Modular Robot Platform for Teaching Digital Hardware Engineering and for Playing Robot Soccer in the AMiREsot League

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Abstract. The design of digital hardware is nowadays very well supported by software tools, which allow hardware description, hardware synthesis, and complex simulations ranging from device to system simulations. For teaching at universities often a bunch of complex software tool chains is available and is used in classes and for lab work, but practical experience with real hardware is often neglected. Our approach is a combination of teaching hardware design theoretically in a large group and to implement hardware in several small project groups to enable the students to learn about real problems of hardware design and integration. Besides the definition of several small projects defined for one semester lab work we have the objective to design a robot soccer platform that is consistent with the rules of the AMiREsot robot soccer league. This complex platform is a very good tool for making advanced experience in the area of hardware and software design.

1 Introduction

The efficient design of digital, analogue, and mixed digital-analogue hardware components and systems usually requires a lot of practical experience. Our approach for teaching design of hardware systems is a combination of teaching hardware design theoretically in a large group and as a second pillar to realize small hardware systems in several mini projects to enable the students to learn about real problems in hardware design and integration. By working on the mini projects the students usually gain relevant skills to be able to work efficiently on more complex projects like the robot soccer platform. Our objective is to develop and program a robot soccer platform, which can be used in the AMiREsot league that requires small autonomous robots with team sizes of 1, 3, or five robots [1].

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In section 2 a few mini projects are introduced to give an idea of the typical tasks and the complexity of the projects. Section 3 introduces our AMiREsot robot platform. Two experiments are reported in section 4. Section 5 concludes the paper.

2 Mini Projects

In this section a brief overview of selected mini projects is given. Within a class individual students or small groups of up to three students have to solve a hardware, software, or often combined hardware-software development task. In the beginning of a semester several topics are suggested, but the students are also encouraged to suggest design projects. Students decide on their projects they want to work on. On a weekly basis the progress and problems are discussed with presence of all students. After a half semester an intermediate presentation has to be given by each group. At the end of the semester a final presentation typically including a demo is foreseen.

Advantage of these projects is that the students get a deep practical inside into design challenges. They make the experience what does it mean to implement a real hardware being able to work as desired that usually requires several iteration of implementation, debugging, and testing. The motivation of the students is usually quite high, because they want to have a system running at the end. In addition, the final presentations at the end of the class help the students not only to share experience, but also to get fruitful insights into several design tasks. The following sections briefly introduce a selection of mini projects.

2.1 VHDL Camera Controller

Task in this project was to develop a camera controller, which is located in the Xilinx Spartan FPGA (Type XC3S100E) [2]. The camera is from Omnivision, model OV9655, offering 1.3M pixel. The controller was completely coded in VHDL and has been synthesized for the FPGA using the ISE tool chain from Xilinx [3]. Due to unavailability of additional RAM on the FPGA-uC-Board the internal block RAM of the FPGA has been used for storing down scaled images. Configuration of the FPGA and testing has been done via a microcontroller (LPC2136 by NXP). The same microcontroller could be used to wirelessly transmit the captured images to a PC via a Bluetooth link using SPP.

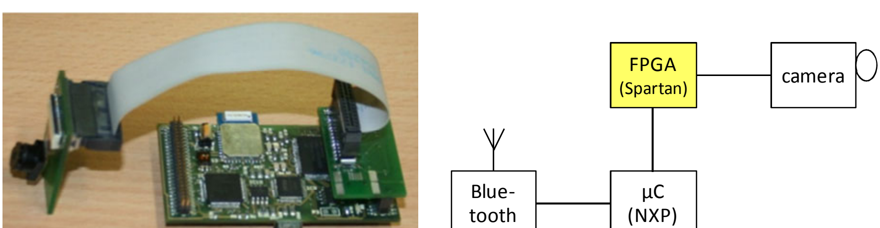

Fig. 1 Small image sensor connected to an FPGA with µC and Bluetooth support

2.2 *Digital Audio Output with DAC and Amplifier*

Basis for several projects is a small microcontroller-FPGA board (cf. also fig. 1). It integrates an FPGA (Spartan XC3S100E), a microcontroller (NXP LPC2136) and a Bluetooth module (Mitsumi WML-C46). Programming of the microcontroller as well as configuration of the FPGA is done via an USB link to a PC running a GUI to access the board. Task of this project was to extend the board by an audio output module integrating a digital-to-analogue converter (DAC), a filter, an amplifier, and a speaker. The student has designed the PCB integrating mentioned components including connectors and he has coded the controller for the DAC using VHDL. A played back sound demonstrated the well working board.

