Intra-vehicular Data Sources

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Abstract—**This article gives an overview of currently used sensors in autonomous driving. A focus is set to LiDAR type of RADAR, a Livox Mid-40 sensor discussed as an example. The conclusion considers an overview about parameters which are essential to differ several LiDAR devices.**

Index Terms—**automotive, automotive data sources, autonomous driving, camera, lidar, radar, ultra sonic, Livox, Livox Mid-40**

1. Introduction

Autonomous driving is an emerging topic which gained more and more importance in the last years. It will take time to achieve a level of full driving automation at which a driver is not obligated to intervene or furthermore not able to intervene. However, the goal is clear, and a software is an important factor to reach it. But the software can be as good as delivered data produced by sensors.
In the following article we will investigate main sensors deployed in autonomous driving cars. Our focus will be set especially on LiDAR and Livox Mid-40, as a detailed example. There we will present its SDK, how the device could be set up and types of data exchanged. Moreover, several parameters listed in the article should be considered as essentials for proper application of a LiDAR in autonomous driving cars.

2. Sensors in Autonomous Driving

In new cars sold nowadays there is a number of sensors that are shored ex factory. Starting with simple assistance systems as a 'parking assistant' or 'blind spot monitor' and advancing to more complex systems as a 'lane keeping assistant' until full autonomous driving - every single assistant requires certain sensors. The most commonly used sensors are cameras, RADAR, LiDAR and ultra sonic, which will described one by one in the following.

2.1. Camera

Cameras are one crucial sensor in the system of autonomous driving. They are reliable and relatively cheap to produce and to build in. With a help of Artificial Intelligence surrounding objects can be identified and classified, road signs can be recognised. However, cameras face limitations such as dependency on weather, light conditions and primarily of clean lenses.
Often described as 'eyes of the car' cameras are the most accurate way to create a visual representation of the surrounding world [1]. For this representation multiple cameras are needed in the front, rear, left and right sides of a car. A sample calculation showing the amount of data created by a camera system for autonomous driving is presented in the following. The sample is based on a system of an Israeli company which provides a fully autonomous driving system based exclusively on 12 cameras [2]. Assuming we take a fictional camera with similar specifications as the 'MPC3' from Bosch [3]. Therefor we get the following specifications being important for data generation:

- Resolution: 2.6 MP HDR (2048 x 1280 pixels)
- Frame rate: 45 frames per second

Assuming a video stream with these specifications, a supposed dynamic range of 24 bit and approximately 20% protocol overhead, we get the following calculation:

- Pixel of each image:
  $2048 \times 1280 = 2621440px$
- Size per image:
  $2621440 \times 24bit \approx 62.9Mbit$
- Amount of data per second:
  $62.9Mbit \times 30 \approx 1.89Gbps$
- Including 20% protocol overhead: $1.89Gbp \times 1.2 \approx 2.26bps$

Given the specifications above one camera consequently requires approximately $2.26Gbps$ of bandwidth without any compression. Transmission of this amount of data is not convenient and thus compression should be used. Applying a modern compression algorithm can reduce the size by a ratio of up to 1:200 (using e.g. the lossy MPEG-4).
Referring to our example of a autonomous driving system with 12 cameras on board, without compression it would result in $28Gb$ the system has to progress every second.

2.2. RADAR

RADAR is a technology of which security in autonomous driving greatly benefits. RADAR is an acronym for "RAdio Detection And Ranging". It is used in autonomous cars among other systems for obstacle detection and Adaptive Cruise Control. It works by emitting an electromagnetic wave. This wave is reflected when meeting an obstacle and bounces back to the origin where it is measured. Thereby, it is able to measure the distance to an object, the approximate size and its roughly speed.

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Compared to the other sensors it is inexpensive, but it is less angularly accurate than LiDAR as it may lose the sight of the target in curves and it may get confused if multiple objects are placed very close to each other. However, unlike LiDAR, RADAR is weather-independent, it is able to detects objects behind other objects and to determine relative traffic speed or the velocity of moving objects [4].

