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Development of a multimodal imaging system based on LIDAR

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Development of a Multimodal Imaging System based on LiDAR

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To my beloved ones

Abstract

Perception of the environment is an essential requirement for the fields of autonomous vehicles and robotics, that claim for high amounts of data to make reliable decisions. With this aim, many different sensors are often combined in a process known as data fusion for obtaining the largest possible amount of information from the environment, even if redundant. In this context, Light Detection And Ranging (LiDAR) imaging sensors have become crucial sensors for such applications due to their 3D geometry sensing capability that overtake Radio Detection And Ranging (RADAR) devices in terms of spatial resolution.

This thesis aims to develop a unique data fusion device consisting of different and complementary imaging modes with a 3D solid-state LiDAR sensor as its core sensor. We aim to reduce the usual parallax error committed during the fusion of sensors situated along large enclosures and to provide a feasible multimodal imaging device easy to integrate with the approach of mechanically reducing the multi-sensor framework inside a single device.

Consequently, this thesis reviews and discusses the current state of the sensors' technology and data fusion. In particular, it focuses on reviewing the different LiDAR techniques and the most used camera model in Computer Vision (CV). Based on that, it provides a discussion about the imaging modes of interest in the perception unit, which includes a pulsed Micro-Electrical-Mechanical System (MEMS) mirror solid-state LiDAR as its principal sensor.

Then, this thesis analytically describes the particular MEMS LiDAR system using Snell's law. Furthermore, it provides a general model for the imaging system that may be used on any other LiDAR for predicting and correcting the variable angular resolution across the Field-Of-View (FOV) that distorts the Point Cloud. Analogously, it mathematically derives the necessary transformations for data fusion between sensor pairs.

Accordingly, this thesis proposes a novel calibration method for LiDAR and fusion systems. It presents the methodology and the materials, that include a multimodal calibration pattern and an automatic guide system, necessary for accurately and automatically calibrating all the sensors included in the unit. The novelty of using the LiDAR depth information for better estimating the location of the target have yielded the calibration to improve the up-to-date calibration methods in the literature.

Finally, this thesis presents the development of a multimodal perception unit based on the above which is aimed to become a TRL8 product, together with some of its potential applications in the field of CV.

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Pablo García Gómez
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List of Acronyms

AI Artificial Intelligence.

AMCW Amplitude-Modulated Continuous-Wave.

APD Avalanche Photodiode.

AV Autonomous Vehicles.

CCD Charged-Coupled Device.

CMOS Complementary Metal-Oxide-Semiconductor.

CV Computer Vision.

DMD Digital Micromirror Device.

DNN Deep Neural Network.

DOF Degree-Of-Freedom.

DOLP Degree-Of-Linear Polarization.

FCPE Fully Connected Pose Estimation.

FMCW Frequency-Modulated Continuous-Wave.

FOV Field-Of-View.

FPS Frames Per Second.

GPS Global Positioning System.

IMU Inertial Measurement Unit.

LED Light Emitting Diode.

LiDAR Light Detection And Ranging.

LWIR Long Wave Infrared.

MCPE Minimally Connected Pose Estimation.

MEMS Micro-Electrical-Mechanical System.

MWIR Mid Wave Infrared.

NaN Not-a-Number.

NIR Near Infrared.

NLSQ Non-Linear Least Squares.

OPA Optical Phased Arrays.

PD Photodiode.

PDF Probability Density Function.

PSE Pose and Structure Estimation.

RADAR Radio Detection And Ranging.

RANSAC Random Sample Consensus.

ROI Region-Of-Interest.

SFTP SSH File Transfer Protocol.

SLAM Simultaneous Localization And Mapping.

SNR Signal-to-Noise-Ratio.

SotA State-of-the-Art.

SWIR Short Wave Infrared.

TCP Transmission Control Protocol.

TDC Time-to-Digital Converters.

TOF Time-Of-Flight.

TOT Time-Over-Threshold.

UI User Interface.

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