LIDAR TECHNOLOGY IN GENERAL PURPOSE APPLICATIONS

Summary. The paper presents examples of the functionalities of the lidar that is used in the automotive industry for advanced driving assistance systems. Firstly, a brief overview of lidar technology and an introduction to communication that is built on a CAN bus is presented. Then, the lidar that was selected for the tests is described along with the principles of how it works and its startup conditions. Finally, a description of the experiment is presented along with the results.

Keywords: lidar, CAN, ADAS, CANoe, startup and tests

TECHNOLOGIA LIDAR W APLIKACJACH OGÓLNEGO ZASTOSOWANIA

Streszczenie. Artykuł prezentuje przykładowe funkcjonalności urządzenia typu lidar, które jest używane w samochodowych zaawansowanych systemach wspomagania kierowcy. Tekst zawiera przegląd technologii lidar, wprowadzenie do komunikacji opartej na magistrali CAN oraz opis wybranego do testów lidaru wraz z zasadami działania i warunkami jego uruchomienia. Dodatkowo opisane zostały przykładowe eksperymenty przeprowadzone z wykorzystaniem urządzenia oraz ich wyniki.

Słowa kluczowe: lidar, CAN, ADAS, CANoe, uruchomienie i testy
1. Introduction

There are many methods and measurement technologies that are used to detect objects and to scan surroundings. They can be based on either the types of electromagnetic radiation or the emission of sound waves. Their use cases depend directly on the conditions in which the measurement is taken and on the physicochemical properties of the particles that the surroundings are composed of. One of the universal technologies that allows miscellaneous types of objects to be analysed is lidar (Light Detection and Ranging), which uses light radiation.

Lidar is a technology that combines a laser with an optical system and is used to recognise surroundings and measure distance. The recognition mechanism is similar to that of radar technology but the main difference is the use of light instead of microwaves. Emission of short, precisely stepped laser impulses with a specific wavelength towards the right is done by an optical system that controls the beam. Usually rotating mirrors are used for this purpose. The light is then observed by a telescope system, which converges the laser beams that are reflected by the objects and which are returned to the scanner. The light is analysed in terms of the intensity and the time measured between emissions and the return of a light beam is calculated [1, 2]. The principle of LiDAR technology is presented in Figure 1.

The wavelength of emitted light depends primarily on the accuracy (resolution) required and the conditions in which the measurement is taken:

- Infrared (1500-2000nm) is used in military technologies. Light with a wavelength close to 1500nm is invisible to night vision devices [3].
- Ultraviolet (250nm) is used in meteorology. Short wavelengths allow dispersions of a beam on aerosol and dust particles that are floating in the air to be observed [3,4].
- Close to infrared (1040-1060nm) is used in terrestrial mapping, for measuring distances in vehicle traffic and for internal use. Lasers that are based on these wavelengths are characterised by a high level of measurement accuracy and are used in airborne scanning,
terrestrial scanning and for indoor mapping. Unfortunately, this wavelength range is vulnerable to any phenomena that may worsen visibility, such as fog, smoke or rain [3-6].

- Blue-green visible (500-600nm) is used in bathymetry. This type of radiation has the ability to penetrate water and allows the bottoms of water reservoirs to be scanned [3, 7, 8].

The range of lidar devices is directly dependent on the power of light beam that is emitted. The most common wavelength used in lidar is near infrared 1050nm and it is considered to be best that its power does not exceed 1W, otherwise, it is not safe to the eyes. Devices of this type have a range from a single metre to several kilometres. Higher wavelengths are not absorbed by the human eye, and therefore, the power of these types of devices can be higher, which lengthens their measurement range to up to several hundreds of kilometres (in space applications) [1-2].

Lidars are usually constructed in two variants due to the type of light that is emitted. The first one is the emission of powerful laser pulses, in which each one is sent after receiving the reflection of the previous one. The distance estimate is based on the time that is measured between an emission and the time the light beam is received using the known speed of light. The second type assumes the constant emission of light in which the phases between sending and receiving are measured [1, 2, 4].

