Pocket Labs Supported IoT Teaching

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Abstract—IoT is both a concept and a specific platform with large variety of applications that rapidly become inseparable part of everyday life not only improving it, but making it more interesting and fun. ICT based, it is devoted to interactions with environment that are usually not available with traditional ICT equipment and platforms. IoT is at the same time both complementary and compatible with existing non IoT world, which offers computing power and resources to IoT, making it a unique and powerful combination. Pocket Lab is a relatively new teaching concept that supports students' creativity and initiative allowing for carrying of and experimenting with real equipment at a time and place of choice, much like using of regular text books for studying. Although the IoT & Pocket Labs are not necessarily interconnected or mutually conditioned, this paper discusses such a real case of teaching practice, where the Pocket Labs are used for teaching of IoT. The paper deals with teaching experience of IoT as a university course. Obtained results and experience may be quite general except for university students profile defined with their previous education and knowledge. Besides the main goal of the course which is an introduction to IoT, some other aims were exploring the students' motivation for studying of IoT as a new technology and emphasizing the importance of new original ideas and views being as important as mastering the IoT technologies.

Keywords—IoT, Pocket Labs, teaching

1 Introduction

The IoT (Internet of Things) and Pocket Labs are popular buzzwords today with the IoT being much better known in wider circles, while the Pocket Labs are a relatively new concept offering new teaching opportunities which are to be further explored and analyzed. The IoT comprises many technologies working together to create a seamless link between real and virtual worlds that yields new qualities and benefits pervading our technical civilization. Some of the best-known technologies used by the IoT are RFID [1], WSAN (Wireless Sensors & Actuators Networks) [2], and Internet / web technologies integrating all aspects of the IoT [3]. Cloud computing has emerged as a virtual computing platform shifting the computing from traditional to SOC (Service Oriented Computing) based on SOA (Service Oriented Architecture) [4]. Due to the particular importance of the web, the Web of Things (WoT) is also considered [5], offering well-known web features for integration of remote devices and user interfaces. The rapid rise of interconnected devices equaling the number of people in 2011 along with growing expectation in the coming years in both number and features [6] makes the ubicomp (ubiquitous computing) even more invisible and useful by seamlessly embedding devices working quietly and unnoticeably for our benefit [7,8]. Such a situation naturally leads to increase of revenues and demand for educated professionals pursuing a new perspective in education for IoT technologies [9] and neighboring areas. Educational institutions, universities in the first place, should have a quick response for a demand of educated professionals of some new perspective educational profile. Furthermore, such a new demand should be foreseen thus resulting in a well-timed response. Adequate courses should be offered by competent faculties capable of providing required educational resources, the skilled staff and laboratory equipment. For the IoT course, the staff should be competent with experience in a range of technologies important for the IoT. Besides the main educational focus, education of IoT professionals should provide certain broader knowledge and skills harmonized with the social layer, thus having a "T" shaped educational profile [10]. The Pocket Labs (PLs) are a convenient educational concept based on small and cheap contemporary IT devices [11, 12] offering students to work on IoT projects while at lectures or when convenient at home. Although the IoT & PLs are not necessarily interconnected or mutually conditioned, this paper discusses such case-based teaching practice where the use of PLs is considered as a natural solution for successful IoT teaching. The paper deals with teaching experience of the IoT university course. Obtained results and experience may be quite general except regarding the university students profile defined with their previous education and knowledge. The IoT course was prepared for the senior students pursuing a bachelor's degree in general IT. Students had a considerable general knowledge in various IT disciplines, but with lack of knowledge from some engineering disciplines dealing with electronics, sensors, actuators, microcontrollers and similar. Besides the main goal of the course which is introduction to IoT, some other aims were exploring the social impact of IoT and emphasizing the importance of new original ideas and views which are as important as mastering the IoT technologies involved.

