University of Victoria

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April 4, 2025

Trade and Investment British Columbia
Suite A, 123 Canada Way
Vancouver, BC, V6C 3E1

Dear Trade Investment BC,

In response to the Government of British Columbia's request for proposals for proof-of-concept designs to modernize any aspect of a hospital, please find enclosed the following report on GHJ Automation Ltd.'s recommended design.

The report details three distinct designs developed by GHJ Automation Ltd to improve safety and patient experience within hospitals. Through a rigorous testing procedure and a comparative analysis used in assessing these designs, this report will suggest a final recommendation of a prototype design that would be beneficial to your organization

It is our sincere hope that the recommendations in this report can lead to an effective final design solution being developed for the Government of British Columbieng for modernizing hospitals which meets all the design objectives. We look forward to the opportunity to work with you. Please Contact us with any questions or concerns you may have.

Sincerely,

Gregory Bian
GHJ Automation Design Team

Enhancing Patient Safety and Hospital Experience

In Response to RFP-202501
PROOF-OF-CONCEPT DESIGNS FOR MODERNIZING BC HOSPITALS

Submitted to

Trade and Innovation BC

Submitted by

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Date

15 March 2025

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Figures and Tables

Executive Summary

This report responds to RFP-202501 by Trade and Innovation BC, which seeks innovative proof-of-concept designs aimed at enhancing patient safety and hospital experience within British Columbia's healthcare system. The report addresses key challenges such as low hand hygiene compliance, risks posed by patient wandering, and inefficient hospital lighting—factors that contribute to hospital-acquired infections, accidental injuries, and patient discomfort.

To address these issues, three distinct proof-of-concept designs were developed and evaluated:

1. **Hand-Hygiene Compliance System** – Monitors and encourages handwashing among staff and patients using infrared and ambient sensors.

2. **Smart Proximity Alert System** – Detects patient movement near hazardous areas to prevent accidents, especially among vulnerable populations.

3. **Smart Lighting System** – Automates lighting control based on ambient light and user preferences to improve energy efficiency and patient comfort.

Each prototype was constructed using a Raspberry Pi Pico and tested in a lab setting following a structured assessment procedure. Metrics such as Mean Time Between Failures (MTBF), response time, integration time, energy consumption, and maintenance duration were used to evaluate each design's performance. These metrics were then weighted according to their importance, and final scores were calculated through a numerical evaluation matrix.

The Hand-Hygiene Compliance System achieved the highest overall score in this comparative analysis. It was found to be the most reliable, intuitive, energy-efficient, and easiest to integrate. Moreover, it directly addresses a pressing public health concern—hospital-acquired infections—and provides a scalable, cost-effective solution.

Based on both qualitative and quantitative evaluation, this report recommends the Hand-Hygiene Compliance System for further development and implementation. Its strong alignment with healthcare objectives, combined with superior test performance, makes it the most promising solution for improving patient safety and hospital operations across BC's healthcare network.

Glossary

Infrared (IR) light	Non-visible light with wavelengths longer than red light.
Potentiometer	An electrical resistor whose value may be varied by a sliding or rotating mechanical action.
Magnetic reed switch	A switch that uses magnetic connection to activate
Infrared emitting diode	A LED that emits infrared light which is invisible to the human eye but can be detected by the infrared receiving diode
Infrared receiving diode	A diode that receives infrared light and sends signals accordingly

Table 1. Glossary of key terms in the report and their definitions

Improving the safety and experience of hospital patients

Underlying Cause

Smart technology has enabled modern buildings like hospitals to incorporate networked systems that automate functionality and streamline operations. Specifically, within hospitals, these systems enhance a wide range of processes, from patient monitoring and data analytics to real-time communication between departments, ultimately contributing to improved care and operational efficiency.

In response to the government of British Columbia's call for innovative approaches to modernize hospital operations, this report has been developed in response to the RFP-202501 which is requesting Proof-Of-Concept Designs for Modernizing BC Hospitals. The proposal outlines and compares three distinct proof-of-concept designs aimed at addressing persistent challenges within hospitals. By thoroughly documenting the technical features, integration capabilities, and potential benefits of each design, the report seeks to persuade Trade and Innovation BC to adopt and scale the most effective solution.

The underlying motivation for these designs' stems from significant issues in BC hospitals, where only 49.6% of patients reported satisfaction with their experience [1]. This low satisfaction rate highlights not only deficiencies in patient safety protocols but also broader challenges in delivering a positive hospital experience. The proposed solutions are designed to mitigate these concerns by addressing the need for improved patient safety protocols and overall service quality.

Goals of this Proposal

This report aims to improve patient safety and hospital experience by comparing 3 solutions using proof-of-concept designs. These designs will ultimately help achieve the goal of these designs, which is to illustrate methods of resolving common issues that patients often face inside a hospital. These solutions aim to meet the following objectives:

- Should be low budget, but good quality so it can be scaled without too much cost
- Should be integrated quickly and timely to be easily scaled to many hospital environments
- Should be energy-efficient and environmentally sustainable
- Should be low maintenance
- Should be reliable in a hospital environment

- Should have an intuitive user interface for healthcare staff

These objectives are crucial to be able to implement seamlessly into a hospital environment. However, it is also important to consider constraints that a hospital may face in implementing a design as such:

- Must comply with provincial and federal healthcare regulations, ensuring data privacy and security
- Must integrate seamlessly with existing hospital technology infrastructure
- Must feature an intuitive user interface to ensure ease of use for healthcare staff
- Must not be excessively complex such that a power outage or software bug can be easily fixed and started up again

