Summer Internship Project
Report

3D LiDAR & Camera Calibration

Submitted by

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Chapter 1

Objective

The objective of this intenship project at XXXXXXXXXXXXXX is to perform 3D LiDAR and camera calibration, aiming to enhance the perception capabilities of autonomous robots. The convergence of camera and LiDAR sensors play a crucial role in providing accurate and comprehensive environmental perception, enabling the robots to operate autonomously in complex environments. This project seeks to optimize the fusion of data from both sensors, ultimately improving the decision making and navigation capabilites of the bots made by the company.

The focus of the same was on the following key aspects:

- Sensor Synchronization and Data Fusion
- Calibration Accuracy and Stability
- Multi-Sensor Adaptability
- Performance and Validation

Chapter 2

Introduction

The advent of autonomous robotics has revolutionized various industries, from transportation to manufacturing and beyond. This includes the promise of greater efficiency, safety and productivity. A key aspect that leads this success of autonomous systems is accurate and reliable perception of the surrounding environment. In this context, the calibration of 3D LiDAR and camera sensors emerges as a critical undertaking, aimed at achieving precise alignment and fusion of data from both sensors. Without the same, a small error of 1° could lead to miscalculations of distances and directions upto 20cm.

2.1 What is Calibration?

Calibration refers to the process of establishing a spatial correspondence between two sensor modalities. It is important to capture the environment from different perspectives and have varying inherent characteristics. Allowing the data to align helps in synthesis of a comprehensive and unified representation of the surroundings, offering an accurate perception of the environment.

2.1.1 Camera Calibration

In camera calibration, the focus is on estimating the intrinsic and extrinsic characteristics of the camera. Intrinsic characteristics of the camera refer to focal length, principal point, lens distortion, etc. that are usually predefined by the manufacturing company. Extrinsic parameters, on the other hand, describe the position and orientation of the camera relative to worlds frame. In this project, our concerns are only restricted to the extrinsic parameters of the camera.

2.1.2 LiDAR Calibration

LiDAR calibration is also similar to camera involving both intrinsic and extrinsic parameters. Accurate estimation of these parameters is crucial for converting raw data into precise 3D point cloud. Here also, extrinsic characteristics refer to position and orientation of the 3D LiDAR with respect to the frame of the robot. We are only concerned about the extrinsic parameters.

2.2 3D LiDAR and Camera Calibration

Calibration helps in enhancing the perception capabilities of autonomous robotic systems. For aligning the data from both the sensors, the position and orientation of both the sensors is crucial to be known in order to perceive the data. The following chapter outlines the work done on the same.

Chapter 3

Work Done

3.1 Research

The first two weeks of the internship were spent conducting extensive research on the issue of what calibration is, what algorithms are involved, and how it is conducted in various circumstances. This was done by reading scholarly articles, research papers and case studies, all aimed at the calibration processes. During the same, the core objective of calibration as outlined by various papers would be to achieve the highest possible accuracy.

This helped in laying down the theoretical groundwork for calibration. These papers elucidated the mathematical formulations and models used in calibration algorithms such as SVD, RANSAC, Ksai's etc. Different sensor configurations and environment are catered with the help of different algorithms which work the best in each case. My goal was directed towards understanding the underlying principles and popular methods like Zhang's camera calibration like Zhang's camera calibration, iterative closet algorithm for LiDAR, etc.

The case studies offered insight into the practical consideration and limitations of calibrations in different scenarios. Environmental factors such as lighting conditions, sensor noise, and dynamic changes in the scene bring a variable range of difference. These factors prepared me for the challenges I would be facing while performing the process myself.

3.2 Experimental setup

3.2.1 velo2cam Package

The calibration was performed using the package velo2cam_calibration available on GitHub. Te package served as a solid foundation for the project by providing a versatile and comprehensive framework to calibrate camera to camera, LiDAR to LiDAR and camera to LiDAR setups. I customised the package to suit the specific requirements of our suits which included using appropriate camera and LiDAR models, sectioning the data received, etc.

