A Platform to Interest Young People in STEM using Robotics and AI in a Playful Way

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Keywords: e-Learning Hardware and Software, Children's Education using Computer Support and K12 Students, Robotics.

Abstract: This paper describes an educational and affordable robotics design of hardware and software for a technical platform for playful learning in STEM fields, providing a low entrance barrier and a smooth transition from playing to developing, depending on the user's age. The platform is installed in a toy car and operates the vehicle motors. A smartphone app serves as remote control. In addition to the simple basic electrotechnical structure for driving, which is comprehensible to users, the design can be extended with actuators or sensors via standardized modules and interfaces. On the software side, experimentation possibilities arise to process captured sensor values or to experiment with an AI-supported image recognition, allowing users to get an insight into up-to-date discussions like AI-based image recognition int the context of autonomous driving. In addition, the system offers smartphone app functions, such as an image display on the smartphone or automated vehicle behavior. Manufacturer-independent and without proprietary specifications, this platform opens up a flexible, expandable technical basis for playfully exploring the interaction of components in one's own interest without prior knowledge or programming experience.

1 INTRODUCTION

Mathematics, computer science, natural sciences, technology - almost no area of life today is not influenced by the disciplines summarized in the acronym "STEM". It is becoming increasingly important for future generations since this field is not only in high demand from the labor market, but it also affects our daily life. Knowledge in these areas is essential for a country to be attractive as business location. (U.S. department of education 2022) states: "In an ever-changing, increasingly complex world, it's more important than ever that our nation's youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions. These are the kinds of skills that students develop in science, technology, engineering, and math, including computer science—disciplines collectively known as STEM/CS." Interesting young people in technology should already start at an early age. Hence an age-appropriate approach is needed and thus a playful and experimental method must be provided to gain experience. (Chatzopoulos et al., 2021) show in their study with 10-11 years old students that the integration of educational robots has a positive impact on students' acquisition of scientific concepts. However the available platforms are rather childish or expensive, when it comes to custom extensions for individual projects (cf. section 2).

This paper presents the development of an open, low-cost and modular technical platform that enables an introduction in the field with low entry barriers. The system shall spike the interest in current topics such as robotics and AI through a playful approach. Children and young people are thus given access to explore modes of action and perspectives with a platform that costs a total of 75€.

Toys always depict contemporary topics and translate the world for young people into their world of experience. The approach is quite different. Accordingly, the approach presented here is one such translation and deliberately represents a foundation of interwoven different elements, much as the term STEM suggests a scientific interweaving of multiple directions.

Exemplary use of the platform in our example is as a technology module for operating toy vehicles and

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Gibert, F. and Schneider, G.
A Platform to Interest Young People in STEM using Robotics and AI in a Playful Way.
DOI: 10.5220/0011084900003182
In *Proceedings of the 14th International Conference on Computer Supported Education (CSEDU 2022) - Volume 1*, pages 346-352
ISBN: 978-989-758-562-3; ISSN: 2184-5026

robots. The realization as a multifunctional vehicle is contemporary and introduces users to new aspects of digitized mobility in a playful way. Especially a modern user interface via a smartphone makes the platform attractive to young adults and children. The AI-based image recognition reflects the current discussion about autonomous driving and gives a glimpse of the challenges to the user. Especially it is possible to train or replace this module. In a further step, the platform can also be improved with additional sensors and hence can learn to process these inputs as well.

We see the platform as a teaser for children and adolescents to start playing with a toy car using a modern smartphone user interface, which reminds users on race car games where they can tilt and yaw the phone to control the car. Even young children from 5 years on can start using the car as a simple toy. Additionally, the vehicle provides several newly features, as displaying the video image on the smart phone but also recognizing images and reacting upon them. Hence a broad spectrum of use cases is available with a low entrance barrier into the field. It starts from simple playing with the car over exchanging parts of hard- and software provided by more experienced users, which targets older children from possibly 10 years upwards until developing custom enhancements with hardware and/or software components. This would be targeted to children of 13 years and older as well as adults.