### 1.1. Overview of solutions

There is variety of solutions and companies that specialise in the production of lidar devices. The internal construction of lidars depends on their purpose and use. For aerial scanning that requires a high level of the accuracy of height measurements and the ability to scan entire areas, Optech Inc. offers lidars that are used in to observe and model urban zones, terrestrial area and to estimate flood risk, to monitor forested, archaeological and excavation sites, quarry areas or sea shores.

Products for robotics and to scan inside buildings are offered by Hokuyo. Lidars to create 3D models of internal spaces can be equipped with rotary heads that spin at high speeds (from a few up to over a dozen spins per second) in order to observe the surroundings.

Many companies such as Laser Technology Inc. specialise in the production of lasers with a non-rotary head that are used to measure the distance and velocity of moving objects. The most common devices of this type are, e.g. the Laser Speed Guns used by the police and other services that supervise and control traffic and safety on roads.

The group of devices for measurement of atmospheric conditions, e.g. wind or the concentration of aerosols that are scattered in the air is used in meteorology both to forecast and to observe current weather conditions close to important areas such as airfields. These and other specialised measurement devices are offered by Lockheed Martin.
Finally, in advanced driving assistance systems (ADAS) that support drivers in traffic, there are solutions that are used in automatic braking systems, to keep a safe distance between a vehicle and any obstacles located in front of it and for active, situation-adaptive lighting systems that react to vehicle parameters and environmental luminance [14, 15]. Such devices are offered by a variety of manufacturers that produce electronic components, including Continental.

1.2. SRL-1 lidar by Continental

Short-range lidar from Continental is an infrared laser sensor. It uses three independent infrared laser beams to measure the distance to objects without a reflector using the technique that measures the time of light with a very high repetition rate. It is usually mounted behind the windshield of the measuring object (car/housing). Its measurement is taken at distances of up to 13.5m at 27-degree angle. The lines of sight of SRL-1 are presented in Figure 7. Lidar
was developed for the automotive industry for use in intelligent drive assistance systems in order to increase driving safety and comfort.

Fig. 6. SRL-1 car lidar by Continental [13]

Typical areas for the use of lidar are as follow:

• simple anti-collision protection for vehicles of every description (particularly autonomous ones),
• positioning, headway control (vehicles of every description, particularly autonomous ones),
• area monitoring system, e.g. of hazardous or non-accessible areas,
• object detection, e.g. in confusing or unclear areas.

The uses of lidar differ depending on the area of use, e.g. edge detection is used in industrial and agricultural environments, while it is used for anti-collision detection in the automotive industry [13].

Fig. 7. Measurement lines of sight of SRL-1 [13]
2. CAN technology

The expanding use of onboard devices that support driving a car drove the need for fast, real-time and safe communication between car subsystems. The response to such a need was the Controller Area Network (CAN) bus.

CAN is a serial communication bus that was designed for automotive purposes in the 1980s. The transmission medium, which is based on two wires, is popularly defined as CAN_H and CAN_L. The maximum transmission speed is limited to 1Mbps at distances of up to 40 metres.

The structure of a network uses devices that work in a multi-master mode, which means that there is no selected supervisory unit that controls the transmission of data. Instead, each node works with the same priority and sending frames is like broadcasting, where each device is able to receive everything that is present on the bus.

In order for a CAN bus to work properly, two 120 Ohm resistors are required to terminate the bus on each side. Resistance is selected to simulate an infinitely long wire, which prevents reflections from the end of the transmission wire that could interfere with the work of the receivers. The number of nodes connected to the network depends primarily on the desired transmission rate, the length of wires, capacitance, power-loading and the topology of the bus. Usually, no more than a few dozen nodes are connected to the bus. Larger amounts can be connected but the network may require signal repeaters, which cause delays in the transmission of frames. A connection diagram of nodes and the structure of a network is presented in Figure 8.

![Fig. 8. Structure of CAN bus](image)

Due to differential voltage signal that is used to transmit data and because the control of protocol and errors are realized physically, a CAN bus is characterized by a high degree of reliability and resistance to disruptions.