Assessment Procedure

The proof-of-concept designs that this report is documenting aim to simulate these functions and requirements. Therefore, it is also important to have a method to test the functionality and effectiveness of these prototypes to see have they may meet these objectives and constraints. To test the prototypes' effectiveness, a series of tests were conducted using the following procedure:

1. Hardware Setup *(Objective: Quick integration)*
    a. Assemble the circuit on a breadboard, ensuring secure connections between the Raspberry Pi Pico, sensors, and actuators.
    b. Upload a test script to confirm all components function properly and test the time for the full integration
2. Sensor Calibration and Response Testing *(Objective: Low Maintenance)*
    a. Run the system continuously until the system can not handle any more updates.
3. Sensor Calibration and Response Testing *(Objective: Intuitive)*
    a. Record response time of sensor data on an user interface and accuracy of values
4. Energy Efficiency and Environmental Sustainability *(Objective: Low power consumption, minimal environmental impact)*
    a. Measure power consumption in idle and active states.
    b. Test power-saving features and assess heat generation.
5. Fault Tolerance and Recovery *(Objective: Handle power failures, software bugs effectively)*
    a. Simulate power failures by unplugging the Raspberry Pi Pico from the power source.

    b. Reconnect to power and record its effectiveness in reconnecting sensors and connecting to the User Interface
6. Long-Term Reliability *(Objective: Reliable)*
    a. Record the number of failures of system code over a 30-minute period.
    b. Assess the mean time between failures (MTBF)

Ultimately, these designs will aim to meet the goal of designing an effective proof of design concept that would act as a possible solution to improving patient safety, that can be implemented in hospitals.

Following the guidelines of the objectives, constraints and goal, we created 3 proof-of-concept designs to improve different areas of patient safety. Our first design addresses the critical issue of poor compliance with hand-hygiene protocols among healthcare workers to mitigate hospital-acquired infections (HAIs). Our second design presents a safety concern of sleepwalking among hospital patients, which can lead to serious falls and injuries. Our third design presents an innovative solution to the issue of wasted energy and patient discomfort caused by manually controlled hospital lighting. The technical aspects and "proof of concepts" will be described in the following section, design proposals.

Design and Development

This section will contain 3 “proof of concept” design ideas aimed at addressing the issues that affect patient safety as detailed in the previous section. The functions described will be performed in the lab to simulate functions that may aid hospitals if they were chosen and scaled. Additionally, these designs will adhere to the objectives and constraints described in the previous section in order to ultimately achieve the goal of this report.

Hand-Hygiene Compliance System

The Hand-Hygiene Compliance system addresses the critical issue of poor compliance with hand-hygiene protocols among healthcare workers to mitigate hospital-acquired infections (HAIs).

Motivation

The World Health Organization (WHO) reports that appropriate hand hygiene can prevent up to 50% of avoidable infections acquired during healthcare delivery [2]. Despite this, only 60% of healthcare workers comply with the hand hygiene protocols [2] which contributes to the spread of infections within hospital environments, leading to increased patient morbidity and mortality, prolonged hospital stays, and elevated healthcare costs [3].

There are many different key factors that play into the spread of hospital-acquired infections. Some of these key factors are poor patient etiquette, like walking around without a mask if contagious, not washing hands, and not staying in the room while quarantined. In addition to these causes doctors can also have a hand in the spread of hospital-acquired infections as well, examples of these causes can range from not writing proper protective equipment to not changing protective equipment as much as they should, such as dealing with a patient and then moving onto the next without changing protective gloves in between. [4]

Hospital Solution

Our first design aims to address these issues and prevent Hospital Acquired Infections from spreading. This design employs ambient sensors to track movements through hospital and washroom doors. Infrared sensors to detect usage of soap dispensers and compares then through an intuitive user interface.

Mechanical System

The following proof-of concept demonstrates a scaled-down prototype version of the system that would into a hospital. This prototype was built using a Raspberry Pi Pico, a red and green LED, an ambient sensor and an infrared emitter and sensor circuit. The ambient sensor simulates the sensor positioned at every soap dispenser. Given a change in resistance from the calculated threshold (~60k Ω), the ambient sensor would trigger the green LED to turn on and the red LED to turn off for 5 seconds while simultaneously updating the user interface to track this value. The infrared emitter and sensor simulates the sensor that detects people entering the washroom. Given a change in resistance from the infrared emitter being blocked making the infrared sensor detect less infrared light (~45k Ω), the sensor will update the user interface to make note of this value. Due to a person needing to enter and exit the washroom, the user interface takes this into account and only updates when the sensor is activated twice.

