Just Keep Swimming: A review of Artificial Intelligence used in different types of unmanned underwater vehicles (UUVs)

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Abstract

Artificial Intelligence (AI) is the result of enforcing neural intelligence into machines. Any machine capable of comprehending its environment and take according action is enacting AI. In recent decades AI has enabled numerous impressive discoveries across all scientific fields. In this paper different types of Unmanned Underwater Vehicles (UUVs) and the applications of Artificial Intelligence are reviewed and briefly explained.

UUVs provide the ability to explore the vast ocean deeper than any human diver is capable of reaching. Combining AI with machines designed for an unpredictable underwater environment has opened a huge number of possibilities. These machines can provide data and execute missions that a human would be incapable of.

This paper delves into early development and applications of UUVs being exposed to extreme environments such as the Antarctic Ocean. Including the recent creation of the first Underwater Robotic Avatar. It explains the AI utilized to provide the ability to maneuver, navigate and map new non-linear environments successfully. It is also shown that despite the various types of UUVs, many of the AI methods are commonly required in each of them.

Contents

1 Abbreviations

Abbreviations	Meaning
AI	Artificial Intelligence
UUV	Unmanned Underwater Vehicles
RUV	Remote Underwater Vehicles
ROV	Remotely Operated Vehicles
TROV	Telepresence Remotely Operated Vehicles
AUV	Autonomous Underwater Vehicles
INS	Inertial Navigation System
FLC	Fuzzy Logic Controller
NN	Neural Networks (NN)
HOSM	High Order Sliding Mode
SMC	Sliding Mode Controller
LQG	Linear Quadratic Guassian
PID	Proportional Integral Derivative
DR	Dead Reckoning
ANS	Acoustic Navigation System
GN	Geophysical Navigation
KFs	Kalman Filters
PFs	Particle Filters
SLAM	Simultaneous Localisation and Mapping algorithms
EKF	Extended Kalman Filters

2 Introduction

A large portion of Earth is habited by water that can unarguably reach over 5km in depth, making it substantially difficult to explore, map and even access. The ocean has been proven to have played a vital role in the beginning and continuation of life on Planet Earth. Understanding the ocean, its existence and the habitats within could help the human race in some of the biggest challenges currently faced. This has led to the development of unmanned underwater vehicles (UUVs).

UUVs are vehicles or drones that can be submerged to effectively explore either linear or non-linear underwater environments. UUVs have an abundance of applications, such as seafloor mapping, monitoring ocean health, monitoring effects of global warming and submerged construction or repairs . This review will explain some different types of UUVs, the technology implemented and consider possible predicaments. The sections consist of RUVs, AUVs and Robotic Avatars. The Objective of this paper is to provide a basic understanding of UUVs and the variations available for further research.

3 RUVs (ROVs, TROVs)

Remote underwater vehicles (RUV) / remotely operated vehicles (ROV) and telepresence remotely operated vehicles (TROV) are types of UUVs that require human interaction, often achieved by a tether connecting the vehicle to a vessel. A ROV is essential as an underwater robot that allows the vehicle's operator to remain in a comfortable environment while the ROV works in the hazardous environment. [1] TROV is an ROV that implements virtual reality in the control design to provide the operator with a more immersive experience.

A quintessential example of a TROV is the "1992 Antarctic Telepresence Experiment" [2]which explored under the Antarctic ice sheets using a TROV. The purpose of this experiment was to observe marine life that may exist below the ice sheets. Partially funded by NASA this experiment also aimed to test virtual reality technology which later came to be implemented in space exploration.

3.1 Control

"A control system comprises of an array of processes that stabilizes the underwater vehicle, so that it obeys the instructions programmed by the operator"[3]. Control of a ROV is a multilayered system, beginning with data of the ROV and its surrounding environment supplied by sensors. AI methods are then implemented in order to convert complicated data provided into manageable information for the user to understand, finally a control interface is designed for an operator to manipulate the vehicle.

A control interface often has a standard quota; displays providing visuals often of the local environment including the ROV and a form of controlling mechanism. Although in the study by Carol Stoke et al[2] a TROV was used to explore the Antarctic sea floor, this telepresence ROV control interface included a pair of Crystal Eyes(TM) glasses. Which allowed the operator to observe the surroundings in a virtual environment.