2 RELATED WORK

The idea of a playful approach is not new, neither is the teaching and explaining intention of systems to make STEM topics tangible. Example from university systems and commercial platforms will be discussed in more detail in a further section.

As a general overview, (Sapounidis & Alimisis, 2020) give a good description of the current state of the use of robots in education for young children.

2.1 Related Research

The PiBot system is a low-cost robotic platform with camera for STEM education (Vega & Cañas, 2018). The system has the same target group as our system. The PiBot bases on a Raspberry Pie 3 controller with sensors attached. The robot is rather targeted to operate autonomously in a delimited environment, whereas we want to emphasize the toy character by providing a remote control on a smartphone. Additionally, we want to integrate an AI component, which is a hot topic today to showcase and experiment with the capabilities of this technology, in our case image recognition.

(Wang et al., 2019) describe a toy car with remote control and image recognition. However, their system strongly relates to the application domain. Possibilities to user the car as an experimental kit for technology acquisition is not intended.

(Chatzopoulos et. Al., 2020) present a low cost robotic platform for building a robot with wheels integrating sensors and actuators. They also integrate a visual programming platform. In contrast to our approach the robot is targeted to their educational context. The robot does not look like a “real” car and it does not integrate a camera and image recognition using AI tools.

2.2 Related Commercial Systems

Lego has set itself the goal of “playful introduction to STEM” (LEGO Group, 2021a) and offers solutions in the form of the Lego Mindstorms series. However, hardware and software are not technically freely extensible or open-source based, so that applicability and learning possibilities are always tied to the manufacturer and the resources provided. As a consequence, expensive components (LEGO Group, 2021b) also pose a significant financial threshold for users. Despite the implementation of an independent project on "PixyCam" (PixyCam, 2021), which takes Lego compatibility into account, no Lego-supported camera is available because the manufacturer does not push this even after years.

The company DJI pursues a similar goal and offers a learning robot as an “all-in-one solution” for experimenting and programming called “DJI RoboMaster Lernroboter” (DJI, 2021). This comprehensive approach is provided for workshops and learning processes though and addresses users with training requirements. The resulting high costs as well as the professional intentions and perspectives. Therefore, they also form entry barriers for younger people who are the target group of our system.

The need for programming and high prices keep many potential young interested parties away from corresponding offerings.

Our goal is that the educational approach we follow, i.e. playful interaction as a starting point for acquiring STEM knowledge and competencies need not be limited to a small interested group of users. Other children and young people can and should also discover STEM content in a playful way. This work demonstrates that it is possible to experience comparable functionality without such high hurdles.

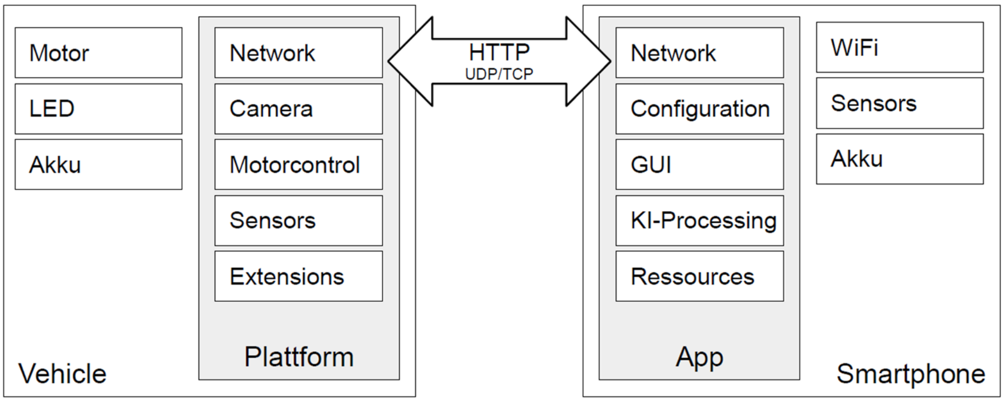

Figure 1: System Architecture.

