Software Design

Document

for

RoboSub

Version 3.0 approved

Prepared by Jin Chiu
Erika Estrada
David Krystall
Kunal Juneja
Jesus Lopez

12/07/18

Contents

Revision History

Name	Date	Reason For Changes	Version
Eagle I	04/17	Initial Software for AUV Competition	1.0
	07/17	Updated software to go with new AUV hardware	2.0
P.E.N.G.U.I.N.	12/18	Updated software to work with new Computer Vision Technology available	3.0

1. Introduction

1.1 Purpose
This Document outlines the software architecture and design for the P.E.N.G.U.I.N. Software controlling the RoboSub senior design project. It goes in depth for the Computer Vision module, The ROS module, and the Arduino module. It also describes the functionality of the ROS, Arduino and Computer Vision modules.

1.2 Document Conventions
This document has very basic formatting, points of emphasis are either highlighted or bolded.

1.3 Intended Audience and Reading Suggestions
This document is intended for future developers of the RoboSub projects or developers looking to understand the software architecture for P.E.N.G.U.I.N.. It is also intended for the California State University - Los Angeles Computer Science department, including students and faculty.

1.4 System Overview
The P.E.N.G.U.I.N. software controls an Autonomous Underwater Vehicle (AUV) which is being developed for an international robotics competition. It is responsible for handling all of the AUV's basic functions. The P.E.N.G.U.I.N. software is comprised of three main components; the first being the ROS module which acts a central hub for all signals taken in from hardware, the second is the Arduino module which takes in commands from the ROS module and guides motors and other hardware needed to complete each task, and lastly the Computer Vision module which combines different image filtering and machine learning algorithms for object detection to provide necessary information to the AUV.

2. Design Considerations

2.1 Assumptions and Dependencies

- P.E.N.G.U.I.N. will be written with a combination of Python and C.
- P.E.N.G.U.I.N. will run on Ubuntu as made necessary by ROS.
- The Computer Vision will be written in Python and uses OpenCV and YOLOv3 for image processing.
- The Arduino portion of the software shall be written in the C programming language.

2.2 General Constraints

- The P.E.N.G.U.I.N. software must run on Ubuntu.
- The Batteries running the AUV can run for approximately 30 mins.
- Must have base C++ libraries installed.
- The Computer Vision will be run using OpenCV, YOLOv3, TensorFlow, Numpy and Scikit Learn these all must be installed for the cv to function
- P.E.N.G.U.I.N. must run on ROS Melodic Morenia

2.3 Goals and Guidelines

- P.E.N.G.U.I.N. has a delivery date of 30 July 2019 (the beginning of the competition)
- P.E.N.G.U.I.N. code must be easily read and modified
- P.E.N.G.U.I.N. modules and submodules must be objected oriented in order to facilitate easy modification for future teams using the code base.
- The software will emphasize efficiency given that we have limited computational capacity
- The software must support full autonomy for the AUV.

2.4 Development Methods

The P.E.N.G.U.I.N. software has been developed using Agile methods.The code we received from last year did not implement modularization as much as we would have liked therefore many classes were rewritten with that in mind. The Team mostly focused on modularize

