APPENDIX: Underwater Robot-To-Human Communication Via Motion

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This appendix exists to provide supplementary material for "Underwater Robot-To-Human Communication Via Motion: Implementation and Full-Loop Human Interface Evaluation". The following four sections are dedicated to links to videos of every communication system used in this work, along with written descriptions of each interaction phrase. Finally, the last section contains information on accessing the data and source code used in this project. For any help in understanding or using the information contained in this appendix, please contact Michael Fulton at fulto081@umn.edu.

CONTENTS

I. KINEME SYSTEM DESCRIPTION

The videos in this section are of the implemented Aqua AUV kineme system, tested in a pool and recorded on a GoPro. The kinme system uses the motion of the robot to communicate information. This is the version used in the multi-dimensional study.

A playlist of videos of each of the following kinemes can be found here:
https://youtube.com/playlist?list=PLmZS-dt4IbKVKT6PYhOiV-f2M6_u78Y_o

1) Affirmative: The robot performs a "head nod" motion, beginning at a neutral orientation, angles down, angles up, and returns to neutral. There is a slight unavoidable forward motion due to the characteristics of the robot's flipper-driven swimming motion.

2) Attention: The robot rotates with a quick tilt to the left and another quick tilt to the right to grab the interactant's attention.

3) Danger: The robot makes broad movements to the left and then right as though looking for something. The robot then moves quickly away from the direction danger was found, shaking back and forth.

4) Follow Me: The robot makes short, quick movements up and to the right similar to a human version of beckoning with their head, then moves in the direction the human should go.

5) Lost: The robot moves back and forth as if searching for where to go.

6) Malfunction: The robot enters a front-down, floating state, using minimal movements to stay in the head down neutral position. When the robot moves it does so with one side, similar to affecting a "limp".

7) Indicate Motion: The robot begins in a neutral state, moves broadly in a direction, returns to the neutral state and moves again in the indicated direction.

8) Negative: The robot moves in sharp, quick left to right motions, similar to a person "shaking their head". Some forward motion is unavoidable as a consequence of the robot's flipper-driven swimming motion.

9) Indicate Object of Interest: The robot begins in a neutral position and moves toward an object. Once close to the object the robot turns around, "looks" back as if confirming that the human is coming over and hovers near the object.

10) Stay: The robot moves to a location. Remains in a neutral position for a little while and then proceeds to make a circular trajectory around that location.

11) Repeat Last: The robot makes a tilting motion as though trying to "hear" better. Forward motion is unavoidable due to the characteristics of the robot's flipper-driven swimming motion.

12) Report Battery Level: The robot begins in a neutral stance, moves into an almost vertical position with the front facing down to signal a battery report is coming. The robot then moves back to the neutral position to show that the battery is low.

II. LED Code System Descriptions

This section describes the LED code system used to compare to the kineme system. The LED code system uses a set of flashing, colored lights to represent each interaction phrase. Along with the videos, a description of the lights sequences and their meaning is included below. In these descriptions, wherever the words left or right are used, they are from robot's point of view, not user's. The videos in this section are of the 3-LED version used in the multi-dimensional study, as recorded underwater by a GoPro.

A playlist of videos of each of the following LED codes can be found here: https://youtube.com/playlist?list=PLmZS-dt4IbKWSkamO6myjrInibIryVQOW

1) Affirmative: The middle light is a continuous green. This code forms a "traffic light" duo with Negative, using green for yes and red for no.

2) Attention: All three lights flash green, requesting attention, but not indicating danger.

3) Danger: All three lights flash red, requesting attention and indicating danger. The flashing is regular and quick.

4) Follow Me: All lights are used with a combination of green and yellow colors. The inner and outer lights switch between yellow/green/yellow and green/yellow/green.

5) Lost: The outer two lights alternate between yellow and being turned off, while the inner light alternates yellow and off, but out of phase with the outer lights. In the video, it appears that the intensity merely changes, due to the diffusing nature of the LED caps.