2 Motivation for introduction of a new IoT course

While considering the introduction of a new course dealing with the IoT for IT bachelor degree program, one of the most important reasons was that the IoT was seen as an important emerging and fast developing ICT concept significantly influencing and changing many areas of human activity such as smart homes and cities, transport, trade, logistics, energy production, consumption and measurement, scientific research, health services, just to name a few. In future the IoT is viewed as perspective with potential to bring significant improvements and benefits connecting real and virtual world of the Internet. At the same time, the current situation with existing IT study program was assessed as fairly satisfactory, favorable, mature and ready to support the teaching of IoT both with staff and new required equipment, for the new IoT lab. The introduction of the new IoT course was estimated to have multiple benefits for both students and the Institution. Students would keep their knowledge up to date, upgrading their previous IT education, and developing remarkable skills built upon the existing IT education, providing them with wider qualifications and increased competitiveness for the IT job market. The institution would benefit from increasing competence and IT competitiveness, both of utmost importance for future development. A systematic study of the IoT also creates foundation and potential at the Institution for scientific research in the field. The IoT offers reliable and cheap hardware that can be used for a variety of students' practices in various study programs. It has already been used at the Institution as a basis for remote web experiments with real equipment and RFID attendance with access control of students and teaching staff.

3 Preparation and planning

The new IoT course was offered for the first time as a course to be selected from the group of electives. The preparation of such a course was a challenge, as targeted students had almost no knowledge and experience with electronics and hardware, but had a solid knowledge and experience with programming of PC and similar platforms. As the sensors and various electronic components and devices are necessary hardware for interaction with the real world, laboratory exercises had to be planned and prepared as an adequate support and illustration for the theoretical part of the course. Such type of exercises is typical for study programs in sciences or engineering which have devoted laboratories planned and equipped well in advance. That has been the case with classical educational programs recognizable within longer time periods, but not with IT, and specially with some new fields of IT / ICT that can appear in a very short time period, become very important with quickly growing hardware and software support which cannot be ignored by the competent and competitive educational institutions, or otherwise they start to quickly lose competence and competitiveness with all logically deducible consequences. Therefore, the IT educational institutions need to be flexible with minimum inertia and to be able to offer state-of-the-art IT educational content. The IoT is an example of a new contemporary IT course that has requirements for specific equipment to be on students' disposal, or otherwise it cannot be adequately and effectively realized with all required educational qualities and goals. The experience with laboratory practice in existing courses from other study programs, like electronics and some other courses at the Department of Physics, was transferred and used for planning the IoT lab within available time and physical resources. One more aspect of the IoT lab was regarded as very important, and that was the availability of the lab for each student to perform the required tasks individually and with minimum possible time limits. Such a requirement directly pointed to PLs [13, 14] and Flipped Lab [15, 16]. The PLs enable students to use educational equipment out of regular classes, at convenient place and time. The Flipped Lab (FL) concept as a special case of the Flipped Classroom (FC) being a wider notion, and in combination with the PLs put students in a position of being active and creative contributors of the educational process with choice of individual or collaborative work.

The somewhat similar educational situation from the point of evaluation is with seminary work which also has to be explained and justified individually. The organization of a new modern IT course implies the competence of the teaching staff. Teaching competence is a complex notion that implies several important components. The first component above all is the thorough and profound knowledge which must always exceed the course content. The second very important component is the experience and familiarity with the course content. Each member of the teaching staff should prove itself as an authority for the subject during all phases of course teaching activities. A good teacher knows the background of the course, how things and concepts have evolved to become what they are today. Imaginative and innovative presenting of the course content should inspire students to start with their own unique original projects. Teaching staff should be active creators in the field of IoT to educate good developers. To be successful in a particular field of profession, it is not important to know everything, since that is impossible, but to know the right things in the right amount of detail. That is exactly the goal of teaching new technologies, to spread the proper knowledge in the right amount of detail at the right time and to assign creative tasks to students that will illustrate the power of the IoT.