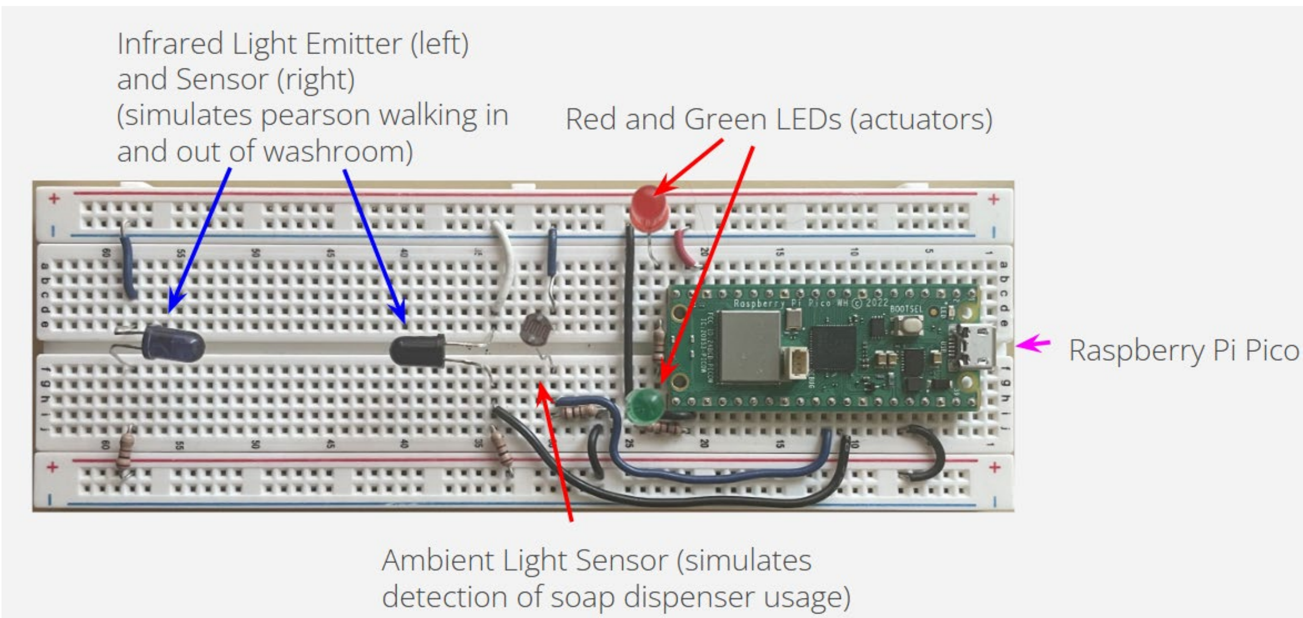

Figure 1. Design Prototype including an Ambient Light Sensor Circuit and an Infrared LED and Phototransistor circuit

User-Interface

The user interface of this system detects the changes in sensor readings as detailed in the mechanical systems section and transfers it to this webpage. The graph plots the number of people using the soap dispenser as a function of how many people enter the washroom to provide a visual and detect any trends that may be valuable to helping a hospital have their healthcare workers comply with the protocols. The user interface also displays the number of people that have entered a washroom, left a washroom and the percentage of people that have washed their hands according to these two previous values. Finally, the user-interface provides a two-way communication method through a reset button which calibrates the sensors to the environment they were place in. The would calibrate the threshold value to the ambient and infrared light in its environment which would aid in the scalability of this design.

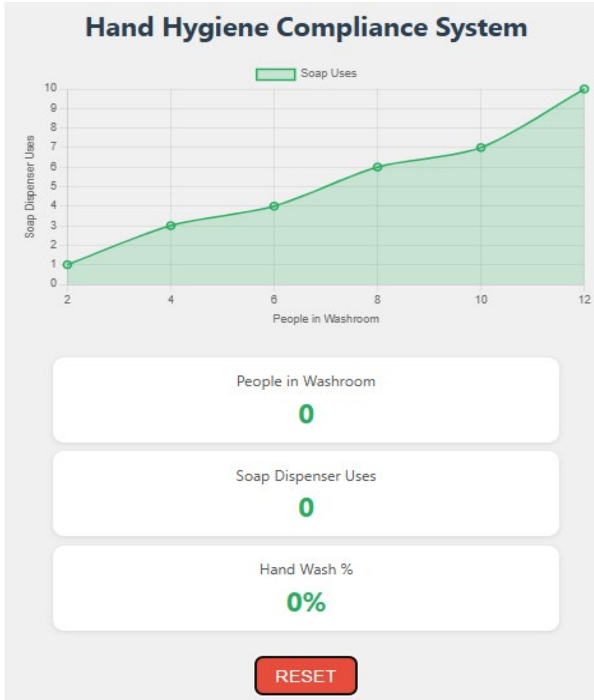

Figure 2. User Interface on a phone depicting how the prototype will display Hand-Hygiene Compliance

Test Results

Following the assessment procedure as detailed in the problem definition, the Hand Hygiene Compliance system recorded the following test results:

1. A Mean Time Between Failure of 7 minutes (Reliable)
2. An average of 0.4 seconds for sensors to update actuators (Intuitive)
3. Around 13 minutes before the Raspberry Pi Pico cannot handle any more updates (Low-Maintenance)
4. 12 minutes to fully complete the circuitry of the breadboard (Integration)
5. 30$ for all the components of the proof-of-concept (Cost)
6. An average of 898J of power consumption over a 10-minute idle time period and 10-minute active state (Energy Efficient)

Smart proximity alert system

This Smart proximity alert system enhances patient safety by providing continuous patient monitoring especially for vulnerable patients such as, elders with cognitive impairment

Motivation

In today's fast-paced hospital environments, it is not always feasible to manually monitor every patient's movement. Vulnerable patients, such as young children and elderly individuals with cognitive impairments, may unintentionally wander into restricted or hazardous areas without being noticed. According to recent data, the mortality rate due to accidental deaths among individuals aged 0–25 is 1.32 per 100,000, classified as Risk Level 2, which is higher than that of accidental deaths involving machinery [8].

