# Design of Communication Methods for Buoyancy Assisted Lightweight Legged Unit

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***Abstract*— Assistive robots with substantial weight may raise safety concerns, particularly in environments such as children's hospitals and nursing homes. The Buoyancy Assisted Lightweight Legged Unit (BALLU) addresses these concerns by utilizing helium balloons and lightweight materials to enhance safety. To improve BALLU's interaction with people, this study aims to develop effective communication methods for BALLU, specifically for indoor navigation in noisy environments. We equipped BALLU with an LED Matrix panel for visual communication, avoiding verbal methods due to potential noise interference. For the pilot user studies, we compared passive communication (LED display only) and active communication (LED display with leg movements). Results indicated a preference for active communication, despite some inconsistencies due to BALLU's sensitivity to airflow, highlighting a limitation of lightweight robots.**

## I. Introduction

Assistive robots are typically designed with considerable weight (e.g. Servi [1] and Scrubber 50 [2]), posing safety risks in environments such as children's hospitals and nursing homes. The Buoyancy Assisted Lightweight Legged Unit (BALLU) [3] is a new robotic design that leverages helium balloons and lightweight materials to enhance safety. To enabling its ability to interact with people, we design effective communication systems for BALLU.

Assistive robotic systems utilize various communication methods to interact with people, including visual, audio, motion-based, and gestures. The choice of communication method often depends on the specific application and user needs. For children with autism spectrum disorder, visual communication through pictograms is often preferred over purely verbal interfaces [4]. For elderly users, communication interfaces should be designed with simplicity in mind, considering potential cognitive and physical limitations [5], [6].

For BALLU's communication system, we seek to have a lightweight [7] and concise information presentation design. Note that to ensure reliability in noisy public settings, verbal communication is not considered in this work. LED displays have shown to be effective for robots conveying emotions through different colors, grabbing attention, and providing simple directional information [8], [9]. We use a flexible 8x32 LED Matrix panel weighing 140g as our communication medium.

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## II. Interaction Design

The main objective of BALLU's design in this work is to provide navigation instructions indoors. We first introduce the hardware of BALLU, then illustrate the interactions.

### A. BALLU

BALLU is physically structured as a bipedal robot (Figure 1. It consists of balloons, a pelvis, and two legs, each equipped with knee joints and feet. The balloons serve as the body of the robot, while the pelvis connects the body and legs and houses the Raspberry Pi Zero, which acts as the onboard controller. All joints on the robot are designed with bearings to enable free swinging without actuation, and the knee joints are specially designed to simulate human knees. To attach the LED matrix, we increased the amount of balloons placed the LED on the top center balloon for balance.

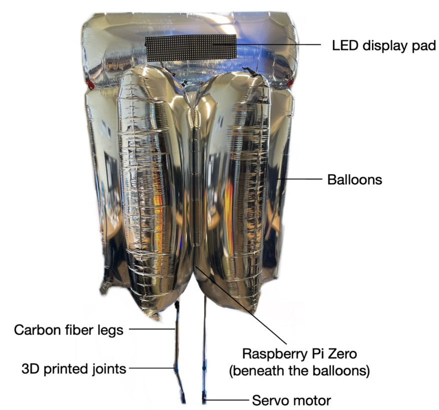


Fig. 1. BALLU with LED display pad attached.

### B. The interactions

BALLU's height and mass enables it to easily attract attention for any displayed instructions. We display instructions including "Exit," "Slow," "Stop," "Wait," "Stand," and directional arrows for people to follow. To further enhance message conveyance, BALLU also moves its legs and represents movements that complement the displayed instructions.

## III. Pilot user study

### A. Method

Pilot user studies were carried out in order to design BALLU communication methods. The studies were designed to (1) test how well the participants could understand the given instructions, (2) collect feedback on the designed communication method, and (3) solicit ideas on how to improve BALLU's communication. We compared two communication method for delivering the 6 instructions mentioned in Section II-B. One is where BALLU only conveys instruction through the LED display, we shorten it as the *passive communication* method. The other is instruction delivery with LED display and leg movements, which we will refer to as the *active communication* method. We further studied the influence of the leg movements by performing a contradictory study, where we displayed directional arrows with opposite leg movements.

