Underwater Robot-To-Human Communication Via Motion: Implementation and Full-Loop Human Interface Evaluation

Michael Fulton[1], Muntaqim Mehtaz[2], Owen Queeglay[3], Junaed Sattar[4]
{ [1]fulto081, [2]mehta216 , [4]junaed}@umn.edu, [3]omqueeg@stanford.edu
irvlab.cs.umn.edu
computer science & engineering
Minnesota Robotics Institute
University of Minnesota

Robotics Science and Systems

How Well Does RCVM Work In The Real World?

Robot communication via motion (RCVM) is a method for AUV-to-human communication previously proposed using simulated AUVs. The original proposal[1] demonstrated better communication performance than an LED communication baseline in simulated environments. In this work, we examine RCVM's efficacy in the real world, focusing on comparing performance with alternative systems and quantifying the effect of interaction distance and orientation.

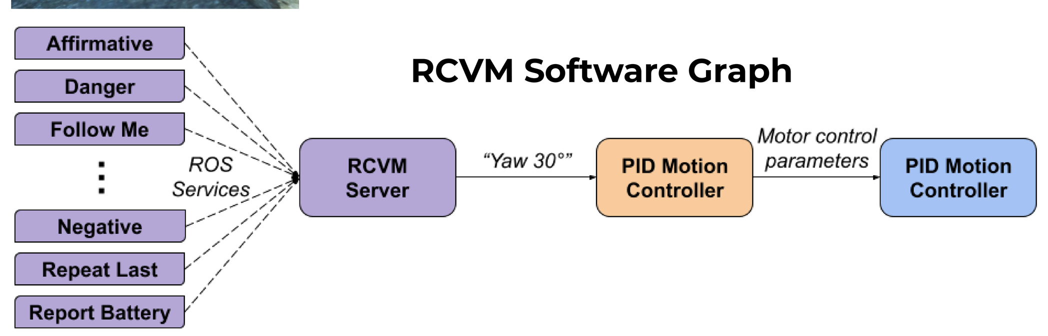
We make three main contributions in this work:

- ♦ Implementation and improvement on the original RCVM prototype.
- ♦ A small pilot study on RCVM in a full-loop interaction context, performed in person.
- ♦ A larger, multi-dimensional study performed online, which examines RCVM in comparison to three other communication systems and explores the effect of interaction viewpoint and content on RCVM.

Streamlined, ROS-Based, RCVM

- ♦ Previous work on RCVM in simulation showed that motion-based communication for AUVs was a feasible method of robot-to-human communication, at least in simulation. The next step is implementing RCVM for a physical AUV, to allow real-world testing.
- ♦ We achieved this by creating a set of ROS services which correspond to kinemes and a server providing said services by interacting with preexisting AUV control architecture. Because of this structure, implementations on multiple robots have the same interface, allowing re-use of code which utilizes RCVM kinemes for communication.

RCVM Software Graph



CODE AVAILABLE

#	Interaction Phrase	Meaning	ICRA19 Status	Pilot Status	MDS Study Status	Phrase Type
0	*Affirmative*	Yes	*Animated*	*Implemented*	*Implemented*	Conversational
1	*Negative*	No	*Animated*	*Implemented*	*Implemented*	Conversational
2	*Possible*	Maybe	*Animated*	**Eliminated**	**Eliminated**	Conversational
3	*Ascend*	Move up	*Animated*	**Replaced with #5**	**Replaced with #5**	Spatial
4	*Descend*	Move down	*Animated*	**Replaced with #5**	**Replaced with #5**	Spatial
5	*Directional*	Move in [direction]	**Not created**	*Implemented*	*Implemented*	Spatial
6	*Stay*	Remain where you are	*Animated*	*Implemented*	*Implemented*	Spatial
7	*Attention*	Look at me	*Animated*	**Unused**	*Implemented*	Conversational
8	*Danger*	Danger nearby	*Animated*	*Implemented*	*Implemented*	Complex
9	*Follow Me*	Follow me	*Animated*	*Implemented*	*Implemented*	Complex
10	*Malfunction*	Something is wrong	*Animated*	**Unused**	*Implemented*	Complex
11	*Repeat Previous*	Repeat last instruction	*Animated*	*Implemented*	*Implemented*	Conversational
12	*Object Indication*	Object here...[direction]	*Animated*	*Implemented*	*Implemented*	Spatial
13	*Battery Indicator*	Battery level is...[battery]	*Animated*	*Implemented*	*Implemented*	Complex
14	*Lost*	The robot is lost	*Animated*	**Unused**	*Implemented*	Complex

Table 1. Changes in interaction phrases, as described in Section 3. Bold texts indicate a modification.