3 TECHNICAL CONCEPT

The solution presented can be conceptually divided into two parts (see fig. 1). First, the platform consists of hardware and software, which in the case of the vehicle application is mounted directly on the vehicle and provides connection and operation of sensors and actuators. Second, a user interface is necessary for interacting with the vehicle. The GUI is realized as an Android app running on an off the shelf smartphone. The smartphone, in turn, provides computational capacity to implement, besides the GUI, an AI component and provides further functionalities, such as sensors, which can be used as additional input for the GUI.

For the purpose of independence and scalability, on the one hand a WiFi connection is used between the platform and the app, whereby both are directly connected and do not require any further network technology or configuration like a WLAN router or such. On the other hand, communication takes place via the standardized HTTP, TCP and UDP protocols. The images from the integrated camera as well as sensor values are sent from the platform to the app and displayed in the GUI. The app in turn sends control or configuration commands to the platform. This client/server architecture does not require an internet connection. The network concept is not Android or even smartphone specific and therefore allows other input devices as clients.

The use of a microcontroller as the platform's computing unit offers the option to connect and operate different sensors and actuators. With a focus on typical voltage levels and standardized electronic components, the control concept allows additional components to be used as actuators via a simple connection. Bus interfaces enable several parallel peripheral devices such as sensors. All hardware is battery-powered, equivalent to conventional remote-controlled vehicle models, which makes the vehicle exchangeable too.

The GUI is designed as a remote control for steering the vehicle with buttons for steering and acceleration. Additional functions can be activated in a menu. Likewise, parameters for operation can be selected to individually configure the platform, i.e. the car.

Through software modules that process data from the hardware, a wide range of applications can be developed. Some exemplary applications are already implemented. As an example, the automatic switching on of the lights is realized as soon as the calibratable light sensor detects low brightness. Furthermore, the automatic stopping of the vehicle is implemented, as soon as the AI-based image analysis detects a “Stop” sign that the vehicle is approaching.

Other models can be dynamically integrated into the application. Depending on the training domain, numerous other scenarios can be implemented as well and users are able to explore either the use of AI-components or the integration of a special behavior of the car in a playful manner.

4 IMPLEMENTATION

The platform consists of a base of hardware components. The microcontroller is programmed in C++. It manages the access point, the communication to the app and the control of the connected periphery depending on the commands.

The Java app, designed according to MVP, includes parts for communication, data processing, graphical display for control, and image processing

```
assets
    modelA.tflite
    modelA_classes.txt

interpreterA = new Interpreter(loadModelFile(context.getAssets(), modelPath: "modelA.tflite"), interpreterOptions);
TensorImage tfImage = TensorImage.fromBitmap(resizedCameraImage);
interpreterA.runForMultipleInputsOutputs(new Object[]{tfImage.getBuffer()}, detectionResultHashMap);
```

Figure 2: Java snippet for Tensorflow Integration.

through a machine learning model. This approach is described in more detail in the next section. Furthermore, the concept supports a modular and extensible operation of the system to new applications and offers the user new insights in the belonging technologies.

4.1 Machine Learning in Android

The computing capacity of the smartphone allows the use of a model trained on street signs ("SSDMobileNet"), the framework Tensorflow (Tensorflow (Google LLC), 2022) realizes its offline integration into the Java application, as fig. 2 shows to some extent. The figure also shows the few simple steps that must be performed within the program code in order to perform this integration. A Tensorflow interpreter instantiated with the model from the resource folders receives the camera image for image processing. This image was preprocessed for resizing and transformed into a TensorImage. On this database, the detection method, which allows multiple detections per image, fills a hashmap with the result data set. This is then evaluated and contains, among other data, the location of the detection in the image, the designation ("classes") of the detected object and a probability value (similarity of the current image object to the training object). The source code can be extended accordingly to integrate further models. Hence there is a possibility for users to experiment with AI-technology and have hands on training and first-hand experiences. We believe that this is very attractive for young people since the use of AI in supported or autonomous driving is constantly discussed in the media. As an additional benefit, users get to know the limitations and challenges using such a technology.