Despite different innovative control interfaces it is often challenging to operate an ROVs with human interaction alone. A study by David Scaradozzi et al [4] attempted to tackle this problem further by implementing a main ROV with a micro ROV attached to carry out the task. The primary ROV assists the micro ROV in navigation, "The system includes vision sensors in the control loop and combines pattern recognition and optical flow techniques" [4].

Also numerous AI control methods have been developed to assist, one commonly implemented heuristic is the Fuzzy Logic Controller (FLC). FLC's have proven to be very effective at handling nonlinear environments by embedding human reasoning. As a result FLC is an appropriate method for handling an unpredictable environment such as the ocean and has been utilized in many ROV's. Another effective control method is Neural Networks (NN) which are effective in both linear and nonlinear function and have proven to be a powerful solution in many fields. Both of these can also be combined to create a Neuro-Fuzzy; other control methods consist of High Order Sliding Mode (HOSM), Sliding Mode Controller (SMC), Linear Quadratic Guassian (LQG) and Proportional Integral Derivative (PID).

3.2 Navigation and Localization

Navigation and localization correlate with ROV control without which it would be near impossible to operate. There are several components that assist with this complication such as attached sensors and submersible cameras. However these alone are not sufficient for the operator to successfully and safely navigate, hence the importance of AI methods.

One such method is INS "The Inertial Navigation System (INS) senses acceleration in all planes to gain a vector from a known datum to arrive at a resolved position based upon vector movement from the known datum."[5]. Another is Dead Reckoning (DR) which is only applicable when ROV location and goal location is determined, with this information the distance and time can be calculated.

However DR can accumulate error rates over long distances meaning regular accurate position updates are required. Acoustic Navigation System (ANS) can calculate an estimation of the ROVs location by sending an acoustic signal then estimating the range of a landmark.

4 AUVs

Autonomous underwater vehicles (AUVs) are similar to ROVs only fully autonomous. It requires no human interaction once in the water and depends upon its sensory data and algorithms to safely traverse through its environment. “SPURV (The Self Propelled Underwater Research Vehicle)” was developed by Stan Murphy and Bob Francois in 1957 in the Applied Physics Laboratory at the University of Washington (Remotely Operated Vehicle Committee of the Marine Technology Society).” [6]. AUVs certainly appear to have several advantages over ROVs, one in particular is its wireless abilities. Since it requires no tether between it and an operator it can reach more remote locations, also human fatigue is no longer an issue.

4.1 Control

Contrary to ROVs, an AUVs control system is fully autonomous meaning it requires control models to take data provided from sensor readings and output accurate results of the required velocity and positioning. “AUV controller has three major operations: planning, control and error diagnostic” [6]. These algorithms are utilized within control architectures; a research article by Kimon P. Valavanis et al[7] reviews currently developed control architectures: Hierarchical, Heterarchical, Subsumption, and Hybrid architecture.

