“Swimming Tango” - An Underwater Navigation and Communications Device

<u>ECE4011 Senior Design Project</u>

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Executive Summary

The project is aimed at creating an underwater means of navigation similar to a mobile GPS that also has ability to communicate via text for the U.S. Department of Defense. The goal is to limit the size of the hardware to within the profile of a handheld tablet. This is to help them link divers and topside personnel for increased diver safety and navigational accuracy. Our group will focus on underwater navigation and mapping, with another group doing the communications. The navigation component will include implementing sensors such as a 2D sonar scanner, an inertial measurement unit (IMU) with accelerometer, gyro, and magnetometer readings, and a camera for computer vision. The sensors will measure and record acceleration and deceleration on the vertical, horizontal, and transverse planes, data about the landscape and topography of the environment, and information on obstacles and how to avoid them. The mapping component of the project will utilize sensory data and attempt to create a 3D visualization, similar to Google's Project Tango. The sensory data will be analyzed and processed using mapping algorithms such as Simultaneous localization and mapping (SLAM). The end goal of the mapping would be to produce a visualization of the underwater environment, which can then be viewed and used for robotic purposes. This product will allow divers and robots to map out and navigate underwater environments effectively for research and defense purposes. The device will save time and money by allowing manned diving missions to map out underwater regions. This data can then be used in robotic and automated missions. The expected outcome of this project is a fully-functional prototype.

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1. Introduction

The Swimming Tango team will design an underwater means of navigation that also has the ability to communicate via text messaging. The aim of the project is to limit the size of the device to that of a handheld tablet, such as the Nexus 7 or the iPad Mini.

Figure 1. Rear-view of a Project Tango Device [1].

1.1 Objective

The team will design and prototype a device no bigger than a handheld tablet that reconstructs Google's Project Tango using a Micron DST SONAR as the sensor, instead of Microsoft Kinect for the US Department of Defense. This is because the device is to be used underwater, and the Kinect does not function well under low-light conditions. The device will be waterproof and will complement the diver's Underwater Breathing Apparatus. It will not interfere with the swimmer's gear or buoyancy [2]. The device will also be capable of supporting a large number of divers on the same network and enable them to communicate with each other using pre-saved text messages. This team will focus on the navigation and obstacle avoidance aspects of the device. Another team will focus on the communications aspect of the same device.

1.2 Motivation

Deep-sea divers face a lot of hazards when they venture out into the ocean. Using such a device would enable them to communicate with other divers in their vicinity, which could be helpful in case of an emergency. Further, the device also tracks the movement of the divers. This could also be used to make sure that the divers can be easily found in the event they lose their way.

The communications side of this device shares functionality with the UDI 28 designed by Underwater Technologies Center (UTC). The UDI 28 allows upto 28 divers (in 2 networks) to communicate with each other through text messaging. For this purpose, upto 28 pre-configured messages can be used. It also includes a compass for basic navigation facilities. The device comes bundled with a software that can be used to perform test dives, display and store information such as diver depth and compass readings and also configure the text messages that can be transmitted [3]. The Swimming Tango team aims to improve upon this device by adding a SONAR, which would allow for real-time tracking of the diver's path.

Figure 2. Image illustrating the key features of the UDI series [3].

1.3 Background

Extensive research has been devoted to the development of navigation and mapping technologies. An important example is Google's Project Tango. Project Tango uses computer vision to enable mobile devices, such as smartphones and tablets, to detect their position relative to the world around them without using GPS or other external signals. This allows application developers to create user experiences that include indoor navigation, 3D mapping, measurement of physical spaces, recognition of known environments,augmented reality, and windows into virtual 3D worlds [1]. This is important because GPS signals are unable to provide location and time information underwater, since the electromagnetic signals from the orbiting satellites are heavily damped in water and hence can not be detected by the receiver in most cases of interest [4]. This project is an attempt at reconstructing Project Tango using SONAR for navigation and obstacle detection, thereby making it a feasible option for underwater navigation.

One of the key algorithms Project Tango uses is SLAM (Simultaneous Localization and Mapping). Project Tango utilizes an IMU and Kinect-like laserscan sensor in order to generate the data for the SLAM algorithm. Our underwater version will try to recreate this setup with SONAR and a position-detecting sensor.

2. Project Description and Goals

The fundamental goal of the Swimming Tango team is to design a system that enables deep-sea divers to communicate with each other via text messaging. The system consists of a device no bigger than a handheld tablet or smartphone. The device must complement the diver's Underwater Breathing Apparatus (UBA), and not interfere with the swimmer's gear or buoyancy. The features of the system include[2]:

- Portability
- Lightweight
- Waterproof
- Long range
- Links a large number of divers

3. Technical Specifications

The two major components of this project are the device to be used for navigation and communications and the SONAR. Table 1 lists the technical specifications for the device, while Table 2 lists the specifications for the SONAR.

