A HOSPITAL BED AVAILABILITY MONITORING SYSTEM USING THE INTERNET OF THINGS

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Abstract: Hospitals are considered the backbone of healthcare systems, and their significance is particularly pronounced during emergencies. However, the rapid overpopulation and recent pandemics have caused tremendous shortages of hospital beds, raising major threats to public health. This developmental research study aims to help improve the management of hospital beds through the design, development, testing, and evaluation of an Internet of Things (IoT)-based monitoring system implemented using Agile Scrum methodology. Based on the results of the hypothesis testing, the authors found that the optical sensors installed in 4 hospital rooms, with varying distance readings, are consistently accurate ($F(3, 388) = 1.000$, $p=0.393$), hence the authors accepted the proposed null hypothesis. Moreover, the beneficiaries, composed of the public, hospital staff, nurses, and a doctor evaluated the system to be overall very good, very efficient, very suitable, reliable, very usable, and very satisfactory. The outcome of this research aims to contribute to the United Nations' Sustainable Development Goals (UN-SDG) on good health and well-being (SDG 3).

Keywords: Hospital bed, Internet of Things, information technologies, crowdsourcing, technology management

1. INTRODUCTION

Hospitals are considered the backbone of healthcare systems around the world. They play a crucial role in maintaining good public health by providing immediate care to sick or injured people; isolation facilities or venues for medical research; and other support functions to the government and communities [1, 2]. One of the measures of quality of hospital services is the satisfaction of patients, primarily on the availability of hospital beds. In one study by [3], they found that there is a negative association between the number of hospital beds vis-à-vis the satisfaction of patients. Moreover, in another study by [4], they found that the availability of hospital beds is a crucial predictor of patient satisfaction. Interestingly, the ultimate root cause of bed shortage in hospitals is due to overcrowding, which is a common dilemma in most hospitals [5, 6], particularly during pandemics [7].

Overcrowding in hospitals happens if there is a huge number of incoming patients; there is a delay in admission, and for worse, premature deaths [8]. Overcrowding in hospitals can be further attributed to various factors, such as poor bed management [9]; issues in supply

chain management [10]; poor coordination [11]; limited manpower [12] lack of a sophisticated system to monitor real-time data [13, 14], inefficient decision-making process [15], changing decisions of patients to stay [16], and prevalence of communicable diseases in hospitals [17], among others. In the Philippines, there are fewer public hospitals than private ones in the entire archipelago, which results in more than 50% of the population who cannot afford basic healthcare services [18]. Recently during the pandemic, many Filipino families struggled to find available hospitals even in nearby towns, cities, or provinces due to overcrowding. This resulted in higher death rates and brought significant distress to patients, hospital managers, health authorities, and local and national government officials [19].

In this current study, the authors proposed a system that can provide vital information on the availability of hospital beds, hence, essentially lessening the cases of overcrowding and effectively managing hospital beds. The intended outcome is to support the healthcare system in the country through the provision of a real-time, efficient, and accurate hospital bed management system. Specifically, the authors proposed to achieve the following objectives:

1. Design a hospital bed monitoring system with the following features:
   a. Web application for patients and the public
   b. Desktop application for hospital administrators
   c. IoT-powered detection system for the availability of hospital beds using reflective optical sensors, microcontroller unit, Wi-Fi module, and system peripherals.
2. Develop the system using the agile scrum methodology.
3. Test the system in terms of functional accuracy through a hypothesis-testing approach.
4. Evaluate the system based on ISO 25010:2011 in terms of performance efficiency, functional suitability, reliability, usability, and satisfaction.