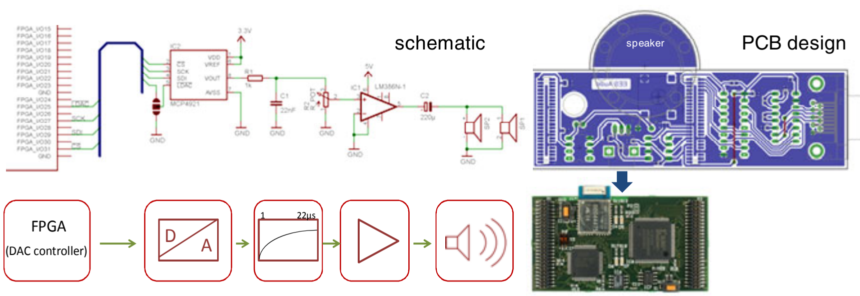

Fig. 2 Schematic and PCB design of an audio output unit

2.3 *LED Hardware Clock*

In the LED hardware clock project a PCB has been designed with a round shape and a diameter of 10 cm. 60 LEDs are integrated to indicate the minutes (or seconds) of the current time. 12 LEDs indicate the hour, see fig. 3.

The clock is controlled by a CPLD (Xilinx XC2C256). To configure the CPLD a VHDL design has been synthesized by using the Xilinx ISE tool chain. Three

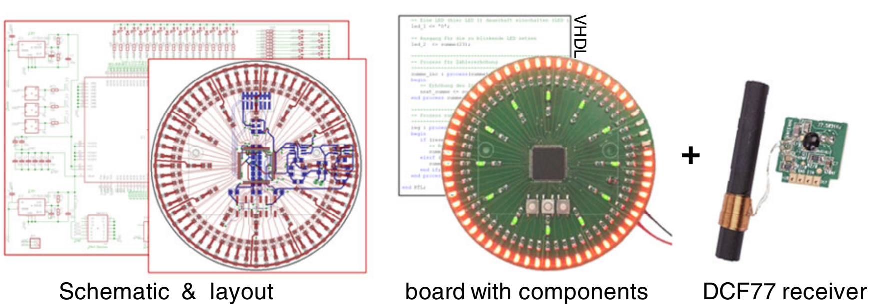

Fig. 3 LED clock design with control via a CPLD configured using VHDL / ISE

buttons can be used to set the clock or to activate a LED blinking demo. Optionally it is possible to connect a DCF77 receiver to automatically get the current time (and date) to initialize the correct time.

2.4 Image Processing on a Mobile Computer under MeeGo

Aim of this project was to port the operating system MeeGo [4] onto the mobile computing platform "Overo Fire" that has been developed by Gumstix [5]. MeeGo is an open source operating system with focus on usage on smartphones. The operating system has been initiated by Intel and Nokia. As an example application under MeeGo we have realized an image processing routine that processes images being captured by a connected USB camera. Via a touch screen TFT programs can be started and the images or video streams are being displayed. The developed system integration can be used as a starting point for mobile processing hardware system of a mobile robot platform, see also section 3.

