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Ship Motion Prediction with Deep Learning using IMU Data and Images

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2022

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# Preface

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# Abstract

(English)

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# Extended abstract

(Nederlands)

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# List of Abbreviations

AI: Artificial Intelligence

ASV: Autonomous Surface Vessel

IMU: Inertial Measurement Unit

LSTM: Long Short Term Memory

CNN: Convolutional Neural Network

NN: Neural Network

ReLU: Rectified Linear Unit

# Introduction

In the last few years, the world has seen an exponential increase in technological advancements. This evolution brought with it a new influence of autonomous systems controlled by artificial intelligence (AI). Each of these systems designed with its own goals and characteristics, optimized for its task. More and more of these systems are being deployed as a direct or indirect replacement for tasks humans could do, but also, for tasks humans can’t physically do. And because these autonomous systems are optimized for specific jobs, they can be more accurate and faster at it than humans.

Because autonomous systems can replace the position of a human, they are especially useful in military operations. They can take over the role of a human in dangerous environments such as an active warzone and therefore eliminate the risk of someone’s life. On the other hand they can also be used as a complimentary asset, providing support and aid in logistics. More and more of these autonomous assets such as drones, surface vessels, tanks and reconnaissance vehicles are being deployed around the world for various different objectives. But with this increasing amount of autonomous assets, there is need for communication between them, to allow them to work together and be aware of the state of each other when they need to interact.

Afbeelding met water, buiten, geel, transport

Automatisch gegenereerde beschrijving“*Interoperability is the key that acts as the glue among the different units within the team, enabling efficient multi-robot cooperation.”* (Royal Higher Institute for Defence, 2022)

Figure 1: Autonomous Surface Vessel (ASV) (Royal Higher Institute for Defence, 2022)

The Robotics & Autonomous Systems lab of the Belgian Royal Military Academy is currently working on two autonomous vehicles in two projects named MarSur and MarLand. Project MarSur is developing an autonomous surface vessel (ASV) (figure 1) that will interact with a drone that is being developed by project MarLand. The drone needs to be able to take-off and land on the ASV. This proposes a challenge since the ASV is continuously moving due to sea waves and can therefore not provide a stable landing surface. For a smooth landing to be possible, the ASV must be capable to determine its state in a three dimensional space and predict its movement in the ocean. These predictions must provide an accurate estimation over a future time series to determine the optimal time for the drone to land. This optimal time is a period where the ASV is as stable as possible so that the impact on the drone will be minimized. To facilitate these predictions, the ASV is equipped with an on board computer and multiple sensors.

## ASV sensors

The ASV is equipped with a ZED-mini stereo IMU camera (figure 2) (StereoLabs, Paris, France). This is a multipurpose sensor that can provide both video from its cameras and numeric data from its Inertial Measurement Unit (IMU), to accurately describe the state of the sensor and its surroundings. The ZED-mini has two built-in motion sensors: an accelerometer and a gyroscope. These provide a real-time data stream at 800Hz of the movement of the sensor along the rotational and translational axes. These types of movements will be described more in depth in the next part of the introduction.

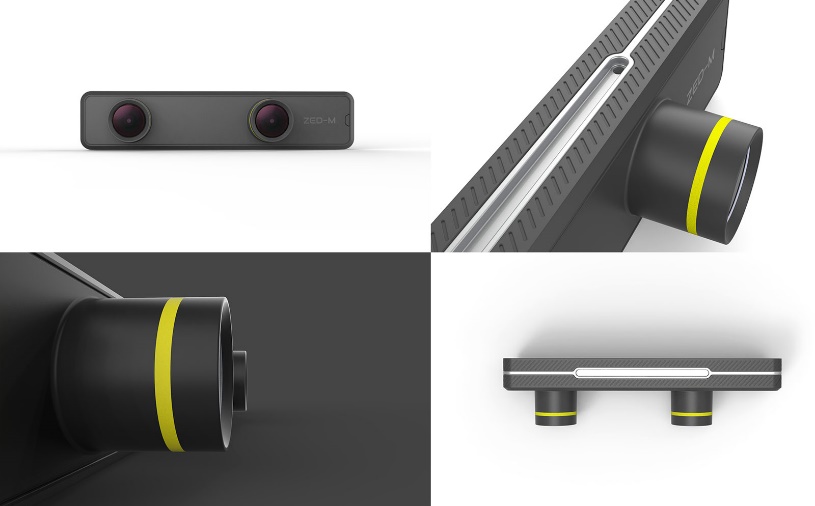


Figure 2: ZED-mini IMU stereo camera (StereoLabs, Paris, France)

