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An Experimental Bench for Testing a S-CAM Front Car Camera

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Abstract—**The paper presents an experimental stand for testing the front car camera S-CAM with embedded image recognition systems. The camera sends CAN messages these are converted to USART messages by microprocessor based system. The messages are interpreted by MATLAB script on the basis of database of traffic signs in accordance with Polish Road Code. The testing stand is mainly aimed for educating students interested in the fields of electronics and technologies related to automotive branch, as well. The second objective is a research on efficiency of traffic sign recognition system being one of functionalities of S-CAM camera. The technical specification of testing stand, its functionality and limitations were also discussed. The bench operation was illustrated with examples of stiff images, animation and real movies.**

Keywords—**automotive technology; driving safety; ADAS; front camera; CAN bus; traffic sign recognition**

I. INTRODUCTION

Every few years many organizations prepare reports discussing the actual situations and changes over several years on road safety, e.g. WHO, EC and OECD. The global situation is presented by World Health Organization in the report [1]. Unfortunately, the number of traffic deaths continues to grow, reaching a high number of 1.35 million in 2016 year! It is hard to image the scale of it and unfortunately any single case there is a very dramatic situations for families.

Let's cite the words of the Director-General of WHO “There is a phone call or a knock on the door that we all dread, in which we are told that a loved one has been killed or seriously injured in a road traffic crash.” However, there are also good news. The rate of deaths relative to the size of the world‘s population has stabilized and declined relative to the number of motor vehicles in recent years. During the same period, the number of vehicles worldwide has steadily increased, while death rates declined from 135 deaths for every 100 000 vehicles in 2000 to approximately 64 deaths in 2016. The rate of depths on the roads is 180 per million inhabitants and is constant over the last 15 years. The other key messages from the global report relating to the road unsafety are as follows [1] “road accidents are: - 8th leading cause of death for people of all ages, - first cause of death for children and young adults 5-29 years of age, - 3 times higher death rates in low-income countries than in high-income countries.”

The indicators for European Union countries generally are more optimistic, i.e. 51 fatalities in 2019 (mean value) but some members, e.g. Poland, is still in a bad situation with 77 deaths [2]. Nevertheless, the data presented in both reports show that significant progress has been achieved in key areas such as legislation, including standards and formal road conventions, quality of roads and urban infrastructure, and improving access and effectivity of post-crash care. The most all of us are involved every day or occasionally in the road traffic and related to it possible emergency situations, so we should request from automotive engineers and companies to design more smart and effective technologies for protection our health and life. Generally, we expect that cars will be equipped with technologies really assisting drivers in dangerous moments and it is necessary taking decision autonomously saving a road agent life – driver, passenger or road occupants. The two terms are today common: Advanced Driver Assistance Systems and Autonomous Driving. They form one broader vision of the next car generation and safety is a primary objective. When dealing about safety it is important to make distinction between functional and nominal safety. The first term refers to the integrity of the operation in a car electrical subsystem that is operating in a safety critical domain. It is concerned with a failure in hardware or software bugs that could lead to a safety hazard. For the automotive industry this is well covered by a risk-based standard ISO 26262 which concerns different Automotive Safety Integrity Levels (ASIL). The main features are as follows:

- covers functional safety aspects of the entire development process including requirements specification, design, implementation, integration, verification, validation, and configuration;
- uses ASILs for specifying the item's necessary safety requirements for achieving an acceptable residual risk;
- provides requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety.

The achieving the goals specified in this standard require the fusion of many technological solutions and theoretical analysis. It can be a little-bit surprising that safety issues can be formalized and described by mathematics. It is realistic today and applicable but we must be aware that any mathematical model works rightly under some limitations and needs pre-assumptions. A very interesting approach to the road safety presenting the mathematical point of view is discussed in paper [3]. The so-called Responsibility Sensitive Safety (RSS) model was proposed. The main goals are as follows: firstly, the

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interpretation of how humans interpret a mindfulness must be understood. Secondly, the so called key agents being engaged in road traffic must be identified. The model assume that risk can be minimized under the condition that all agents comply with RSS parameters. The statistics show, that accidents are resulting mainly from decision-making processes. The conclusion is that human is the riskiest and most unpredictable agent. According to the Authors of [3], the future is fully autonomous driving with human passive role.