4 Content of the new IoT course

New IoT course consists of theoretical lectures and laboratory practice with equipment supporting the IoT. Content of the IoT course was selected according to current knowledge and experience of teaching staff for IoT and some papers describing the IoT teaching at other institutions. As a result of literature review, it can be concluded that the IoT is present at educational institutions for two main reasons: 1) For purposes of studying the IoT as a course [9, 17 - 21], and / or 2) as an aid for teaching, with the IoT itself not being taught as a course [22 - 25]. The IoT as a general teaching aid dominates the presence of IoT in education if compared with the IoT studying. That is similar to contemporary general IT being used as an important technology for education, and the IT studies in particular. The IoT becomes as important for the education as it already is for intelligent homes, cities, transport, and many other purposes.

As already mentioned, the general IT students that attended the course were not familiar with some of the equipment required for the IoT. Special care was taken in order to cover such topics efficiently, giving necessary basics and leaving at the same time enough space for the most important IoT concepts which are students' primary competence. Competencies of the teaching staff in both IoT theoretical lectures and practical laboratory exercises include profound knowledge and working experience in many disciplines such as general IT, microcontroller programming, electrical measurements and control, data acquisition, and network programming as the most important ones.

4.1 IoT course modules

The course content is modular with 6 modules selected to cover the most important aspects of the IoT.

The first module is introductory and devoted to “IoT How & Why”, and practically unlimited perspectives based on innovative ideas & concepts and further science & technology advance. Students were encouraged to think freely and use imagination.

The second module “Signals & Measurements” covered the missing concepts related to basic electronic circuits, components, sensors, electrical measurements, actuators, control that IT students were not familiar with.

The third module covered the microcontrollers with emphasize on similarities & differences with microprocessors and when to use which. Third module was also a new one for students, but the main difference in comparison with the second module was that it was easier to impart new skills following the previously existing IT knowledge and concepts, while a proper base was also provided for the new concepts of the second topic.

The fourth module introduced the actual IoT devices which mainly consisted of various small microcontroller based boards and other electronic components which were used for the practical experimental work in this course.

The fifth module covered the IoT server programming or the “cloud” component of the IoT. Cloud support for the IoT is very important although less directly visible. That module was the easiest to build upon previous IT knowledge, as the students were already very well versed in network and web programming.

Finally, the sixth module introduced practical projects that integrated all previous modules.

Each of the modules also provided students with practical examples illustrating introduced concepts.

4.2 IoT Pocket Labs

The concept of the PLs ideally suited this IoT course. The course was supported by the host Institution and the Project (Acknowledgements), which provided each student with specific IoT equipment required during the course. Students used the IoT equipment during practical lessons, and were allowed to take the equipment for work at home or some other convenient place. In order to provide support for PLs and make it more effective, all teaching materials, examples, instructions and tasks were publicly available from the IoT course web page. The PLs helped students to handle the material presented at classes they did not attend for various reasons. That gave students the opportunity not only to work through the course at their own pace, but also to try their own original solutions for the tasks they were given. Starting with the tasks defined in detail, as the students advanced through the course, they were given tasks that were more loosely defined giving the opportunity for developing original concepts and solutions. Students presented their solutions and discussed differences and alternatives.

The PLs for the IoT course were based on the well-known Arduino family [26] of boards and shields that proved to be adequate and reliable [27, 28]. Students used universal breadboards for creating electronic circuits with sensors and actuators. The PLs were combined with an excellent "Autodesk Circuits" [29] free on-line simulator of electronic circuits which also included some of the Arduino boards. In the meantime, online circuits projects moved to Tinkercad [30] with similar features. Use of the online simulator further extended the PLs concept allowing students to try and experiment with many circuits and boards available within the safe virtual environment of the simulator. However, not all the projects could be created and tested in simulator, as it did not support all the required electronic components used in the IoT course. Projects supported by the simulator served as a documentation and prototypes for the real projects implemented with PLs.