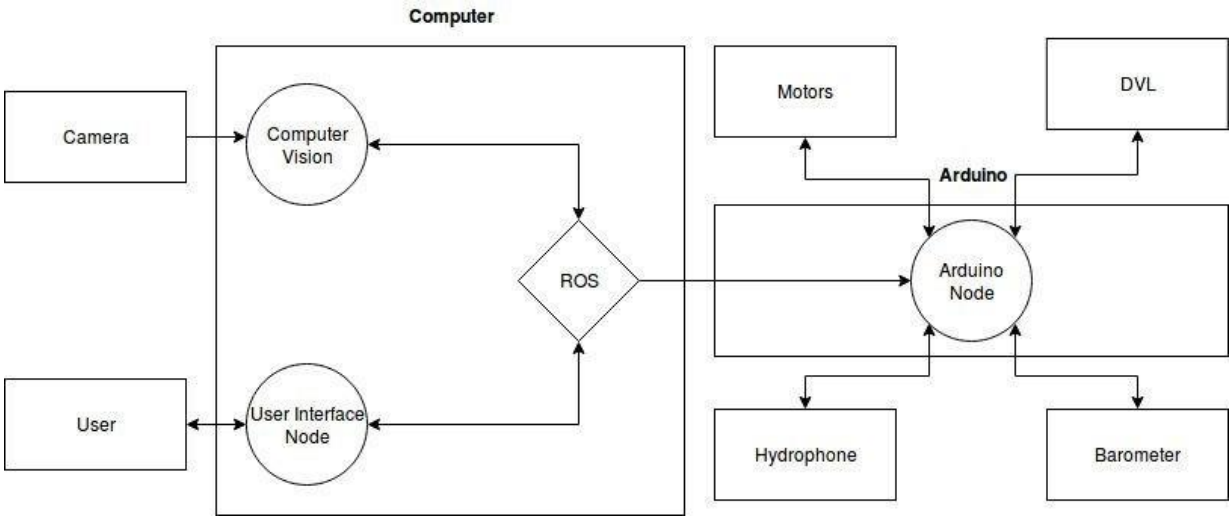
existing code and updating methods to be more efficient and more legible. Furthermore, there was a more object oriented approach such that further teams will not have to do this as well. The Computer Vision was developed using various IDEs. The Computer Vision implements the strategy pattern of object oriented design. The Computer Vision was created using OpenCV and YOLOv3. We added YOLOv3 this year in order to be able to analyze live-feed from the cameras and act faster. Additionally, the introduction of a 1070 TI GPU will allow us to introduce TensorFlow to RoboSub. The machine learning algorithms were done by testing different image preprocessing techniques as well as implementing different processing protocols in order to minimize the computational workload used by CV.

3. Architectural Strategies

- The vast majority of the project was written in Python to provide uniformity between the ROS side of the project and the Computer Vision side.
- The machine learning algorithms were created with various Python libraries including SciKit Learn, Keras,TensorFlow, YOLOv3 and OpenCV.
- The Computer Vision module relied heavily on OpenCV and YOLOv3 for image processing and filtering.
- ROS was used to interface with the Arduino Module (which controls the hardware) because it provides a robust set of functions that would otherwise have to be written from scratch.
- Data will be collected by the Arduinos and the Cameras and interpreted by the ROS module.
- The list of tasks completed and to be complete will be handled by the ROS module
- The hardware used for signal processing includes Hydrophones, two cameras, a doppler velocity log and an Inertial Measurement Unit