There are two versions of the protocol for CAN that are currently used – 2.0A and 2.0B. In both cases, a frame consists of start, arbitration, control, data, control sum, confirmation and end sections. The arbitration section contains an identifier that defines the priority of a
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message and is used to grant access to the bus – the lower the identifier is, the higher priority the frame has. The use of an identifier is related to a specific frame and not to the device itself, and therefore, identifiers need to be unique for the entire network. The difference between the standards lies within arbitration field – 2.0A has an 11-bit identifier while 2.0B has a 29-bit identifier. Additional fields in the arbitration section are the request to transmit (RTR), which is required for access to the bus and a definition of whether the identifier is extended or not (IDE). The control section contains a reserved bit to separate the fields and a field that defines the amount of bits to be transmitted as data (DLC). The control section consists of the control sum (CRC) that is required to calculate whether the frame is received correctly. The last field is the acknowledgement, which is used to verify that a frame was received by any node. The structure of a frame in both versions is presented in Figure 9.

The CAN bus is used in real-time systems, e.g. automotive solutions or industrial networks, due to its ease of implementation, reliability and safety, which is achieved by using electrical access to a network and unobstructed transmission access to the bus [16-18].

2.1. CANoe

Canoe from Vector CANoe is a comprehensive software tool for the development, testing and analysis of entire electronic control unit (ECU) networks and individual ECUs and offers a wide range of functionalities that cover:

- simulations for real and virtual systems and buses,
- analysis of bus communication/statistics,
- creation of a database for simulations – including the definition of messages, signals and variables for future use in applications,
- handling of CAN events using CAPL programming,
- creation of a user interface,
- creation and conversion of log files that have various extensions (ASCII/excel).

It is also equipped with a tool that allows script tests to be created, connecting with google maps for live tracking using GPS or, for example, a video window that can be connected to a live stream.
Models created in CANoe can identify and correct problems at an early stage. They can be used as the basis for analysing, testing and integrating bus systems. There are both graphically oriented and text-based evaluations.

Referring to the description of CANoe: “At the beginning of the development process, CANoe is used to create simulation models that simulate the behaviour of ECUs. Over the further course of ECU development, these models serve as the basis for analysing, testing and integrating bus systems and ECUs. This makes it possible to detect problems early and correct them. Graphic and text-based analysis windows are provided for evaluating the results.”

The software is compatible with CAN, LIN, MOST, FlexRay, J1708, Ethernet, Wi-Fi and AFDX bus systems [19].

Another important thing is that CANoe supports all of the hardware interfaces that are available from Vector. Optimal bus access is possible for every use case thanks to the large selection of different computer interfaces (PCMCIA, USB 2.0, PCI, PCI-Express, PXI) and bus transceivers [20]. A detailed juxtaposition of the interfaces that are supported is presented in Figure 10.

Fig. 10. Vector hardware connection diagram [20]
Rys. 10. Schemat połączeń fizycznych za pomocą różnych interfejsów Vector [21]

3. Experiment

The experiment was performed using a Continental SRL-1 and a set of tools for controlling and monitoring a CAN.

In order to create the measurement station, hardware had to be connected and its requirements had to be fulfilled. Lidar requires several components in order to work on
a CAN bus. Specifically, the start-up was performed in a CANoe system with the following components:

- Lidar
- Vector VN1630A Interface
- PC computer with CANoe software
- Wiring for the lidar connection
- Power supply for lidar

Hardware connection requirements are:

- Power supply connected to lidar,
- Sensor plug connected to the CH1 plug-in on the Vector VN1630N,
- The Vector VN16030N connected to a computer using a USB cable. The device provides the bus interface for the CANoe software and enables data exchange between the CAN devices and the PC. A correctly working device signals activity using the green diode “Status”.

The device is terminated internally with a 120 Ohm resistor, and therefore, there is no need to terminate the bus additionally if a sniffing/interfacing unit is used. The connections of a system is presented in Figure 11.

![Connection diagram of the experimental setup](image)

**Fig. 11.** Connection diagram of the experimental setup

**Rys. 11.** Schemat podłączenia na stanowisku eksperymentalnym

### 3.1. Startup conditions

Lidar is not a standalone device in an automotive system. In order to provide continuous measurement, it needs to cooperate with numerous components such as the active engine, throttle pedal or ABS system. To activate lidar, several CAN frames that come from additional equipment have to be sent using a specific, manufacturer-defined content. Because these external devices were not available on the laboratory stand, they had to be emulated. Therefore, the simulation is performed by transmitting the frames that contained the status data provided by the other CAN devices in a car system. Each of those frames was defined in
CANoe software and was sent to lidar during the entire experiment. The information about the frames (IDs and transmitted data) that are related to specific devices were taken from manufacturer of the lidar device. Due to the confidentiality they cannot be presented in this paper.

