CS6755 Final Project: Robotic Medical Crash Cart

Nhan Tran, Wendy Huang, Frank Kim, Daniel Zhou
{nt322,yh374,ck766,lz489}@cornell.edu

Figure 1: A. Our robotic medical crash cart with the human detection visualization displayed on an integrated screen. B. Our interaction prototype in which the robot tracks and follows a human target. C. A human user stands in front of the robot's camera to initiate the "follow me" interaction.

1 Introduction

Our final project aims to transform a medical crash cart into a robotic system that can interact with healthcare workers. By automating the movement of these heavy carts, we could free up healthcare workers to focus more on patient care rather than logistical tasks. This solution could help alleviate the pressing issue of staff shortages faced by healthcare facilities nationwide.

This report provides an overview of our project, detailing the development process, innovative technologies implemented, and the unique "follow me" interaction designed for this purpose (Figure. 1). Furthermore, it includes findings from a preliminary user study conducted to evaluate the effectiveness of the pilot "follow me" interaction.

Through our work, we hope to contribute to a future where hospital robots are widely accepted as valuable contributors to healthcare, taking over repetitive tasks and helping professionals focus more on what matters most - patient care.

2 User Interview on Medical Crash Cart

A medical cart is a mobile unit designed to facilitate the efficient and organized delivery of medical supplies, equipment, and medications. As can be seen in Figure. 2 which captures three types of carts we came across during our user interview, different carts are used in different hospital wards: the daily medical cart carries supplies, the emergency cart carries more restrictive supplies, and the meal cart carries food throughout the hallways. In order to understand the real problem of using those carts, we have reached out to nurses at Samsung Medical Center in South Korea and Cayuga Medical Center in Ithaca and interviewed them in order to gain inspiration for our interaction prototype. We interviewed two nurses with more than 5 and 10 years of experience in the intensive

Figure 2: Different types of carts in a hospital environment. A. The daily medical cart carries medications and equipment for daily care. B. The emergency cart is sealed every time and placed at a specific location. C. The meal cart is electrified in order to reduce the labor of carrying by hand.

care unit (ICU) and Neonatal intensive care unit (NICU) and asked three questions. First, we asked how medical workers are using those carts in normal situations and emergency situations. Then, we asked about the practical validity of our idea of adding an autonomous navigation function to those carts. Lastly, we asked what kind of functions will improve the productivity of medical workers in the hospital environment.

For the first question, both interviewees mentioned that emergency carts and daily medical carts are managed with strict human protocols in order to minimize the chance of medical accidents. Especially, emergency medical carts are sealed every time whenever they were used during emergency situations. Also, emergency carts are placed in multiple locations for minimizing the distance of carrying the cart. In NICU, they are placed nearby operating rooms (OR) or delivery rooms in order to deal with code blue (massive hemorrhage). After the cart was used, a nurse refills and aligns every piece of equipment and medication inside the cart and seals them so that they always know that the inventory is ready. For normal medical carts, those medications and equipment are managed with logistics software therefore nurses can continue the work from the previous shift.

For the second question, both interviewees were skeptical about using the autonomous navigation function for emergency medical carts but agreed with automating the normal medical carts. They are worried about the secondary accident caused by the automated cart during emergency situations. Also, both interviewees described that during the emergency situation, human resources are focused on the spot so the cart may not be able to navigate in a dense population. However, both interviewees were positive about adding the autonomous navigation function to the daily medical cart as they can alleviate the physical load and stress levels caused by carrying heavy carts.

For the third question, an interviewee raised the idea of adding a small chair to the medical cart as medical workers always need to walk and stand during their scheduled rotation.

From this interview, we found out that adding the “follow me” function to the normal medical cart can alleviate the physical labor of medical workers which can potentially reduce the medical accident rate. Therefore, we focused on implementing the “follow me” function on normal medical carts.