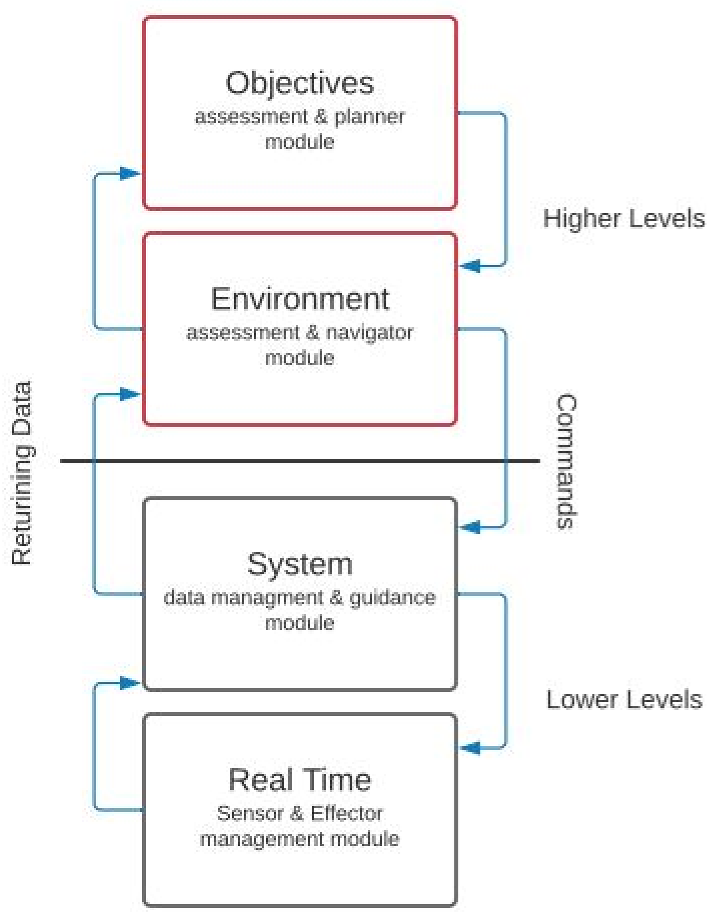

Figure 1: Hierarchical Architecture

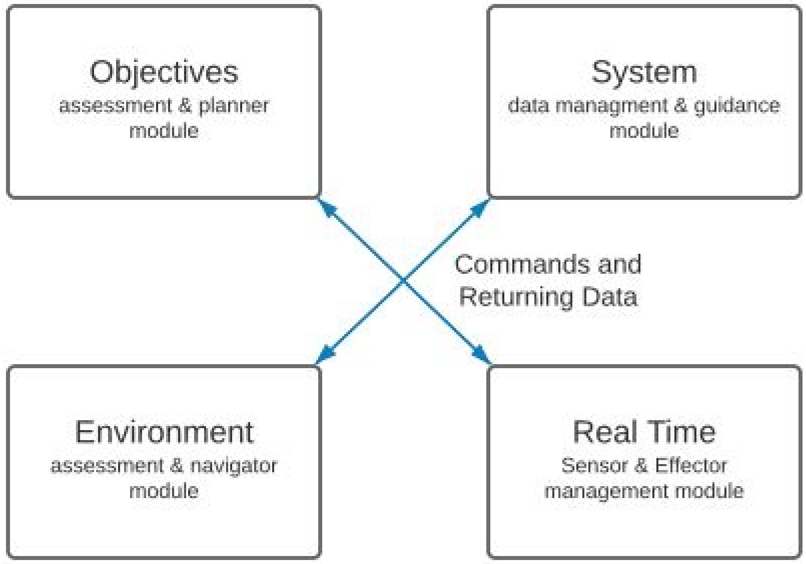

Figure 2: Heterarchical Architecture

As shown by the arrows in figures 1-4 each architecture communicates differently. Hierarchical implements a top down layout, higher levels are designated to manage objectives and lower levels for executing certain functions to achieve these objectives. Heterarchical however utilizes a parallel structure allowing each section to directly interact without supervision. Subsumption also consists of a parallel system, each separate section processes particular sensory data and produces related commands, importance levels are still triggered by sensor data.

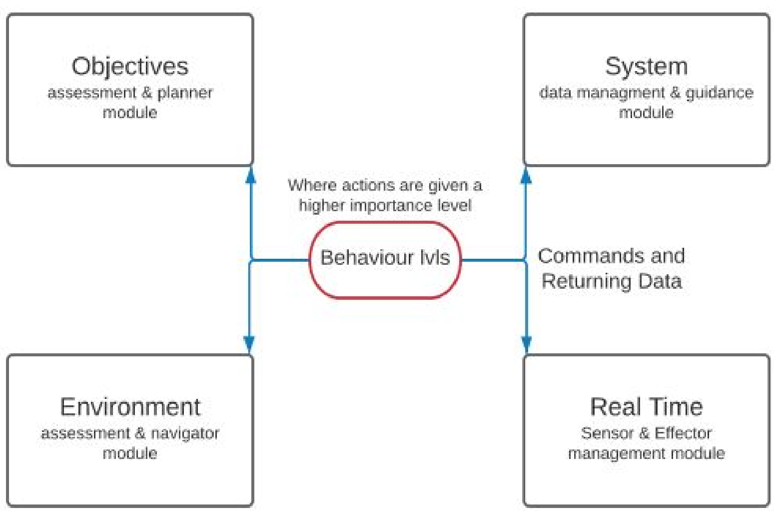

Figure 3: Subsumption Architecture

Finally Hybrid is when two of these architectures are applied, Hierarchical is implemented for higher levels with either Heterarchical or Subsumption used for lower levels executing normal operations. Higher levels are where objective and environmental data and decisions are processed leaving the lower levels to manage real time and system data and problem solving. In case of an emergency higher levels will override the lower levels to execute the correct maneuver.