Currently, a lot of effort is put into the implementation of this concept by automotive companies and scientists. The taxonomy with detailed definitions for six levels of driving automation, ranging from no driving automation (Level 0) to full driving automation (Level 5) was proposed by SAE in standard J3016 [4]. Level 0: No Driving Automation, Level 1: Driver Assistance, Level 2: Partial Driving Automation, Level 3: Conditional Driving Automation, Level 4: High Driving Automation, Level 5: Full Driving Automation. For level zero there are no ADASs assisting the driver in handling steering and acceleration/deceleration. Everything is handled manually by the driver. Level one consists of ADASs assisting the driver in handling either steering or acceleration/deceleration under certain cases with human driver input. In level two the ADASs handle both steering and acceleration/deceleration under certain environments with human driver input. In general, in levels 0 to 2, the driver monitors the driving environment. In contrast, at higher levels, multiple safety functionalities are handled by the system, but the driver intervenes when needed. Level four vehicles handle multiple safety systems and operate in a wider range of environments. Level five of automation is the end goal of autonomous driving, where all of the systems in the car are operated by the ADAS, under all driving conditions and would not require any human intervention. The most common ADAS technologies supporting driver are presented in Table I.

TABLE I
EXAMPLES OF ADAS SYSTEMS

Abbr.	Full name
ABS	Anti-Lock Braking System
AP	Autopilot
ESC	Electronic Stability Control
ESP	Electronic Stability Program
ACC	Adaptive Cruise Control
TPMS	Temperature Pressure Measuring System
AEB/FCW	Automatic Emergency Braking/Forward Collision Warning
BSM	Blind Spot Monitor
LKA/LD	Lane Keeping Assist/Lane Detection
TJA	Traffic Jam Assist
ALC/ADB/AHLS	Adaptive Light Control/Adaptive Driving Beam/Automatic Hi-Low System
DFD	Drowsiness and Fatigue Detection
SLW	Speed Limit Warning
POD/OD	Pedestrian and Obstacle Detection/Object Detection
TSR	Traffic Sign Recognition
TLR	Traffic Light Recognition

A review of the most popular available technologies used in ADAS and descriptions of their application areas are discussed in [5]. A classification of ADASs based on the different types of sensors used and discussed outdoor and indoor monitoring with vision-based ADASs are presented in the paper [6]. The importance of sensor fusion techniques from vision cameras, lidar, radar, and ultrasound sensors and advanced communication systems, such as V2I (vehicle to infrastructure) or V2X (vehicle to everything) was also pointed out. This fusion of data from information geosystems with data collected by the vehicle is another challenge. Many solutions being developed were tested locally in specific region or countries. Even in the EU member countries the appearance of the same signs may vary and road conventions too or right/left-hand traffic issue. These factors limit some possibility of the ADAS technologies to specific location and is also conditioned by the availability of data provided by IT infrastructure. Furthermore the precision and stability of GNSS position contributes to the automated vehicle system safety. Greater availability of GNSS-based positioning can be achieved through the use of multi-frequency and multi-constellation GNSS antennas and receivers, which implies interoperability and compatibility between GNSS constellations and radio frequency signals. However, safety and security aspects should be considered to ensure proper integrity. A detailed overview of past, present and future designs are provided in [7] and many research papers and company documentation. It will be omitted here as a bulk topic suitable for another article. Let's concentrate on some ADAS technologies mentioned in Table 1. For example, the experimental bench for testing the TPMS system was discussed in [8]. The review of solutions for drowsiness detection is mentioned in the paper [9]. The intrusive systems may yield a more accurate detection of drowsiness; drivers seem to be more reluctant to use this type of system. Among the nonintrusive systems, those focusing on eye features are the most investigated, followed by head-movement detection, mouth shape, and head pose, are reported. The automotive companies' point of view on ADASs is broadly discussed in the white paper [10]. That publication summarizes widely known safety aspects by definition of principle of automated driving, law and standards, technological limitations, requirements for system verification and validation, cybersecurity and many others. It also represents guidance for potential methods and considerations in further development. This paper can be strongly recommended for further reading.