3 Interaction Design

3.1 Follow Me

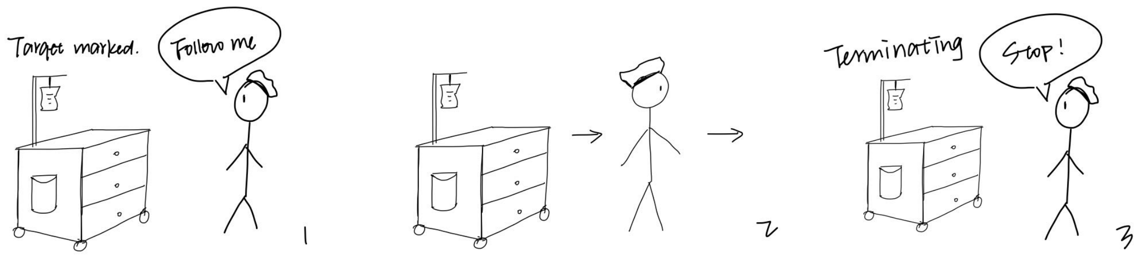


Figure 3: Our sketched storyboard during the interaction design process

In the fast-paced environment of hospitals, healthcare professionals frequently move between different locations, carrying various tools and equipment for patient care. To optimize this process, our project presents a robotic tool-cart equipped with a human following feature. We envision this robot to automatically carry the required tools and follow healthcare workers while effectively navigating and avoiding crowded areas, thus conserving effort and improving patient treatment efficiency. Figure. 3 illustrates our interaction prototype during the design phase. The concept of a "nurse-following robot" has previously been explored by integrating a Kinect sensor with Xbox 360 video games into a high-speed vision system [1]. Expanding on this groundwork, our design emphasizes user-friendly interactions and ease of operation.

To achieve efficient nurse-following capabilities, the robot will use a step-by-step interaction approach as follows:

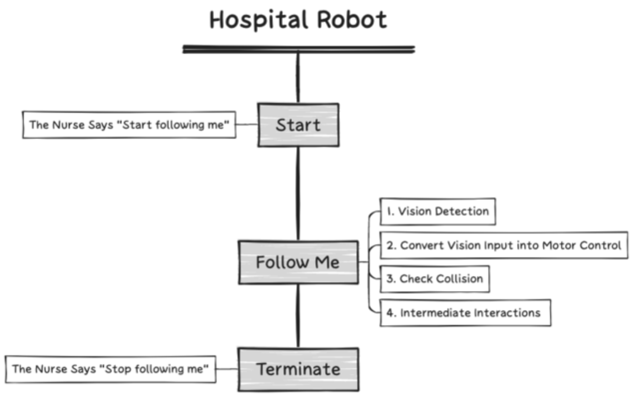


Figure 4: A general flow chart for Medical Crash Cart Robot

1. Firstly, the target person will be set by saying *"Follow me"*.
2. While moving around with the target person, the robot will automatically avoid obstacles and people, saying *"Excuse me"* or *" Oh you're right"* if necessary.
3. If the robot loses sight of the target person, it will search for them and re-follow once the person is re-identified.
4. The robot will adjust its speed to match the target's speed and the environment.
5. Lastly, the robot will unfollow the target person if requested by saying *"You can stop following me."*.

To ensure our robot could interact with healthcare workers smoothly and safely, and also could fit in real scenarios in the hospital, our robot uses a simple behavior tree illustrated in Figure. 5.