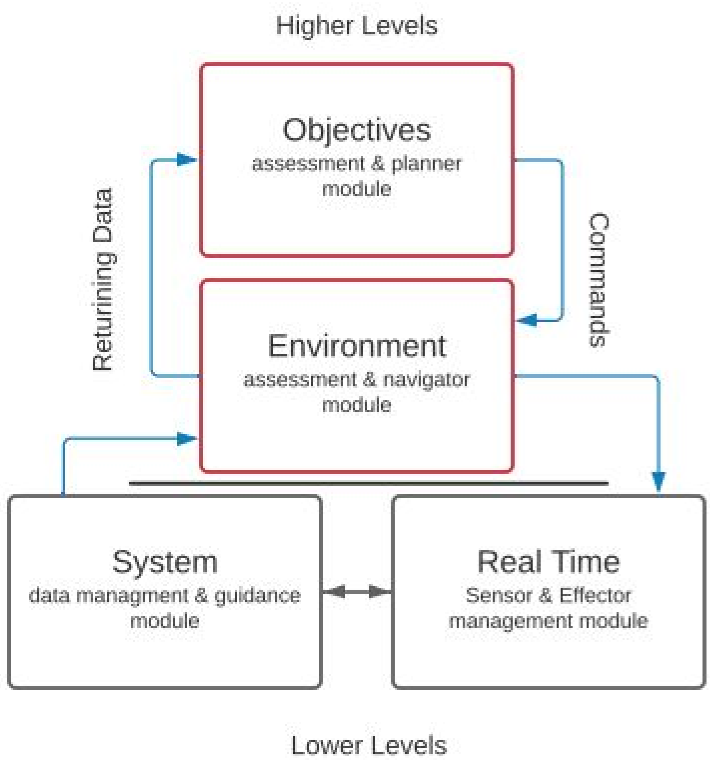

Figure 4: Hybrid Architecture

4.2 Navigation and localization

ROVs use various automated methods, such as INS and ANS, to assist in navigation and localization which are also implemented in AUVs. One other method of navigation utilized by both ROVs and AUVs is Geophysical Navigation (GN) which uses landmarks and environmental features in order to gain the UUVs local position. However whereas in ROVs they are used to assist the operator, AUVs are fully autonomous meaning these methods provide data to AI filtering systems to process and make decisions upon.

Filtering algorithms fundamentally make predictions regarding the position of an autonomous machine, the currently developed methods are Kalman Filters (KFs), Particle Filters (PFs) and Simultaneous Localisation and Mapping algorithms (SLAM). KFs as explained by Stutters et al use sensory data while factoring in possible sensory noise to get a best estimate of the AUVs current position. This estimate along with observation data is then utilized to make a prediction of the next step. Since KFs only require the previous state making them fast and ideal for reasoning in real time although limited. Due to its limitations the KF is only suitable for linear environments, Therefore Extended KF was developed to implement first-order Taylor to construct a viable option for non-linear environments.

SLAM is often implemented alongside methods such as EKFs, SLAM uses observation data and landmarks to generate a map of its environment. Sonar is also commonly used alongside AUVs with SLAM integrated in order to provide landmark data in a non-linear environment. With these landmarks and a previously predicted position SLAM continuously calculates the AUVs location and updates a generated map of the immediate surroundings.