2.LITERATURE REVIEW

Fortunately, several technological innovations were developed to address the problem of hospital bed management. For instance, [19] developed a real-time, web app with a trigger feature, however, it lacks a warning system for the shortage of ICU and CCU beds, which may result in an influx of ICU and CCU patients. [20] also developed another web-based bed management system with a referral feature; however, it does not have a provision to add new beds. In another study by [21], they utilized an IoT beacon with mobile and web apps. However, it has some concerns in location tracking and data security. In another study by [22], they developed a web-based ICU bed information system with a comprehensive dashboard, however, it lacks an electronic medical records-archiving feature and patient regulation system. Lastly, [23] also co-developed an autonomous robot that detects hospital room nameplates using the YOLOV4 method which is deemed 94% accurate. However, its movements are limited in tight spaces, and it has a buzzing sound that creates unnecessary noise.

Moreover, numerous technological inventions have been patented that aim to monitor hospital beds. In the work of [24], they utilized a pressure sensing system, display monitor, and alarm system to monitor available hospital beds. While the said system is informative and functional overall, it is found to be efficient, it requires numerous computer peripherals

such as a handheld Personal Digital Assistant (PDA) and a nursing station computer, hence, it is expensive to set up. Meanwhile, [25] also patented an integrated patient bed system using various diagnostic tools and equipment such as fluoroscopy, x-rays, CT-scan, ultrasound, cardiac monitor, dialysis machine, blood analysis, etc., to monitor critically ill patients. While the system is comprehensive in data generation, it is costly and complicated to manage. Overall, these technological developments and patents are deemed efficient, real-time, and sophisticated. However, further work is needed to explore alternative and sustainable solutions to optimize the monitoring of hospital beds, through simplified and decentralized management of data through continuous innovation of feature sets and the Internet of Things (IoT) framework [26].

3. METHODOLOGY

3.1 System Design

The following Figure 1 illustrates the overall design of the proposed system. In terms of its software dimension, a patient or the public can access the website application through his/her smartphone or computer to view the availability of hospital beds in nearby locations. Meanwhile, hospital staff can access the admin module through a dedicated desktop application, pre-installed in a specific hospital. The desktop app is based on the Create, Read, Update, and Delete (CRUD) processes for database management, which can manage the availability of hospital beds in direct communication with the hardware prototype through the IoT infrastructure.

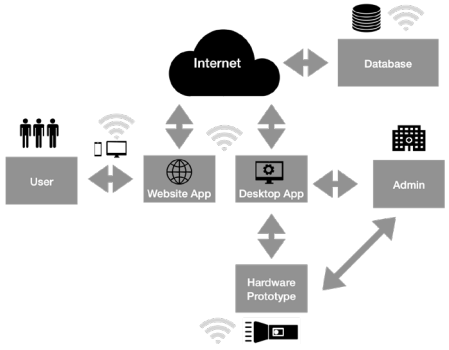


Figure 1. System block diagram

The system maintains a dedicated database that serves as a repository of all processed data for both web and desktop applications. Depending on the information requested by the user, the database collects the data from the desktop application and displays it to the web application. As illustrated in Figure 2, the database is composed of 2 tables, namely “admins” and “hospitals”. The “admins” table includes the login credentials, such as username and password, as well as the user ID and hospital ID. Meanwhile, the table “hospitals” contains the demographics of various hospitals enrolled in the system, such as hospital ID, hospital name, type, bed admission type, as well as latitude and longitude of the hospital address, contact number, and system settings. Moreover, the system has a hardware prototype, which is divided into two parts – the lower part, which includes the battery holder and nameplate slot, and the upper part, which includes the microcontroller unit (MCU) and 2 optical sensors.

The following Figure 3 shows the three-dimensional model of the hardware prototype. The enclosure was designed to be slightly elevated optimize the detection consistency.

