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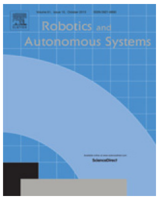

Self calibration of multiple LIDARs and cameras on autonomous vehicles

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HIGHLIGHTS

- Solution for the automatic calibration of multiple LIDAR, Cameras and other 3D sensors, with minor user intervention.
- Applicable both in static sensor-rich setups and in mobile systems, such as autonomous cars and other ADAS contexts.
- Accessible methodology for the community since it uses standard algorithms and libraries in a ROS framework and a simple ball.

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ABSTRACT

Autonomous navigation is an important field of research and, given the complexity of real world environments, most of the systems rely on a complex perception system combining multiple sensors on board, which reinforces the concern of sensor calibration. Most calibration methods rely on manual or semi-automatic interactive procedures, but reliable fully automatic methods are still missing. However, if some simple objects could be detected and identified automatically by all the sensors from several points of view, then automatic calibration would be possible on the fly. The idea proposed in this paper is to use a ball in motion in front of a set of uncalibrated sensors allowing them to detect its center along the successive positions. This set of centers generates a point cloud per sensor, which, by using segmentation and fitting techniques, allows the calculation of the rigid body transformation among all pairs of sensors. This paper proposes and describes such a method with results demonstrating its validity.

1. Introduction

Many vehicles with autonomous navigation capabilities, and also many advanced drivers assistance systems, rely on LIDAR (Light Detection And Ranging) and vision based sensors. Moreover, most of the developed systems use multiple sensors simultaneously. Thus, when there is more than one sensor in the same setup, a calibration procedure must take place to combine data from different sensors in a common reference frame. In order to solve that necessity, this work presents a new extrinsic calibration method. Differently from the majority of existing methods, which are manual or semi-automatic, the proposed method is automatic, with no requirement of manual measurements or manual correspondences between sensors data. Instead of using those approaches, a ball is used as a calibration target allowing the detection of its center by all sensors and then perform the several registration steps. To estimate the full transformation between the sensors, at least three 3D point correspondences between the sensors are needed, but more may be used for precision purposes. These points can be estimated during the ball movement, which furthermore increases the accuracy of the method as a significant number of points can be obtained along that path.

1.1. Context of the work

This work is part of the ATLASCAR project [1], carried out at the University of Aveiro, whose main purpose is the research and development of solutions on autonomous driving and Advanced Driver Assistance System (ADAS). For that goal, a common Ford Escort car is equipped with a rich set of sensors dedicated mainly to the perception of the surrounding environment (Fig. 1).

The car is equipped with several exteroceptive sensors, namely a stereo camera, a 3D LIDAR, a foveated vision unit and two planar laser range finders. The planar lasers already installed on the car are two Sick LMS151, and a custom made 3D LIDAR using a Sick LMS200 in a rotating configuration adapted from [2]. Additionally, a new multi-layer LIDAR (sick LD-MRS 400001) and two Point Grey cameras are available as well as a SwissRanger 3D TOF used occasionally in some experiments and contexts. This paper will focus on the sensors illustrated on the right side of Fig. 1, and Table 1 presents some of the 3D range sensors main properties.

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Fig. 1. ATLASCAR, a Ford Escort SW 98 adapted for autonomous driving capabilities on the left. Sensors used in this work—Sick LMS151 and LD-MRS40001, Point Grey camera and SwissRanger—on the right.

Table 1
Properties of the main 3D range sensors onboard the ATLASCAR.

	Sick LD-MRS400001	Sick LMS151	SwissRanger sr4000
Scan planes	4, with full vertical aperture of 3.2°	1	
Field of view	2 scan planes: 85° 2 scan planes: 110°	270°	43.6°(h) × 34.6°(v)
Scanning frequency	12.5 Hz/25 Hz/50 Hz	25 Hz/50 Hz	
Angular resolution	0.125°/0.25°/0.5°	0.25°/0.5°	
Operating range	0.5–250 m	0.5–50 m	0.1–5.0 m
Statistical error (1σ)	±100 mm	±12 mm	±10 mm

1.2. Related work

Over the past several years, a number of proposed solutions for the calibration between a camera and a laser were introduced, including some automatic on-line calibration solutions as presented in [3]. In [4] a method to estimate the motion of a camera–laser fusion system was developed that projects the laser points onto the images. Features are then selected using the Kanade–Lucas–Tomasi feature tracker [5] and tracked between frames to be used as 3D–2D correspondences for the motion estimation using a three-point method based in the algorithm developed by Bock et al. [6]. In [7] a plane with a printed black ring and a circular perforation is used to solve the extrinsic calibration between a camera and a multi-layer LIDAR; the method consists of estimating different poses of the calibration target detected simultaneously by the camera and the multi-layer LIDAR, resulting in a set of point correspondences between frames (circle centers of each pose), that are used to compute the extrinsic calibration by using the singular value decomposition (SVD) along with the Iterative Closest Point (ICP) algorithm to refine the resulting transformation. A similar approach is used in [8] to calibrate the same set of sensors; a planar triangle plane is used as target to extract correspondences between sensors, and the extrinsic calibration between sensors is solved using the Levenberg–Marquardt algorithm that projects the laser points into the image. There are also some other studies for the specific problem of calibration between LIDAR sensors, however, there is still room for improvement since no fully automatic method using perception sensor information, and adapted to any configuration, is available. Previous works on the ATLASCAR project used a technique that also uses a calibration target, but it requires manual input from the user [9]. Other authors developed algorithms to calibrate one [10] or two [11] single-beam LIDARs within the body frame; both methods use approaches that rely on establishing feature correspondences between the individual observations by preparing the environment with laser-reflective tape, which additionally requires an intensity threshold for correspondences and some initial parameters. A more recent method [12] is based on the observation of perpendicular planes; this calibration process is constrained by imposing co-planarity and perpendicularity constrains on the line segments extracted by the different laser scanners; despite being an automatic calibration method, it does not provide the versatility of the method presented in this paper. Finally an approach using a sphere target to perform extrinsic calibration of multiple 3D cameras was presented in [13], which presents some similarities with the current proposal since the user also moves the target to different positions and heights within a shared viewing area. In that process, the algorithm automatically detects the center of the ball in the data from each camera, and then uses those centers as corresponding points to estimate the relative positions of the 3D sensors. However, this approach [13] is only used with Kinect sensors with a smaller ball and a reduced working range.

2. Proposed solution

The proposed solution in this paper is to estimate the rigid body transform between different sensors (SICK LMS151 and LD-MRS400001, Point Grey camera and SwissRanger) using a ball as calibration target. The only restriction of the calibration target is about its size (diameter). The size of the calibration target is related to the angular resolution of the sensors used; after some empirical experiments, it was concluded that the ball must have a diameter large enough for the sensors to have at least 8 measurements of the target at 5 m.

The approach used to obtain the calibration among all the devices is achieved in three stages. First, each sensor must detect the ball; then, the ball is placed in motion in front of the sensors allowing them to detect its center along successive positions, creating a synchronized point cloud of detected centers for each of the sensors. The condition to consider a new reference point (ball center) for each point cloud is that each new point is separated from the previous one by a minimum distance pre-defined to 15 cm, but can be defined by the user. Finally, a sensor is chosen as reference and the remainder are calibrated relatively to it, one at a time, by using our own developed algorithms or ones available on the Point Cloud Library (PCL) [14] or on OpenCV [15].

3. Ball detection algorithms

The method to find the center of the ball depends on the type of data. In the following sections the methods used for the ball detection in the different sensors are described.