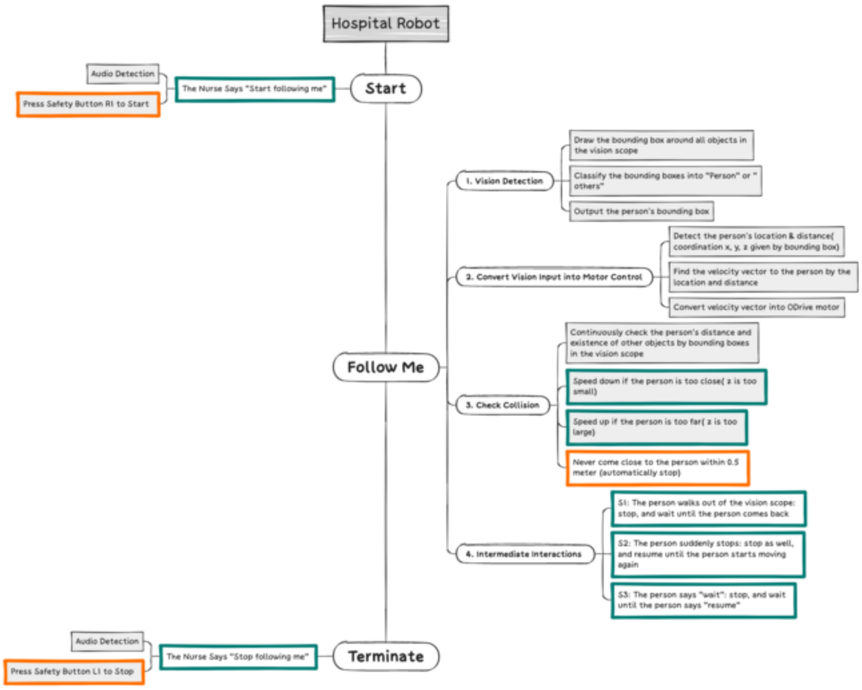


Figure 5: A detailed flow chart for Medical Crash Cart Robot. This chart includes intermediate interactions, safe button design, vision detection, and auto-functionalities. The orange box highlights the safety design of the medical crash cart robot. The interaction designs are marked green.

Here, we want to highlight how our design could facilitate the interactions. To start the human following algorithm, the healthcare workers could simply say "follow me". For safety measures, we also allow a teleoperation mode so that the users can take over the control using joysticks. Then the robot will use vision detection to auto-follow the target person and adjust the speed. At the same time, healthcare workers could pause the program by voice detection if there are some required medical operations and emergent situations as we present in Figure. 5.

Additionally, we equip the robot with a speech module in order to notify its internal state and alert the surrounding people. In the future, we also want to incorporate postures and body language detection to deal with scenarios are noise suitable for voice interactions.

4 Robot Design

4.1 Hardware

We designed our robot hardware following a bottom-to-top design approach. Initially, we transformed a hoverboard into a robust foundation that hosts the majority of our critical components, encompassing batteries, the ODrive, and a Raspberry Pi, which was later upgraded to a Jetson Xavier. Subsequently, we procured a compact medical crash cart, typically found in dental clinics, and firmly anchored it atop our mobile hoverboard base.

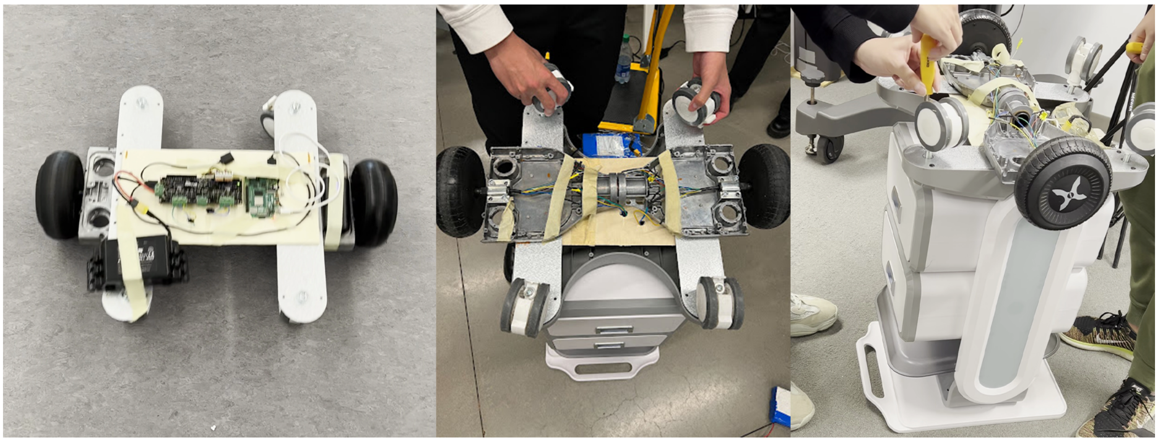


Figure 6: A. Our robot chassis is built on top of the hoverboard. B. We repurposed the four compact, pivoting wheels from the cart, attaching them to the hoverboard to serve as auxiliary wheels. C. We then used the Odrive motor controller to drive the hoverboard wheels.

4.1.1 Hoverboard

A hoverboard is a piece of equipment that the user stands on in order to travel around by hovering above the ground. We opened up the hoverboard and replaced its wiring and power supply with ours. Then, our hoverboard underwent a two-stage evolution as can be seen in Figure. 6. Initially, we utilized the rudimentary top surface that came with the hoverboard, which led to a degree of instability and tilt during motion. To improve it, we transitioned to the second stage of development.

In this phase, we retrofitted the hoverboard with the sturdy base of the medical crash cart, expanding the surface area available to support the internal components. In addition, we repurposed the four compact, pivoting wheels from the cart, attaching them to the hoverboard to serve as auxiliary wheels. This modification considerably amplified both stability and maneuverability, refining the overall performance of the hoverboard.