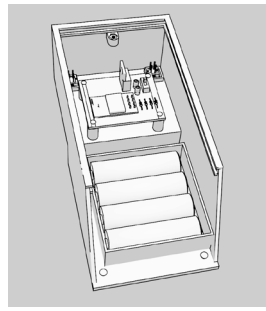
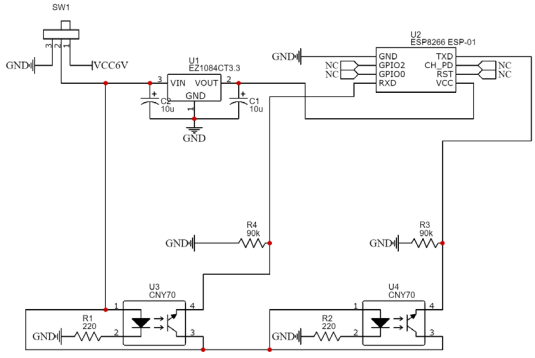


Figure 2. Database Diagram *Figure 3. Hardware Prototype 3D Model*

Meanwhile, the following Figures 4 and 5 show the schematic and Printed Circuit Board (PCB) designs of the hardware prototype, respectively.



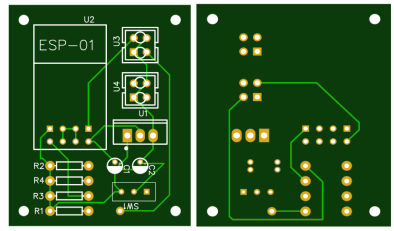


Figure 4. Schematic Diagram *Figure 5. PCB Design*

Meanwhile, the following Figures 6, 7, and 8 detail the operational flowcharts of the web app, desktop app, and hardware prototype, respectively. These flowcharts serve as guides for the public, hospital staff, and technical support towards the effective operationalization of the system.