6) Malfunction: All three lights flash simultaneously with the red color. While the lights flash regularly for Danger, for Malfunction they flash erratically.

7) Indicate Motion: All three lights are used with yellow color. The lights flash quickly in a sequence moving from left to right or right to left depending on the desired direction, repeating several times. The yellow indicates that the direction the lights flash is where the interactant should move, in contrast to Indicate Object, where the color used is blue.

8) Negative: The middle light remains a continuous red color. This code forms a "traffic light" duo with Affirmative, using green for yes and red for no.

9) Indicate Object of Interest: All three lights are used with blue color. The lights flash quickly in a sequence moving from left to right or right to left depending on the location of the object, repeating several times. The blue indicates that the direction the lights flash is where the interactant should look for an object, in contrast to Indicate Motion, where the color used is yellow.

10) Stay: All three lights flash yellow simultaneously.

11) Repeat Last: The left light remains a continuous blue color.

12) Report Battery Level: The right light remains continuously yellow while the left two lights flash slowly in either green or red. Green corresponds with good battery status while red corresponds with low battery.

III. LCD System Descriptions

The videos in this section are of the LCD system used to compare to the kineme system in the multi-dimensional study. The videos shown here were recorded in a pool with a GoPro. The LCD system uses a two-line, sixteen character digital display to show text for each interaction phrase, the exact wording of which is described below. In these descriptions, wherever the words left or right are used, they are from robot's point of view, not user's.

A playlist of videos of each of the following LCD messages can be found here:
https://youtube.com/playlist?list=PLmZS-dt4IbKXPeBbLDIlgH2rALkJYTVJ-

1) *Affirmative:* YES
2) *Attention:* ATTENTION
3) *Danger:* DANGER NEARBY
4) *Follow Me:* FOLLOW ME
5) *Lost:* I'M LOST
6) *Malfunction:* MALFUNCTION
7) *Indicate Motion:* MOVE LEFT (RIGHT)
8) *Negative:* NO
9) *Indicate Object of Interest:* OBJECT BELOW LEFT (RIGHT)
10) *Stay:* STAY HERE
11) *Repeat Last:* REPEAT PREVIOUS
12) *Report Battery Level:* BATTERY LOW

IV. Audio System Descriptions

The videos in this section are of the audio system used to compare to the kineme system in the multi-dimensional study. The videos shown here were recorded in a pool by a GoPro. The audio system uses a Google Text-To-Speech API to produce a voice for the interaction phrases, the exact wording of which is described below. In these descriptions, wherever the words left or right are used, they are from robot's point of view, not user's.

A playlist of videos of each of the following audio messages can be found here: https://youtube.com/playlist?list=PLmZS-dt4IbKWiJOGFWUthbFwWYfquDK23

1) *Affirmative:* Affirmative.
2) *Attention:* Attention.
3) *Danger:* Danger.
4) *Follow Me:* Follow Me.
5) *Lost:* I am lost.
6) *Malfunction:* I am malfunctioning.
7) *Indicate Motion:* Move left (right).
8) *Negative:* Negative.
9) *Indicate Object of Interest:* Get the object on the left (right).
10) *Stay:* Remain where you are.
11) *Repeat Last:* Repeat last command.
12) *Report Battery Level:* Battery is low.

V. Source Code and Data Availability/Access Instructions

If you are interested in obtaining the data for any of the studies referenced in this paper, please contact Michael Fulton at the University of Minnesota. Data is not publicly available for privacy reasons, but may be shared on a case-by-case basis, depending on the application. However, the code for various implementations of RCVM is publicly available on Github.

- The core ROS package used by all implementations of RCVM can be found at: https://github.com/IRVLab/rcvm_core/releases/tag/v1.0
- The Aqua implementation used in the multi-dimensional study can be found at: https://github.com/IRVLab/rcvm_aqua/releases/tag/v1.0