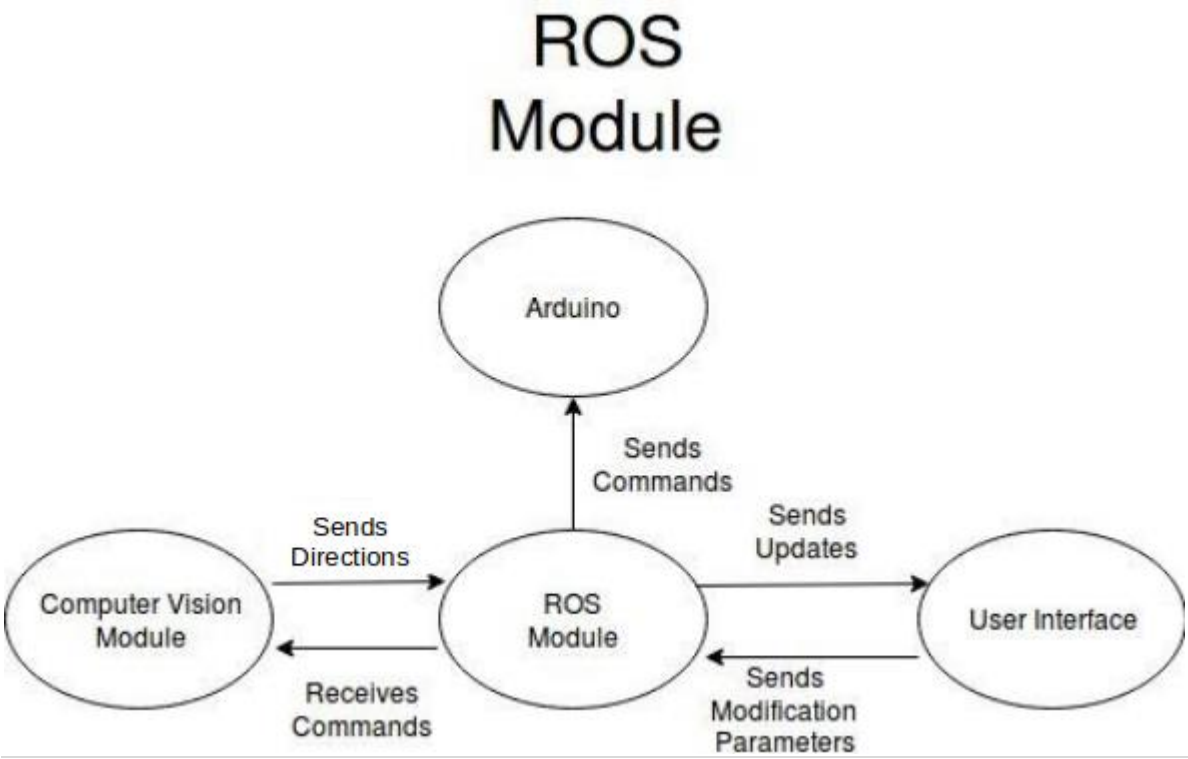
4. System Architecture

4.1 Data Flow Diagram



4.2 Level 1 DFDs

4.2.1 ROS Module

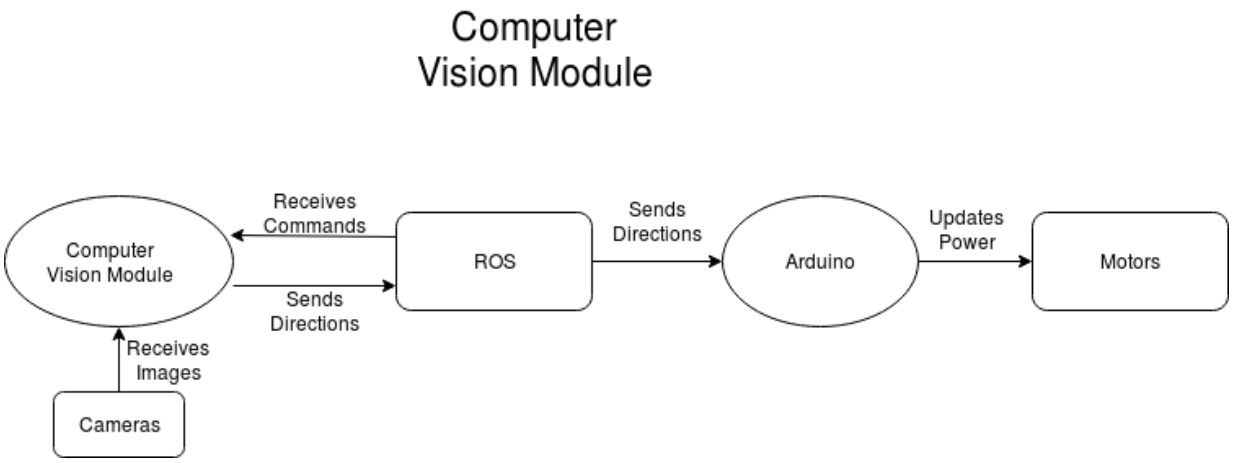


The ROS module is an interface between the Main Computer and the Arduinos.The ROS module communication between hardware and software through the use of publishers and subscribers. A publisher will broadcast the data to be used by a subscriber which in this case is an Arduino that will tell the hardware what action to take. A subscriber will listen to data being published by the Arduinos. The data can then be used by the subscriber to complete its desired function.