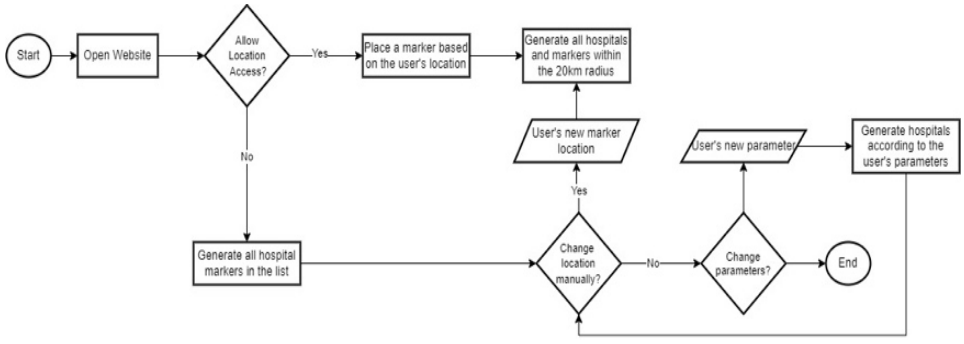


Figure 6. Website App Operation

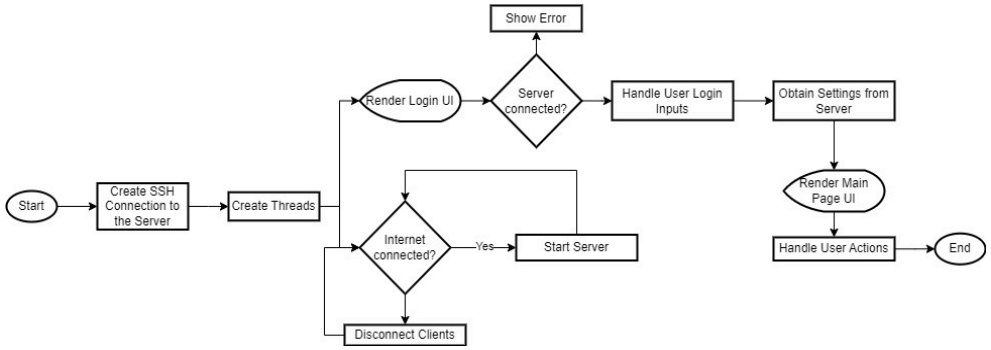


Figure 7. Desktop App Operation

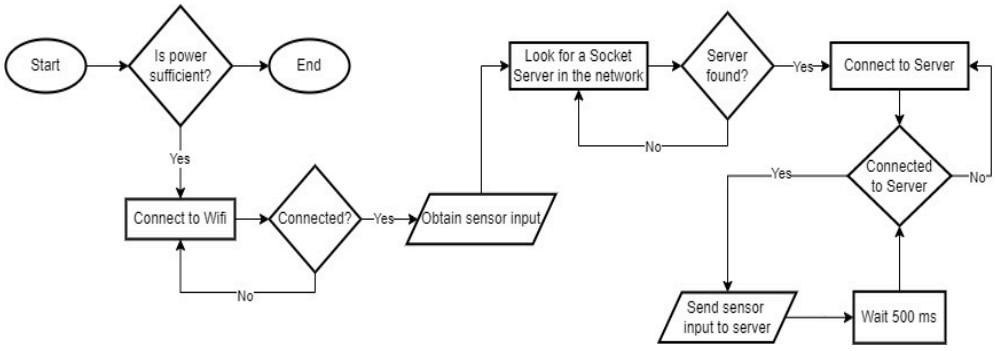


Figure 8. Hardware Operation

3.2. Development Framework

The authors utilized the Agile Scrum methodology as the basis of the development process, as shown in Figure 9, which covers both the software and hardware dimensions of the system.

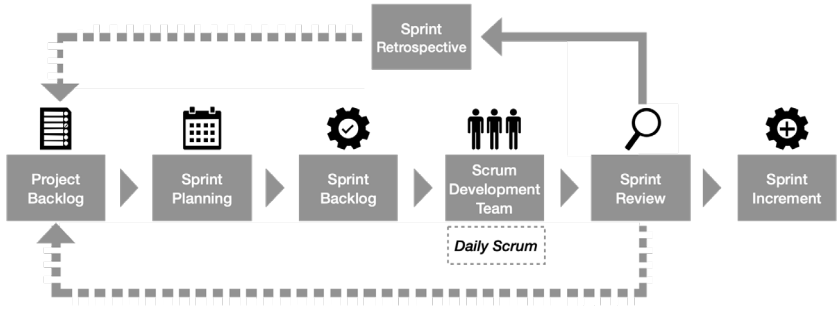


Figure 9. Agile Scrum Methodology

Initially, the authors contributed to the project backlog by specifying the objectives, and the knowledge, software, and hardware requirements of the project. Then, they conducted sprint planning to detail the objectives, related studies, patents, methodologies, and testing and evaluation procedures. Also in this phase, the authors agreed on the specific hardware and software technologies, frameworks, and feature set. Then, they divided the tasks among

all members of the team depending on their strengths and capabilities. They also agreed on the timelines, milestones, financial costs, procurement details, communication scheme, risks, and contingency plans. Afterward, the authors prepared the sprint backlog, which lists the specific tasks, deliverables, in-charge, and target deadlines for each objective. Then, they carefully executed the objectives in coordination with technical experts, hospital authorities, and beneficiaries. Initially, they prepared the designs of the hardware, followed by the software dimensions of the system, and conducted iterative development processes for both platforms. For every phase of the development process, the authors reviewed each output to ensure conformity with the project specifications. The hardware prototype was designed to have 2 optical sensors, in which each sensor was configured to represent one bed or a total of 2 beds in a room. The authors programmed each optical sensor to detect the availability of each bed through a white nameplate. As for the testing, the authors configured each optical sensor such that once blocked, it would mean that a specific bed in a room is not available. Specifically, the authors programmed each sensor with "no block", "block left", "block right", and "block both" configurations to indicate "no bed available", "1 bed on the left is available", "1 bed on the right is available", and "both 2 beds are available", respectively. With test rooms 1, 2, 3, 4, and 5, the authors varied the distance readings to 1mm 5mm, 10mm, 15mm, and 16mm, respectively. The responses of the sensors were captured automatically using a script and were collated through CSV format for further statistical analysis.