5 IoT Technology

5.1 IoT platforms

Network component of the IoT projects for remote access, can be implemented with existing non IoT specific technology, relying on web user interface and http protocol as a usual choice for the IoT interactive web pages. Such an approach yields quite good results. There are also some quite interesting IoT specific contemporary technology enhancements like MQTT [31] communication protocol, Cayenne [32] friendly cloud IoT project development environment which can be additionally or alternatively used for IoT projects development. Both approaches are based on and support the same IoT network enabled devices. IoT network enabled devices covered by the course are Arduino UNO [33] with Ethernet adapter on shield [34], Arduino Ethernet [35] with integrated Ethernet adapter, Arduino Yun [36] with both Ethernet and WiFi network adapters connecting two worlds with microcontroller for GPIO and lite Open WRT Linux environment for more intensive processing. Although the Raspberry Pi [37] with GPIO looks quite similar to microcontroller based devices, it is a Linux only device better suited for intensive processing tasks and less for precise time measurement which is quite easy with microcontrollers. Very popular and cheap ESP8266 controller based multifunction device [38] provides WiFi connection, simple web server and some basic GPIO.

5.2 NodeJs for IoT

Traditional cloud approach in this IoT course is based on NodeJS [39] which is a lite JavaScript server platform that runs well on various hardware and software platforms including mentioned IoT Linux platforms. The main task for software running on NodeJS platform is network communication and data transfer among IoT devices and programs running in the cloud. Various NodeJS modules extend and cover required functionalities such as the web server with "express" [40] module, serial communication with "serialport" [41] module, web sockets with "socket.io" [42] module, remote upload of compiled Arduino sketches with “avrgirl-arduino” [43] module, “sqlite3” [44] module for sqlite3 database and similar. Remote upload of compiled Arduino code enables full remote software control of Arduino devices in addition to Linux based devices. During software development phase and part of the testing phase, more powerful PC’s can be used, with developed JavaScript software transferred to less powerful IoT devices for final testing and exploitation. http is used as the main protocol for remote communication and data transfer.

5.3 MQTT protocol

IoT devices usually act as remote sources of sensor data and actuator controllers. In most cases, the amount of transferred data in communication with IoT devices is lower comparing to average transfer of web pages. If http is used for IoT, headings can be larger than actual transferred data, producing unnecessary traffic and consuming bandwidth. MQTT is a standard machine to machine protocol suitable for transfer of low volume data like from sensors over low bandwidth networks. There are three principle sides with MQTT, a broker server and two types of clients that subscribe for topics and publish topics. Server broker is a mediator which directs published messages on certain topics to topics subscribers. Messages may contain data from the sensors, data for controllers driving the actuators, or any other data. There are various MQTT implementations like open source Mosquitto [45], in the form of libraries for programming languages (MQTT.js [46] client for Node.js and the browser) and IDEs (Arduino IDE [47]), thus providing a range of choices for IoT projects. IoT cloud platforms like Cayenne offer support for MQTT. Various MQTT implementations can be combined according to project specifics.

5.4 IoT Cloud

Cloud technology developed for transfer of computing and processing to safe and powerful remote hardware platforms with network access, is also an important aspect of any IoT system that connects and integrates all remote devices belonging to an IoT project. Some IoT clouds like Cayenne offer significant support for rapid and simplified development and building of the IoT projects. All mentioned IoT devices covered by the course are directly supported by the Cayenne, providing the students with an opportunity for rapid IoT prototyping and testing, and also offering alternative final project implementation.

The principle of connecting network enabled IoT devices to Cayenne cloud is quite similar to connecting of commercial surveillance cloud IP cameras. IoT devices do not have to be visible on public IP addresses, but can be within LAN which is the case when using PLs at home. Cayenne provides software components for various IoT devices which when installed automatically connect IoT device to cloud. Once connected, GPIO of the IOT device becomes available and controllable from the cloud. Besides devices, various common sensors and actuators are supported, providing graphical display and widgets on a virtual dashboard. Fig 1 shows web page with installed and connected devices on the left, and widgets on dashboard for selected

Raspberry Pi device on Cayenne. Installed devices have two operation modes, simple mode with using of GPIO and graphical presentation with widgets for projects requiring basic functionalities, and mode with using of the Cayenne cloud API for more demanding projects. Besides web access, Cayenne cloud can also be managed by mobile application. Fig. 2 shows two mobile app windows. On the left is mobile app window with list of installed devices, and window app with analog channels counts of Arduino Uno with Ethernet shield on the right.