4.2 Modularization and Extensibility

In order to address the spectrum of problems that MINT poses, the platform is modularly expandable in various respects and therefore flexibly designed.

On the hardware side, the ESP32 microcontroller (Espressif Systems, 2021) is extended by an expander IC to provide more connection pins. It addresses, for example, the motor control, an H-bridge to control the DC motors. The expander IC also offers connection pins for LEDs, for example to realize the front light of the vehicle. But not only outputs but also inputs can be defined to receive data. According to this extension principle via analogue pins and level control or via defined digital interfaces like SPI and I2C, the platform can be extended by various sensors and actuators. Fig. 3 shows an example of a circuit for the SPI interface. The interfaces are inexpensive, open source and often multilingual tutorials are available. Therefore, they are used as key components of our platform.

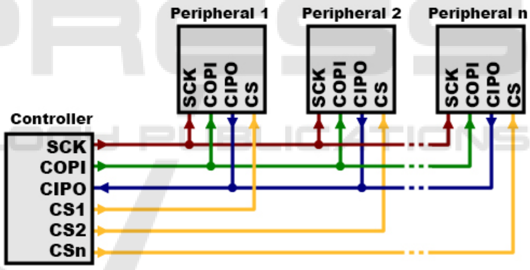

Figure 3: Example of multiple SPI slave devices to one master device (SparkFun Electronics, 2022).

On the software side, the hardware extensions described above, already result in numerous possibilities that can be installed and activated in order to extend the system. In addition, the app also offers expansion potential, e.g. in adding further graphical user interface elements. Parameterization is already provided in the menu to configure the behavior of the AI evaluation, user feedback such as visual feedback or vibration alert, configuration of the vehicle's steering, image compression, etc. according to current usage intent. Accordingly, additional menu items and functionalities can also be added.

Beyond the individual hardware and software features, there are completely new ways in which these enhancements can be used: by combining both areas as well as adding further software modules for data processing such as the exemplary stop automatic, the users can find their own paths and explore the system playfully.

Figure 4: App usage to control the car via sensor.

Fig. 4 shows the app usage on the smartphone, whose sensor detects the rotation and controls the steering of the vehicle in the background. The live image of the camera is visible in the center of the smartphone.

5 CONCLUSIONS AND FUTURE WORK

First, the results of this work will be summarized and then discussed, and their further development will be highlighted.

5.1 Conclusion

The technical platform, which finds concrete application in the work as a modularly changeable model car, is designed to be simple yet flexible and thus expandable. It comprises a microprocessor, a camera module, actuators and sensors and thus a system of parameterizable input and output options. Both the AI-based evaluation of camera images and the programmable interaction of sensors and hardware allow for the intended freedom of design and experimentation. The technology is based on available standard components.

This solution eliminates special, expensive components or the need for users to individually write software to make the system work. Especially important for further extensions is that there are no proprietary parts or vendor dependencies.

Based on this platform, we have realized a modular architecture which opens new possibilities for young users to discover and test digitalization and mobility while playing and experimenting. They can gain numerous insights from the STEM world within their own horizon of knowledge and possibly extending the horizon step by step. Having in mind the different approaches or steps mentioned in the beginning, the platform offers from simple playing for younger children (5 years and older) over changing preconfigured parts of hardware or software modules for older children (10 years and older), when the maturity and interest in the vehicle hopefully grows to adolescents (13 and older), which are even more advanced in their skills and want to program the vehicle on their own or add completely new behavior.

Experiences can not only be made only on the positive possibilities of our technical environment, but also the ambiguities and faults and its recognizable limits, such as those of artificial intelligence, which will be explained in greater detail in the next section. Here, we see an interesting starting point for older children and adults to gain more insights into the field of artificial intelligence, in our case image recognition in the context of autonomous driving. Since this topic is discussed in the media intensively nowadays, we se a potential high interest to get experiences and more profound knowledge in this field.

In contrast to the related systems presented in this paper, this platform therefore offers young people a low entrance barrier in the robotics and/or AI field. A playful and independent way of getting started and finding their way around has been created.