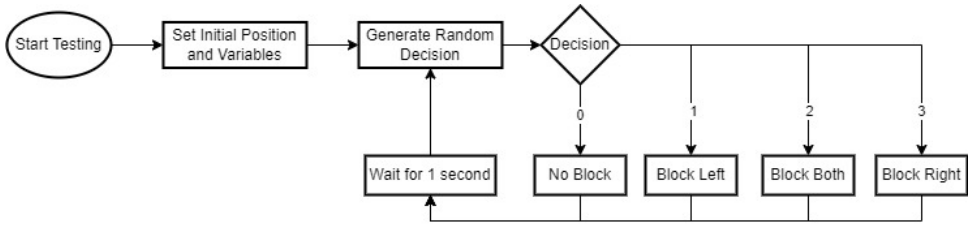


Figure 10. Testing Contraption Flowchart

Subsequently, the authors tested the null hypothesis (H_0) of the study, which states that "there is no significant difference in the functional accuracy of the system in sample hospital rooms" with a 95% confidence level and 5% error. They utilized the one-way Analysis of Variance (ANOVA) technique based on the sample size of 5 hospital nameplates with 98 test cases in each room. The analysis was conducted using one-tailed test through a statistical application software Statistical Package for the Social Sciences (SPSS) version 25. The F-statistics was computed using the following equations where: $Fs = F\ statistic$; $MSTbg$ = Mean square per treatments between groups; $MSEwg$ = Mean square per error within groups; Λ_{xy} = an observation; $\prod_x$ = group total; Gt= grand total; o_x = number in group x; and o = total observations:

$$Fs = \frac{MSTbg}{MSEwg} \tag{1}$$

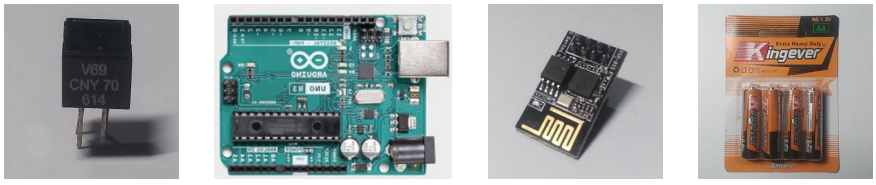
$$MSTbg = \sum_{x=1}^{z} \left(\frac{\prod_x^2}{Ox}\right) - \frac{Gt^2}{O} \tag{2}$$

$$MSEwg = \sum_{x=1}^{z} \sum_{y=1}^{z} \Lambda_{xy}^2 - \sum_{x=1}^{z} \left(\frac{\prod_x^2}{Ox}\right) \tag{3}$$

In terms of the sprint retrospective phase, the authors involved 50 patients, the public, and another 6-hospital staff to evaluate the system using the ISO 25010:2011 international standard. They utilized a survey questionnaire based on the criteria of performance efficiency, functional suitability, reliability, usability, and satisfaction. Each question has a 5 Likert scale, where 1 and 5 were the possible lowest and highest scores, respectively. The survey form has a provision to capture the comments and suggestions from the respondents. The authors then collated and analyzed the responses using a spreadsheet and ran through the SPSS v25. Lastly, the authors carefully compiled and studied all observations, insights, and results of prototyping, quantitative analysis, survey, and feedback from the respondents for the further improvement of the system in the future.

4. RESULTS AND DISCUSSION

Shown in Figure 11 are the main components of the hardware prototype, namely: (a) 2-CNY70 reflective optical sensors, which can detect the presence of the hospital room nameplate indicating that a particular bed is occupied or not; (b) Arduino UNO MCU R3, which includes the ATmega328P processor that controls the operations of the system; (c) ESP8266 ESP-01 Wi-Fi module, which is used to connect to the internet and sends bed availability data to the online database and updates the desktop and website applications used by the general public and admin, respectively; (d) 4 piece-1.5V batteries used to power the whole hardware prototype. These hardware and software components are inter-connected through an IoT architecture.



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

Figure 11. Hardware Components

Meanwhile, the following Figures 11a and 11b depict the actual external and internal pictures of the hardware prototype, respectively.