### B. Procedure

The study spanned across 6 sessions, each with groups of 2 to 7 participants. At the beginning, the researcher played an introduction video on BALLU followed by a short presentation of BALLU's design. Participants were then asked to fill out a pre-demo questionnaire of their current understanding and perception of BALLU. Once all participants completed the questionnaire, we carried out the three different demonstrations: passive communication, active communication and contradictory leg movements. Participants were asked to complete questionnaires immediately after each demonstration. Finally, a post-demo questionnaire, which is identical to the pre-demo questionnaire, was given. We furthermore asked them to write down their thoughts on possible uses. The study was then concluded with an open question and answering session for them to learn more about BALLU.

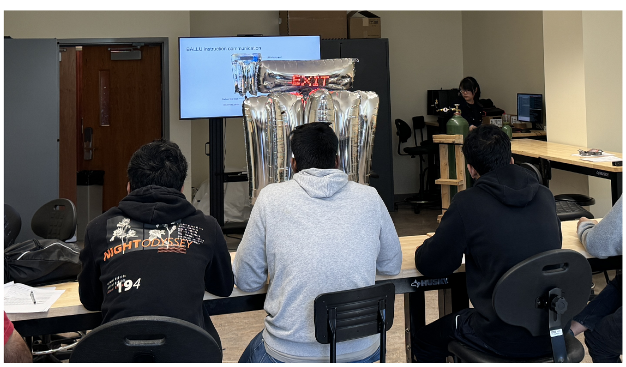

Fig. 2. Pilot user study. The monitor in the room plays the introduction video. BALLU is placed in the center of the room for all demonstrations, with the researcher beside it to execute the demonstrations. Participants sit in front of BALLU and write down their thoughts on the provided questionnaire.

### C. Measurements

For understanding participant's perception of BALLU, we designed a 5-Likert Scale questionnaire [10] with questions referenced from the System Usability Scale [11] and robot acceptance scale [12], which is our pre-demo and post-demo questionnaire. We separately designed questions for each demonstration. Aimed to evaluate participant's understanding of the instructions, we asked them to rank their own level of understanding for both passive and active communication. We then compared communication method effectiveness based on the change in level of understanding.

### D. Results

**Perception of BALLU.** Figure 3 presents participants' ratings on four main aspects of BALLU: feeling safe around BALLU, its friendliness, its capability of performing tasks, and its clarity in communicating instructions. Each aspect is rated on a scale from 1 to 5, where 1 indicates strong disagreement and 5 indicates strong agreement. Most participants (35% each) rated feeling safe around BALLU at 4 and 5, indicating a high level of agreement that BALLU makes them feel safe. Similarly, 60% rated BALLU's friendliness at 5 and 25% at 4, suggesting a positive perception of its friendliness, which is crucial for user acceptance and interaction. However, the perception of BALLU's task performance was mixed, with 40% rating it at 4 and 30% at 2, indicating both acknowledgment and skepticism. The communication of instructions showed the least agreement, with 42.9% rating it at 2, 28.6% at 3, and 23.8% at 4.

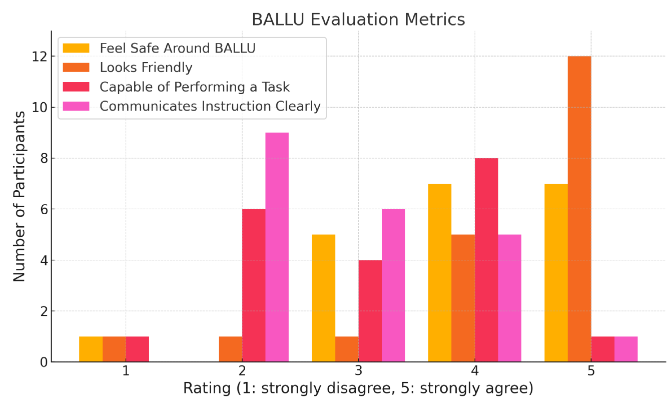


Fig. 3. Human's perception of BALLU as an assistive robot.

