1. Home

The purpose of navigation is to determine the position, velocity and attitude of platforms, humans and animals. Obtaining accurate navigation commonly requires fusion between several sensors. The Autonomous Navigation and Sensor Fusion Lab (ANSFL) researches questions and challenges in the fields of autonomous navigation, inertial navigation systems, and estimation theory, as well as in related fields. Our focus is mainly (but not only) on marine platforms, such as autonomous underwater vehicles, buoys, drifters, and unmanned surface vehicles. The current research goals are to devise innovative inertial and sensor fusion algorithms, to develop novel inertial navigation system architecture, and to pioneer deep-learning-based navigation approaches.

1. Research

2.1 Deep Learning Based Navigation

Deep learning (DL) is a machine learning method that takes an input and uses it to predict an output. It is an automated formation of useful representations from data. Over the last five years, there have been major breakthroughs in deep learning algorithms in the fields of computer vision, speech recognition, text translation, and autonomous vehicles, among others.

This past year, deep learning has been applied to pedestrian dead reckoning (PDR), an indoor navigation approach. Instead of the traditional algorithms, deep learning frameworks were applied, both to recognize an activity and to determine a user position. Using these DL-based PDR algorithms resulted in dramatic improvements in the determination of a user position.

Our proposed research seeks to advance, drive, and implement original deep learning approaches for marine navigation, particularly for autonomous underwater navigation. This area of research is new and innovative, and we are among the first to pioneer it.

2.2 Enhanced INS/DVL Fusion for AUV Navigation

Fusion between an inertial navigation system (INS) and a Doppler velocity log (DVL) is commonly used in the navigation of autonomous underwater vehicles (AUV). In normal operating scenarios, the navigation accuracy of these systems is sufficient to enable the AUV to reach its goal. However, partial or complete DVL outages may occur if AUVs are operating in complex environments, such as passing over fish and other sea creatures, or those where the distance between the DVL and seafloor exceeds the DVL range. In such situations, the navigation solution will depend mainly on the INS solution, which will drift over time.

In this research, we aim to devise algorithms that facilitate velocity vector estimations for complete DVL outage situations over short time periods. We also intend to develop approaches for handling partial DVL availability conditions and for circumventing the drift of INS solutions. Currently, we are developing several algorithms and theories which are being tested through simulations and sea-based experiments.

2.3 Looking for Alternative INS Architectures

In general, an inertial navigation system (INS) consists of a navigation computer and an inertial measurement unit (IMU). If the initial conditions and IMU measurements are available, position, velocity, and orientation can all be calculated. The inertial sensors — namely, the accelerometers and gyroscopes — are part of the IMU. A traditional IMU architecture has three accelerometers to measure specific force and three gyroscopes to measure angular velocity, all arranged in orthogonal triads.

Experimental INSs were first developed in the 1920s. However, the sensor and computation technology at the time was not adequate for practical application. In February 1953, Draper’s team demonstrated an INS flight on a Boeing B-29, ushering in the INS era, initially for military use and later (1960s) for civil aviation. This was followed by the development of strapdown INS technology in the 1970s. Later, the micro-electro-mechanical system (MEMS) revolution brought about a dramatic reduction in INS size, weight, and power consumption, allowing INS technology to be incorporated into new applications and instruments, such as wildlife and livestock tracking, smartphones, and medical instruments. Throughout this period, immense efforts have been devoted to improving sensor performance and reducing their size. However, there has been no corresponding attention to the architecture of three orthogonal accelerometers and three orthogonal gyros, which has not changed significantly from the beginning of the modern INS era. In fact, it remains the only architecture available as an off-the-shelf product.

In this research, we seek to design new INS architectures and to build, evaluate, and derive relevant theory. Several architecture models are currently at different stages of development, so there is substantial potential to develop these further.

2.4 Buoy Height Measurements

A buoy is a floating platform equipped with sensors which measure both the shelf conditions and the surrounding physical conditions. Buoys can be classified into two categories: 1) moored buoys, which float on the surface but are secured to the seabed, so that their specific location is relatively fixed; and 2) drifting buoys (often of a Lagrangian type), which can move freely with winds and water currents. Moored buoys are commonly larger and more expensive than drifting buoys. Of the thousands of buoys currently deployed worldwide, the majority are drifting buoys.