Although such incidents are relatively rare, the potential consequences are severe, including the possibility of fatal outcomes. Implementing a smart patient proximity monitoring system can significantly reduce this risk by autonomously detecting and alerting staff when patients approach restricted zones. This system reduces reliance on constant human supervision, enhances patient safety, and can ultimately lower operational costs by minimizing the need for additional monitoring personnel.

Hospital solution

A system that tracks patient movement nearby hazardous areas and sends live data to hospital staff while alerting the patient that they are at a hazardous area.

Mechanical system

The proof-of-concept design includes

- **Red led**
  - This led turns on when its dark to improve visibility and blinks to warn patient that they are near a hazardous area
- **Magnetic reed switch (contact sensor)**
  - This magnetic reed switch simulates the movement of a door and when the magnet is disconnected with the switch, it represents an open door, suggesting that a patient has left the room and activates the infrared sensor
- **Infrared emitting diode**
  - Works with infrared receiving diode
- **Infrared receiving diode**

- When the contact sensor is disconnected suggesting that the patient has left the room, this receiver activates to detect possible patient movement. By activating only when the patient door is open, it ensures that it is a patient's movement rather than a hospital staff and improves efficiency by remaining inactive when not in use.

- **Light sensor**
    - Light sensor detects light level at the hazardous area and when the light level is below a certain threshold value, it automatically turns on the red led to improve visibility for anyone walking along the hazardous area

- **Raspberry Pi Pico microcontroller**
    - The motherboard of the system, allowing system to run as accordingly and receives inputs from the sensors and gives output to the user-Interface

Below is an image of the proof of concept

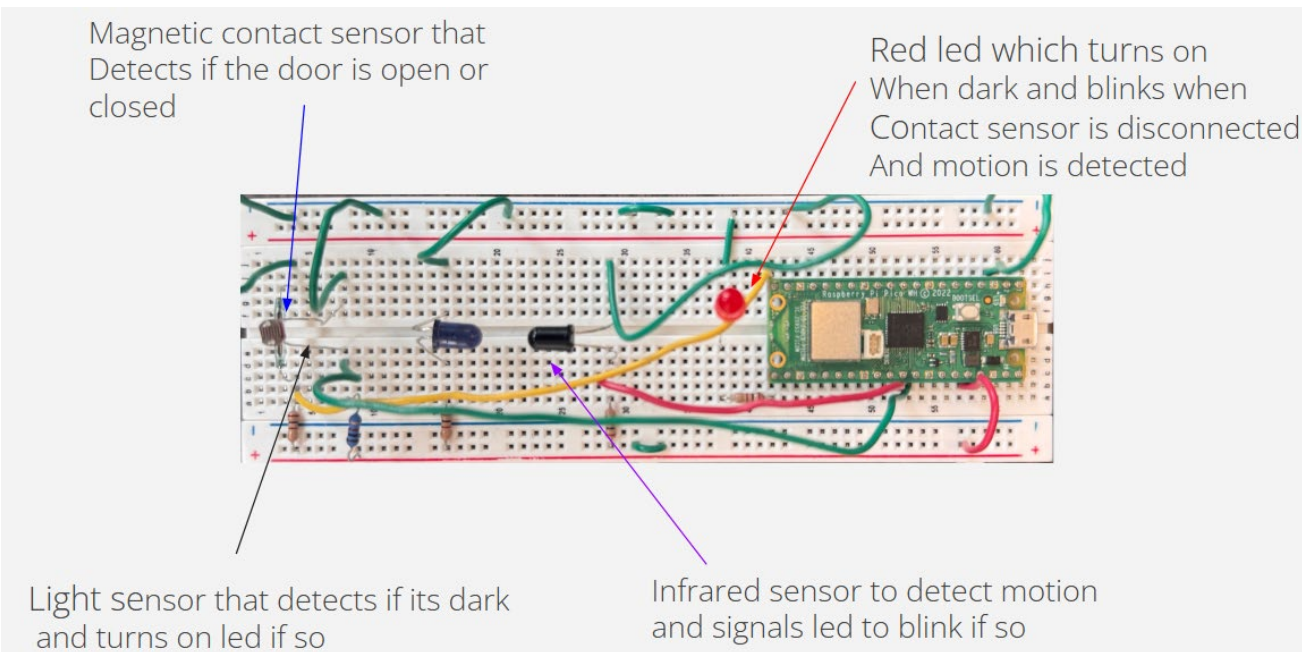

Figure 3. Design Prototype including an Infrared LED and a breadboard

User Interface

User interface has 2-way communication system that allows for users to manually deactivate the entire system as well as Control the led to switched on or off. It also updates the status of the door, shows the light level and give real time data of events.