In addition to implementing RCVM for physical AUVs, we improved the original phrasebook by eliminating phrases with no practical use, combining phrases with similar meanings into a simpler, combined phrase, and fine tuning the definitions of kinemes overall. More details on this task are available in the paper as well as in [2].

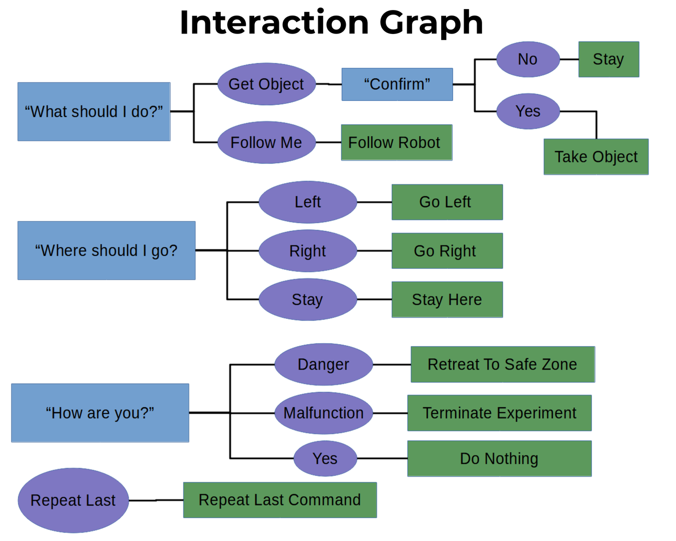
RCVM Achieves Acceptable Performance In Initial Testing

Study Procedures

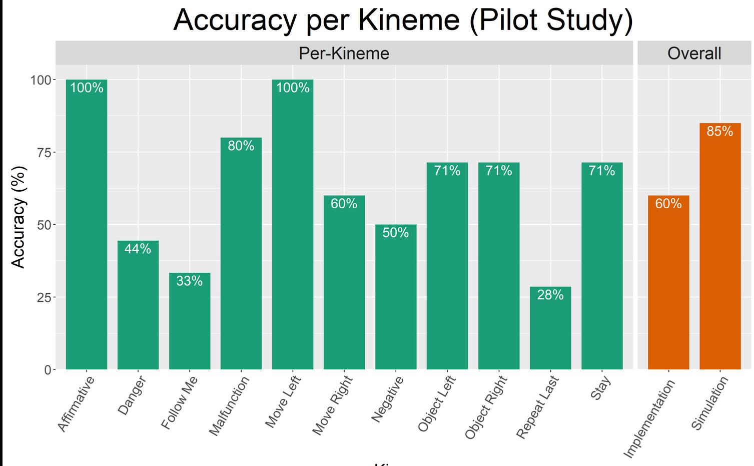
- ♦ We trained participants on the meaning of RCVM kinemes, as well as a small set of control gestures.
- ♦ Participants asked the AUV a question via gesture.
- ♦ The AUV responded to the question via kineme, selected and initiated by study staff.
- ♦ Participants then took the relevant action for the kineme they perceived, as indicated in the graph.

Given the actions that participants took, the kineme they had perceived and acted upon can be inferred, since each action relates to only one kineme.