Table 1. Technical specifications of the device [2].

Specification	Feature
Screen size	ideally between 4-7 inches
Thickness	preferably not more than 9mm (excluding SONAR)
OS	Linux with ROS
Max. depth	66 Feat of Seawater (FSW)
Max. number of divers supported	56 on one network
Max. communications range	1000m
Navigations equipment	SONAR, IMU

Table 2. Technical specifications of the SONAR [5].

Specification	Feature
Size	Smallest digital CHIRP SONAR in the world. Dimensions shown in Figure 3.
Max. depth	750m (around 2460 feet)
Max. range	75m
Min. range	0.3m
Power requirement	12-48V DC at 4 VA average power
Communications protocols	RS-232, RS-485 (twisted pair)

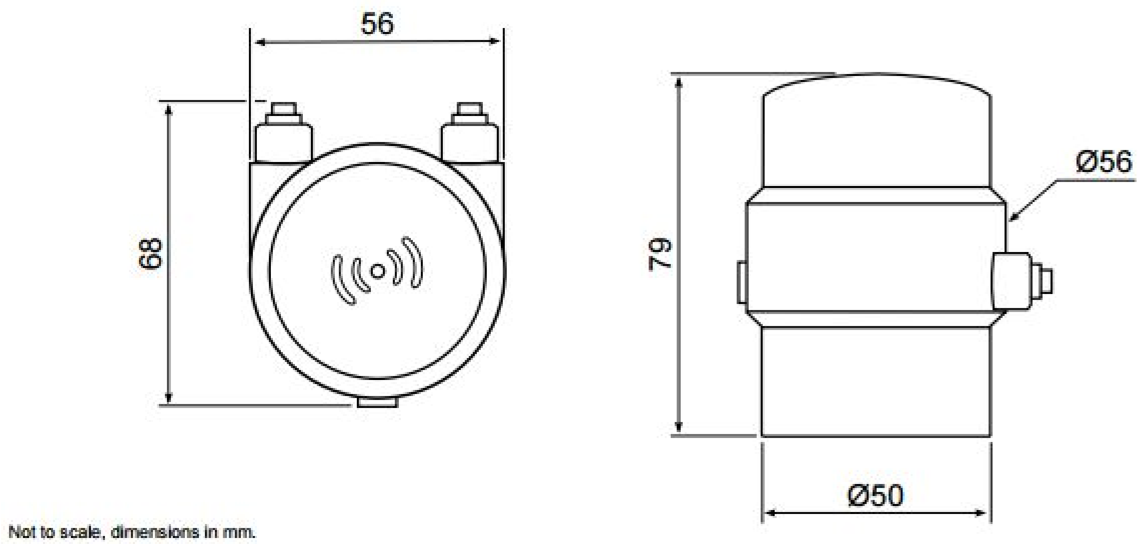

Figure 3. SONAR dimensions [5].

4. Design Approach and Details

4.1 Design Approach

The design being looked into will be very similar in style to the Project Tango tablet design. The physical product will be a tablet-sized device with a touch screen for input. There will be a slight protrusion in the back of the device for the SONAR sensor, but this protrusion shouldn't detract from the overall tablet profile. The current vision of the front of the device will look like this:

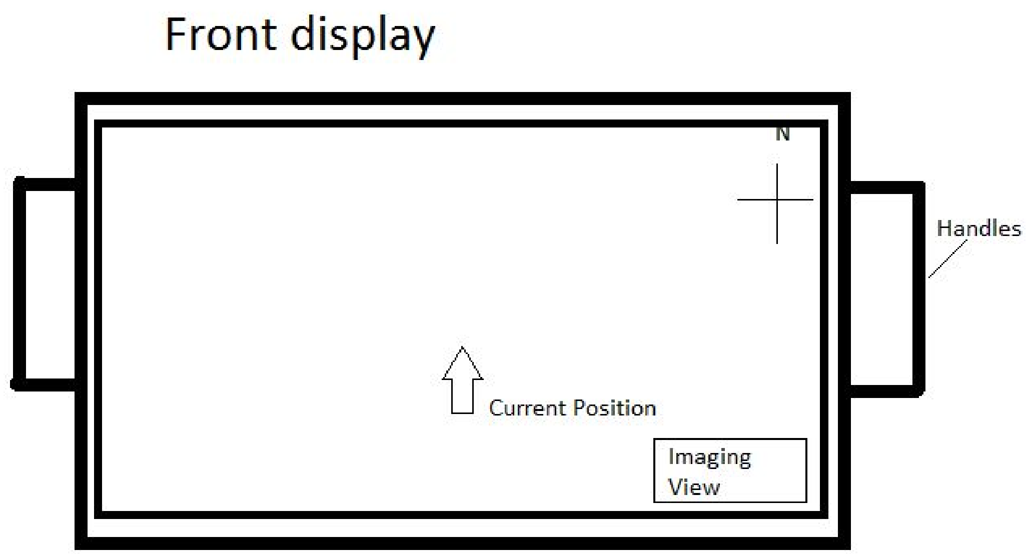

Figure 4. Front view of the device.

The GUI shown above will be used to show the current position of the tablet with respect to what has been mapped. The GUI will also display compass heading, some raw data and information, and the ability to switch between the map view and the SONAR imaging view.

The device will contain the DST Micron SONAR sensor (see Figure 5), an undecided IMU, and an undecided position sensor. The team is currently researching different IMU's and position sensors to use. These sensors will be used to provide directional information, compass heading, and absolute distance the tablet has moved, relative to a starting point.

Figure 5. The Micron DST SONAR [5].

The team is planning for the device to run linux with ROS. ROS was chosen because of its easy to use software packages, community activity, and prior experience with the software. ROS will provide an interface to use and obtain data from the sensors we implement. A ROS package for underwater sensing and navigation, MOOS, will be used to specifically interface and interpret the SONAR findings.

4.2 Codes and Standards

At this point in time, the project is still in the planning phase. While the approach has been settled upon, the exact parts to be used have not been decided yet, except for the Micron DST SONAR. With that in mind, the following are the codes and standards that the team anticipates would significantly affect the project:

- It is anticipated that some of the sensors would interface through the following protocols:

- Serial Peripheral Interface (SPI): It is an interface bus commonly used to send data between microcontrollers and small peripherals such as shift registers, sensors, and SD cards. It uses separate clock and data lines, along with a select line to choose the device you wish to talk to [6].
- Inter-integrated Circuit Protocol (I^2C): It is intended to allow multiple “slave” digital integrated circuits (“chips”) to communicate with one or more “master” chips. Like the Serial Peripheral Interface (SPI), it is only intended for short distance communications within a single device. Like Asynchronous Serial Interfaces (such as RS-232 or UARTs), it only requires two signal wires to exchange information [7].
- Universal Serial Bus (USB): It is a set of interface specifications for high speed wired communication between electronics systems peripherals and devices with or without PC/computer. The USB was originally developed in 1995 by many of the industry leading companies like Intel, Compaq, Microsoft, Digital, IBM, and Northern Telecom. The major goal of USB was to define an external expansion bus to add peripherals to a PC in easy and simple manner [8].
- RS-232: It is a standard for serial communication transmission of data. It formally defines the signals connecting between a DTE (data terminal equipment) such as a computer terminal, and a DCE (data circuit-terminating equipment, originally defined as data communication equipment), such as a modem [9].
- RS-485: It is a standard defining the electrical characteristics of drivers and receivers for use in balanced digital multipoint systems. The standard is published by the Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA) [10].

- While this team will focus solely on the navigation and mapping aspects of the device, it is expected that some of the sensors used will interface with the communication device. In such cases, the Federal Communications Commision (FCC) standards must be followed.
- It is also expected that open-source software, such as Robot Operating System (ROS) and Mission Oriented Operating Suite (MOOS) will be used. As such, the project has to comply with the required software licenses, such as the GNU General Public License (GPL).

4.3 <u>Constraints, Alternatives, and Tradeoffs</u>

Constraints

- Cost is arguably one of the most important design constraints for any project. It is the budget available that decides what components can be used and even what approaches could be used to obtain the desired result. As already mentioned, the exact components have not been decided as of this moment in time, but it is anticipated that a fairly large budget will be required. For instance, the SONAR which will be used is the Micron DST SONAR, which costs upwards of $500.
- Time is just about as important a design constraint as cost. Since the team just has one semester to work on this project, it is highly unlikely that a prototype could be built from scratch. As such, a suitable starting point would have to be chosen. One possible option is the UDI 28, designed by Underwater Technologies Center (UTC).
- The size of the device is also an important constraint, as this could affect the choice of sensors to be used.