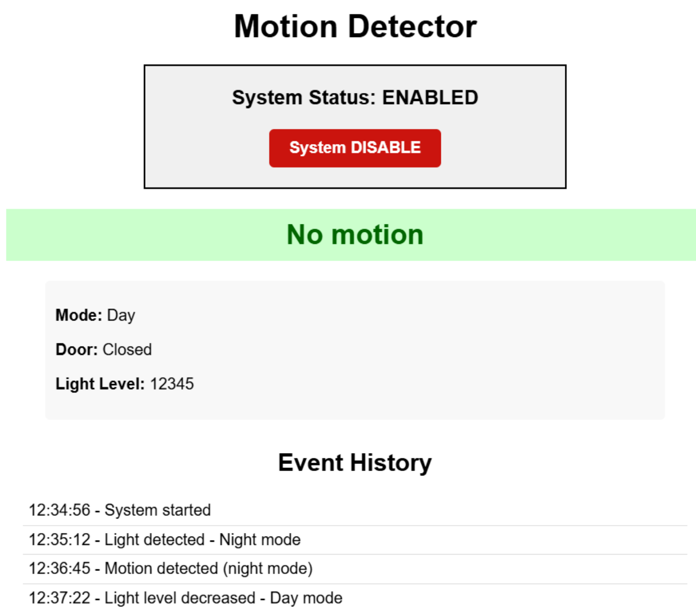

Figure 4. User Interface on a phone depicting how the prototype will display patient movement and status of system

Test Results

Following the assessment procedure as detailed in the problem definition, the Smart Proximity Alert System recorded the following test results:

1. A Mean Time Between Failure of 6 minutes (Reliable)
2. An average of 0.6 seconds for sensors to update actuators (Intuitive)
3. Around 12 minutes before the Raspberry Pi Pico cannot handle any more updates (Low-Maintenance)
4. 23 minutes to fully complete the circuitry of the breadboard (Integration)
5. 30$ for all the components of the proof-of-concept (Cost)
6. An average of 1012J of power consumption over a 10-minute idle time period and 10-minute active state (Energy Efficient)

Smart Lighting System

The Smart Lighting System addresses the issue of inefficient manual lighting systems in hospitals.

Motivation

Hospital lights tend to remain on unnecessarily, leading to wasted energy and potential discomfort for patients sensitive to bright lights. On the other hand, some patients struggle due to insufficient and poorly distributed light. For these reasons, manually controlling the lights can be a hassle and a distraction for nurses and staff, and continuous monitoring isn't always feasible [5].

Another major lighting issue within the hospital environment is the night lighting system. This issue affects almost everyone, from the patients, nurses, security staff and site managers to doctors working on call [7]. Even if a member of staff warned the patients about the lights that needs to remain on overnight, several patients still reported that they were confused and uncomfortable.

Hospital Solution

This design aims to address these problems and improve overall patient satisfaction. Two different sensors have been used to assemble this design as well as a mode switch function.

Mechanical system

This design will consist of a smart system controlled by Raspberry Pi Pico along with two different sensors (see figure 4). The first sensor used in this design is an ambient sensor that detects the light level of the room which will be displayed on the user interface (see figure 5). When the light levels are below the threshold which the patients will input according to their needs and preferences, the LED light will automatically turn on. Another sensor that this system employs is the temperature sensor, measuring the temperature of the room accurately. Although the only role for this sensor in this design is to measure and display the temperature of the room on the user interface (see figure 5), it can be further developed into a smart alerting system where the staff will be notified if the measured temperature of the room is deviant.

In addition, this design includes a function where the user can switch between auto-mode and manual-mode from the user interface (see figure 5). In auto-mode, the design will function automatically as described. However, in auto-mode, the LED light can be turned on/off manually by the user. This function will come in handy in cases where the room will remain empty for a long period of time or when the patient is asleep.

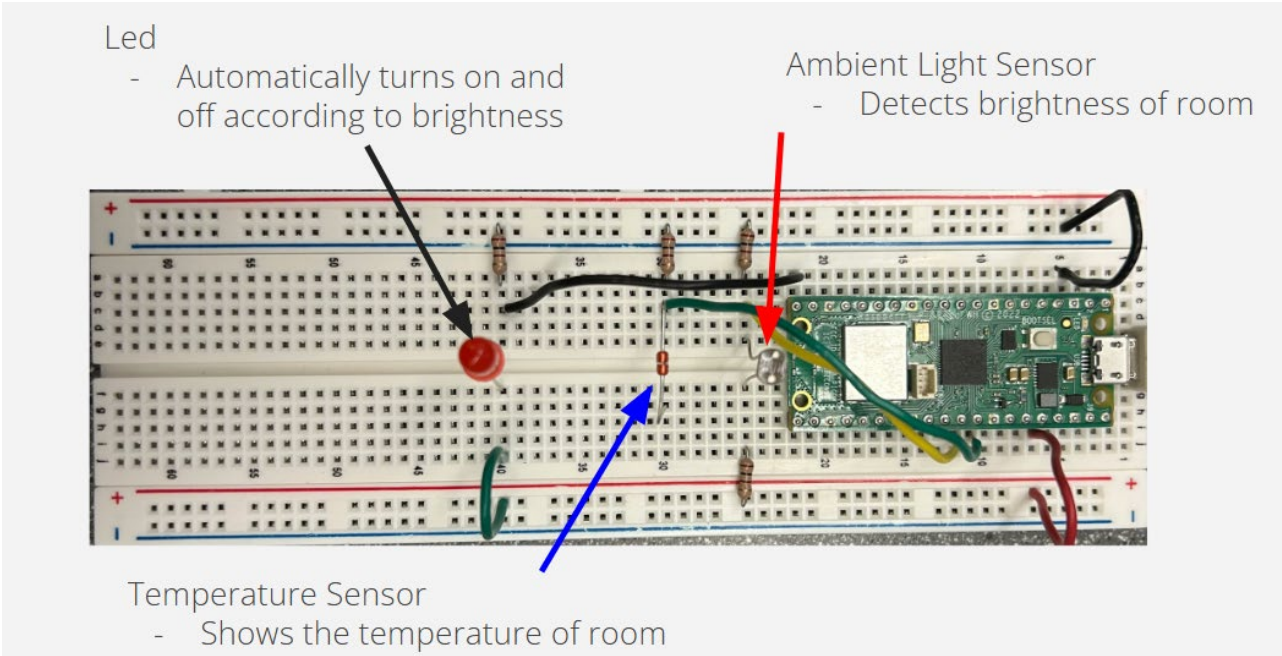

Figure 5. Design Prototype including an Ambient Light Sensor Circuit and an Infrared LED and Raspberry Pi Pico