2.3. LiDAR

LiDAR is another sensor being seen as an indispensable technology for autonomous driving in order to reach Level 5 autonomy (see Figure 1). The typically used term LiDAR is an abbreviation for "Light Detection And Ranging". LiDAR is a technology similar to RADAR and it is able to optically measure distances or speed. Instead of radio waves, that are used for RADAR (see section 2.2), LiDAR uses laser for scanning the environment. This works by sending out rapid laser signals sometimes reaching up to 150.000 pulses per second. When the laser beam meets an obstacle it is reflected and bounces back. Nearby the laser source reside sensors measuring the time that the laser need to go to the obstacle and bounce back. With this information a quite precise three-dimensional model of the surrounding environment is created.
With LiDAR it is possible to detect objects within a range from just a few centimetres to up to several hundreds of metres.
Assuming the Livox Mid-40 LiDAR sensor, which we get to know better in Section 3, we can roughly calculate the amount of data which is produced. The necessary specifications are as follows:

- point rate: $100000\frac{pints}{s}$
- point size: $72bit$ to $104bit$

Further assuming a protocol overhead of about 20% we get the following:

- Minimum and maximum amount of data per second:
  $100000\frac{1}{s} \times 72bit = 7.2Mbits$
  $100000\frac{1}{s} \times 104bit = 10.4Mbits$
- Including 20% protocol overhead: $7.2Mbits \times 1.2 = 8.64Mbits$ $10.4Mbits \times 1.2 = 12.48Mbits$

Overall the LiDAR generates an output of $8.64Mbits$ to $12.48Mbits$ that is sent to the processing unit for further processing. Compared to the output of a camera, this amount is relatively small and compression is not necessarily needed for transmission.

2.4. Ultra Sonic

Ultra sonic sensors are mostly used in autonomous cars for systems like parking assistants and nearby obstacle detection [5]. Ultra sonic sensor sends out ultrasonic impulses that are reflected by nearby obstacles, the time between sending and receiving the reflection is measured. It is applicable within a range from a couple of centimetres to a couple of metres. Although the scope of ultra sonic sensor in autonomous driving is different from LiDAR they are comparable by ability to see objects through other objects, being weather and day time independent, being relatively cheap and being equal in resolution. However, disadvantages should be considered as small objects as well as multiple fast moving objects cannot be detected and the field of view is more limited.

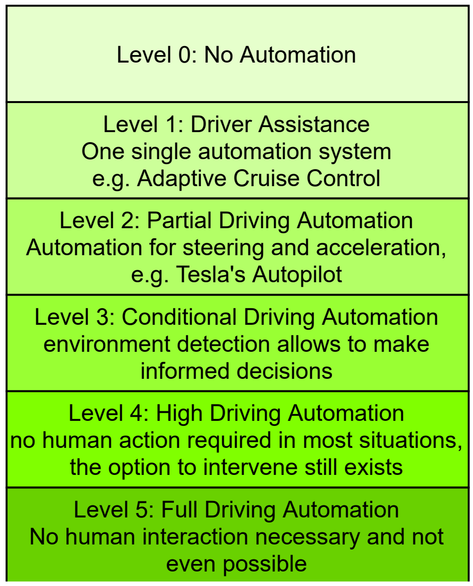

Figure 1: Levels of Autonomous Driving

2.5. Other Sensors

There is a number of other sensors available and actively used in cars. Most of them are used for motor control to guarantee smooth operation. These sensors include e.g. mass air flow sensor, engine speed sensor, oxygen sensor etc.. Others are assigned to lower levels of autonomous driving such as wheel speed sensors, steering sensors, break sensors etc..

3. The Livox Mid-40

LiDAR is often said to be an indispensable technology to reach higher levels of autonomous driving. Nevertheless, there are hot tempered discussions whether to use LiDAR or rely other technologies such as RADAR or cameras, others see enormous potential in LiDAR. A broad range and high accuracy of depth perception, suitability for 3D mapping and a number of fields with huge and unrevealed potential.
However, in this section we go a bit more into details and examine the 'Livox Mid-40' - a LiDAR sensor from Livox.