4.2.2 Arduino Module

The Arduino Module is used for the main computer to communicate with each piece of hardware. Each Arduino has different functions. They receive commands from the main computer then send commands to other Arduinos. Each Arduino receives data from hardware and then sends data to hardware. The barometer, and hydrophone will send data to their corresponding Arduino, while the motos will receive instructions from the Arduino.

4.2.3 Computer Vision Module



The Computer Vision works as follows. First the CV receives a command from ROS indicating what type of object or task it is looking for. Next the Computer Vision selects a corresponding Detector Class. Each Detector is designed for a specific task. The Detector implements a Preprocessor interface and a Classifier interface. The preprocessor interface implementation determines what type of filtering will be done with each image and it also returns general regions of interest that are likely to include the target object. Then the CV sends each of these regions to
a classifier. Classifiers used include, but are not limited to, Support Vector Machines and Convolutional Neural Networks. The classifiers then return positive matches. The cv takes the

regions with a positive match and provides directions to ROS to guide the AUV towards it. ROS relays this information to the Arduinos which then trigger the motors to navigate towards the direction of the detected object.

5. Policies and Tactics

5.1 Choice of which specific products used

Python, ROS and Arduino IDE were used to develop the P.E.N.G.U.I.N.. The Computer Vision was written completely in Python and used a variety of different libraries. Most significant was the use of YOLO this year to include live-feed recognition from the camera instead of analyzing each individual frame separately. OpenCv was used for image processing, colorspace shifting and feature extraction. Additionally,TensorFlow, SciKit-Learn, Numpy, Pandas,TensorFlow, and Keras were used as well. SciKit-Learn, Keras, TensorFlow were used to apply deep learning algorithms for the object detection. The CV was developed using the Python Libraries in the Pycharm IDE. Additionally Matplotlib was used to provide key visual representations of data which were useful during the development of the image processing protocols. For testing, Ubuntu computers and the RoboSub were used.

5.2 Plans for ensuring requirements traceability

Traceability for the software requirements will be provided in an attached software requirement document. This document provides detailed information as to what all of the requirements, which requirements were met and how those requirements were met.

5.3 Plans for testing the software

There are a variety of testing methodologies that P.E.N.G.U.I.N. will use to ensure that all requirements are met and that updates to the source code do not cause any errors. There are testing requirements for each of the individual components of P.E.N.G.U.I.N., as well integration testings to assure that all separate components connect correctly.

Some of ROS tests include but are not limited to;

- Directing the AUV to drop a fixed distance
- Directing the AUV to complete a circle
- Directing the AUV to navigate forward a fixed distance then rotate and return to its starting position
- Having the AUV fire torpedoes
- Having the AUV release chips used for tasks

Some of the CV tests include but are not limited to;

- Finding the correct object through as series of images
- Intersection over union for each classifier to gauge accuracy of classifiers
- Testing that the CV updates directions properly.
- Testing that the proper methods are implemented in each of the Classifiers

Additionally integration testing includes but is not limited to;

- Having the AUV navigate towards a buoy detected from the cameras.
- Having the AUV navigate through a gate detected from by the cameras
- Having the AUV find a correct numbered die in a set of multiple dice

Additionally, any methods, modules or functions that maneuver the AUV, modify hardware signal data, process images, or affect direction shall be subject to testing to ensure that data flows consistently throughout the software and that the proper implementations of each module are applied.

5.4 Software Maintenance

The P.E.N.G.U.I.N. software shall be stored on a variety of devices, and using version control which is accessible to all members of the RoboSub team, including Computer Science and Engineering. Furthermore, documentation shall be maintained such that future developers of the RoboSub project can easily understand and modify existing code. Members of the current team will do their best to attend meetings to prepare the next team working on RoboSub the following year.

5.5 Engineering Trade-Offs

P.E.N.G.U.I.N. will use Python as its language, though it is a high level (slow) language it is easier to implement and modify. We have decided this to be able to continue using the Agile software development methodology used by the Computer Science subdivision of the RoboSub team.