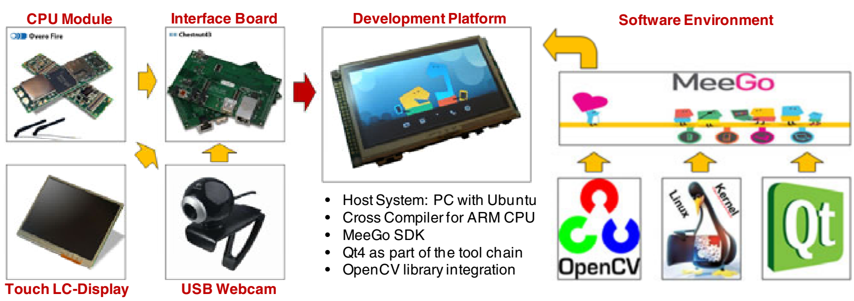

Fig. 4 Integration of display, camera and CPU module running MeeGo

2.5 Remote Control of a Mobile Robot Platform

A wireless connection to a robot realized via Bluetooth enables a designer to easily debug a mobile robot platform without negative effects caused by a cable connection. The Bluetooth connection can also be used to realize a remote control of a vehicle including the display of sensor signals on the remote control device. Basis of the remote control is standard smartphone (here Palm Treo running Windows). For connecting to the robot platform a Bluetooth point-to-point connection (SPP profile) is used. On the mobile robot a Bluetooth devices based on a BTM-182 (Rayson [6]) has been integrated. With the depicted application running on the phone (see fig. 5) the robot can be controlled forward, backward, left and right. Additionally, the current battery voltage of the robot is displayed.

Fig. 5 Remote control and wireless debugging via Bluetooth

3 Mobile Robot Platform

In this section a mobile robot platform is introduced that benefits from the mini projects by integrating already evaluated hardware components and software. The mobile robot platform has a modular architecture that eases adaptation of the platform with respect to technical demands of a project. An important aim of the development of the platform is its use for playing robot soccer in the AMiREsot league. AMiREsot is one of the leagues that are played at national and international robot soccer tournaments under the umbrella of the FIRA organization [7]. AMiREsot robots have a small size with a maximum diameter of 110 mm, cf. fig. 6. Matches can be played with team sizes of one, three, or five robots. All robots in the pitch have to act autonomously, i.e., they have to sense, decide, and act based on integrated sensors and information processing hardware. A wireless communication system can be used to control the robots during kick-off.

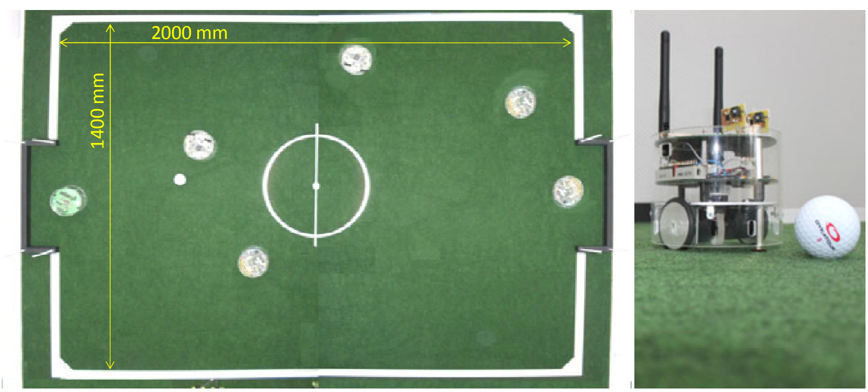

Fig. 6 AMiREsot robot soccer pitch (left), robot in front of goal with ball (right)

This paper introduces an AMiREsot robot platform. It is a modular design integrating the drive system, power supply, necessary electronics, and IR sensors in the base board. An extension board offers computing resources by a mobile processor and an FPGA. For perception a camera can be integrated by attaching it to the processor via USB or to the FPGA to do parallel image pre-processing.

The architecture of our AMiREsot robot is depicted in fig. 7. The minimal configuration is a combination of the mechanical base and a board containing sensors and a microcontroller. The extension of the robot's functionalities is realized by additional modules that can be stacked on top of each other. For communication between the boards mainly I^2C is used. But depending on the requirements of the communication other busses or high speed serial IOs can be used. For example, the top module integrating a touch screen is connected to the subjacent board via a standardized touch screen interface. Main board used for information processing and behaviour execution is the extension board with a mobile computing stick and an FPGA. The FPGA is used to speed up image processing, e.g., to find blobs.