5.2 Future Work

The system has been initially developed having the needs of a child of about 13 years in mind. The potential user has been interviewed and integrated in the development process as good as possible in the period of the current travel and contact restrictions. Further evaluation must be done in the future. Since we target three different scenarios from “playing” over “exchanging of parts” to “customizing the vehicle” and additionally a forth possibly orthogonal scenario, which relates to getting to know the AI we have to develop different, partially long-running tests in order to find out, if our hypotheses hold that there car stipulates the interest in the underlying concepts of the “toy” and leads to getting into the teams STEM and AI.

The technical solution achieved can be further developed on various levels. For example, better images are possible with a higher-quality camera, which, in addition to visualization, also optimizes the connected image processing. Thus, more

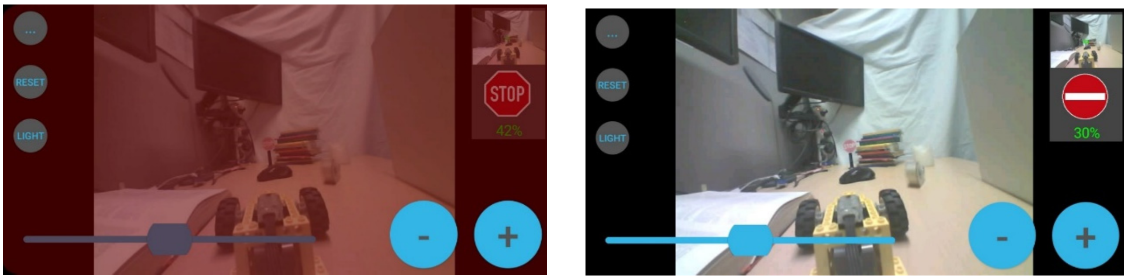

Figure 5: Correct interpretation ”Stop” Sign colors display red (left) and misinterpretation of ”Stop”sign as ”Do not enter“ (right).

sophisticated visual evaluation can be realized, but also errors in detection can be reduced. Depending on the environmental situation and the visual quality of the replicated road signs in the example of the vehicle application, the “Stop” sign was not correctly detected in 100% of the cases, and the automatic stop of the vehicle was therefore not always executed (see fig. 5 and fig. 6).

These rare misinterpretations were caused, among other things, by a too large distance to the object, visual similarities between two signs, or resolution limits of the camera images. Other objects in the immediate environment however rarely interfered with the correct recognition of the traffic signs. For gaming purposes these success rates are probably sufficient. Furthermore, misinterpretations are real existing phenomena when dealing with the corresponding technology. Their occurrence in the scenario is thus quite an expected representation of the real world and should not be interpreted exclusively as a fault or shortcoming of this solution.

In accordance with the numerous possible variants of use of the platform, possible technical compositions of the system must be built up in the future and examined for any errors and incompatibilities. Existing functions must be optimized, and additional modules should be included.

Further automatic functions beneath the presented “Stop” function using AI-based image recognition and the automatic light switching by the brightness sensor can be added as well in order to provide an ever-richer stock of settings with which young users can research. These examples are plausible reactions within the domain and display an exemplarily implementation of such a behavior.

Equally helpful for user acceptance can be a visualization of the components involved or the technical conditions and limitations. Complementary explanations of STEM aspects in the app can also accompany or suggest a setup.

In addition to various interchangeable, compatible machine learning models, Tensorflow, among others, also provides training of models for new domains and custom data with tools and guidance. In this direction, the platform benefits from the option to integrate the seemingly limitless possibilities of AI usage into the app via the framework.

A next extension can be a multi-user operation. If currently only a single user can act with his smartphone per platform, several users are conceivable in the future, who complement or challenge each other playfully.

The example of the vehicle application illustrates that more than one participating platform can be used as a technical module. For example, two vehicles could also be designed with the goal of reacting to each other based only on their technical capabilities.

In the area of GUI design, new requirements arise as more components and scenarios are realized. As a consequence, an almost completely configurable design with visual elements and functions is conceivable, which considers or simplifies as many use cases as possible.

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