One of the technologies given in Table I is the ability to 'Traffic Sign Recognition' requiring an analysis of camera images and sophisticated algorithms for pattern classification. Typically, deep neural networks are used for object detection which comprises Convolutional layers and Spatial Transformer Networks. The different adaptive and non-adaptive stochastic gradient descent optimization algorithms were evaluated among others in [11]. The state-of-the-art various object detection systems with Yolo V3, Resnet 50, Densenet, and Tiny Yolo V3 classifiers combined with spatial pyramid pooling for building feature extraction are discussed here [12-14]. Another approach was proposed in [15]. In that paper, it was designed and implemented a sign detector by adopting the framework of R-convolutional neural networks (CNN) and the structure of MobileNet. Additionally, the colour and shape information has been considered to refine the localization of small traffic signs, which are not easy to regress precisely. The authors state that both the detector and the classifier proposed are proved to be superior to the state-of-the-art method.

In the next section of this paper, an experimental test bench assembled in the Faculty of Electrical Engineering at Częstochowa University of Technology (Poland) will be discussed in details. The bench is mainly aimed at educating students interested in the fields of electronics and automotive technologies as well. The second objective is to research on the efficiency and correctness of the traffic sign recognition system in different simulated scenarios.

II. AN EXPERIMENTAL TESTING STAND FOR TRAFFIC SIGN RECOGNITION

The key element of the stand is the S-CAM 3.5 type camera seen in Fig. 1.

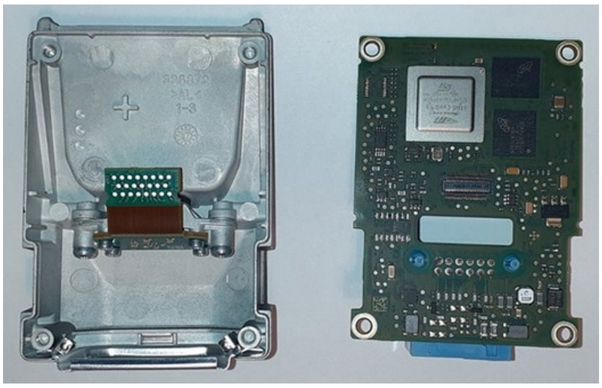


Fig. 1. View of the camera's optical module and PCB

The camera is autonomous system not needing any maintenance or supervision supplied with a voltage in the range of 12-15V and delivering a grayscale image in 320x240 pixels low resolution. An exemplary view from the camera is shown in Fig. 2. The image is used by the following technologies implemented in camera electronic board: ADB, AHL, LD, OD, TFL and TSR – look in Table 1 for reference.

