Lego Radar Train — An Educational Workshop on Radar-based Advanced Driver Assistance Systems

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***Abstract*—In modern vehicles a variety of sensors like radar, camera and lidar are combined in order to precisely sense the environment. This data is utilized by advanced driver assistance systems (ADAS) to provide comfort features and increased safety for the occupants. To cope with the demands of this growing market, it is necessary to attract young people to so-called science, technology, engineering and mathematics (STEM) studies and encourage them to contribute to this highly innovative topic. Therefore, we developed a workshop on radar-based ADAS to motivate pre-university students for STEM education and careers. In this paper we will present the individual hardware and software components as well as the basic structure of this practical hands-on training. Finally, we will shortly outline the spin-off projects resulting from the continuous development.**

***Index Terms*—advanced driver assistance systems, FMCW radar, educational platform, experiential learning, Raspberry Pi, LEGO**

I. Introduction

The increasing demand for modern vehicle safety and comfort features is a key driver for the development of ADAS such as the lane keeping assist (LKA) or adaptive cruise control (ACC) [1]. Further, due to stringent government regulations it is estimated that the ADAS market will grow to more than a \$100 billion within the next seven years [2]. Therefore, it is of high importance to attract young researchers and engineers to this highly innovative field. Beyond that, it is also essential to extend the well-founded basic knowledge imparted by theoretical lectures, with practical hands-on courses promoting innovation, creativity and problem-solving competencies on system level [3].

By comparing educational platforms for ADAS and autonomous driving (AD), which are typically based on model vehicles, we ascertained that most of them solely rely on camera data [4], [5], [6]. More advanced model vehicles, which are often designed for competitions like the Carolo Cup [7] or the Audi Autonomous Driving Cup (AADC) [8] further provide ultra-sound sensors or even lidar [8], [9], [10]. Nevertheless, to the best of our knowledge there is no platform supporting radar sensors. However, various state-of-the-art ADAS like ACC, autonomous emergency braking (AEB) or the blind spot assistant (BSA) are based on radar [11]. In contrast, ultra-sound sensing is usually only used for short-range applications at low speed like parking maneuvers [12]. Lidar sensors on the other hand are due to their size, mechanical restrictions and high price hardly used for ADAS in modern vehicles.

For this reason, we developed a workshop on radar-based ADAS together with students for students. The basis of our workshop is a Lego train equipped with a Raspberry Pi mini-computer and various sensors that can be utilized in order to automate a model vehicle. The initial setup was developed together with two students from an engineering-focused secondary school in the course of their final examination project in 2018. This type of an Austrian school is officially denoted as higher technical education institute (in German: Höhere Technische Lehranstalt, HTL) and starts with grade nine, lasts five years and formally enables graduates to attend university [13]. The main target audience of this workshop is also formed by HTL students. Students attending this training are further invited to contribute to the framework as part of their final examination project. The reason for precisely addressing young people of this age is to make them enthusiastic about the topic and encourage them to start studies with focus on computer science and signal processing. Firstly, this is beneficial for universities since the interest in STEM studies is comparably low [14]. Secondly, high-tech companies rely on the graduates of these fields of study.

Finally, it should be noted that the Lego Radar Train workshop represents the entry-level of a greater student project, which emerged from a cooperation between Infineon and the Institute of Signal Processing at the Johannes Kepler University (JKU) Linz called *miniaturized ADAS*. This project further includes two different radio controlled model cars equipped with additional sensors. However, in this paper we present those parts of the miniaturized ADAS platform utilized for the Lego Radar Train workshop. Furthermore, we explain the intended use of the available sensors and actors and give an insight on how this practical course is organized.

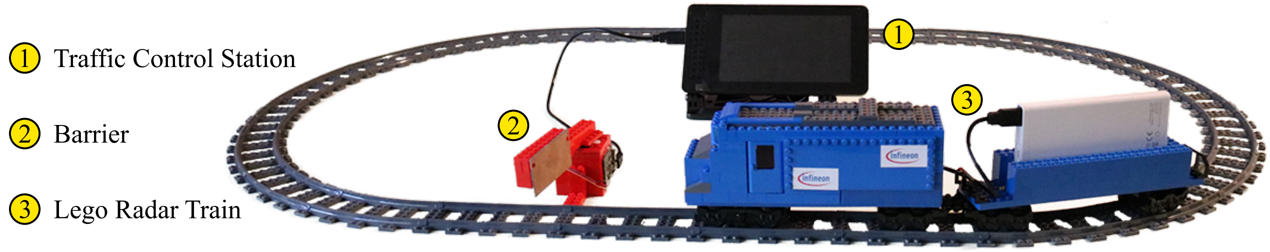


Fig. 1: Lego Radar Train workshop kit.