**Passive versus active communication.**

Figure 4 presents participants' ratings on two key aspects of analyzing whether to include leg movements in instructions (i.e., active communication): their preference for active communication and the perceived improvement in instruction clarity due to leg movements.

For the preference for active communication, the ratings shows a preference for instructions incorporating leg movements, with the highest concentration at rating 4 (35%). Remaining ratings were spread across other categories, indicating that a proportion remains undecided or slightly disagree. Regarding the improvement of instruction clarity with leg movements, results indicate a general agreement that leg movements improve instruction clarity, with 70% of the participants showing moderate to strong agreement (ratings of 3, 4, and 5). However, 15% rated it at 1, indicating some level of disagreement.

**Contradictory study.** When BALLU displayed a right arrow and turned left:

- 15 participants chose to follow the arrow direction.

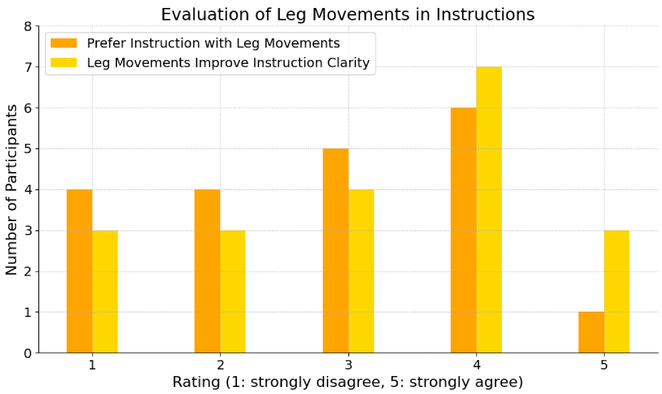


Fig. 4. Active communication preferred over passive communication.

- 2 participants chose to follow the leg movement.
- 3 participants chose to stay in place.

This preliminary study hints on the LED display being the primary medium for communication.

The data collected from the pre- and post-questionnaires reveal changes in participants' perceptions of BALLU. Most characteristics of BALLU does not show statistically significant changes, as their p-values are all above .05. The only significant change is observed in the consistency of BALLU's performance, which decreased from a mean of 3.45 (SD = 1.19) to 2.70 (SD = 0.98), $t(19) = 2.88$, $p = .009$. This finding aligns with our post-discussion, where many participants expressed surprise at how easily BALLU is affected by airflow.

### *E. Qualitative Responses*

Participants highlighted both surprising elements and potential improvements for BALLU. Many noted its large size, slow movements, and unexpected buoyancy and hopping abilities. Some found the direction of the arrow indicators confusing, while others appreciated BALLU's friendly appearance and effective lighting system.

In terms of practical applications, participants envisioned BALLU being useful in emergency and disaster scenarios where its lightweight and portable design could effectively guide individuals through hazardous terrains or assist during evacuations. Additionally, the potential for deployment in educational and public spaces was discussed, including schools, kindergartens, and hospitals, though concerns about its ability to handle wind were noted.

Participants suggested several improvements to enhance BALLU's functionality and user interaction. These included installing arms to aid in gesture communication, enlarging the LED display for better visibility, and increasing the robot's overall speed. Concerns regarding the stability of the gas inside BALLU, potential deflation, and the robustness of the balloon were raised, with recommendations to integrate a sound alarm system to signal changes.

## IV. Discussion and Conclusion

BALLU is a lightweight robot designed to be safe for operation around children and the elderly. However, its lightweight nature limits the amount of additional hardware that can be installed for communication purposes. In this work, we studied how instructions are perceived when conveyed by BALLU via LED displays and leg movements. User studies with 20 participants indicated that while a simple LED display is sufficient, complementary leg movements are preferred. However, some participants noted that a few leg movements did not match the LED display instructions due to BALLU's sensitivity to airflow.

To enhance BALLU's effectiveness in assisting people, future efforts should focus on improving the stability of its leg motions and ensuring that each movement clearly matches the instructions. Additionally, developing more intuitive ways for BALLU to communicate instructions, potentially through multimodal methods, would be beneficial.

## V. Acknowledgement

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