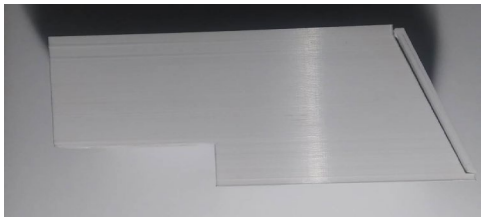


Figure 11a. External View

Figure 11b. Internal View

The casing is made of a 3D-printed material, with dimensions of 55.5 mm in height, 108.5 in length, and 68 mm in width. Beneath the casing is a slightly elevated panel with 17x53x61mm detection space, sufficient enough to sense the presence of a nameplate. The nameplate is manually inserted by the hospital staff in a designated slot to indicate the

presence of a patient in a particular bed per room. In the context of the hardware prototype, the system can detect up to 2 beds or 2 patients per hospital room.

In terms of the software dimensions, the system operates into 2 platforms – web and desktop applications. Illustrated in Figure 12 is the screenshot of the website application. The authors designed the web application using Figma for the user interface and developed it using Hyper Text Markup Language (HTML), Cascading Style Sheets (CSS), JavaScript, Structured Query Language (SQL), Hypertext Pre-processor (PHP), and Asynchronous JavaScript XML (AJAX). The app features an interactive map, through Leaflet Application Programming Interface (API) and other programming techniques and algorithms, which allow the user to view, zoom, drag, or pan the location of the nearest hospital with the greatest number of available beds. Moreover, the app shows hospitals based on current location and allows users to manually view specific locations based on latitude and longitude. The app also provides alternatives to users depending on personal preferences such as public or private hospitals, room types such as ward, semi-private, or private, as well as contact details of a specific hospital. The app also works offline using AJAX and automatic location tracking using Geolocation API, and it features a Nearest Location Finder algorithm, programmed using SQL and PHP, which expedites the querying and location tracking processes. Shown in Figures 13, 14, 15, and 16 are the screenshots of the actual implementation of the Leaflet API, AJAX, Geolocation API using JavaScript, and the Nearest Location Finder algorithm, respectively.

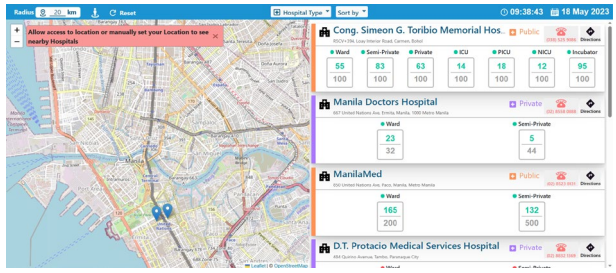


Figure 12. Website Application (Manila Area)

```
<div id="map" style="width: inherit; height: inherit;"></div>
<script>
    const map = L.map('map');
    map.setView([14.598491742125102, 120.98333635023232], 13);
    const tiles = L.tileLayer('https://tile.openstreetmap.org/{z}/{x}/{y}.png', {
        maxZoom: 19,
        attribution: '&copy; <a href="http://www.openstreetmap.org/copyright">OpenStreetMap</a>'
    }).addTo(map);
    if (sessionStorage.getItem("manual_location")){
        selfmarker.addTo(map);
        go_to_self();
    }
```