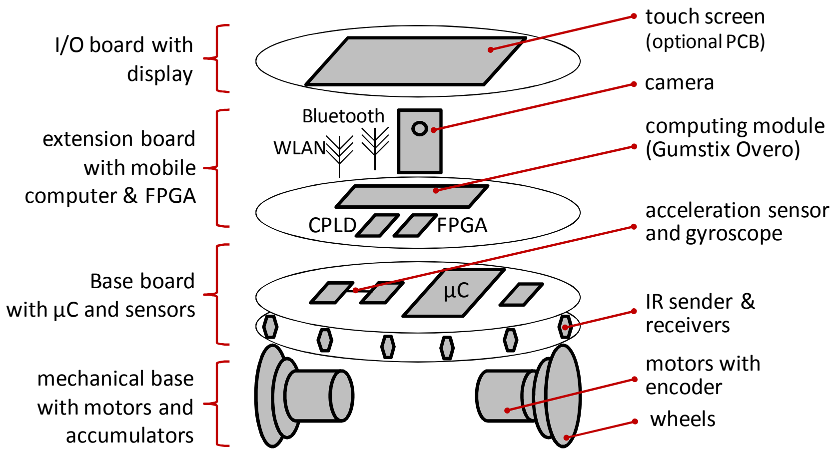

Fig. 7 Modular architecture of the AMiREsot robot soccer platform

3.1 *Mechanical Structure and Chassis*

Our AMiREsot platform follows a modular approach, i.e., the base module is a mechanical platform with an aluminium board at which motors and accumulators are mounted, see figure 8.

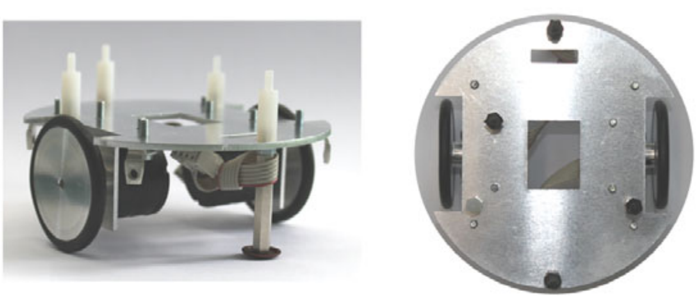

Fig. 8 Mechanical base with mounted motors and wheels; side view and top view

Diameter of the platform is 100 mm. Considering an additional plastic (e.g. PMMA) cover the total diameter is within the range of 110 mm specified in the AMiREsot soccer rules. Depending on the specific needs of the platform for performing experiments additional modules can be mounted on top of the mechanical base via plastic spacers. The motors are from Faulhaber type 2619S006SR 33:1 IE2-16 with max. power of 1,1W each. The accumulators are two packs of three AA NiMh accumulators with a capacity 2400 mAh at 7.2 Volts. Battery life time for a fully equipped robot driving at medium speed is about 4 hours.

3.2 Base Board

The minimal configuration of the AMiREsot platform is a combination of the mechanical base and a PCB integrating a microcontroller and sensors. The microcontroller (STM32F103 from ST Microelectronics [8]) controls the motor speed and reads sensor signals from 12 IR sensors symmetrically arranged at the cover of the robot. By connecting a Bluetooth module to a serial line of the microcontroller a cable replacement can be realized and used for debugging. An extension board is connected via 34 pin connector. Here a relatively large pin spacing of 2,54 mm has been used to ease interfacing and development of boards (PCBs) that are fabricated manually by students as part of a mini project.