Fig. 2. The scene seen by camera in the grayscale

On PCB of the camera the vision processor responsible for image acquisition and the STME-EyeQ 3 SoC produced by STMicroelectronics are assembled. The SPC5643 chip from NXP is a microcontroller based on the architecture of the Power processor family. It includes analog-to-digital converter, CAN bus driver and I/O subsystem. Its primary role is managing the CAN bus to integrate the camera with other car subsystems. The FL256SDVHC chip from Spansion company is a 32 megabyte flash memory. Micron's B1332BDBH is a 1GB low voltage DDR2 SDRAM. Two such integrated circuits are placed on the PCB of the camera. The chip STME-EyeQ 3 SoC has implemented the architecture and algorithms designed by the MobilEye company and was used first time in Tesla Highway Autopilot technology from 2015. The newer versions STME-EyeQ 4 and 5 were released in 2018 and 2019. The EyeQ6 chip (2021) consist of four channel LPDDR 2 CPU cores (8 threads) supported by accelerators: 1xPMA, 2xVMPs and 1xXNN. The above abbreviations mean: Programmable Macro Array – dataflow machine, Vector Microcode Processor - VLIW and SIMD based machine, and Deep Learning Accelerator - dedicated high-performance AI engine as the main source of horsepower for convolutional neural network. The latest generation of EyeQ 6 High offers a complete SDK package and OpenCL environment and support for TensorFlow, allowing you to implement your own algorithms in EyeQ. Moreover, EyeQ 6 supports co-hosting of third-party applications, simplifying the complexity of electronic systems and relieving the on-board computer. Such large computing power of SoC makes a real vision of "Autonomous driVing on Chip" concept [16].

The camera and all elements of the stand are shown in Fig. 3. The camera (2) with an additional lens imitating the windshield effect in the car is mounted on an aluminium tripod (1). The camera broadcasts data on the CAN bus in the 2.0 B mode, i.e. CAN frames are equipped with a 29-bit identifier and 4 or 8 bit data field. The transmission speed is 500 kbps. Frames can be captured in many ways. One of them is using a Microchip CAN bus monitor (6) with a dedicated software for data visualization and recording.

Another solution may be to use an universal embedded system (5) with an STM32 microprocessor running the C language based software. This enables the observation of raw data or converted to the text string on a PC (8). Thereby, data can be received with a classical serial terminal. Two ways of collecting data (frames) sent by car camera are presented in Fig. 4 – using Microchip CAN bus monitor and embedded system with dedicated specially created software. Data can be grabbed also in manner used by engineers testing such a S-CAM camera at the ZF Engineering Center in Częstochowa, i.e. by the use of the Neo10 module (3). It emulates the behaviour of the on-board computer of one of the Fiat car models and uses the PTM32 communication protocol. Such a solution enables access to the hardware resources of the camera, e.g. matrix calibration, memory dumps, monitoring of reported system errors. The key function of the dedicated software delivered with the camera is, of course, the interpretation of messages about identified traffic situations. Much greater flexibility, demonstrating didactic value, offers an open self-made solution. The CAN frames, after conversion to the RS232 standard, are loaded into the MATLAB environment. Received data are assigned with database of messages and additionally with the collection of images representing road signs used in Poland with shapes and colours specified in the Polish Road Code [17]. They are displayed on the monitor (7) imitating the scene in front of the car. The MATLAB script, based on the CAN frame identifier, searches the message database in the * .dbc debug file format. If message identifier matches then the description of the message fields is imported, which allows for message proper "unpacking". An exemplary description of the message is shown in Fig. 5 with sign number hold by the 'SG_ SignType_10' field. For messages representing the recognized signs (TSR), graphic files are loaded from the disk for visualization of recognized signs on the control monitor (8).

