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F3

Faculty of Electrical Engineering
Department of Control Engineering

Master's Thesis

Indoor localization system for automated vehicles based on Ultra-Wideband technology

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Cybernetics and robotics

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Datavision s. r. o.
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ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Název diplomové práce anglicky:

Indoor localization system for automated vehicles based on Ultra-Wideband technology

Pokyny pro vypracování:

Seznam doporučené literatury:

[1] THRUN, SEBASTIAN, WOLFRAM BURGARD, AND DIETER FOX - PROBABILISTIC ROBOTICS, 2005 - Massachusetts Institute of Technology, USA (2005)
[2] GREWAL, MOHINDER S., ANGUS P. ANDREWS, AND CHRIS G. BARTONE - GLOBAL NAVIGATION SATELLITE SYSTEMS, INERTIAL NAVIGATION, AND INTEGRATION - John Wiley & Sons, 2020
[3] KELLY, ALONZO - MOBILE ROBOTICS: MATHEMATICS, MODELS, AND METHODS - Cambridge University Press, 2013
[4] MOORE, THOMAS, AND DANIEL STOUCH - A GENERALIZED EXTENDED KALMAN FILTER IMPLEMENTATION FOR THE ROBOT OPERATING SYSTEM, Intelligent autonomous systems 13. Springer, Cham, 2016. 335-348
[5] HOL, JEROEN D., et al. - TIGHTLY COUPLED UWB/IMU POSE ESTIMATION, 2009 IEEE international conference on ultra-wideband. IEEE, 2009
[6] LI, JIAXIN, ET AL. - ACCURATE 3D LOCALIZATION FOR MAV SWARMS BY UWB AND IMU FUSION, 2018 IEEE 14th International Conference on Control and Automation (ICCA). IEEE, 2018.

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III. PŘEVZETÍ ZADÁNÍ

Diplomantka bere na vědomí, že je povinna vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
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Acknowledgement / Declaration

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I hereby declare that I wrote the presented thesis on my own and that I cited all the used information sources in compliance with the Methodical instructions about the ethical principles for writing an academic thesis.

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Prague, May 21, 2021

Abstrakt / Abstract

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Klíčová slova: ultra-wideband, imu

Překlad titulu: Interiérový lokalizační systém pro autonomní prostředky s využitím technologie Ultra-Wideband

The most awesome abstract

Keywords: ultra-wideband, imu

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1.1 Section 1

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Chapter 2
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2.1 Section 1

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Chapter 3
Sensors

In chapter 3 the overview of used sensors and their properties is given. The main aim is to describe an ultra-wideband technology(UWB), an inertial measurement unit (IMU) and an odometry.

3.1 Inertial measurement unit

An inertial measurement unit (IMU) is a device that utilizes measurement systems such as gyroscopes and accelerometers to estimate the relative position, velocity and acceleration of a vehicle in motion[1]. The sensor is typically integrated with an on-board computational unit and could contain more sensors as a magnetometer or thermometer.

The gyroscopes measure changes its angular velocities and accelerometers a specific forces, which can be easily transformed into linear accelerations[1]. The IMU typically contains three orthogonal accelerometers and three orthogonal gyroscopes. Because of that, it can measure angular velocities and specific force in each axis to maintain a 6-DOF estimate of the pose of the vehicle (position (x, y, z) and orientation ($roll$, $pitch$, yaw). The process of the computation can be seen in the figure 3.1.

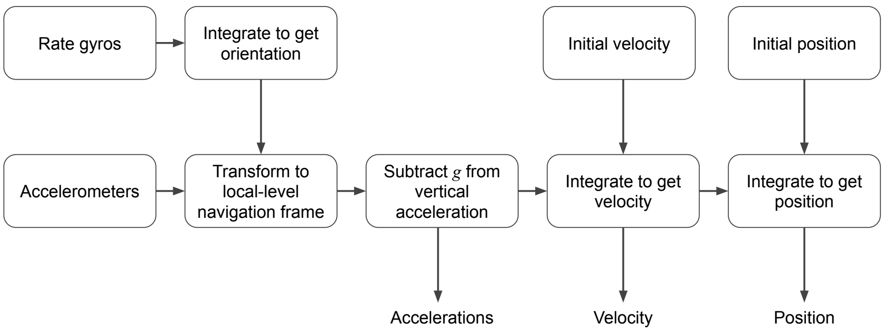

Figure 3.1. IMU block diagram [1]

There are two basic inertial navigation systems (also called mechanization architectures)[1][2] how the IMU is mounted to a vehicle.

- In **gimbaled systems**, the IMU is attached to a stabilized platform that maintains its inertial orientation as the vehicle manoeuvres.
- In **strap-down systems**, it is rigidly attached to the vehicle.

The mechanization determines which navigation equations are used during the estimation of linear accelerations and angular velocities of the vehicle.

IMU's are extremely sensitive to measurement errors given by properties of used gyroscopes, accelerometers and their mounting. As the data are once or twice integrated, any error in measurement causes a linear or quadratic error in the pose estimation. Even with a small measurement error, over time, the IMU's drift becomes significant, and it needs to be externally compensated. The IMU's provides a short-term stable solution because gyroscopes and accelerations have relatively low noise characteristics in a short period of time, and it has a high data rate (100 Hz - 200 Hz).