3.1. Requirements

To begin with the LiDAR, a couple of requirements has to be complied with. Before all technical requirements, it has to be mounted properly, meaning there has to be enough space between the device and surrounding object to guarantee proper functioning of the fan. For technical requirements a few aspects have to be fulfilled. Firstly, the system (e.g. in an autonomous car) has to provide electrical tension between 10-16V direct current. Secondly, the

LiDAR requires an average power of 10W and at peaks in situations under extreme conditions (-20°C and during startup) up to 40W. Regarding the processing unit, the LiDAR provides a 100BASE-TX cable capable to transfer 100Mbit/s which has to be handled by the system.

3.2. Livox SDK

The Livox SDK is the Software Development Kit for the Livox Mid-40 and all Livox products applied to quickly connect to Livox sensors and receive data. It consists of Livox SDK communication protocol, Livox SDK core and Livox SDK API [6]. In the following, each of these points will be detailed.

3.2.1. Livox SDK Core. The structure of the Livox SDK Core can be described as in Figure 2 (based on [6]).

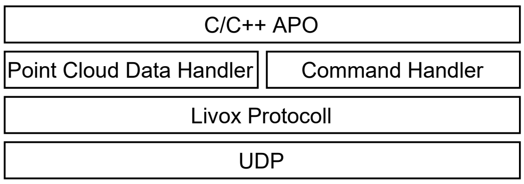

Figure 2: Livox SDK Core

As communication protocol between LiDAR sensor and Livox SDK the User Datagram Protocol (UDP) is applied. These serves being a basis for the Livox SDK Communication Protocol (see Section 3.2.1 which enables communication between a sensor and a user. The 'Point Cloud Data Handler' and 'Command Handler' support transmission of the correspondent data types defined in the Livox SDK Communication Protocol. And on top of that a C/C++ API provides convenient integration of C style functions into custom C/C++ programs.

3.2.2. Livox SDK Communication Protocol. The Livox SDK Communication Protocol enables communication between user programs and the LiDAR sensor. With its help, the user is able to set the LiDAR sensor in mainly three states. These cover 'normal', 'standby' and 'power-saving'. When mode switching is completed and the device is in LiDAR mode, there are additionally two states 'initializing' and 'error' (see Figure 3) [6].

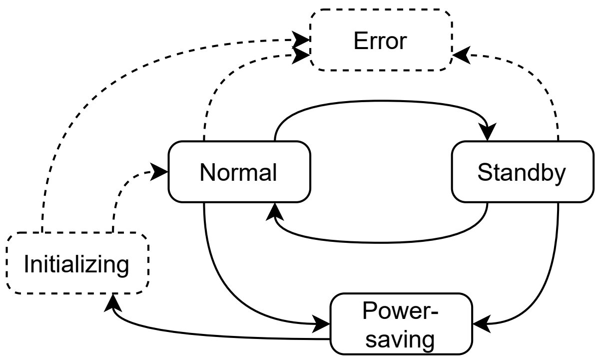

Figure 3: Operating States

It basically consists of two different packet types describing the different kinds of communication taking place between a user and a sensor. The two types are 'Control Command Data' and 'Sample Data'. The 'Control Command Data' type is used for the organizational part covering configuration and query of LiDAR parameters and status information [7]. The other part is covered by the 'Sample Data' type which transfers all kind of data generated by the LiDAR, e.g. point cloud data, time stamps or IMU data (not for Livox MID-40/70/100).
The model of communication is based on the master-slave principle with the LiDAR as slave and the user who acts as master receiving point cloud data.

3.2.3. Point Cloud Data. The main data for autonomous driving produced by the LiDAR sensor is the measurements of the surrounding environment. These dimensions, defining measured points and their reflectivity in a three-dimensional coordinate system, are then packed in the point cloud data format and sent to the processing master. The format can be seen in Figure 4 which is based on the documentation [6].