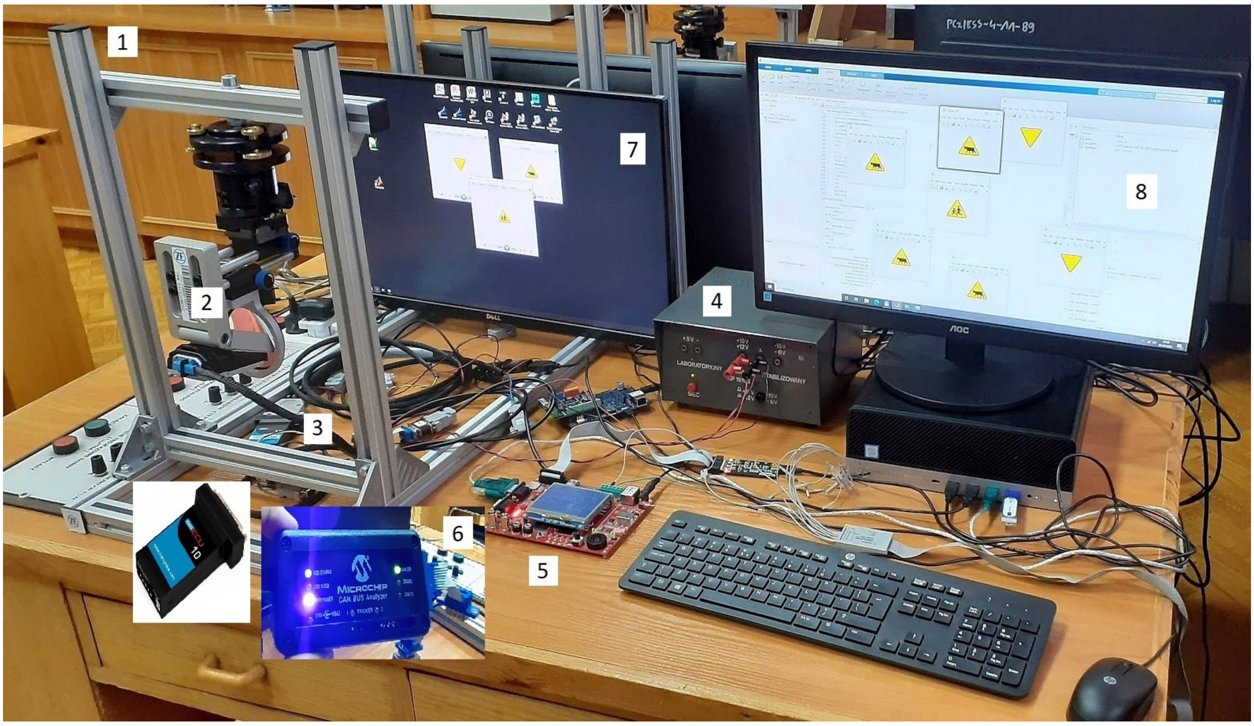
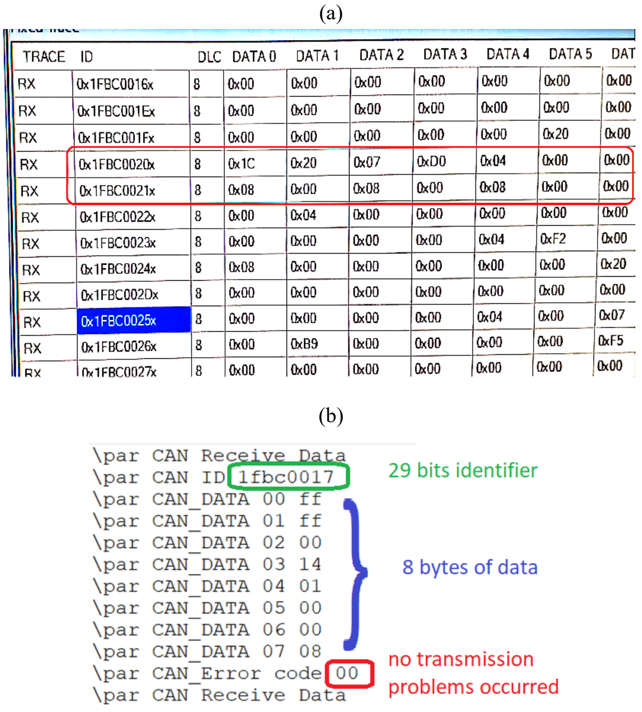


Fig. 3. The test bench: (1) – the mounting frame, (2) – S-CAM camera with optical setup, (3) – Neo 10 ECU emulator, (4) – power supplier, (5) – embedded system, (6) – CAN bus monitor, (7) – monitor simulating scene in front of car, (8) – host computer for data acquisition and analysis with MATLAB scripts and databases.