II. Hardware Platform

The aim of the workshop kit is to offer an environment already providing basic functionality. This means that the available sensors and actors are entirely integrated and the required communication interfaces are completely implemented. In addition, our system provides high-level functions for each component in the system, which give access to pre-processed data that can directly be used in the train's control unit. This minimizes the entry barrier and allows to focus on the development of the decision logic.

The idea to integrate the platform into a Lego train is based on the educational level of the participants. With the train being tied to rails, the students do not have to take care about steering, which reduces the problem by one dimension and leads to a quick sense of achievement. Additionally, the Lego kit is arbitrary expandable, and can potentially be used to encourage the students creativity.

To further decrease the entry barrier the processing unit of our workshop kit is represented by a Raspberry Pi, which is probably the most widely used commercially available mini-computer, and supported by a huge community. The first of two RPis is embedded in the train in order to process the sensor data and accordingly react to various situations. The second one is functioning as traffic control station integrated in a touchscreen. Furthermore, this station is connected to a controllable barrier, which is equipped with a MicroPython pyboard. This barrier represents a potential obstacle with which the train should not collide. The overall composition of the workshop kit is depicted in Fig. 1, while all integrated sensors and actors as well as their intended purposes for the guided part of the workshop are listed in Table I.

TABLE I: Overview of available sensors and actors as well as their intended use and costs

Sensor/Actor	Use case	Costs
Radar 60 GHz	range estimation of obstacles	150 €
Raspberry Pi camera	object detection	25 €
Accelerometer/Gyroscope	positioning	8 €
Current Sensor	battery management	9 €
H-Bridge	motor control	3 €
Servo Motor	vehicle drive	15 €
OLED Display	information output	5 €
Buzzer	attract attention	1 €
Touchscreen	train control, visualize data	70 €

In the following we will describe the three main components of the workshop in more detail.

A. Traffic Control Station

The traffic control station is composed of a touchscreen with an integrated Raspberry Pi 3B+. It serves as the central control unit and is able to control the barrier via USB or remotely start and stop the train via WiFi. Moreover, it can be used to wirelessly collect the sensor data of the train and visualize it on the screen. To do so, the traffic control station acts as a WiFi access point to which the train automatically connects.

B. Barrier

As depicted in Fig. 2 the barrier consists of a servomotor that can be rotated back and forth by 90°. This can be triggered by the traffic control station via the MicroPython pyboard in order to block the track. MicroPython is a lean implementation of Python 3, which can be efficiently executed on the pyboard that runs the programming language on the bare metal. Therefore, the board offers a low-level Python operating system that can be utilized to control all kind of actors. This perfectly fits our application needs.

Due to the fact that Lego stones provide a very poor radar cross section we attached a reflector plate made out of copper. Accordingly, the barrier is clearly visible in the radar measurement performed by the train.

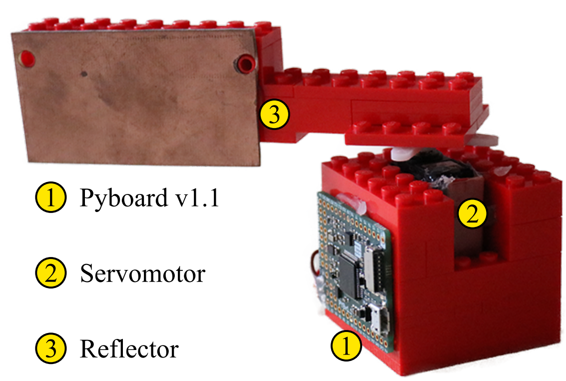


Fig. 2: Barrier consisting of a MicroPython board and a servo in order to force the train to perform an emergency brake.

