-talkie. Furthermore, the usage history reports are shown in Figure 12(b) can be opened for the administrators or executives to analyze the cost-effectiveness or to consider of maintenance and maintenance management or even to stop the systems due to long use conditions.

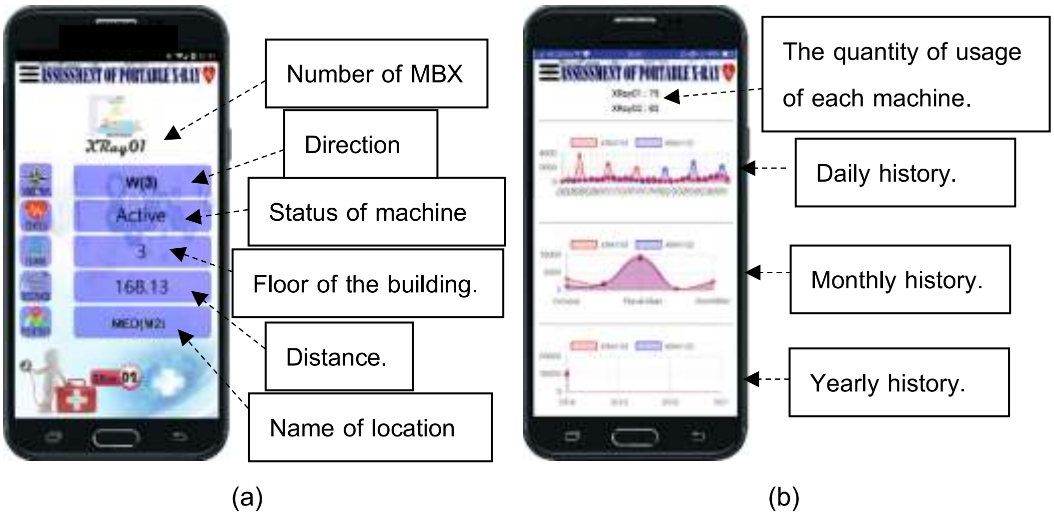


Figure 12 The system was able to show information for mobile applications.

4.2 Test results for quality of work.

The results of the testing of both MBX machines were found out, by the method of targeting to travel to the same target for both devices, for ten trips in four floors, and four rooms in each floor, which was obtained by simple randomization. Travel was done without fixed walking paths, and then the accuracy of the position informed via the system was analysed.

In Table 1, the results of the data analysis showed that the average score of the accuracy of travelling to provide services in the target position of the system installed on the 1st MBX machine was 88.13 percent, and the standard deviation was 1.66. The average score of the accuracy of travelling to provide services at the target location of the system installed on the 2nd MBX was 90.16 percent, and the standard deviation was 1.31. It can be concluded that both MBX machines had no statistically significant difference at the 0.05 level.

Table 1 Test results for the performance of MBX tracking and monitoring system

Machine	Location	Average Accuracy(%)	S.D.	T-test	Sig
MBX-01	Room1…16	88.13	9.81	-0.74*	.465
MBX-02	Room1…16	90.63	9.29		

*significant at 0.05

4.3 The results of the satisfaction level.

The evaluation form was carried out by three radiologists using the MBX monitoring and tracking system.

Table 2 Satisfaction

Topic	Rating		interpret
	Mean	**S.D.**	
1. Responsive purpose.	4.36	0.71	Good
2. Information accuracy.	4.24	0.88	Good
3. Convenience in use.	4.54	0.76	Very Good
Total	**4.38**	**0.87**	**Good**

Table 2 the analysis results of the users' satisfaction with the MBX examination and tracking systems summarizes. It was found that the users were most satisfied with all aspects ($\overline{x}$ = 4.38, SD = 0.87). The convenience in use was at the highest level ($\overline{x}$ = 4.54, SD = 0.76), followed by responsive purpose ($\overline{x}$ = 4.36, SD = 0.71) and the systems information accuracy ($\overline{x}$ = 4.24, SD = 0.88), respectively.

5. Conclusion.

From the overall quality assessments of every system, the MBX tracking and monitoring was good. They ensure that the systems are of sufficient quality for actual use. However, the system still has faults. Some areas may need to be improved, for example, an error caused by calculating the distance from the encoder that is related to the movement speed, as well as the direction that is rough, causing errors in the position of the target room in the range of ± 5m. and in the power supply system of the tag. A system to reserve energy and charge should contain in order to be more effective.

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