3.1.1 Accelerometers

Accelerometers can measure external forces acting on the vehicle. They measure a specific force relatively to a non-rotating inertial space in a specific direction. They are sensitive to all forces including gravity and fictitious forces[1]. These forces needs to be compensated during transformation to local-level navigation frame which is not inertial.

Mechanical accelerometers have a mass spinning steadily with respect to a free movable axis, they are not used a lot anymore, but they can be found in very old submarines.

Microelectromechanical systems based accelerometers (MEMS) TODO

3.1.2 Gyroscopes

Gyroscopes are used for estimating a rotational motion of a body, each gyroscope measures angular rate ω (inertial angular rotation) relatively to a non-rotating inertial space in one axis. There are basically three main categories of gyroscopes[1].

Mechanical gyroscopes have a mass spinning steadily with respect to a free movable axis, they are not used a lot anymore, but they can be found in very old submarines.

Optical gyroscopes are based on the Sagnac effect, which states that frequency/phase shift between two waves counter-propagating in a rotating ring interferometer is proportional to the loop angular velocity. As a light source, the laser is typically used. Currently, this technology gives the best performance. Examples can be ring laser gyroscopes (RLG) or fibre optic gyroscopes (FOG).

Vibrating gyroscopes are based on the Coriolis effect that induces a coupling between two resonant modes of a mechanical resonator. Example can be MEMS sensors[3], these are typically the cheapest, and they can be found basically everywhere, for example, in every mobile device. As MEMS gyroscopes have no rotating parts, have low power consumptions requirements, and are small, they replaced others in robotics applications.

The performace and application of each technology is perfectly demonstrate in figure 3.2.

3.1.3 Allan variance analysis

3.1.4 Error characteristics of IMU

3.1.5 Grades of IMUs

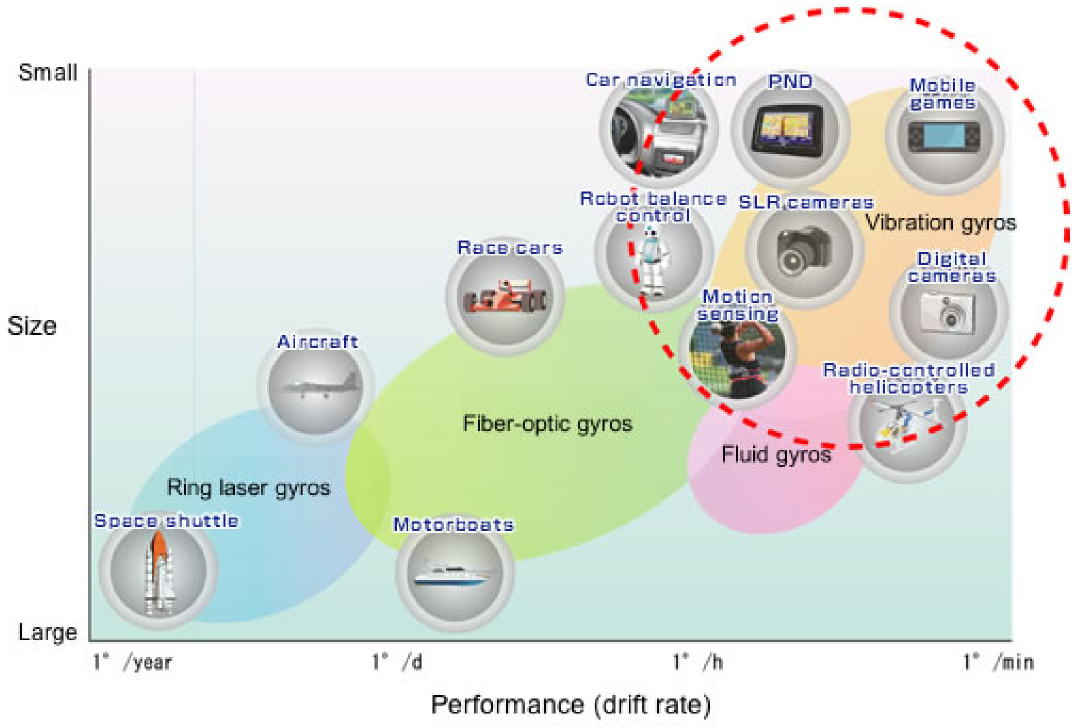

Figure 3.2. Gyroscopes technology plotted by size and performance.[4]

References

[1] Bruno Siciliano, and Oussama Khatib. *Springer Handbook of Robotics*. Springer-Verlag, 2007.

[2] Peter Teunissen, and Oliver Montenbruck. *Springer handbook of global navigation satellite systems*. Springer, 2017.

[3] Priyanka Aggarwal. *MEMS-based integrated navigation*. Artech House, 2010.

[4] © 2021 Seiko Epson Corp. *Gyro sensors - How they work and what's ahead*. https://www5.epsondevice.com/en/information/technical_info/gyro/.

Appendix A
Abbreviations and symbols

A.1 A list of abbreviations

All abbreviations used in this thesis are listed below.

AVAR	Allan variance analysis.
DOF	Degrees of freedom.
IMU	Inertial measurement unit.
MEMS	Microelectromechanical systems.
UWB	Ultra-wideband.

A.2 A list of symbols

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