The Arduino portion of the software will be written in the C programming language as Python cannot be used to control the Arduinos.

Drivers will be written for the Doppler Velocity Log as the model which is on the AUV (Teledyne Pathfinder) only has drivers for Windows and the ROS portion of project can run exclusively on Ubuntu.

5.6 Coding Guidelines and Conventions

All portions of the source code that are written in Python must follow conventions outlined in the Pep 8 style guidelines.

Additionally the CV follows Object Oriented Design principles and implements the “Strategy Pattern” which will enable P.E.N.G.U.I.N. to switch implementations of CV Detectors and Classifiers at runtime.

Coordinates shall be handled as follows:

X direction : -1 Left, 0 Steady, 1 Right

Z direction : -1 Down, 0 Steady, 1 Up

Y direction : -1 Back, 0 Steady, 1 Forward

5.7 Choices of Algorithms or Idioms to implement functionality

P.E.N.G.U.I.N.’s CV follows the Strategy Pattern design idiom in order to facilitate runtime transitioning between different classifiers and preprocessor that will be needed for each task’s unique requirements. The remaining portion of the project is implemented using object oriented design principles for easy modification and legibility. The Strategy Pattern is not necessary of the non-CV portions of the project as they will not require large changes during runtime.

5.8 Interfaces for End-Users

P.E.N.G.U.I.N. will come with a command line interface to enable easy modifications of values during competition. The CLI is not meant for large changes in the P.E.N.G.U.I.N. software, rather it is mostly used for modifications of simple variables. P.E.N.G.U.I.N. will also have a GUI that will be used during tests. The GUI is exclusively to be used during testing and to have an easy way to control the AUV in case someone not familiar with CLIs has a desire to control the AUV.

5.9 Hierarchical Organization of Source Code

P.E.N.G.U.I.N. is started by launching the CLI which will set up the AUV class which will oversee all the communication and functionality of the AUV through the use of ROS. The AUV class manages all the modules for controls, sensors, and tasks such as Navigation and Computer Vision. The Arduino module will then receive information that is sent by the Navigation module through ROS and commands the individual hardware components based off of the directions given by the Computer Vision module.

5.10 How to build and/or generate the system's deliverables (how to compile, link, load, etc.)

To start P.E.N.G.U.I.N. you must clone the Robosub repository from GitHub on a computer running Ubuntu 18.04. By running robosub.py with python it will then automatically install all the dependencies needed to run P.E.N.G.U.I.N. with a series of scripts. After the installation and a restart of the system, running the python code again with all of the Arduinos properly connected will allow the user to operate P.E.N.G.U.I.N..

5.11 Abstract Classes and Interfaces Used

P.E.N.G.U.I.N. uses interfaces for the Computer Vision. Specifically it uses an Preprocessor interface and a Classifier interface. These interfaces are used to ensure that the proper methods are used for every component of the Computer Vision given that classifiers and preprocessors will be changed during runtime.

Additionally the task handling portion of the ROS module uses a Task interface to ensure consistency of implementation throughout each task despite each task having different needs.

6. Detailed System Design

6.1 ROS Module (Module)

6.1.1 Responsibilities

The ROS module is responsible for communication between each node such as the main computer node and Arduino node. ROS will enable the main computer and the Arduinos to publish and subscribe to data.

6.1.2 Constraints

The constraints of the ROS module requires older versions of operating systems. ROS is also limited to only being able to run on Ubuntu.

6.1.3 Composition

ROS is composed of a network of ROS nodes that send and receive data with publishers and subscribers through the use of streaming topics.

6.1.4 Uses/Interactions

The ROS module is used by all the other modules to send and receive information with each other.

6.1.5 Resources

The ROS module has access to the data that is published to it, which come from the main computer and Arduinos

6.1.6 Interface/Exports

Provided in source code.

6.2 Computer Vision (Module)

6.2.1 Responsibilities

The Computer Vision is responsible for detecting objects throughout the course, confirming that those objects are the ones associated with the task at hand and providing information to the other modules to help navigate throughout the course or to a specific task.