Interaction Graph



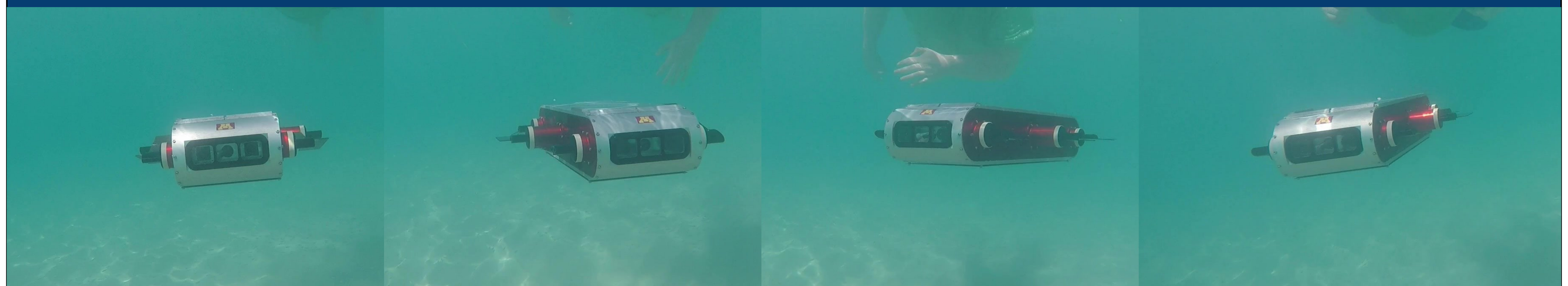
Accuracy per Kineme (Pilot Study)



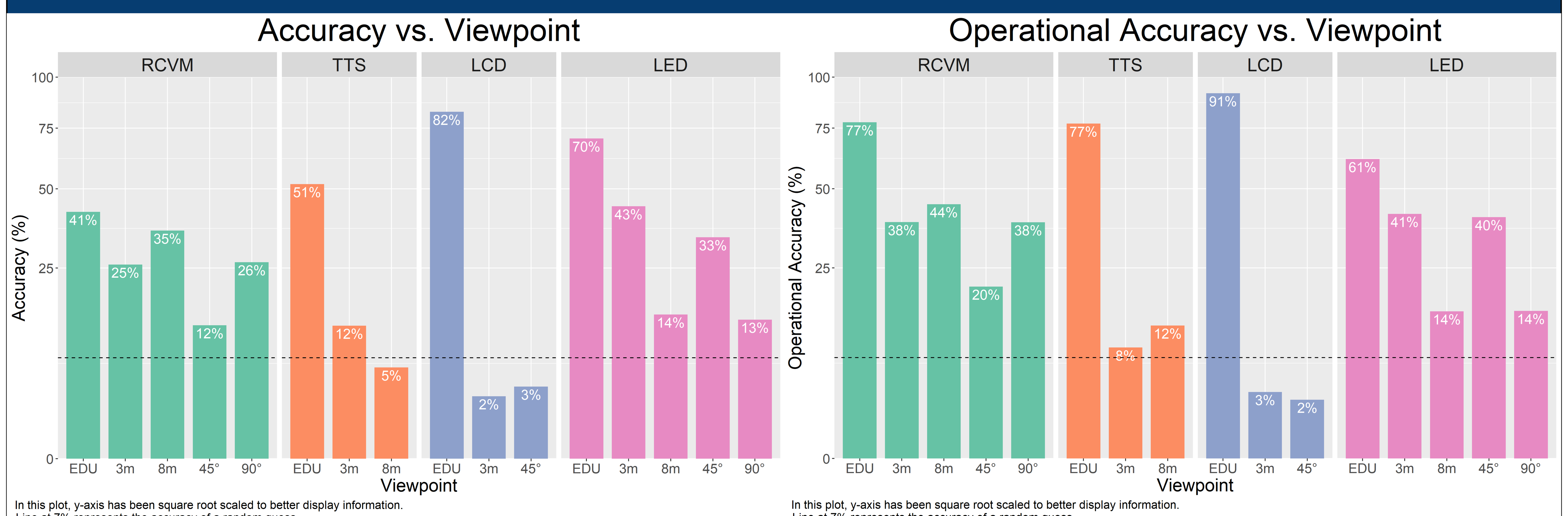
From the inferred kinemes, we can calculate recognition accuracy for this full-loop, real-world test of RCVM. We find the following:

- ♦ RCVM still has reasonable recognition accuracy (60%), indicating that participants have learned at least some kinemes.
- ♦ The accuracy overall is perceptibly less than the simulation results, likely due to the stochastic nature of underwater environments.
- ♦ Some kinemes are recognized incredibly accurately, while others struggle significantly.

Robot Communication Via Motion is a method for AUV-to-human communication.