User Interface

- Lighting Level – displays the light level (brightness) of the room
- Temperature – displays the temperature of the room
- Manual Light Control – Led On/Off button in manual mode
- Mode Control – Switch between manual mode and auto mode

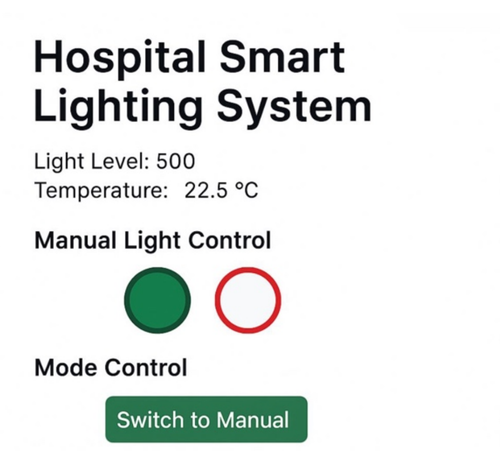

Figure 6. Image of the User Interface of Design Concept #3

Test Results

Following the assessment procedure as detailed in the problem definition, the Smart Lighting System recorded the following test results:

1. A Mean Time Between Failure of 4 minutes (Reliable)
2. An average of 0.7 seconds for sensors to update actuators (Intuitive)
3. Around 12 minutes before the Raspberry Pi Pico cannot handle any more updates (Low-Maintenance)
4. 43 minutes to fully complete the circuitry of the breadboard (Integration)
5. 30$ for all the components of the proof-of-concept (Cost)
6. An average of 977J of power consumption over a 10-minute idle time period and 10-minute active state (Energy Efficient)

Comparative Analysis

In order to evaluate these designs according to the objectives they were meant to meet as detailed in the problem definition, it is important to provide a scale of which objectives are most important for each design. Hence, a weighted was created prioritizing objectives relating to functionality and usability as the most important. This is because although being low-cost and energy-efficient are important, ultimately if the system does not work and is unusable, every objective will fail as a result.

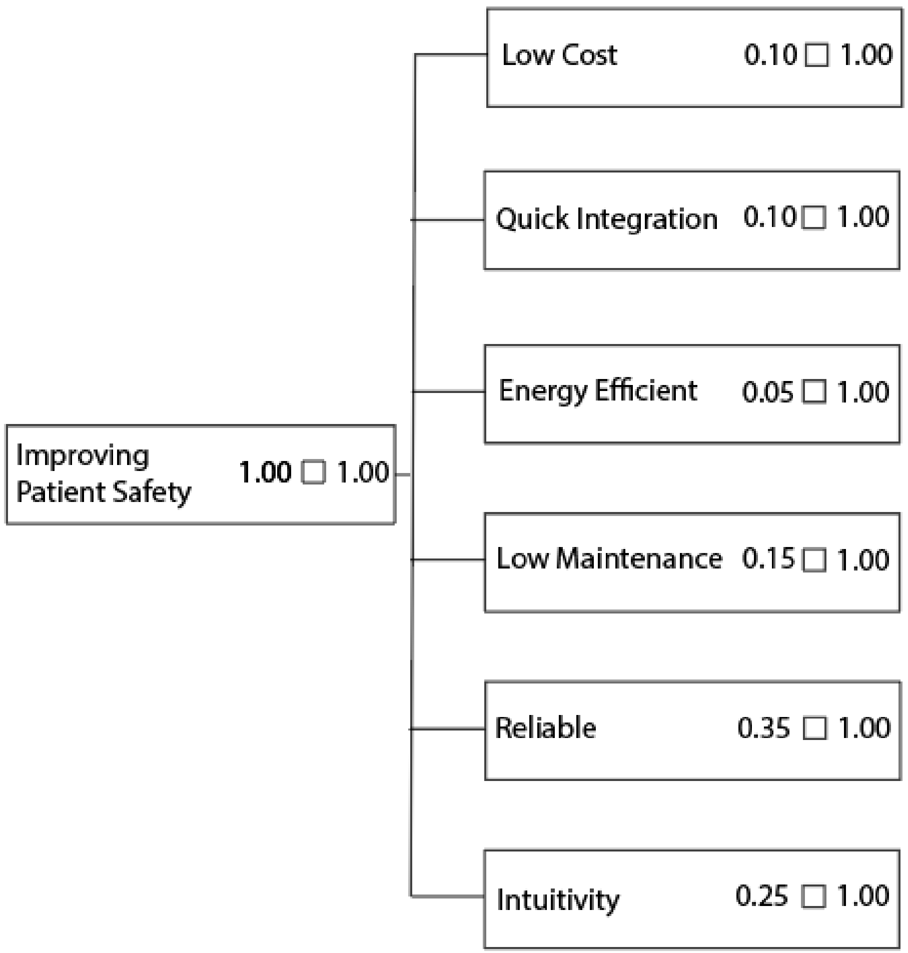

Figure 7: Weighted Criteria Tree

Each objective from this weighted criteria tree was then quantified in metrics charts as shown in Appendix C to provide a scale for each objective. These metrics would ultimately be tested in the laboratory following the assessment procedure outlined in the problem definition. Results of these tests are shown in each design's description Each scale on the metric would then be multiplied by how important the objective is based on the weighted criteria tree and once each prototype is tested for each objective, a final score can be produced. This is shown in the following numerical evaluation matrix.