6.2.2 Constraints

The CV is constrained by the two cameras the AUV has at its disposal one front facing and one bottom facing, additionally it is constrained by having limited CPU power. This means that techniques must take into CPU usage into account. Additionally, CV is constrained by the nature of the competition. Each run has a time limit which means that each CV algorithm

must be accurate, efficient and simple. We are hoping that YOLOv3 helps with the time limit constraint.

6.2.3 Composition

The CV is composed of a series of different Detectors, which implement different Classifiers and Preprocessor in order to find their intended targets. Additionally each specific detector has differing built-in methods that will help it fulfill its intended purpose.

6.2.4 Uses/Interactions

The CV interacts with the ROS module to provide navigation information to the Arduino module.

6.2.5 Resources

The CV has access to an Intel i5 Processor as well as an Nvidia GTX 1070-Ti GPU

6.2.6 Interface/Exports

Provided in Source Code.

6.3 Arduino (Module)

6.3.1 Responsibilities

The Arduino Module is responsible for the communication between the main computer and the hardware.

6.3.2 Constraints

A constraint and limitation of the Arduinos include its limited memory space. Another constraint and limitations of the Arduinos are the limited pin spaces on the Uno Arduinos

6.3.3 Composition

The Arduino Module is composed of all Arduinos and hardwares

6.3.4 Uses/Interactions

The Arduino Module interacts with the ROS module to provide or receive information to and from the main computer as well as the hardware

6.3.5 Resources

The Arduino Module have access to 1 Arduino Mega and several Arduino Unos

6.3.6 Interface/Exports

Provided in Source Code.

7. Detailed Lower level Component Design

7.1 Detector.py

7.1.1 Classification
This file is an interface which describes the methods all detectors must implement,it is a component of CV

7.1.2 Processing Narrative (PSPEC)
It is a python file that is loaded onto the AUV and makes sure that all Detector implementations contain the proper methods needed for runtime.

7.1.3 Interface Description
The Detector interface has preprocessor and classifier required fields, as well as a detect abstract method.

7.1.4 Processing Detail

7.1.4.1 Design Class Hierarchy
All detectors inherent from Detector.py

7.1.4.2 Restrictions/Limitations
Must use as little CPU/GPU resources as possible.

7.1.4.3 Performance Issues
Some detectors may be slower or faster depending on the classification method which is implemented for that particular detector

7.1.4.4 Design Constraints

7.1.4.5 Processing Detail For Each Operation

7.2 CVController.py

7.2.1 Classification
This file is an interface which lets Houston.py and the Camera interact

7.2.2 Processing Narrative (PSPEC)
It is a python file that is loaded onto the AUV which will help the coordinates of the AUV be sent to Houston.py

7.2.3 Interface Description

7.2.4 Processing Detail

7.2.4.1 Design Class Hierarchy

7.2.4.2 Restrictions/Limitations
Must use as little CPU/GPU resources as possible.

7.2.4.3 Performance Issues

7.2.4.4 Design Constraints

7.2.4.5 Processing Detail For Each Operation

7.3 Houston.py

7.3.1 Classification
This file is an interface which will receive data from Computer Vision to send out instructions to the hardware

7.3.2 Processing Narrative (PSPEC)
It is a python file that is loaded onto the AUV which helps all the components of the AUV to work together

7.3.3 Interface Description
The Houston interface utilizes task manager, navigation and computer vision classes.

7.3.4 Processing Detail

7.3.4.1 Design Class Hierarchy

7.3.4.2 Restrictions/Limitations
Must use as little CPU/GPU resources as possible.

7.3.4.3 Performance Issues
Some tasks may be slower or faster depending on how complicated the task may be

7.3.4.4 Design Constraints

7.3.4.5 Processing Detail For Each Operation

7.4 Navigation.py

7.4.1 Classification
This is an interface file which will will publish directions onto ROS for the motor's navigation

7.4.2 Processing Narrative (PSPEC)
It is a python file that is loaded onto the AUV which will help with the navigation of the AUV