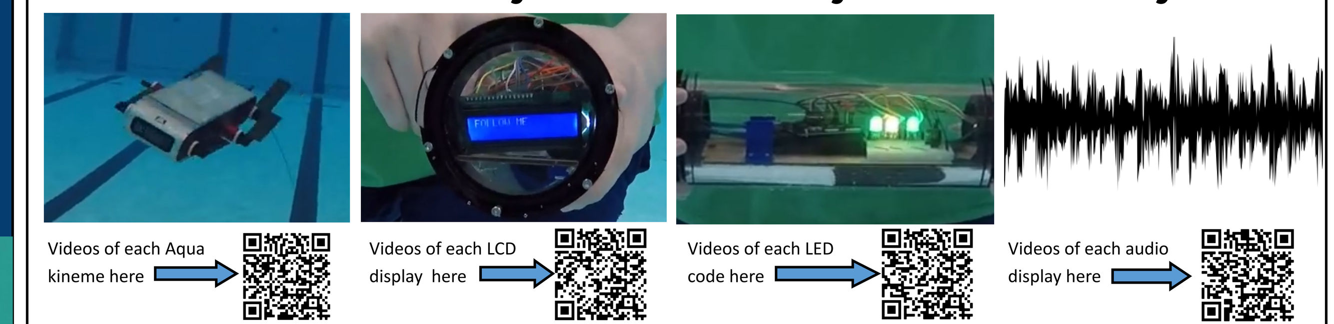
This paper presents the first implementation and evaluation of RCVM on a physical AUV.



In this plot, y-axis has been square root scaled to better display information. Line at 7% represents the accuracy of a random guess.

RCVM is less negatively affected by changes in viewpoint than compared communication systems.

Diverse AUV-To-Diver Communication

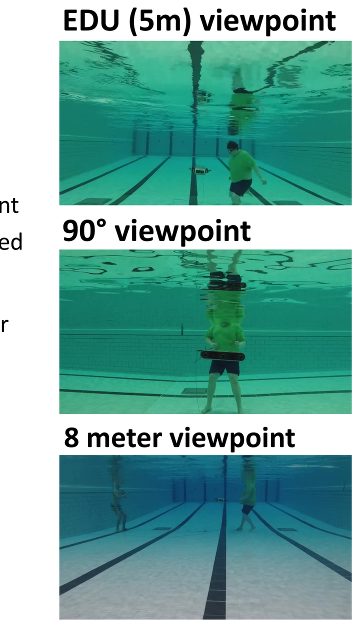


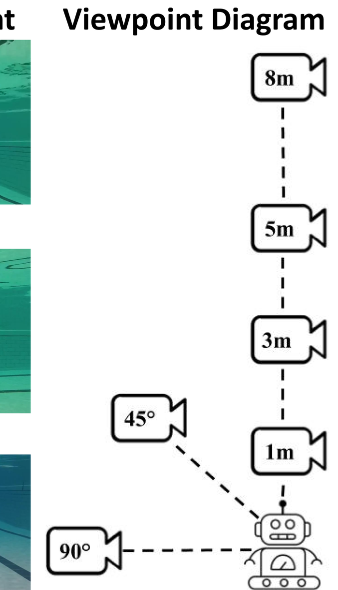
- ♦ The LCD system displays phrases on a small, two-line digital display. The information density of this display is similar to integrated displays in other AUVs.
- ♦ The LED system displays information in sequences of light illuminations. Comprised of 3 RGB LEDs arranged in a line, the color of a light and its rate of flashing are used as encoding spaces for communication.
- ♦ The TTS system displays phrases by playing a Google Text-To-Speech audio of the phrase over a waterproof speaker.