Criteria	Weight	Hand-Hygiene Compliance System		Smart proximity alert system		Smart Lighting System	
		Value	Score	Value	Score	Value	Score
Reliable	0.35	2	0.70	2	0.70	1	0.35
Intuitive	0.25	5	1.25	4	1	4	1
Low Maintenance	0.15	3	0.45	3	0.45	3	0.45
Integration	0.10	4	0.40	3	0.30	2	0.20
Cost	0.10	4	0.40	4	0.40	4	0.40
Energy Efficient	0.05	3	0.15	3	0.15	3	0.15
Total Score		3.35		3		2.55	

Table 2: Numerical Evaluation Matrix

Based on this numerical evaluation matrix, the highest attaining score is the Hand-Hygiene Compliance System, with a total score of 3.35. This suggests that, when weighted according to the most critical objectives—such as reliability and intuitiveness—it performs the most effectively out of the three designs.

The Smart Proximity Alert System follows with a score of 3.00, showing strong functionality, particularly in reliability and cost, but falling slightly behind in intuitiveness and ease of integration. Lastly, the Smart Lighting System, while still meeting core objectives and performing well in cost and intuitiveness, achieved the lowest overall score of 2.55 due to lower reliability and more complex integration.

These results support the final recommendation that the Hand-Hygiene Compliance System not only addresses a critical healthcare issue but also does so with the highest overall performance across functional, usability, and efficiency-related objectives. It is the most suitable design for real-world implementation in hospital settings based on the data-driven analysis conducted.

Conclusion

This report conducted a comparative evaluation of three healthcare technology prototypes—Hand-Hygiene Compliance System, Smart Proximity Alert System, and Smart Lighting System—through both secondary research and primary testing. Each design was assessed against key objectives including reliability, intuitiveness, low maintenance, ease of integration, cost, and energy efficiency.

Primary testing showed that the Hand-Hygiene Compliance System had the best performance overall, with the highest reliability (MTBF of 7 minutes), fastest response time (0.4 seconds), easiest integration (12 minutes), and lowest energy consumption (898J). Secondary research reinforced its relevance, addressing poor compliance rates in hospitals—a major contributor to hospital-acquired infections.

The Smart Proximity Alert System followed closely, offering strong safety benefits for vulnerable patients and showing solid performance in reliability (6-minute MTBF) and responsiveness (0.6 seconds). However, it consumed more power and took longer to assemble. The Smart Lighting System, while tackling energy waste and patient comfort, showed the lowest reliability (4-minute MTBF) and was the most complex to integrate (43 minutes). Objectively, each design demonstrated clear strengths:

- **Hand-Hygiene Compliance System:** Highly functional, intuitive, and efficient; minimal weaknesses.
- **Smart Proximity Alert System:** Strong safety application and moderate complexity; slightly less efficient.
- **Smart Lighting System:** Addresses real needs but limited by lower reliability and higher integration time.

In terms of scalability, the Hand-Hygiene System is best suited for immediate implementation due to its simplicity, robustness, and critical healthcare impact. The Proximity Alert System is scalable with moderate adaptation. The Smart Lighting System, while valuable, may require further refinement before widespread deployment. Hence, the Hand-Hygiene Compliance System most effectively meets the defined objectives and constraints. Its performance across both technical and real-world criteria positions it as the optimal solution for improving healthcare environments through reliable, user-friendly, and sustainable innovation.

Recommendation

Proposed design

Based on the comparative analysis of all three prototypes, the Hand-Hygiene Compliance System has been selected as the proposed design. This decision is supported by its superior performance across the most critical objectives: reliability, responsiveness, energy efficiency, and ease of integration. The system's versatility, scalability, and simplicity make it well-suited for real-world healthcare settings, where effective infection control is a top priority. These strengths were confirmed through both empirical testing and alignment with healthcare industry needs identified in secondary research.

Further Improvements

While the current prototype successfully demonstrates the system's core functionality, several enhancements can be made to transition it from a proof-of-concept to a fully deployable solution:

- **Data Analytics Integration:** Adding a cloud-based platform and machine to automate and analyze compliance trends and generate reports for hospital administration.

- **Scalable Deployment:** Developing modular sensor units instead of infrared and ambient for better efficiency during deployment across multiple hand hygiene stations.

- **User Identification:** Incorporating RFID or facial recognition to differentiate compliance between staff and hospital patients

- **Enclosure:** Designing a professional-grade enclosure to protect hardware in hospital environments.

Benefits

Implementing the Hand-Hygiene Compliance System offers several key benefits:

- **Reduced Infection Rates:** By increasing compliance with hand hygiene protocols, the system helps lower hospital-acquired infections (HAIs).

- **Improved Patient Outcomes:** Fewer infections mean shorter hospital stays, reduced complications, and better recovery for patients.

- **Operational Efficiency:** Automation minimizes the need for manual monitoring, saving staff time and effort.