4.1.2 Crash Cart

Restricted by the dimensions of the provided hoverboard base, we decided to purchase a mini medical crash cart atop it (Figure. 7 Amazon link). The crash carts of such a size are often seen in dental clinics rather than emergency rooms, offering a compact yet functional alternative for our robotics prototype.

After successfully drilling and attaching the upper structure to the hoverboard base, we mounted on top of the robot a RealSense D435i depth camera (Figure. 1). This camera empowers the robot with visual awareness, facilitating object detection and recognition.

To further enrich the robot's functionality, we also integrated a Bluetooth speaker into its system. This enables our robot the ability to verbally announce when a human target is tracked.

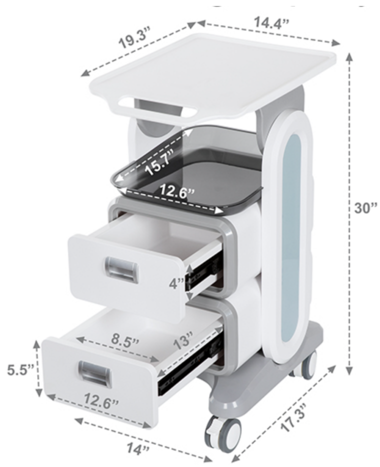


Figure 7: We redesigned the base of a portable professional cart for ultrasound and small medical clinics.

4.2 Software

Our software infrastructure comprises four interconnected components: joystick, speaker, vision, and robot control, each playing a distinct role in the functionality of the system (Figure. 8).

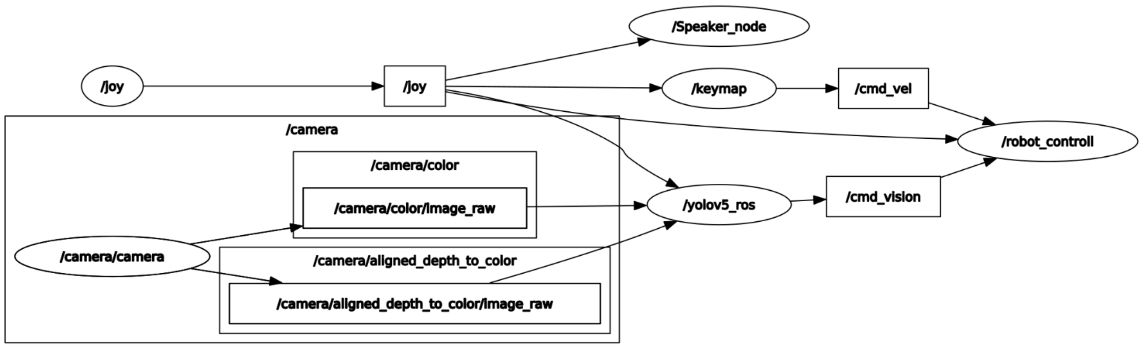


Figure 8: A diagram showing our software architecture

4.2.1 Joystick

We have enhanced the ROS node associated with the joystick, originally provided by the coursework, by incorporating a Bluetooth speaker communication function. Each button press triggers a specific command, which is then audibly delivered by the speaker, facilitating the Wizard-of-Oz style control of the robot. Additionally, we have integrated the joystick node with the robot controller and vision nodes to ensure safety. Specifically, pressing the L1 button allows the joystick to control the robot, while the R1 button enables vision-guided autonomous navigation.

4.2.2 Speaker

The speaker node processes command input from the joystick and audibly communicates it, signifying the initiation and termination of human-robot interaction. Although ideally, the speaker node should be linked with the vision node for flawless execution of the ”follow me” task, we've restricted the connection to the joystick to avoid any confusion during testing.

4.2.3 Vision

The vision component plays a pivotal role in the robot's operation. A mounted RGBD camera on the medical cart feeds the RGB image and corresponding depth image to the 'yolov5-ros' node. This node applies the YOLOv5 object detection algorithm and determines the closest individual, based on distance and the maximum size of the bounding box, as the target. Upon target identification, its bounding box is updated by comparing the centroid, depth, and bounding box size of the target from the previous frame with the present frame. Once the target is detected, the command velocity is determined based on the distance from the depth image and the size of the bounding box. For example, if the target is less than 0.7m away, the robot halts, and the speaker announces, "The target is too close, I am stopping." The difference between the center of the target bounding box and the image center, when multiplied by a tunable gain, becomes the robot's angular velocity, if the center of the target bounding box is either to the left or right of the image center. The vision component generates this command velocity from visual inputs, which the robot controller node subscribes to. By pressing the R1 button on the joystick, the robot starts receiving its command velocity from the vision component.