7.4.3 Interface Description
The Navigation interface utilizes ROS

7.4.4 Processing Detail

7.4.4.1 Design Class Hierarchy

7.4.4.2 Restrictions/Limitations
Must use as little CPU/GPU resources as possible.

7.4.4.3 Performance Issues
Navigation is dependant on task manager and Houston, runs as fast as the classes will run

7.4.4.4 Design Constraints

7.4.4.5 Processing Detail For Each Operation

7.5 HardwareInterface.ino

7.5.1 Classification
The kind of component, such as a subsystem, class, package, function, file, etc.

7.5.2 Processing Narrative (PSPEC)
A process specification (PSPEC) can be used to specify the processing details

7.5.3 Interface Description

7.5.4 Processing Detail

7.5.4.1 Design Class Hierarchy
Class inheritance: parent or child classes.

7.5.4.2 Restrictions/Limitations

7.5.4.3 Performance Issues

7.5.4.4 Design Constraints
7.5.4.5 Processing Detail For Each Operation

8. Database Design

This project did not require any database.

9. User Interface

9.1 Overview of User Interface

The user interface is in the form of a command line interface. It will allow users to adjust the values of some of the variables used in P.E.N.G.U.I.N. and will display logs and the status information of P.E.N.G.U.I.N. using the built in commands.

9.2 Screen Frameworks or Images

9.3 User Interface Flow Model

help - logging, model, motor, navigation, tasks,
test logging - on, off, toggle, state
model - (model number),
view motor - on, off,
toggle, state navigation -
cv, keyboard
tasks - view, set, reset

10. Requirements Validation and Verification

The methodologies and testing strategies identified at this point include four major approaches: TESTING, DEMONSTRATION, INSPECTION, and ANALYSIS with various variations to adapt to the characteristics:

- **Testing** using additional ad-hoc created software including a correlation testing unit.
- **Demonstration** of the specified capability
- **Inspection** of the software code possibly using additional inspection techniques
- **Analysis** of the specific code operation/algorithm to prove functionality.

Requirements Related to: **1. Robot Operating System**		
Requirement No.	Requirement Description	Method for Testing
4.1.1-1	Robot Operating System shall be installed on Ubuntu 18.04.	Inspection
4.1.1-2	Robot Operating System shall have ROS Melodic Loggerhead installed.	Inspection
4.1.1-3	Robot Operating System shall receive data from IMU.	Inspection
4.1.1-4	Robot Operating System shall receive data from Cameras.	Inspection
4.1.1-5	Robot Operating System shall receive data from ATmega2560.	Inspection
4.1.1-6	Robot Operating System shall send data to ATmega2560.	Inspection
4.1.1-7	Robot Operating System shall be run on the Computer.	Inspection

Requirements Related to: **2. User Interface**		
Requirement No.	Requirement Description	Method for Testing
4.1.2-1	The User Interface shall be a CLI.	Demonstration
4.1.2-2	The User Interface shall be used with ROS.	Inspection
4.1.2-3	The User Interface shall provide methods of changing AUV parameters.	Demonstration
4.1.2-4	The User Interface shall provide AUV testing capabilities.	Demonstration

Requirements Related to: **3. AUV Tasks**		
Requirement No.	Requirement Description	Method for Testing
4.1.3-1	The AUV Tasks shall be to Find the Casino.	Demonstration
4.1.3-2	The AUV Tasks shall be to Enter the Casino (Gate).	Demonstration
4.1.3-3	The AUV Tasks may be to Shoot Craps.	Demonstration
4.1.3-4	The AUV Tasks may be to Buy a Gold Chip.	Demonstration
4.1.3-5	The AUV Tasks may be to Try the Slots	Demonstration
4.1.3-6	The AUV Tasks may be to Hit the Jackpot.	Demonstration
4.1.3-7	The AUV Tasks may be to Play Roulette.	Demonstration
4.1.3-8	The AUV Tasks may be to Cash in Your Chips.	Demonstration