(a)

TRACE	ID	DLC	DATA 0	DATA 1	DATA 2	DATA 3	DATA 4	DATA 5	DAT
RX	0x1FBC0016x	8	0x00	0x00	0x00	0x00	0x00	0x00	0x00
RX	0x1FBC001Ex	8	0x00	0x00	0x00	0x00	0x00	0x00	0x00
RX	0x1FBC001Fx	8	0x00	0x00	0x00	0x00	0x00	0x20	0x00
RX	0x1FBC0020x	8	0x1C	0x20	0x07	0xD0	0x04	0x00	0x00
RX	0x1FBC0021x	8	0x08	0x00	0x08	0x00	0x08	0x00	0x00
RX	0x1FBC0022x	8	0x00	0x04	0x00	0x00	0x00	0x00	0x00
RX	0x1FBC0023x	8	0x00	0x00	0x00	0x00	0x04	0xF2	0x00
RX	0x1FBC0024x	8	0x08	0x00	0x00	0x00	0x00	0x00	0x20
RX	0x1FBC002Dx	8	0x00	0x00	0x00	0x00	0x00	0x00	0x00
RX	0x1FBC0025x	8	0x00	0x00	0x00	0x00	0x04	0x00	0x07
RX	0x1FBC0026x	8	0x00	0xB9	0x00	0x00	0x00	0x00	0xF5
RX	0x1FBC0027x	8	0x00	0x00	0x00	0x00	0x00	0x00	0x00

(b)

```
\par CAN Receive Data
\par CAN ID 1fbc0017
\par CAN_DATA 00 ff
\par CAN_DATA 01 ff
\par CAN_DATA 02 00
\par CAN_DATA 03 14
\par CAN_DATA 04 01
\par CAN_DATA 05 00
\par CAN_DATA 06 00
\par CAN_DATA 07 08
\par CAN_Error code 00
\par CAN Receive Data
```

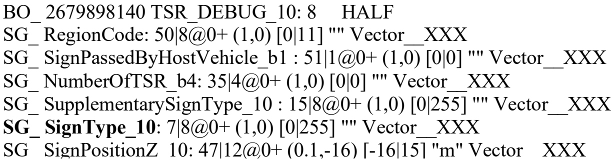
29 bits identifier

8 bytes of data

no transmission problems occurred

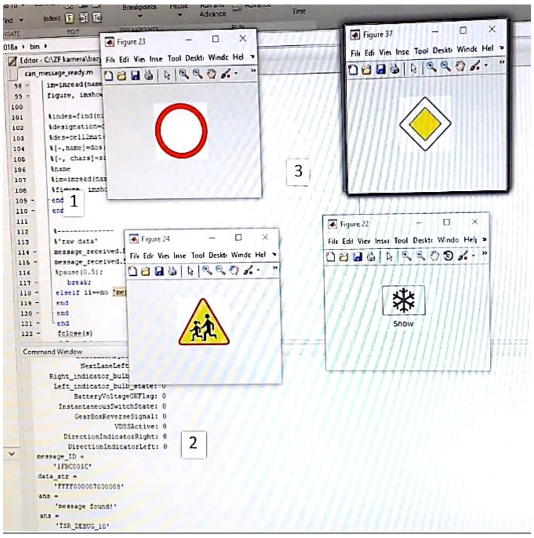
Fig. 4. The CAN frames received by (a) Microchip CAN bus monitor and (b) embedded system with STM microprocessor