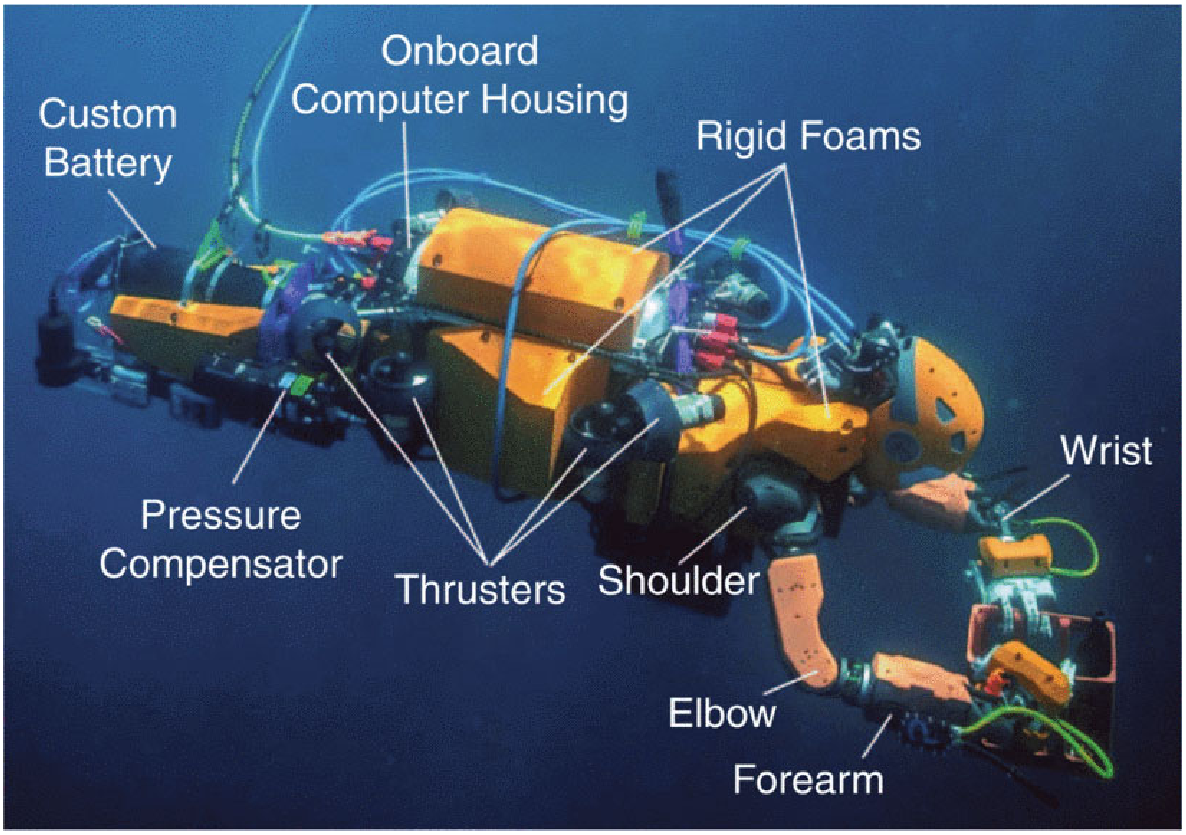

Figure 5: Ocean One [8]

5 Robotic Avatars

Ocean One in figure 5 developed by Oussama Khatib from Stanford University California[8] made its debut in 2016 as the first Robotic Avatar to successfully navigate an ocean environment successfully. The idea behind Ocean One is to provide the ability to delicately interact with the environment and artifacts below the safe depth that human divers are able to venture. As stated by Oussama Khatib et al[8] Ocean One's first mission on 11Th of April 2016 consisted of it successfully exploring the Lune wreckage, communicating with assisting divers using common hand signals and recovering an archaeological artifact.

5.1 Control

Ocean One, by implementing artificial arms, wrists and hands on the UUV, pushes the commonly used ROV control system to the next level. With this new level of controllability required the usual ROV or TROV operator designs do not provide the level of interaction necessary. The operator design for the Ocean One also includes two haptic control devices that provides the capability to move the avatars arms, wrists and hands. “The robot mimics the motion of the pilot's hands with its own, and the robot's senses are shared with the pilot: the pilot sees what the robot sees and feels what the robot feels”[8].

6 Conclusion

A review of the different types of UUVs has been conducted including ROVs, TROVs, AUVs and Robotic Avatars. Along with a brief look at the different control methods utilized in each as well as navigation and localization methods in ROVs, TROVs and AUVs. These navigation and localisation systems are also implemented in the Ocean One Robotic Avatar discussed previously. It has been shown that many of these UUV systems share AI methods that allow for effective exploration and mapping of a non-linear underwater environment. Detailed graphs of some of these complicated systems have been designed to assist in the digestion of this dense information. A large number of reliable informative sources have also been provided if the reader wishes to conduct further research into this subject.

This review has shown that over three decades huge accomplishments have been made in the field of UUVs starting with an early ROV exploring below the Antarctic ice sheets in the 1990s. Through to an advanced Robotic Avatar successfully carrying out a mission in 2016. Along with various methods to safely transverse and map such an unpredictable unknown environment being developed and improved on along the way. With this information one can imagine and research the various applications of these impressive machines. It appears that the UUV field is one to keep a close watch on in the coming future.

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