C. Lego Radar Train

The Lego train is the essential part of our workshop kit. It is controlled by a second Raspberry Pi 3B+, which is powered by a power bank located in the carriage. The main sensor of the train is Infineon's 60 GHz frequency modulated continuous wave (FMCW) radar sensor. This tiny sensor was initially developed to be integrated into smart phones to perform gesture recognition. Currently, the train is equipped with a development version of the radar chip shown in Fig. 3, which is used in the Pixel 4 [15]. This sensor was designed for short distances while offering very high range resolution, which perfectly meets the requirements of our miniaturized application. By placing absorber material in front of the module we applied mechanical beam forming in order to inhibit a field of view of 180°. This enables the use of basic radar signal processing algorithms and ensures that the radar is only detecting obstacles located directly in front of the train.

Another interesting sensor is the MPU-6050 that combines a 3-axis accelerometer and a 3-axis gyroscope on a single chip. In combination with signal processing algorithms it enables to estimate the position of the train on the track. Furthermore, the train provides a camera, which could potentially be used for object detection, and an equipped current sensor can be utilized to implement a proper power management. The train offers actors like an organic light-emitting diode (OLED) display to indicate error messages, a buzzer to attract attention, and a bridge circuit to control the train's motor.

III. Software Platform

The code base provided in the workshop is utilized for every project in the *miniaturized ADAS* ecosystem. Therefore, we implemented a configurable and highly scalable framework for educational purposes, which offers an easy to use experience. In addition, we aimed on keeping the initial hurdle as low as possible and therefore decided to use the very popular programming language Python. In order to consider the data of multiple sensors simultaneously and provide a reusable design enabling real-time capability, multithreading and even multiprocessing implementations are indispensable. Due to the fact that such approaches are not straightforward we employed a co-routine concept based on greenlets [16]. Co-routines, in combination with message passing systems, allow the design of concurrent systems avoiding the challenges usually associated with traditional multi-threading techniques. This makes our platform easily accessible to students without a strong background in parallel computing. Based on this framework interns developed the already mentioned high-level functions for each component that is supported by *miniaturized ADAS*. Since the requirements for sensors are naturally different compared to actors, we designed two fundamental concepts that will be described in the following.

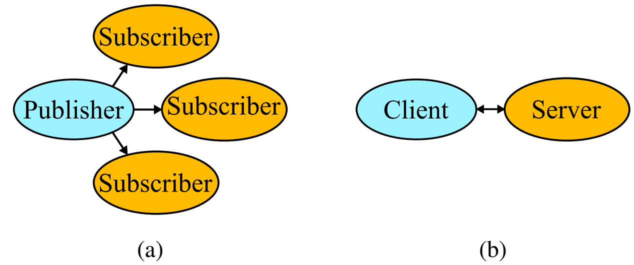


Fig. 4: Schematic representation of the basic communication framework for (a) sensors and (b) actors.

A. Sensor Communication Framework

The sensor communication interface is based on a publish-subscribe pattern. This means that a sensor provides its data regardless of whether any subscriber is connected to receive the data. The basic design of such an interface is schematically depicted in Fig. 4a.

Considering the example illustrated in the class-diagram shown in Fig. 5, it can be seen that the data of the radar sensor