- **Cost Savings:** Preventing infections can significantly reduce healthcare costs associated with extended care and treatments.
- **Scalability:** The system's low-cost design and versatility in different environments allows for widespread implementation across various healthcare facilities.
- **Data-Driven Decisions:** With improvements, data tracking using the graph on the user interface will support evidence-based decisions to improve hygiene compliance strategies.

References

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[7] U. Jemima, “Night Lighting in Hospitals – and its Impact on Staff and Patients”, *Lighting in Hospitals*, June 2011.

[8] B.C. Injury Research and Prevention Unit., & Rajabali, F, “Unintentional Injuries in British Columbia: Trends and Patterns Among Children and Youth.” *BC Injury Research and Prevention Unit*, 2005.

Appendices

Appendix A: Work Logs

Work Log				
Deadline	**Task Description**	**Assigned to:**	**Status**	**Total Time Spent**
Feb 28	Design Proposal	Gregory/Jamyang	Completed	10 hours
Mar 8	Completion of Research to prove effectiveness of prototypes	Gregory	Completed	3 hours
Mar 8	Completion of Research in optimizing proof-of-design prototypes	Jamyang, Henry	Completed	2 hours
Mar 14	Completion of project template	Gregory, Jamyang, Henry	Completed	8 hours
Mar 15	Test Design for effectiveness	Gregory, Jamyang, Henry	Completed	4 hours
Mar 15	Complete proof-of-design prototypes	Gregory, Jamyang, Henry	Completed	10 hours
Mar 17	Complete refined prototypes	Gregory, Jamyang, Henry	Completed	2 hours
Mar 20	Creation of progress report	Jamyang	Completed	4 hours
Mar 23	Team presentation PowerPoint	Henry, Gregory	Completed	2 hour
Mar 28	Team presentation practice	Gregory, Jamyang, Henry	Completed	1 hour
Mar 30	Team presentation	Gregory, Jamyang, Henry	Completed	3 hours
April 4	Final Report	Gregory, Jamyang, Henry	Completed	15 hour
April 7	Submit Final Report to the client	Gregory	Completed	1 hours

Table 3. Work Logs

Appendix B: Gantt Chart

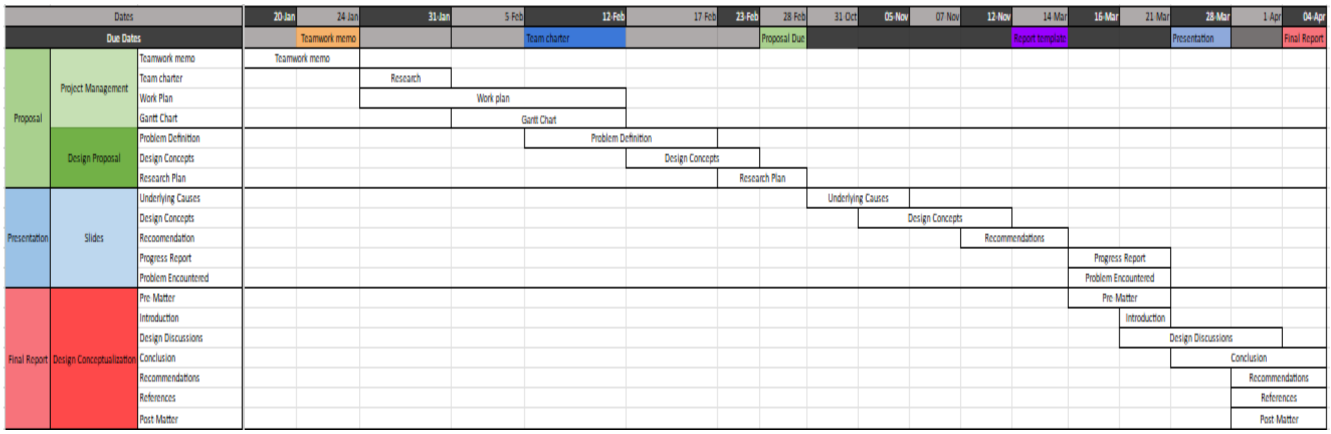

Figure 8: Gantt Chart

Appendix C: Objective Metrics

Reliable (MTBF)

Scale	Quality Description	Range
1	Very Unreliable	<5 min
2	Unreliable	5-15 min
3	Average	15-25 min
4	Reliable	25-30 min
5	Very Reliable	>30 min

Intuitive (sec)

Scale	Quality Description	Range
1	Very unintuitive	3-5 sec
2	Unintuitive	2-3 sec

3	Average	1-2 sec
4	Intuitive	0.5-1 sec
5	Very intuitive	0-0.5 sec

Low Maint. (Min)

Scale	Quality Description	Range
1	Very High Maintenance	>30
2	High Maintenance	15-30
3	Average	5-15
4	Low Maintenance	1-5
5	Very Low Maintenance	<1

Integration (Mins)

Scale	Quality Description	Range
1	Very Slow	>60 min
2	Slow	40-60 min
3	Average	20-40 min
4	Quick	10-20min
5	Very Quick	<10 min

Cost ($)

Scale	Quality Description	Range
1	Very Expensive	>80$
2	Expensive	60-80$
3	Average	40-60$
4	Cheap	30-40$
5	Very Cheap	<30$

Energy Efficient (J)

Scale	Quality Description	Range
1	Very Inefficient	>1440J
2	Inefficient	1080-1440J
3	Average	720-1080J
4	Efficient	360-720J
5	Very Efficient	<360J

Table 4: Objective Metrics