Figure 13. Leaflet API Implementation

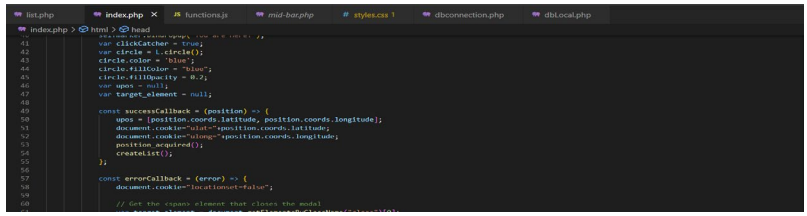


Figure 14. AJAX Implementation

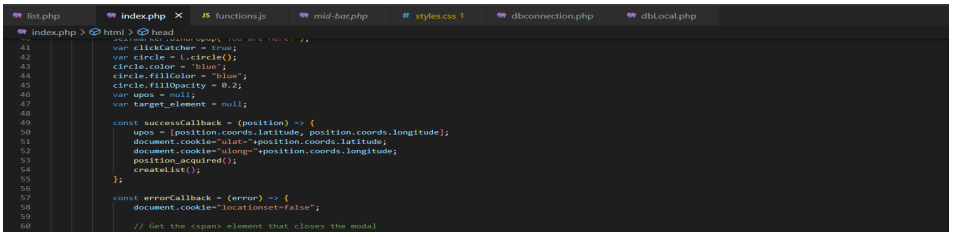


Figure 15. Geo Location API Implementation Using JavaScript

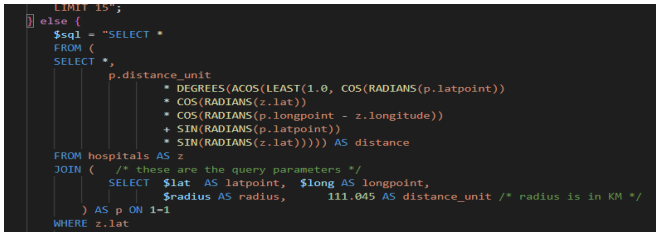


Figure 16. Nearest Location Finder Algorithm using SQL and PHP

Meanwhile, the desktop application of the system supports both the hardware and the central database. The authors utilized Figma for the user interface and developed the application using the Microsoft #NET framework and Windows Presentation Foundation. The desktop is intended for hospital staff, which allows them to monitor and update the availability of hospital beds based on the data fed by the hardware prototype. It features real-time querying updates, configured using C# programming language. The results are then subsequently displayed on the web application for the information of the public. Shown in Figures 17a, 17b, and18 are the screenshots of the desktop application's homepage, modification page, and the C# Programming language implementation, respectively.

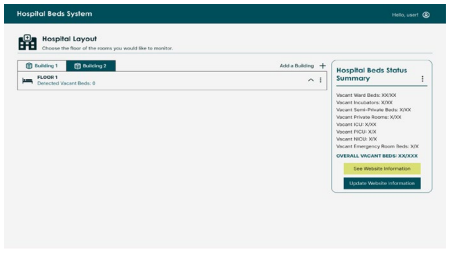


Figure 17a. Desktop App Homepage

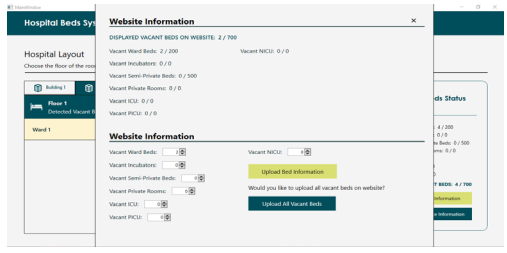


Figure 17b. Desktop App Modification

Figure 18. C# Programming Language Implementation

The authors then tested the system by focusing on the functional accuracy of the hardware prototype, through its reflective optical sensors installed in 5 nameplates. Shown in Figure 19 is the actual testing procedure conducted. Each nameplate was tested for approximately 15 minutes with an interval of less than a second.

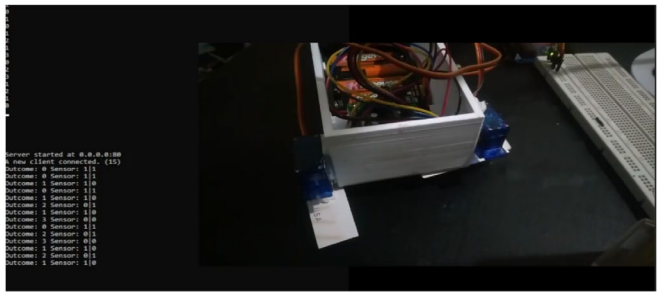


Figure 19. Testing Setup with Screenshot

The authors found out that the true detection range of the hardware prototype is from 1mm to a maximum of 15mm only. Unfortunately, 16mm yields to no data detection, hence, the authors excluded it in further testing the H_0. The following Table 1 shows the summary of testing from the sample test cases. In this scenario, only 12 out of 98 test cases per set of 1mm, 5mm, 10mm, 15mm, and 16mm detection reading.