4.2.4 Controller

Our robot controller, although primarily based on the controller provided by the HRI course, has been modified to subscribe to the command velocity from both the joystick and vision components. It also directly interfaces with the joystick input, allowing the human controller to safely manipulate the robot by pressing the L1 button. When the R1 button is pressed, the robot shifts its command source to the vision output, enabling it to execute the ”follow me” function.

5 User Study

In order to assess the efficacy and collect preliminary feedback for our medical crash cart robot's "follow me" interaction, we conducted a small and informal user study at Cornell Tech. The study included participants from a diverse age group and followed a five-step procedure.

5.1 Procedure

1. The researchers explain the task to the participant: moving from a designated Point A to Point B.

2. At the start of the experiment, the robot operator triggers the robot to say, "Hi, I am a hospital robot. Please say 'follow me!' ", to initiate the interaction.

3. As the participant begins walking, the operator prompts the robot to say, "I am following you", so the participant is aware the robot is following them to Point B.

4. If the robot gets too close to the participant, the operator instructs the robot to say, "I am too close to you. I will slow down."

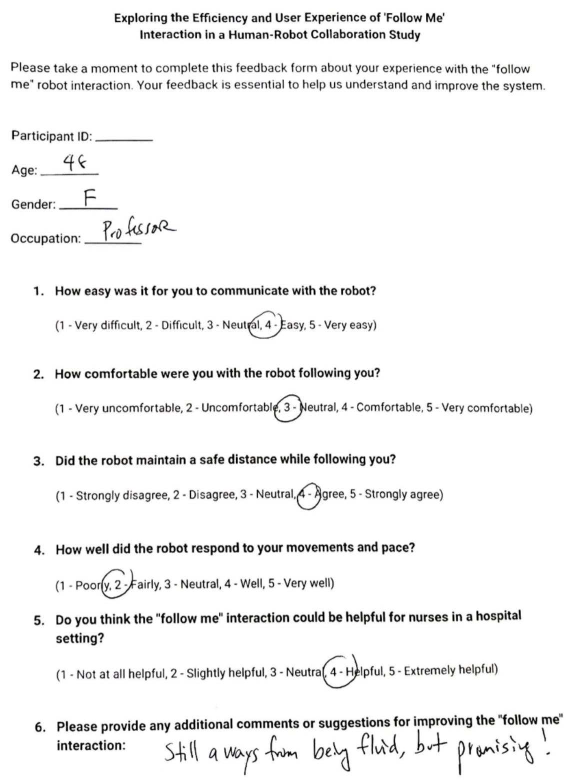
5. Upon reaching Point B, the operator triggers the robot to say, "Ok, stop following. Have a nice day!"

5.2 Questionnaire

To quantitatively measure user satisfaction, we developed a questionnaire for the participants to rate their experience.

We began by collecting basic demographic information (age, gender, occupation) to identify potential correlations between these factors and users' perceptions of our prototyped interaction.

The main part of the questionnaire consists of five questions rated on a scale from 1 to 5, where 1 indicates negative sentiment and 5 corresponds to a highly positive response. The questionnaire concludes with an open-ended question for suggestions to improve the interaction.



Exploring the Efficiency and User Experience of 'Follow Me' Interaction in a Human-Robot Collaboration Study

Please take a moment to complete this feedback form about your experience with the "follow me" robot interaction. Your feedback is essential to help us understand and improve the system.

Participant ID: ________

Age: 46

Gender: F

Occupation: Professor

1. **How easy was it for you to communicate with the robot?**

   (1 - Very difficult, 2 - Difficult, 3 - Neutral, 4 - Easy, 5 - Very easy)

2. **How comfortable were you with the robot following you?**

   (1 - Very uncomfortable, 2 - Uncomfortable, 3 - Neutral, 4 - Comfortable, 5 - Very comfortable)

3. **Did the robot maintain a safe distance while following you?**

   (1 - Strongly disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly agree)

4. **How well did the robot respond to your movements and pace?**

   (1 - Poorly, 2 - Fairly, 3 - Neutral, 4 - Well, 5 - Very well)

5. **Do you think the "follow me" interaction could be helpful for nurses in a hospital setting?**

   (1 - Not at all helpful, 2 - Slightly helpful, 3 - Neutral, 4 - Helpful, 5 - Extremely helpful)

6. **Please provide any additional comments or suggestions for improving the "follow me" interaction:** Still a ways from being fluid, but promising!