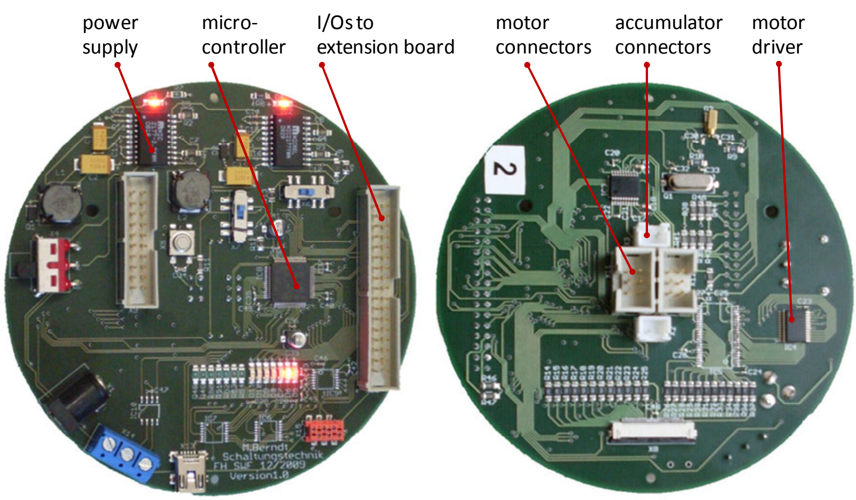

Fig. 9 Base board with microcontroller and interfaces; top view and bottom view

3.3 Extension Board

By using the base board only on the robot platform a simple behaviour like the Braitenberg behaviour can be realized using the IR sensors. Or it is possible to remotely control the robot. For advanced behaviour especially playing robot soccer a vision sensor and a more powerful processor is mandatory. The extension board for the robot which has been designed by a student integrates a processing module offering up to date mobile computing power. Core device is the computing module “Overo” from the Gumstix company [5]. This computing module has a small footprint and it can be easily exchanged by latest hardware if desired. On the robot platform we are using Linux that eases programming of the robot by using C as a programming language. We have added functions into the operating system which provide access to the sensor data of the base module and also access to the motor controller to set the speed of both motors.

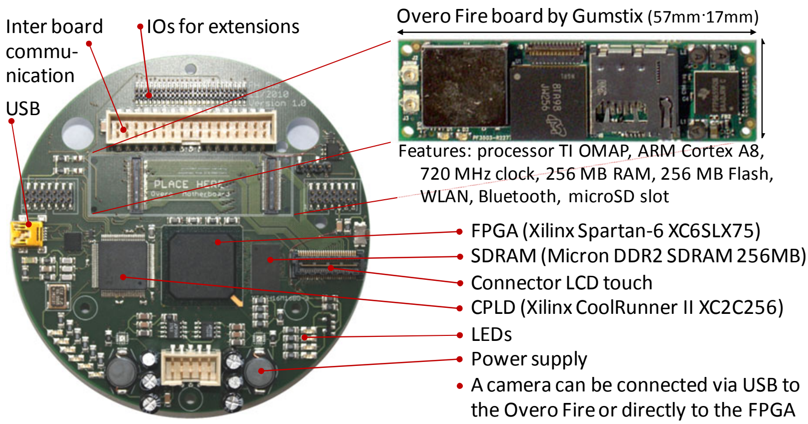

Fig. 10 Extension board with computing module and FPGA

The mobile processor is running Linux. It can be programmed in C, C++, via shell-script or Phyton. It is also possible to install other compilers and then to use other programming languages. The minimal functionality of the processor board is to realize a simple behavior on the robot, i.e. to set motor speed of both motors by writing the speed data into the microcontroller of the base board via I^2C. The mobile processor can be accessed by SSH. It is possible to log in via WLAN or Bluetooth in order to program or to remotely control the robot.

The board supports the usage of an FPGA, i.e. it is possible to (re-)configure the FPGA from the operating system that eases hardware access and speeds up software development. As configuration controller a CPLD is used. Via I^2C the configuration data is transferred from the processor to the CPLD. The FPGA is programmed in VHLD or Verilog with use of the XILINX ISE Design Suite. Data captured form the camera can be stored in 256MB DDR2 SDRAM. From this the FPGA can calculate the position of the robot, the ball and the goals to name an application example in the robot soccer context. Symbolic information as extracted positions can be sent to the mobile processor via the I^2C bus.

4 Experiments

Main objective of the development of the presented robot platform is to perform robot soccer matches with varying team sizes starting with one robot per team. Currently we are realizing the image processing to be able to detect opponents, the ball, the goals, and the lines in the pitch. This part has not been finished yet, therefore it still not possible to play matches. Currently the robot can be remote controlled by a PDA via the Bluetooth link, see figure 11. We can test ball pushing behavior, dynamics of the robot and are able to collect sensor data to implement and optimize the behavior of the robot.