Table 1. 12 over 98 Sample Test Case Results

No.	1mm		5mm		10mm		15mm		16mm	
	Expected	Actual	Expected	Actual	Expected	Actual	Expected	Actual	Expected	Actual
87	3	3	3	3	0	0	2	2	1	NaN
88	0	0	0	0	3	3	3	3	2	NaN
89	2	2	2	2	1	1	1	1	3	NaN
90	3	3	3	3	0	0	0	0	2	NaN
91	1	1	1	1	2	2	3	3	1	NaN
92	3	3	3	3	3	3	2	3	0	NaN
93	2	2	2	2	2	2	0	0	2	NaN
94	3	3	3	3	1	1	2	2	0	NaN
95	2	2	2	2	3	3	1	1	3	NaN
96	0	0	0	0	0	0	3	3	2	NaN
97	2	2	2	2	1	1	2	2	1	NaN
98	3	3	3	3	2	2	1	1	2	NaN

Furthermore, shown in Table 2 is the result of the inferential statistics. The authors found that there was no statistically significant difference in the detection accuracy of the 4 optical sensors determined by the one-way ANOVA ($F(3, 388) = 1.00$, $p=0.393$). Hence, the authors accepted the H_0. This means that the optical sensors are consistent and at par with each other in detecting accurately if a specific hospital room is available, partially available, or not available.

Table 2. ANOVA Test Results

	Sum of Squares	***df***	***Mean Square***	***F***	***Sig.***
Between Groups	0.008	3	0.003	1.000	0.393
Within Groups	0.990	388	0.003		
Total	0.998	391			

After the testing, the authors engaged 62 respondents, composed of 50 from the public who have experienced being admitted to a hospital, 6 hospital admin staff, 5 nurses, and 1 doctor, to evaluate the system through an online survey questionnaire based on the ISO 25010:2011. Summarized in Table 3 is the result of the evaluation. Overall, the respondents perceived that the system is "very good" with an overall average rating $\bar{x} = 4.31$. This means that the system is acceptable for the projected beneficiaries. Most of the respondents provided positive reviews and insightful suggestions for the enhancement of the website.

Table 3. Evaluation Results

Criteria	***Mean***	***Descriptive Rating***
Performance Efficiency	4.37	Very Good
Functional Suitability	4.46	Very Good
Reliability	4.21	Very Good
Usability	4.34	Very Good
Satisfaction	4.18	Very Good
Overall Average ($\overline{x}$)	4.31	Very Good

5. CONCLUSIONS

The proposed system aims to contribute to a more efficient bed management and decision-making process among patients and hospital managers alike. Specifically, the website application can provide real-time and accurate information on bed availability in hospitals through automatic location tracking or a manual query. It provides an interactive map that allows users or the public to view the navigational route to the selected hospital, including contact details, making it more convenient for communication purposes. Meanwhile, the desktop app allows the hospital admin staff to monitor and update bed vacancies based on the data fed by the hardware prototype through the IoT architecture. It has a secured login system, and it has a provision for adding or removing device keys to recognize or unrecognize nameplates. Moreover, the use of the IoT infrastructure, locally available materials, and the agile scrum methodology are deemed effective in attaining the study's objectives. Test results show that the system is consistently accurate in detecting the availability of hospital beds, while the expected beneficiaries have well accepted the system as per ISO 25010:2011 international standard. Hence, the system is considered a viable solution to ease the overcrowding of hospitals and a proactive communication tool for potential in-patients or the public. The outcomes of the system are expected to contribute to the UN-SDG-3 on good health and well-being. Future research should focus on applying the system to more hospitals at the regional or national levels to ensure consistency and reliability.

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