The package performs calibration by selecting samples from both camera and LiDAR and then transforming the two sensor frames into a unified coordinate system. This transformation is done using the principle of SVD (Singular Value Decomposition) algorithm and finding the centroids of the point cloud of the sensors. For selecting the samples from camera sensor, the algorithm detects QR pattern present on the markers and find their centers. Similarly, for LiDAR, the program identifies the circle cutouts of the markers and finds their centers. Following this process resulted in precise alignment and fusion of data from both the sensors. The results are listed below

$$x = 0.00214304,\ y = 0.0858439,\ z = 0.138853 \text{ (in meters)}$$
$$\text{roll} = -1.53377,\ \text{pitch} = 0.0081907,\ \text{yaw} = 0.0102178$$

3.2.2 Challenges Faced

During the project, several challenges were encountered related to pattern recognition and algorithm for both camera and LiDAR sensors. The first arose when the camera or LiDAR failed to recognise the pattern accurately. The possible reasons for the same were inaccurate measurement in distances, and sensor placement. The distance between the wall, marker and the wall play a vital role in recognising the markers and collecting the sample frames.

Another key issue arose while working on camera where the algorithm creates a rotated_camera_frame to establish a transformation link tf between camera and LiDAR. The process involves rotational transformation which led to difficulties and misalignment in the calibration process. Overcoming the challenge demanded iterative adustments to achieve the desired alignment and transformation accuracy.

A significant obstacle was the excessive computation time required in the process. The algorithm's complexity hindered with the real-time performance due to the large chunk of data it was considering for running the process. To address the concern, we implemented strategies to filter the data received on specific criteria, we managed to reduce the area searched for the markers. This not only reduced the computation time but also reduced the noise from the testing environment.

Despite the challenges encountered, the learning experience were invaluable. I gained a deeper understanding of the intricacies in Camera-LiDAR calibration and developed proficiency in handling complex data processing task. The improved pattern recognition and precise transformation contributed to enhancing the overall performance of the algorithm. Moving forward, I am excited to apply these learnings to future projects and continue pursing the challenges in the robotics technologies.

Chapter 4

Future Work

For continuous improvement and advancement in the calibration process, the future work will focus on exploring alternative algorithms that will result in even higher levels of accuracy and precision than what was achieve in this project. Building on the foundation laid by the successful utilization of the velo2cam_calibration package, I started creating an alternative algorithm that harnesses the point clouds generated by both the camera and LiDAR sensors to establish a robust calibration framework. The primary objective of this approach is to seamlessly overlap and align the point clouds from both the sensors, refining the calibration results.

Though the algorithm is in its nascent stages and not yet perfected, it demonstrates potential for achieving calibration accuracy. As challenges are inevitable, the current implementation encounters certain compilation errors. However, this serves as an opportunity to further investigate and fine-tune the algorithm, addressing the errors to pave way for enhanced results.

A key aspect of the future work will be to fine-tune the algorithms parameters and configurations to ensure optimal calibration results. Moreover, evaluation the algorithms performance in diverse environments and under dynamic conditions will be essential to ascertain its robustness. While the velo2cam_calibration package served as an excellent starting point, exploring novel approaches is essential to unlock the full potential of sensor fusion and calibration for autonomous robots. The challenges encountered in the current implementation are viewed as opportunities for growth, motivating us to persist in refining the algorithm.

Chapter 5

Conclusion

The summer internship at XXXXXXXXX has been a trans formative and intellectually enriching experience. The primary objective was to explore and implement 3D LiDAR and camera calibration methodologies to enhance the perception capabilities of autonomous robotic systems. Throughout the internship, I embarked the journey of learning, experimentation and problem-solving, contributing to the development of cutting-edge calibration techniques.

The internship provided me with invaluable insights into robotics technology, sensor fusion and calibration methodologies. Collaborating with mentors enriched my understanding of practical implementation and real-world challenges. The relentless pursuit of excellence fostered an environment where I could learn and grow, both as a student and a professional. I am immensely grateful for the opportunity to contribute to a company that drives innovation and pushes the boundaries of robotics technology.

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