Additionally, lidar requires a power restart after the start of a measurement as the simulation of ignition.

The last step after meeting the conditions and connecting the hardware properly was loading the proper configuration into CANoe and starting the simulation.

3.2. Results

The experiment was divided into two parts. The first one was on the measurements of distance on three channels, where each channel corresponds to one laser beam of a device while the second one was on the measurements of the velocity of an approaching object.

The results of the first part are presented in Figures 12 and 13. The figures present graphs that were taken from the live simulation. The values of the distance to an object are presented on three axes. Each axis corresponds to an individual laser beam of the lidar: the left, the central (middle) and the right one respectively. Figure 12 presents the movement of an object that appeared on the right channel at a distance of ca. 2.5 metres (3rd axis) and moves to the left channel through the middle in approximately 3 seconds (1st and 2nd axes). Then, the object moves from the right to the middle channel and towards lidar to a distance of ca. 2 metres. The differences in the shapes of trends observable during crossing of beams by the object mainly come out of its imprecise linear movement during the experiment. Sudden drops on the side charts show the moment that the object appeared in all three beams.

Figure 13 presents the rapid movement of an object through all channels at different distances. At the beginning, the object moves to the right channel (3rd axis), changes its distance to lidar with random dependence to move towards all of the beams at a distance of ca. 3 metres. The object finally moves rapidly through all three channels (from left to right) at a distance of ca. 1.5 metres. What is noticeable is that a temporary zero value is indicated on each channel, after which the proper measurement is continued. This event occurs whenever an object suddenly appears at a distance of less than ca. 2 metres from lidar.
The results of the second part of the experiment are presented in Figures 14, 15 and 16. Figure 14 presents the rapid approach of an object that was visible on the middle channel. The velocity (5th axis) rapidly increased from 0 to ca. 12 kilometres per hour in less than 400
milliseconds. Meanwhile, the distance that was measured between lidar and the object decreased from ca. 4m to less than 1m. The zeroes present for both the distance and velocity measured on the side channels indicated that the object was small and that it was moving in between the beams of the left and right lasers.

![Graph showing distance and velocity measurements](image)

**Fig. 14. Rapidly approaching object on the middle channel**

**Rys. 14. Szybki ruch w kierunku lidaru na środkowym kanale**

The experiment for an object that approached more steadily is presented in Figure 15. The velocity observed on the middle channel fluctuated around 4 kilometres per hour and the total time of the movement towards lidar was about 3 seconds. The fluctuation in the velocity measurements (3 to 6 kph) is the result of the imprecise control of the speed of the moving object. What is interesting is that the accuracy of the measurement was visible as “steps” during the speed changes. The shortest observable period of time in which the changes occurred was 20 ms. This phenomenon may indicate the minimum sampling frequency of the measurements, delays related to communication on CAN bus or may be a result of the refreshing frequency of the graphs that were created in CANoe.
Figure 16 presents a set of three rapid approaches that were visible and measured on all of the channels. The most significant changes were made on right beam (6th axis), where an object reached a velocity of more than 10 kilometres per hour and travelled distance of about 4 metres (3rd axis). Each approach was preprocessed with a small velocity peak, which was probably the positioning of an object. Changes in the distance are mostly seen on the right channel while changes in the velocity and distance on the middle and left channels are noticeable only at the end of a movement when object was close to lidar. This indicates that the object was moving mostly along the right laser beam but was big enough to enter the measurement zone of the other beams when it was close to the measurement device. An important observation is that movement away is noticeable after reaching lidar on each axis that presents the distance to an object although the velocity does not change. This indicates that the measurement of velocity is only done for objects that are approaching. The speed of the objects that are moving away is not calculated.
4. Summary

Lidar technology is a solution that is used to detect objects and to scan the surroundings. There are many technological realisations of lidar devices whose uses are mostly related to the types of objects that are detected and the conditions in which the measurements are taken. This multiplicity makes lidar technology a very flexible solution that can be used in a wide variety of areas.