Trade-offs

- Given that the device has to be within a particular size range, sensing options are limited. One potential tradeoff is having to settle for using a 2D sonar scanner and take readings enough to construct a 3D model, instead of a 3D sonar module. Another tradeoff could involve having to decide on making the item more portable by reducing the size, or including larger, more accurate sensors, thereby making the device larger and bulkier.
- Another tradeoff would be between battery life and both the amount of sensors and quality of sensors. Because the device will be mobile and used underwater, a larger battery life is preferred.
- Computational power and speed versus battery life and sensor complexity would also need to be discussed by the team. Less refined sensor input would mean that more computation will be needed to filter the sensor input.

5. Schedule, Tasks, and Milestones

The Swimming Tango team will be designing and implementing this prototype over the next semester. Figure 6 depicts a PERT chart that lists the major tasks and the person assigned to each task.

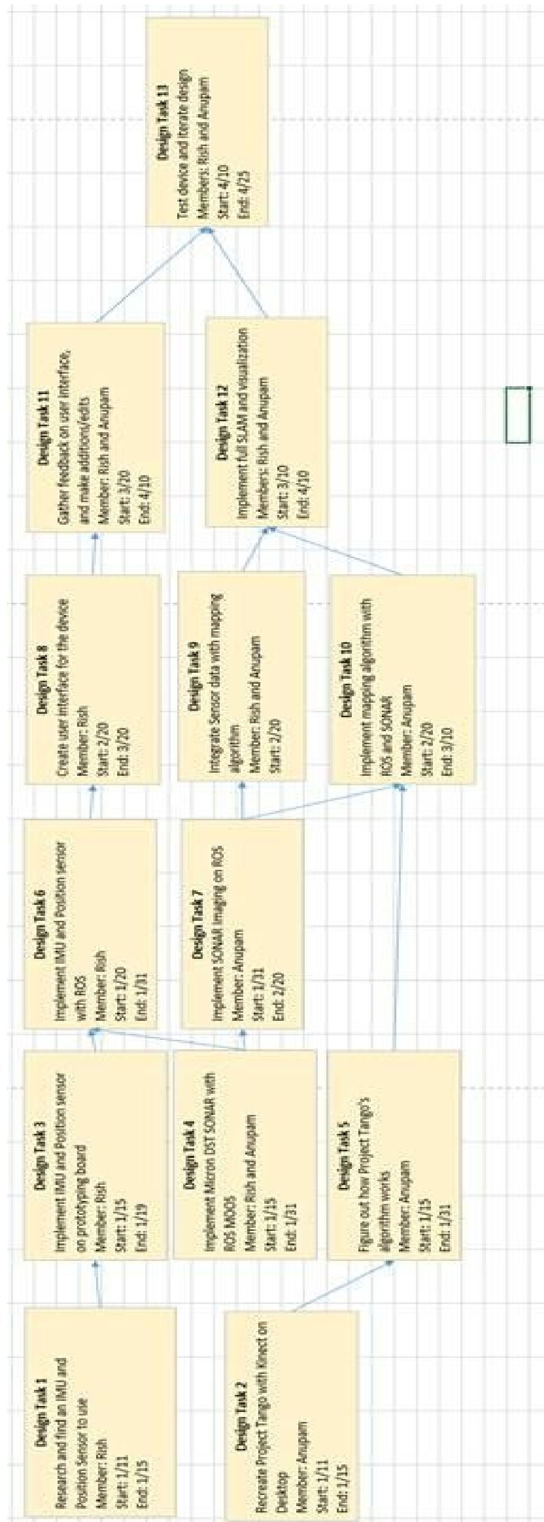

Figure 6. PERT chart depicting the project timeline (in landscape).

The tasks have been tabulated in Appendix A for the purpose of clarity.

6. Project Demonstration

To fully demonstrate the project, the team will need to display the device's ability to map an underwater environment, while showing its current position in the environment. In order to accomplish this, we will need to recreate an underwater environment with obstacles. The team will use a large tank of water with various rocks and obstacles to emulate this environment. The device will be mounted to either a teleoperated submersible robot, or a custom movable mount created for the device.

The actual demonstration will involve moving the device around and showing the GUI of the tablet. The device's GUI will be projected to a source external to the tank, so the viewers of the demonstration can see the data the device is gathering in real time. Once the device has finished mapping the entire tank, the results of the mapping performed by the device will be displayed.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

The target market of this product is primarily the U.S. Department of Defense. However, it can be used by any deep-sea diver. Underwater Technologies Center (UTC) has developed a line of smartwatch-like devices called UDI. These devices allow divers to communicate with each other through text messages, just like this product. However, this product allows more divers to communicate with each other on the same channel, thereby avoiding the need to use multiple channels. In addition, this product provides real-time tracking of a diver's position, since it is fitted with a

Micron DST SONAR. The product will however be slightly larger than the UDI devices in order to be able to accommodate the extra sensors.