RCVM Remains Consistent At Challenging Viewpoints

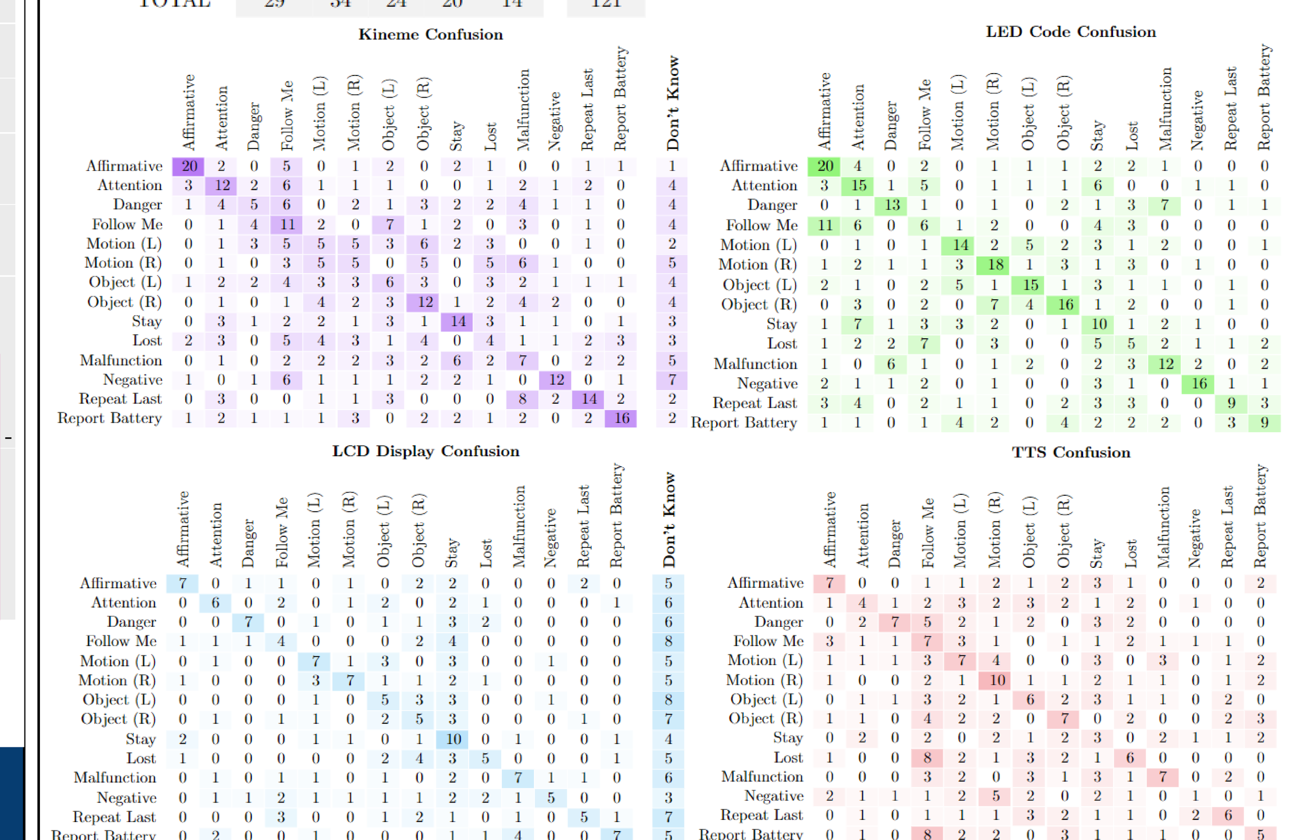
EDU (5m) viewpoint

- ♦ 121 participants were recruited via Amazon MTurk.
- ♦ Participants were trained to understand the system they would be testing using the **EDU viewpoint**.
- ♦ Participants were tested on the same system, at a different viewpoint. They selected the meaning of a video (displayed in random order) from a drop down list.
- ♦ Participants also selected their confidence in their answer and were timed for each question.





	Viewpoint					
System	EDU	3m	8m	45°	90 °	Total
KINEME	7	8	7	7	7	36
TTS	8	10	10	0	0	28
LCD	7	8	0	6	0	21
LED	7	8	7	7	7	36
TOTAL	29	34	24	20	14	121



References and Acknowledgements

[1] Michael Fulton, Chelsey Edge and Junaed Sattar, "Robot Communication Via Motion: Closing the Underwater Human-Robot Interaction Loop," 2019 International Conference on Robotics and Automation (ICRA), 2019, pp. 4660-4666, DOI: 10.1109/ICRA.2019.8793491.

[2] Michael Fulton, Chelsey Edge, and Junaed Sattar. Robot Communication Via Motion: A Study on Modalities for Robot-to-Human Communication in the Field. J. Hum.-Robot Interact. 11, 2, Article 15 (June 2022), 40 pages. DOI: 10.1145/3495245

[3] **(This Paper)** Michael Fulton, Muntaqim Mehtaz, Owen Queeglay, and Junaed Sattar. " Underwater Robot-To-Human Communication Via Motion: Implementation and Full-Loop Human Interface Evaluation", Robotics: Science and Systems, 2022.

A project page for RCVM can be found at the link in this QR code.

This work was supported by the US National Science Foundation awards IIS-#184536 & #00074041, and the MnRI Seed Grant.