Besides mentioned cloud environments, Cayenne and TinkerCad, cloud version of the Arduino IDE, the Online IDE, was very convenient for quick demonstrations of code functionality at lectures. Besides IDE accessible from browser, it also contains

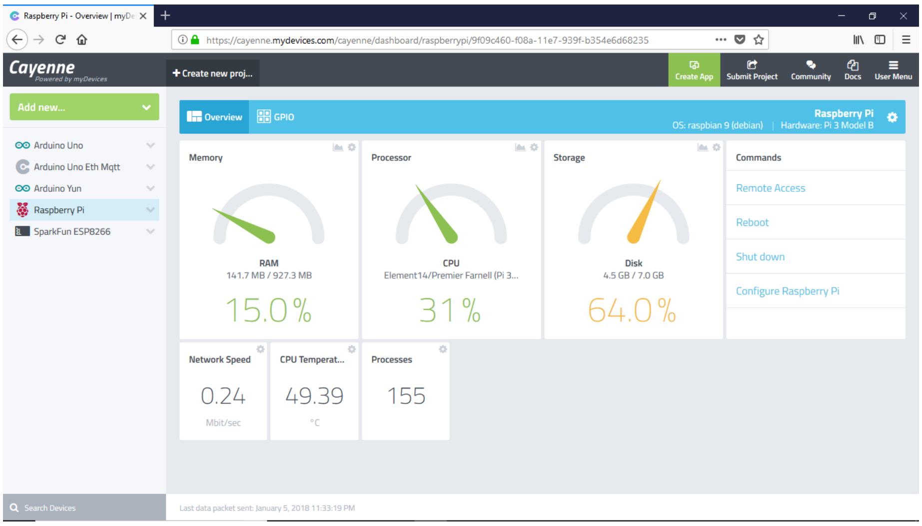

Fig. 1. Cayenne web page with devices and dashboard for Raspberry Pi

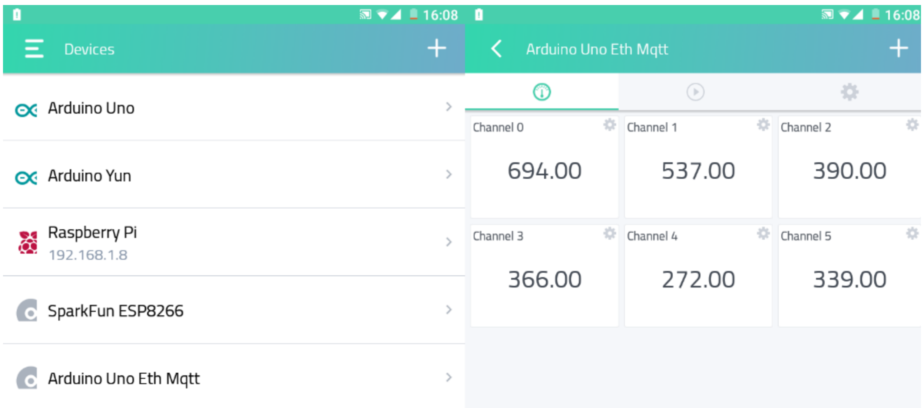

Fig. 2. Cayenne mobile app with installed devices and Arduino Uno analog channels

code repository. Selected code from the repository can be compiled and uploaded to IoT board by USB cable from browser, for demonstrations of various pieces of code with same IoT hardware. Students are able to see from overhead projector the whole process of compiling, uploading and live testing of code at lectures.