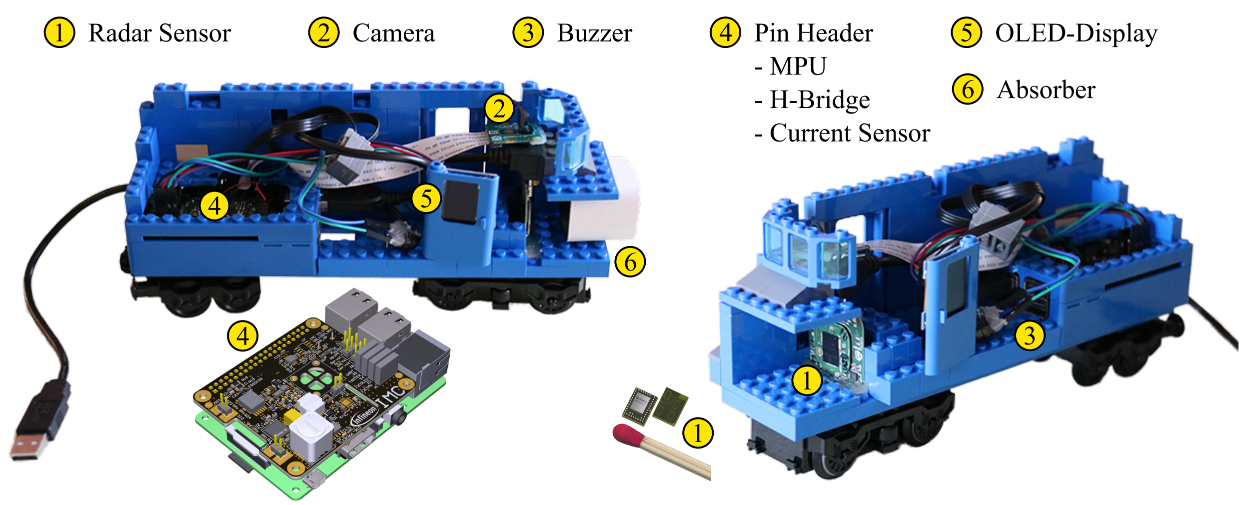


Fig. 3: Lego Train equipped with multiple sensors and actors including a 60 GHz radar controlled by a Raspberry Pi.

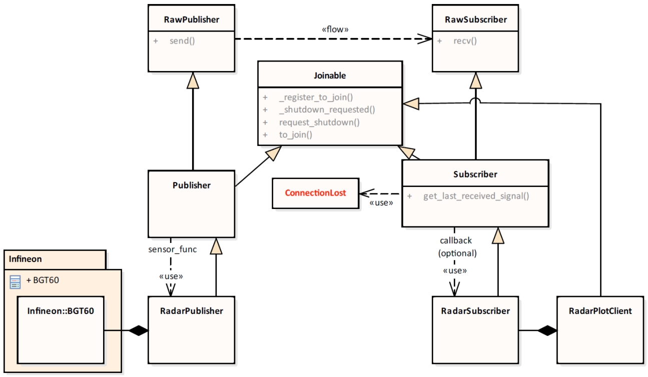


Fig. 5: Class diagram describing the framework for sensor communication by the example of the radar sensor.

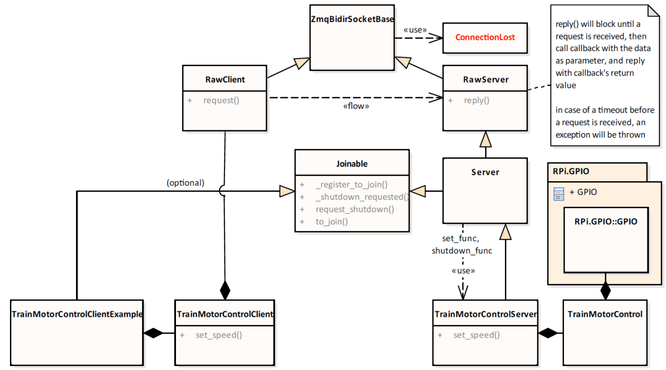


Fig. 6: Class diagram describing the actor communication framework depicting the train motor control unit.

is provided by the *RadarPublisher*. After receiving the raw signal, the *RadarSubscriber* is pre-processing the data in order to estimate the range of objects in front of the train by performing a fast Fourier transform (FFT). This data can for example be used by other instances to perform an emergency brake or plot a so-called range spectrum, indicating the presence of potential objects at a certain distance. Therefore, it is possible to arbitrarily extend the workshop or any other application based on our platform. In Section IV we will give an insight on how this was successfully done in previous workshops.

Furthermore, we implemented a time-out that enables to detect malfunctioning sensors. By catching the exception resulting from a time-out the system can be programmed to adequately behave in such situations. This can be used to introduce the students to the topic of functional safety and encourage them to implement a safe design similar to what industry is targeting with the ISO 26262 standard.

B. *Actor Communication Framework*

The second basic interface used for actor communication describes a point-to-point connection. As shown in Fig. 4b exactly two parties, referred to as client and server, have to be available for the data exchange. This is enabled by a permanent data stream between the involved entities. Keeping our application in mind and considering the example of the train motor control one can assume that a change in velocity is only rarely necessary. Nevertheless, in order to ensure a constant data flow the present speed value is transmitted in a certain time interval, for the case the speed value should be maintained. As indicated in Fig. 6 this request is answered by an arbitrary defined reply implemented in the corresponding Server. If the connection is broken the instance waiting for the next message will throw an exception after a certain amount of time. In order to guarantee a stable procedure the exception has to be handled accordingly. This periodic signal exchange, also referred to as heartbeat in computer science literature, allows for a functional safe implementation of the actors as well.