An interesting function of the camera is sending frames with special meaning, the so-called "Failsafe". They informs about abnormal camera working conditions. The reasons for this may be a frozen windshield of the car, heavy rain and snow, blinding the camera, partial dirt on the lens or its complete covering.



```
BO_ 2679898140 TSR_DEBUG_10: 8    HALF
SG_ RegionCode: 50|8@0+ (1,0) [0|11] "" Vector__XXX
SG_ SignPassedByHostVehicle_b1 : 51|1@0+ (1,0) [0|0] "" Vector__XXX
SG_ NumberOfTSR_b4: 35|4@0+ (1,0) [0|0] "" Vector__XXX
SG_ SupplementarySignType_10 : 15|8@0+ (1,0) [0|255] "" Vector__XXX
SG_ SignType_10: 7|8@0+ (1,0) [0|255] "" Vector__XXX
SG  SignPositionZ  10: 47|12@0+ (0.1,-16) [-16|15] "m" Vector   XXX
```

Fig. 5. An excerpt of message description



```
im=imread(nam
figure, imshow

%index=find(n
%designation=
%des=cell2mat
%[~,name]=dos
%[~, chars]=s
%name
%im=imread(na
%figure, imsh
end
end

%--------------
%'raw data'
message_received.
message_received.
%pause(0.5);
    break;
elseif ii==no
end
end
end
fclose(s)
```

```
          NextLaneLeft
Right_indicator_bulb
 Left_indicator_bulb_state: 0
      BatteryVoltageOKFlag: 0
  InstantaneousSwitchState: 0
      GearBoxReverseSignal: 0
               VDSSActive: 0
   DirectionIndicatorRight: 0
    DirectionIndicatorLeft: 0
message_ID =
    '1FBC001C'
data_str =
    'FFFF000007000008'
ans =
    'message found!'
ans =
    'TSR_DEBUG_10'
```

Fig. 6. Screenshot from control screen: (1) – excerpt of a Matlab script, (2) – example of decoded message, (3) – the recognized four signs

Next figure, i.e. no. 6, presents the MATLAB script (1), the decoded message (2) and examples of recognized four signs (3) – one of the failsafe case related to bad visibility condition due to snowing.

III. SELECTED RESULTS OF CAMERA TESTING

The camera effectivity can be validated in different types of simulation that contribute towards different testing goals. Regardless of the type of simulation, any simulation result should be reproducible at a later point for traceability and maintenance purposes. The basic test of the camera's effectiveness consisted in verifying the correctness of recognizing single signs with a graphic format and colours complying with defined in the Polish Road Code. For this purpose, a collection of all signs saved in separated image files. The all road signs are divided into categories:, warning signs A1-A34, prohibition signs B1-44, mandatory signs C1-19, information signs D1-53, direction and localities E1-22 and supplementary ones F1-22.

Lets' remind that the primary aim of ADAS systems is to increase the level of safety of road users. The driver should only receive the necessary information that has a real impact on the assessment of the situation and the decisions taken. The provision of irrelevant data may have a counterproductive effect, i.e. by distracting the driver, increasing the risk on the road. For this reason, the camera focuses mainly on signs from the warning, prohibition and mandatory A, B and C categories. The initial tests show that tested camera correctly recognized 82% of signs from category A, except for those found in a rare locations, e.g. A-26 - airport, A-27 - quay or river bank or A-34 situations - road accident. The results of the tests in the remaining groups are as follows: 64% from category B, excluding those that do not apply to passenger of vehicles, e.g. B-10 - no entry of mopeds or B-29 - no use of sound signals, where this prohibition is valid for rules in built-up areas and therefore this sign seems to be redundant; 53 % from group C - the camera ignores, for example, C-18 - obligatory to use anti-skid chains or C13 - a bicycle path; 17 % from group D, i.e. information signs. Signs from categories E and F were skipped during tests and not verified.

In real operational situations, the camera analyses the moving scene while the vehicle is driving. To simulate such scenarios, graphical animations (movies) with single sign are displayed as in the Figure 7. The goal is to figure out if any sign will be correctly detected or omitted. Another considered case can be evaluating the maximum speed of the car while the recognition functionality is still working properly.