Lidars provide very precise distance measurements thanks to combination of laser and optical systems that concentrate a light beam. In the case of the Continental SRL-1, which is primarily used in automotive solutions, an additional feature worth noticing is the fast response time of a device. Using it on a CAN bus increases the resistance to interference of a system and provides a real-time factor that makes the solution safe and applicable in areas in which human health and life are critical factors. Moreover, a CAN bus has very few physical requirements, and therefore, the entire system is relatively inexpensive and it is possible to construct it in non-automotive conditions, such as individual stands.
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The experimental stand that was created for the tests allowed components of a real CAN system including the SRL-1, which is typically used as ADAS device, to be used. The experiments consisted of measurements of the distance and velocity of approaching objects.

The device can be used successfully in a variety of use cases. In automotive systems, it is used to measure the distance to a vehicle that is moving in front of the host vehicle during a drive at a low speed. This functionality is used in automatic emergency braking in the event that a driver is not paying attention or in maintaining a safe distance between moving vehicles.

Lidar can additionally be used in places that have heavy pedestrian traffic such as parking lots. The analysis of distance on specific channels can indicate the location of a pedestrian that is close to a vehicle and can then activate safety procedures that would make it safe to leave a parking place.

Data with the amount of reflected light can be used to indicate the visibility level on the road. A low amount of emitted light returning to the receiver may mean the dispersion of the laser beam on aerosols that are scattered in the air, e.g. in fog, which could initiate a warning for the driver to be aware.

Finally, because of the measurement range of the SRL-1, lidar can be used in internal solutions. Mounting lidar on a robotic system could support the movement of a device (e.g. mobile platforms) through the observation of the nearest surroundings and by providing the data to the procedures for avoiding obstacles.

It is worth remembering that lidar does not calculate the velocity of an object that is receding (calculating velocity is performed only for approaching objects). This mechanism can easily be added into any processing unit as an additional functionality that expands the possible areas of the use of lidar.

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Omówienie

Technologie wspierające bezpieczeństwo na drogach i w ruchu samochodowym rozwijają się obecnie bardzo dynamicznie, powodując powstawanie całych gałęzi rozwiązań dla konkretnych zastosowań. Systemy wspierające kierowcę podczas jazdy nazywane są ogólnie Advanced Driver Assistance System (ADAS) i konstruowane są w oparciu o urządzenia pomiarowe podłączone do magistrali CAN. Jednym z takich urządzeń jest lidar. Jest to moduł zbudowany z emitera wiązki laserowej i odbiornika z układem teleskopu, służący do pomiaru odległości i obliczania prędkości zbliżania się do obiektu. Istnieje wiele rozwiązań wykorzystujących tę technologię, nie tylko w systemach samochodowych. Na potrzeby pomiaru odległości do przeszkód na drodze stosuje się przede wszystkim lidary krótkiego zasięgu wykorzystujące wąski zakres długości fal zbliżony do podczerwieni. Lidar współpracując z licznymi dodatkowymi systemami i urządzeniami pokładowymi wykorzystywany jest do wspomagania powolnej jazdy, np. podczas stania w korkach zarówno do utrzymywania bezpiecznej odległości do pojazdu znajdującego się z przodu jak również do uruchamiania systemów hamowania awaryjnego.

W artykule przedstawiono przegląd technologii i urządzeń typu LiDAR oraz krótko opisano technologię CAN wykorzystywaną w sieciach samochodowych. Następnie zaprezentowano przykład działania i warunki uruchomienia lidaru wykorzystywanego
w systemach ADAS. Poprzez transmisję ścisłe określonych danych pochodzących z zewnętrznych urządzeń zaprezentowano wykorzystanie lidaru w trybie pomiaru ciągłego, który poprzez dostarczanie informacji o odległości na trzech niezależnych kanałach, prędkości zbliżającego się obiektu i stopniu światła odbitego od przeszkody i powracającego od urządzenia pozwala na rozszerzenie zastosowania lidaru poza obszar systemu samochodowego. W sekcji badań opisano stanowisko eksperymentalne, na którym testowano urządzenie oraz pokazano przykładowe możliwości modułu razem z krótką analizą ich wykorzystania.

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