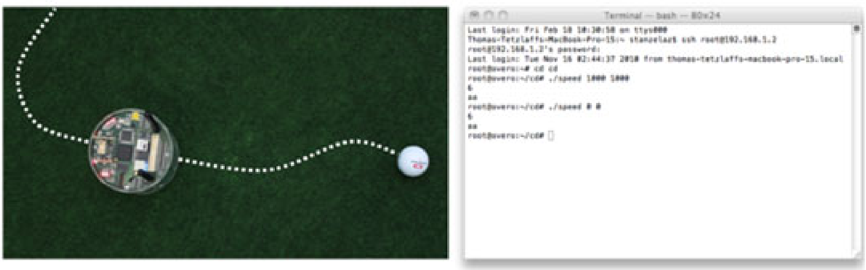

Fig. 11 AMiREsot robot in the pitch following and pushing the ball

A fully equipped AMiREsot robot, i.e., with integrated base board and extension board, is shown in fig. 12 left. Besides playing robot soccer the platform can be used to teach students in several engineering disciplines. This is processor and microcontroller programming, FPGA hardware design, classic control, behavior design including cooperative behavior schemes, perception, and computational intelligence. As one example in control a student has used the robot platform to realize a pole balancing behavior, see figure 12 right. Sensor signals as input for the controller are the incremental encoders of both motors, gyroscope data, and acceleration data from a 3d accelerometer. To get appropriate signals the gyroscope has been mounted on top in an upright position.

5 Conclusions

The design of microelectronic systems is a complex task. Our approach to teach the students in design of these systems is to define mini projects which have been identified to be very useful for the students in learning to design, to program, to commission, and to test real systems. Students make several practical experiences and by presenting the achieved results they get a very good overview of all projects that have been developed within the class. In total, approximately 10 new projects are defined every semester. Our experience is that students like this kind of project work. They like the proposed topics, they are requested to work self-contained and they like to show a running demonstrator at the end. The amount of time of the students spent for the projects is about two hours per person per week plus about three additional days at the end of the semester to complete the final demo and the presentation.

Students who are motivated to spend more time for a project work are welcome to work on the AMiREsot robot soccer platform. Currently they are working on the image processing to robustly detect the ball, the opponents, the goals, and the robot's position. Our objective is to have within the next 6 months a robot that is able to play matches 1 vs 1. Afterwards we focus on team play with 3 robots per team. Students who are interested have the option to attend international robot soccer tournaments as organized by the FIRA.

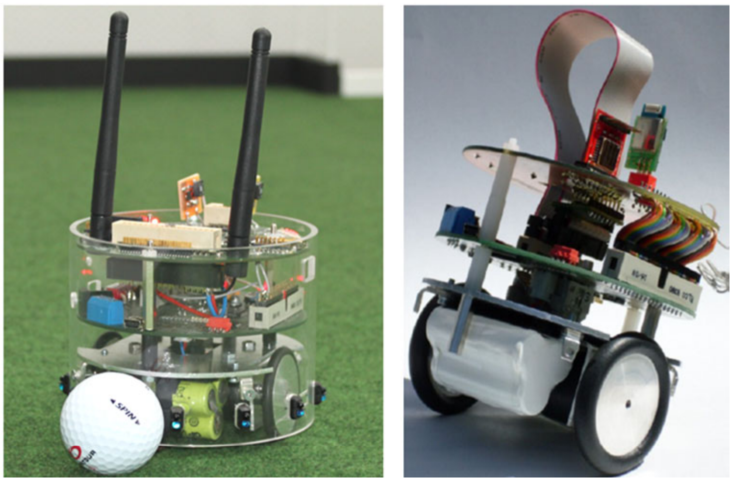

Fig. 12 AMiREsot robot (equipped with base board, extension board) in the pitch (left); self-balancing robot with additional gyroscope and accelerometer (right)

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