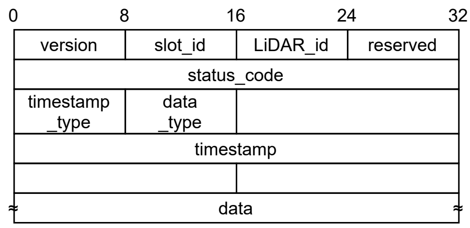

Figure 4: Point Cloud Data Format

Next to information about configuration and organisation, there is a timestamp type which should be highlighted at this point. The Livox SDK provides three types of timestamps: PTP (defined in IEEE 1588v2.0), GPS (requires PPS and UTC timestamp) and PPS (pulse per second). In case there are multiple synchronization sources available, the synchronization mode is selected in the order PTP > GPS > PPS. Talking about bandwidth, it is important to consider the data field or more precisely the amount of data fitting into that field. It mainly depends on the datatype transmitted in the packet. For the Livox Mid-40, there are two types that are transmitted, the Cartesian coordinate format with $104bit$ and the spherical coordinate format with $72bit$. As per header only 100 units of either type is transmitted, the amount of data is at most $10.4Kbit$. Including the header, the amount of data for the whole packet would rise by $96bit$. For the other fields and more information about the point cloud data format refer to the Livox SDK.

3.2.4. Livox SDK API. The Livox SDK API simply provides a set of C functions that can be accessed in C/C++ programs to get access to a Livox device.

3.3. Setup

All the physical hardware is located and provided by the 'Chair of Network Architecture and Services' in Garching. In the setup, there are mainly two components which can be seen in Figure 5.

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Figure 5: Setup

On the one side there is a host running an Ubuntu 20.04 image. Additionally, it has Livox Viewer 0.10.0 (64 bit) installed to process the data from the LiDAR.
The LiDAR from Livox of type 'Mid-40' is on the other side, connected to the host with a cable of type '100base10-tx'.

3.4. Livox Viewer

The Livox Viewer is a visualization software for the Livox LiDAR sensor. Its core function is to receive point cloud data recorded by the LiDAR, processes them and creates a three-dimensional visualization. Moreover, it is able to show and manipulate configurations such as the frame time and to store or display point cloud data. An example how it looks like can be seen in Figure 6.
The current version of the Livox viewer requires either

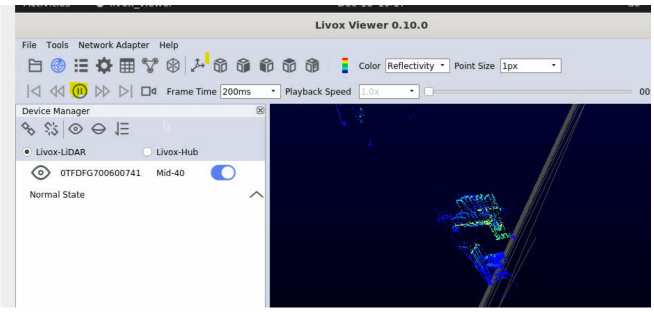

Figure 6: Livox Viewer

Windows 7/8/10 (64 bit) or Ubuntu 16.04 (64 bit) and a dedicated graphics card is recommended, especially if multiple LiDAR sensors are in use.

4. LiDAR Comparison Parameters

As for all electronic devices, there are some parameters identifying and differing them from each other. It is also applied to LiDAR and to its broad field of application. In the following we will have a look on LiDAR in context of autonomous driving built-in in cars.

4.1. General LiDAR types

One can generally differ between two techniques that LiDARs use to detect their environment. On one hand, there is the spinning LiDAR able to spin 360° and thus detects its whole surrounding environment. Often used for developing prototypes, it is not common for series production, unlike, on the other hand, solid-state LiDARS. This name functions more like an umbrella term covering multiple types of solid-state LiDARS.

4.2. Mounting

In order to set a device properly into a car, several parameters have to be considered. Firstly, specific dimensions to integrate it into a car's body as well as temperature requirements if autonomous driving functions should also work in extreme situations. Secondly, there should be followed several power requirements. Especially it has to meet parameters from a on-board system like the required voltage and the amount of power consumed by the LiDAR. Moving to processing of the provided data, the required bandwidth should be considered to function with the on-board system.

4.3. Specification

Diving more deeply into the specifications there are a couple of important points to examine.
In order to get most extensive and accurate data, there are crucial parameters to note such as visual field (FOV), detection range and maximum point rate. According accuracy, range precision, angular accuracy or beam divergence should also be considered. Using more parameters is not necessarily better, however, all depends on use cases and costs.

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