Figure 9: A completed questionnaire from a participant

5.3 Survey Questions

1. How easy was it for you to communicate with the robot?

(1- Very difficult, 2- Difficult, 3- Neutral, 4- Easy, 5- Very easy)

2. How comfortable were you with the robot following you?

    (1- Very uncomfortable, 2- Uncomfortable, 3- Neutral, 4- Comfortable, 5- Very comfortable)

3. Did the robot maintain a safe distance while following you?

    (1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly agree)

4. How well did the robot respond to your movement and pace?

    (1- Poorly, 2- Fairly, 3- Neutral, 4- Well, 5- Very well)

5. Do you think the "follow me" interaction could be helpful for nurses in a hospital setting?

    (1- Not at all helpful, 2- Slightly helpful, 3- Neutral, 4- Helpful, 5- Extremely helpful)

6. Please provide any additional comments or suggestions for improving the "follow me" interaction:

The goal of our survey was to understand the usability and acceptability of the "follow me" feature of our robot in a hospital setting.

6 Results and Discussion

Given the limited sample size, the collected data may not comprehensively represent the authentic responses of our target user base in hospitals, which includes both nurses and patients. Despite this, the feedback from the questionnaire was predominantly positive and encouraging.

1. **Communication with the Robot:** The participants gave a neutral score of 3, suggesting there is a need to enrich the robot's dialogue repertoire to facilitate smoother interaction.

2. **Comfort Level with "follow me" Interaction:** This feature received a favorable score of 4, indicating a broad acceptance among participants.

3. **Safety Distance Maintenance:** The robot's safety protocols received a reassuring score of 4, demonstrating that our current safety measures are largely endorsed by users.

4. **Responsiveness of the Robot:** The robot's responsiveness to participant instructions received a high score of 4, indicating a general satisfaction with its performance.

5. **Impact of "follow me" in a Hospital Context:** When assessing the potential impact of the "follow me" feature in a hospital setting, participants gave a high score of 4.5. This suggests that this feature may be useful in hospital setting.

These results, although promising, are preliminary. Further testing with a larger sample size will provide a more representative assessment of the robot's performance and user satisfaction. Based on the feedback received, our next step is to enhance certain areas of the robot's functionality, particularly improving its communication abilities.

Here is a video of a sample interaction: **Video Link**

7 Conclusion and Future Work

By transforming a traditional medical crash cart into an intelligent robotic system, we have showcased the possibility of the "follow me" interaction mode that may streamline some of the routine yet crucial tasks that healthcare workers perform. The insights gained from our user study provide a preliminary foundation for future improvements and refinements to this robotic system.

Moving forward, there are several enhancements and modifications that can be made to this system to make it more efficient and user-friendly.

- **Improve the PID Controller:** To enhance navigation and tracking performance, we aim to refine the PID controller. This will enable the robot to follow the users more accurately and responsively.
- **Optimize the YOLO model:** The current full YOLO model requires considerable time to start up. We aim to experiment with smaller, more streamlined models that can maintain a balance between performance and efficiency.
- **Enhance Interaction Modalities:** We are considering adding more interaction modalities for initiating and terminating the "Follow Me" feature. For instance, recognizing specific postures or body languages could be an intuitive and hands-free way for healthcare workers to control the robot.
- **Address Safety Concerns:** Although our robot already maintains a safe following distance, we aim to further explore safety protocols for our feature termination. It is crucial that the robot can quickly and safely cease movement when necessary.
- **Enrich Robot Expressions:** We plan to enrich the robot's dialogue repertoire and non-verbal cues to facilitate smoother and more interactive communication with the users, making the robot feel more approachable and less machine-like.

References

[1] B Ilias **andothers**. "A nurse following robot with high speed kinect sensor". **in***ARPN Journal of Engineering and Applied Sciences*: 9.12 (2014), **pages** 2454–2459.