Requirements Related to: **4. AUV AI**		
Requirement No.	Requirement Description	Method for Testing
4.1.4-1	The AUV AI shall be able to Find the Casino	Analysis
4.1.4-2	The AUV AI shall be able to Enter the Casino (Gate).	Analysis
4.1.4-3	The AUV AI may be able to Shoot Craps.	Analysis
4.1.4-4	The AUV AI may be able to Buy a Gold Chip.	Analysis
4.1.4-5	The AUV AI may be able to Try the Slots.	Analysis
4.1.4-6	The AUV AI may be able to Hit the Jackpot.	Analysis
4.1.4-7	The AUV AI may be able to Play Roulette.	Analysis
4.1.4-8	The AUV AI may be able to Cash in Your Chips.	Analysis

Requirements Related to: **5. Arduino**		
Requirement No.	Requirement Description	Method for Testing
4.1.5-1	The Arduino shall receive data from the Sensors.	Inspection
4.1.5-2	The Arduino shall send commands to the Pneumatic Control.	Inspection
4.1.5-3	The Arduino shall send commands to the Motor Control. .	Inspection
4.1.5-4	The Arduino shall receive data from the Computer.	Inspection
4.1.5-5	The Arduino shall send data from the Computer.	Inspection
4.1.5-6	The Arduino shall be connected to ROS.	Inspection

Requirements Related to: **6. Computer Vision**		
Requirement No.	Requirement Description	Method for Testing
4.1.6-1	The Computer Vision shall receive data from the Cameras.	Inspection
4.1.6-2	The Computer Vision shall output processed data.	Inspection
4.1.6-3	The Computer Vision shall provide coordinates.	Inspection
4.1.6-4	The Computer Vision shall detect objects associated with tasks	Inspection
4.1.6-5	The Computer Vision shall detect tasks	Inspection
4.1.6-6	The Computer Vision shall provide depth perception	Inspection
4.1.6-7	The Computer Vision shall use classifiers for object detection	Inspection
4.1.6-8	The Computer Vision shall provide distances from objects	Inspection
4.1.6-9	The Computer Vision shall provide directions to ROS	Inspection

Requirements Related to: **7. Sensors**		
Requirement No.	Requirement Description	Method for Testing
4.1.7-1	The Sensor data shall be published to ROS.	Inspection

Requirements Related to: **8. Pneumatic Control**		
Requirement No.	Requirement Description	Method for Testing
4.1.8-1	Pneumatic Control shall be capable of receiving commands from ROS.	Inspection

Requirements Related to: **9. Motor Control**		
Requirement No.	Requirement Description	Method for Testing
4.1.9-1	Motor Control shall receive commands from the Arduino.	Inspection
4.1.9-2	Motor Control shall operate at command level.	Inspection
4.1.9-3	Motor Control shall allow the AUV full horizontal and vertical movement.	Demonstration

11. Glossary

ROS - Robot Operating System

CV - Computer Vision

AUV - Autonomous Underwater Vehicle

CLI - Command Line Interface

Hz - Hertz

IMU - Inertial Measurement Unit

USB - Universal Serial Bus

IDE - Integrated Development Environment

12. References

Website address referenced

1. Robosub Competition
   - http://www.robonation.org/competition/robosub
2. Operating System
   - http://wiki.ros.org/lunar/Installation/Ubuntu
3. OpenCV Library Documentation
   - https://docs.opencv.org/trunk/index.html
4. Robot Operating System Documentation
   - http://wiki.ros.org/Documentation
5. Arduino
   - https://www.arduino.cc/en/Guide/Introduction
   - https://www.arduino.cc/en/Reference/Wire

Documents Referenced

1. Robosub Draft Tasks 2018
   a. http://www.robonation.org/sites/default/files/2018%20RoboSub%20Tasks_DRAFT%2011%2001%2017.pdf
2. YOLO Version 3 Report
   a. https://pjreddie.com/media/files/papers/YOLOv3.pdf