7.2 Cost Analysis

Table 3 shows a breakdown of the material costs of the prototype. Since the exact components have not been decided yet, the costs mentioned in this section are just estimates. However, the team anticipates that these would be reasonably close to the true cost. The most expensive equipment is the SONAR. However, this will be given to the team free of charge.

Table 3. Prototype Equipment Costs.

Product description	Quantity	Unit Price ($)	Total Price ($)
Tritech Micron DST SONAR	1	$500-600	0 (received for free)
Triple Axis Accelerometer and Gyro	1	$39.95	$39.95
Project Tango Development Tablet	1	$512	0 (received for free)
TOTAL COST			$39.95

The total development costs shown in Table 4 were determined with an assumed labor cost of $40 per hour. Fringe and overhead costs are factored into the higher costs and will be amortized over all units produced. The values in the labor hours field are just estimates.

Table 4. Development Costs

Project Component	**Labor hours**	**Labor Cost**	**Part Cost**	**Total Component Cost**
DEVICE DEVELOPMENT				
Assembly, OS Development and Install	100	$4,000	$39.95	$4,039.95
Testing	50	$2,000		$2,000
SWIMMING TANGO IMPLEMENTATION				
Algorithm formulation	80	$3,200		$3,200
Coding	120	$4,800		$4,800
Debugging and Testing	120	$4,800		$4,800
DEMO PREPARATION	120	$4,800		$4,800
GROUP MEETINGS	300	$12,000		$12,000
PAPERS AND PRESENTATIONS	100	$4,000		$4,000
TOTAL LABOR	990	$39,600		
TOTAL PART COST			$39.95	
TOTAL COST (LABOR + PART)				**$39,639.95**

Using the fringe benefit as 30% of total labor and overhead costs as 120% of material and labor costs, the total development cost for the device is $113,343.89, as shown in Table 5.

Table 5. Total Development Costs

Component	Cost
Parts	$39.95
Labor	$39,600
Fringe benefits	$11,880
Subtotal	$51,519.95
Overhead costs	$61,823.95
TOTAL COST	**$113,343.89**

The device will be sold to the general public at a cost of $249.39 per device. The initial production run will consist of 5,000 units sold over a five-year period. A group of testers will be employed at $10 per hour in order to test the device and report any bugs. There will also be another group of people employed at $15 per hour who will be in charge of assembling the device. Sales expense in the form of advertising will make up 6.02% of the final selling price. At the selling price, the expected revenue is $1,246,950, yielding a profit of $50 per unit. All costs are tabulated in Table 6.

Table 6. Selling Price and Profit per Unit.

Component	Cost
Parts cost	$39.95
Assembly labor	$15
Testing labor	$10
Total labor	**$25**
Fringe benefits	$7.50
Subtotal	**$72.45**
Overhead	$86.94
Subtotal, input costs	**$159.39**
Sales expense	$15
Amortized development costs	$25
Subtotal, all costs	**$199.39**
Profit	$50
Selling Price	**$249.39**

8. Current Status

So far, initial research into the inner workings of Project Tango has been done. The team is also researching underwater sensor interfaces for ROS to get an idea of how to implement the DST Micron sensor. The sensor to detect current position is being researched at the moment.

9. References

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APPENDIX - A:

LIST OF TASKS

Task	Start Date	End Date	Person Responsible	Risk Level
Research and find an IMU and position sensor	1/11	1/15	RA	Low
Recreate Project Tango on Desktop	1/11	1/15	AG	Low
Implement IMU and Position sensor on prototyping board	1/15	1/19	RA	Medium
Implement Micron DST Sonar with ROS and MOOS	1/15	1/31	RA, AG	Medium
Figure out how Project Tango's algorithm works	1/15	1/31	AG	Low
Implement IMU and position sensor with ROS	1/20	1/31	RA	High
Implement SONAR imaging on ROS	1/31	2/20	AG	Medium
Create UI for device	2/20	3/20	RA	Medium
Integrate sensor data with mapping algorithm	2/20	3/10	RA, AG	High
Implement mapping algorithm with ROS and SONAR	2/20	3/10	AG	High
Gather feedback on UI and make changes	3/20	4/10	RA, AG	Low
Implement full SLAM and visualization	3/10	4/10	RA, AG	Medium
Test device and iterate design	4/10	4/25	RA, AG	Medium

AG - Anupam Goli

RA - Rishabh (Rish) Ananthan