Several applications require buoy data, the main one being weather forecasting. Here, buoy data is crucial, because the buoys can be deployed in remote ocean areas where no other source of valuable data is available. Continuous data from weather forecast buoys is also extremely valuable in tropical storm forecasting and in preprocessing data during a storm.

Among the important values commonly measured by buoys are wave height and period, the parameters which define the sea state. Either an expensive set of accelerometers/gyroscopes, or other sensors which rely on external sources such as GPS, can be employed to measure these parameters. The former is not suitable for drifting buoys, while the latter may be unavailable in some situations. Our goal in this research is to use only low-cost inertial measurement units, supported by appropriate new algorithms, to determine wave height and period with the necessary accuracy.

1. The Team
* Prior to joining the Department of Marine Technologies in October 2019, I was a research fellow at Rafael – Advanced Defense System Ltd (2007-2019), and an adjunct lecturer at the Technion — Israel Institute of Technology (2011–present). In July 2014, I worked in Prof. Yaakov Bar-Shalom’s Tracking and Fusion Lab at the University of Connecticut during a short sabbatical. I hold B.Sc. (2004) and M.Sc. (2006) degrees in Aerospace Engineering, and a Ph.D. in Mapping and Geo-information Engineering from the Technion (2011).
* Itzik Klein received B.Sc. and M.Sc. degrees in Aerospace Engineering from the Technion — Israel Institute of Technology in 2004 and 2007, respectively, and a Ph.D. in Civil Engineering from the Technion in 2011. At present, he is an Assistant Professor at the University of Haifa, heading the Department of Marine Technologies’ Autonomous Navigation and Sensor Fusion Lab. His research interests include navigation, novel inertial navigation architectures, autonomous underwater vehicles, sensor fusion, and estimation theory.
* Barak Or received B.Sc. (2016) and M.Sc. (2018) degrees in Aerospace Engineering as well as a B.A. (2016) degree in Economics from the Technion — Israel Institute of Technology. Prior to undertaking his current Ph.D. work, Barak served as an Algorithm Engineer at Qualcomm, in the fields of ML and DSP.
1. Teaching
* The course focuses on inertial navigation systems theory and applications. It is divided into three parts:

1) Inertial sensors: accelerometers and gyroscopes are addressed, including their principles of operation, different technology implementations, and sensor calibration.

2) Navigation mathematics: mathematical foundations, such as reference and coordinate frames, transformation matrixes and their properties, quaternions, and more.

3) Navigation systems: strapdown navigation kinematics, coarse alignment, and pedestrian dead reckoning.

* The course covers the fundamentals of linear and nonlinear estimation theory, as applied to INS fusion with external sensors and information. The course is divided into three parts:

1) Inertial navigation systems: a brief review of basic navigation mathematics fundamentals and INS kinematic equations.

2) Estimation theory: a presentation is given of optimal state estimation in a Kalman framework: linear Kalman filter, extended Kalman filter (EKF), and unscented Kalman filter (UKF). The two implementations derived are a total state and an error state.

3) INS fusion with external sensors and information: focusing on fusion between INS and global navigation satellite systems (GNSS), we derive two integration approaches —loosely coupled or tightly coupled architecture — and examine their usage in vehicle navigation and geodetic applications. We also address topics within the INS fine alignment process, indoor navigation fusion approaches, autonomous road vehicle navigation, and more.

* The course focuses on autonomous underwater vehicle navigation. After a brief review of inertial navigation theory and optimal state estimation in a Kalman framework, external sensors that are commonly used to aid the INS in AUV navigation are presented. We derive relevant theory, principles of operations, error sources and more, for Doppler velocity log (DVL), magnetometer, terrain-referenced navigation, and model-aided INS. Finally, we address several fusion approaches between the sensors and the INS.
1. Open Positions

Postdoctoral research fellow positions are available in navigation, deep learning, and sensor fusion. The positions will provide an opportunity to advance breakthrough scientific discoveries in those fields.

Appointments are for one year, with the possibility of renewal pending satisfactory performance and continued funding. Funds for some conference travel and research expenses will also be provided. Openings are available immediately, but there is flexibility in start dates.

While all candidates will be considered, the ideal candidate will have the following qualifications:

Position Requirements

* Applicants should have a doctorate degree in engineering, computer science, or a related discipline.
* Programming expertise in Python, MATLAB, or another programming language is essential.
* Experience with deep learning frameworks and tools is useful.

Applicants should apply directly for this position by email, attaching a curriculum vitae (CV) and a list of publications.