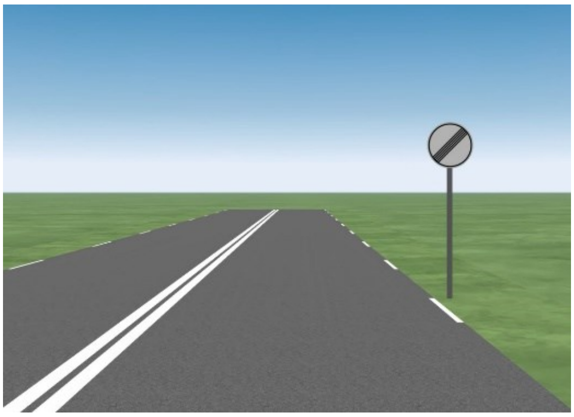


Fig. 7. Frame from animation with single sign

Next level of more demanding tests can be analysis of scene (images or videos) recorded on real roads in various weather conditions. If the system is aimed to work automatically in the manner of "system in the closed loop", the signs to be recognized must be correctly tagged with timestamp. For example the "Image Labeler" tool provided by MATLAB package can be used. This app provides an easy way to mark rectangular region of interest (ROI) labels, polyline ROI labels, pixel ROI labels, and scene labels in a video or collection of images. Frames or single images must be labelled manually. Any labelled object can be characterized by many defined attributes, e.g. sign category, number of signs, visibility and the most important data - sign numbers. During performed test only one attribute was defined just 'sign_no' as string collecting numbers complying with the same database used for testing single sign as shown in Fig. 3. Figure 8 presents the effect of working of "Image Labeler" app. There are visible the image and sign number 169 marked by yellow ROI rectangle. The result of labelling can be text file or complex variable (object) for further processing by any MATLAB script.

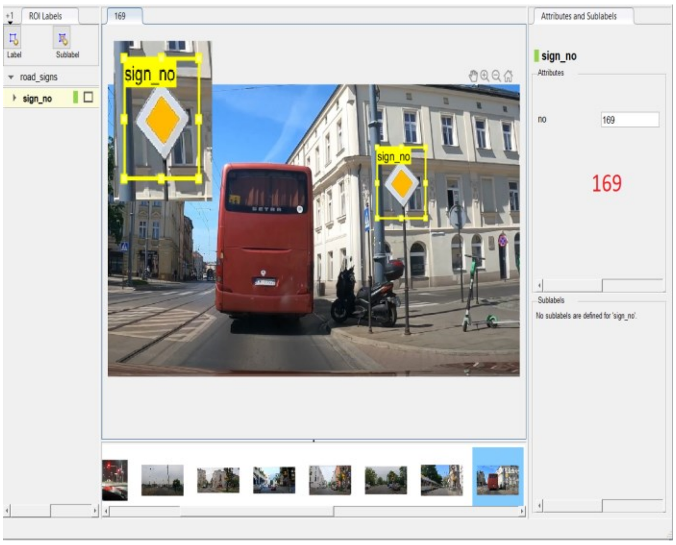


Fig. 8. Screenshot from "Image Labeler" app with marked sign no. 169

CONCLUSION

The presented test bench has significant educational value as it integrates knowledge from various areas, mainly electronics, telecommunications and IT. It allows the student to familiarize himself with its elements, assembly and commissioning, and to conduct various test scenarios. Thanks to the open architecture, it gives students the opportunity to introduce their own modifications in the software in the C language of the embedded system, e.g. for error detection of incoming CAN transmission (CRC codes) and outgoing RS232 (parity bit), basic data visualization on the touch display. Also, the MATLAB script can be equipped with, for example, a GUI interface by creating your own user application or increasing the functionality of the entire system by automating the tests with the analysis of the correctness of the recognized cases according to the principle "hardware and software in the closed loop". The presented test bench is inspired and similar to the real actual test stand used in the Engineering Center of the ZF company in Częstochowa, which allows to reproduce the working conditions that students may encounter in their real professional work.

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