The two forward facing lenses on the ZED-mini provide stereo video. This can be used to map the objects in front of the ZED-mini in a three dimensional space. A stereo image is a combination of two separate images that are captured from two slightly offset point-of-views (PoV) such as the lenses on the ZED-mini. These two PoV’s imitate the left and right human eye and create a perception of depth when the two images are fused together to create one stereo image. This process is called stereoscopy. In computer vision, these two images can be compared to each other to extract three dimensional information from two dimensional images.

The data from the motion sensors and the camera’s will be used as input to predict the future movement of the vessel. The deep learning models will digest a sequence of data and images of the past to predict a sequence of data in the future. To do this, the model will try to find trends in the data and continue these trends with regards to the information gathered from the images with incoming waves. Two important parameters will be how much historic data the model takes as input and how much data it can accurately predict in the future.

## Ship motion in six degrees of freedom

The motion of a ship or any rigid object in a three-dimensional space can be described in six degrees of freedom. These six degrees can further be divided into two categories: translational and rotational movement. Where translational movement is movement along one of the three axes in a three dimensional space, rotational movement is the rotation of an object around these same three axes. These three reference axes run through the center of mass of the ship and are laid out as follows:

* Vertical Z-axis runs vertically through the vessel
* Transverse Y-axis runs horizontally across the vessel
* Longitudinal X-axis runs horizontally through the length of the ship

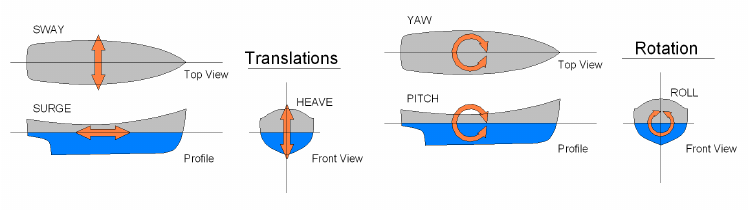


Figure 3: Translational movement (right) - Rotational movement (left)

Each type of motion, translation or rotation, among each of the three axes has a different impact on the movement of the vessel (figure 3). The translational movements are expressed in linear units such as meters and are named as followed:

* Sway: side to side movement along the transverse Y-axis
* Surge: forward and backwards movement along the longitudinal X-axis
* Heave: upward and downward movement along the vertical Z-axis

The rotational movements are expressed in angular units and are named as followed:

* Yaw: rotational movement around the vertical Z-axis
* Pitch: rotational movement around the transverse Y-axis
* Roll: rotational movement around the longitudinal X-axis

To predict the motion of a ship, one must differentiate between these different motions. Together they form the complete three-dimensional orientation of a ship. But not all of them need to be predicted. Surge and yaw are controlled by the ASV’s autonomous systems and are respectively controlled by the amount of thrust and the rudder position – steering the ship. Surge and yaw will also not change very drastically during the landing or take-off of a drone, since this behavior would directly impede our main goal of providing a smooth landing. On the other hand, the sway of a ship, also referred to as drift, is primarily caused by sideways winds or currents in the water and will have minor impact on the stability of the ship whenever the drone needs to take-off or land. If the drone aims for a GPS-tracker present in the ASV, it will follow the vessels movement no matter the sway.

This leaves three main factors remaining that have the most impact on the stability of the vessel: roll, pitch and heave. These three movements have one thing in common, they are all directly caused by the waves in the ocean and are very hard to control. Different techniques exists to dampen these movements and keep the vessel as stable as possible, but most of them are infeasible or ineffective on smaller vessels. To provide a stable landing zone for the drone, the pitch and roll of the vessel should remain constant and as close to zero as possible. For the model to determine this window of landing/take-off opportunity, different parameters will have to be defined such a the maximum difference in consequent prediction values, the length of the window and the interval in which all predicted values should lie. For example the roll and pitch values should all remain in a [-3°, 3°] interval, the stable window duration must be at least five seconds and there should be no difference larger than two degrees between consecutive predicted values.

## Technologies

To develop the deep learning neural networks, Python will be used.

# Objectives

# Materials and methods

DATA, Technologies, ml models

# References

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