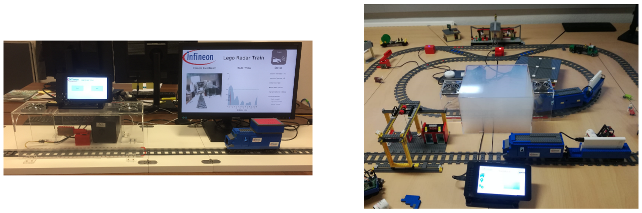
IV. Workshop

Our experiential hands-on training for young students puts special focus on imparting knowledge through experience. Additionally, we are providing direct feedback to encourage the students to reflect on their implementations [3]. The workshop has already been successfully held twice and is planned to be further extended this year. Fig. 7 gives an insight into one of the workshops and should convey the atmosphere.

In general the workshop is divided into six exercises with increasing complexity. After successfully solving each assigned task the students are invited to answer problem-related questions. This enables to check whether the appearing issues were solved correctly and offers the opportunity to reflect on the students solutions and eliminate potential misunderstandings.

Firstly, the students get a short introduction on how to remotely control the Raspberry Pi in order to program the train. This is followed by the first exercise, which consists of simply running short test programs to start the train or perform a radar measurement. The aim of this very simple tasks is to introduce the students to the software framework and familiarize them with the provided high-level functions. In the second task the students are encouraged to display some debugging output on the OLED display. After that, the challenge is to perform a radar measurement and trigger an emergency brake in case of a blocked rail. This exercise is extended by task four, which requests to implement a simple

Fig. 7: Workshop 2019 at HTL Leonding with more than sixty participating students.



(a) (b)

Fig. 8: Demonstrators based on the miniaturized ADAS platform used in the Lego Radar Train intended for (a) trade shows and (b) permanent exhibition.

bang-bang controller in order to position the train at a certain distance to a detected obstacle. The penultimate task is to improve the provided workshop version of the *MpuSubscriber*, which is simply providing the raw sensor data. Following the given instructions on how to adequately process the data provided by the *MpuPublisher* the student's version should give access to the train's position on the track.

Finally, to further promote the students creativity they are invited to realize their own scenario. If the students are not able to think of their own application we encourage them to implement a smart barrier. The idea is to prevent the barrier from closing while the train is passing it. This can be done by properly using the position data provided by the MPU. Anyhow, typically the students are keen on developing their own use case. In the last workshop two groups merged to build up a larger track out of their kits, which was able to accommodate both trains. By slightly adapting the bang-bang control implemented in task four they implemented a simple ACC. Further examples that have been implemented in the final task are a derail detection, a battery charge indicator or a camera based detection of a pre-defined symbol.

V. Spin-off Projects

The further development of the workshop setup by students in the course of internships and examination projects led to multiple derivatives of the Lego Radar Train. The two most impressive demonstrators are depicted in Fig. 8. The smaller version shown in Fig. 8a offers full plug and play capability, can easily be packed in a box and is therefore perfectly suited to be presented at trade-shows. As a highlight this version of the Lego Radar Train is able to showcase an emergency brake in a foggy environment, which highlights the benefits of radar sensors over cameras for this use case. The larger version of the train presented in Fig. 8b is currently developed and intended for permanent exhibition. In addition to the already mentioned fog tunnel this track is long enough to permanently accommodate two moving trains. Beyond that, the construction includes two railway sidings offering a wireless charging station for two additionally parking trains. By properly triggering the controllable railroad switches the trains are able to change their position in case of low battery. Therefore, an all-day operation in automatic mode can be ensured.

VI. Conclusion & Outlook

In this paper we presented our experiential workshop for HTL students, which strives to make young talents enthusiastic about STEM education and careers. In order to reach students all around the world we plan to open-source both the hardware and the software components as well as a reference implementation of the exercises. Additionally, we constantly improve our platform and currently plan to enhance the workshop by machine learning algorithms that can be executed on the Raspberry Pi in combination with a neural compute stick.

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