6 Experience with IoT teaching

Although being an elective course among the alternative courses offered, the IoT course was selected by almost 100% of students. Some of the possible reasons for such an initial success were in the fact that the IoT was novel, interesting, and attractive by itself. Students already had some notions about the IoT. Also, the students were given information during the presentation of elective courses. The presentation of the IoT course included a demonstration of an interesting IoT WiFi device that was tablet-controlled. Students liked it very much and showed immediate positive reactions. The presentations of alternative courses offered were not that attractive and effective. It seemed that the students liked the IoT for what it can offer. Later, during the IoT course, students showed interest and motivation, but not all of them The two almost equal groups of students formed spontaneously, one consisting of those who regularly attended the lectures and the other consisting of students who did not attend the IoT lessons regularly. But when it came to the presentation of students' projects, the results of both groups of students were almost the same. It followed suit during the final exam. The explanation for that could be in the PLs that allowed each student to study and work on their own. The anticipated outcomes that were the motivation for creation and introduction of this new course were fulfilled. The results achieved at the IoT exams were above average. The students showed their motivation most when it came to design and implementation of their own IoT projects. Some projects were implemented using the IT technology more advanced than presented in lectures. The students also developed a strong sense of teamwork. As a rule of thumb, students are attracted to courses where they can see the results of their work in the real world. The IoT enables them to create systems for controlling real devices that interact with the physical world.

In order to formalize and better define the software development of various IoT systems, the Arduino serial interface (ASI) with acquisition boards was specified. Serial communication with acquisition board can be wired using the UART (Universal Asynchronous Receiver Transmitter) over USB or wire connected digital pins, TWI (Two Wire Interface), SPI (Serial Peripheral Interface) or computer network communication. Three level ASI specification is presented in Fig. 3.

External implementation in Fig. 3 can be for instance serial monitor from Arduino IDE or some other general communication program like PuTTY where user types commands according to specification, or custom user application implementing ASI. The first level consists of communication specification with the Arduino UNO board which is Arduino basic and best-known representative. Second more specific ASI for other boards which usually have more resources than UNO and specific features, was specified as a second level inheriting from the first level. Second level has separate

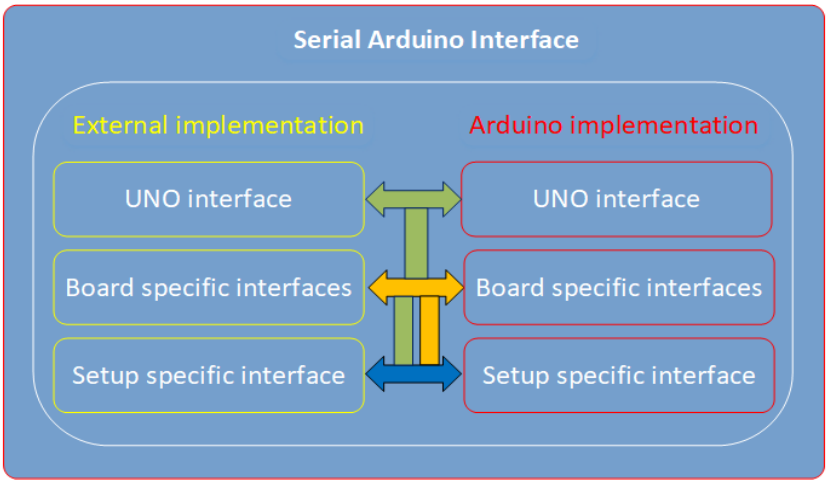

Fig. 3. Three level ASI specification

specification for each non-Uno board. Third and the most specific level has specification for each hardware setup, that can inherit from both upper levels. Hardware configuration can for instance have a sensor or actuator with digital serial communication requiring use of some specific library which must be included in software uploaded to Arduino board, therefore requiring specific interface. Specified third level interface served as a starting point for new projects.

Described interface concept is quite similar to connection of IoT devices with Cayenne. Provided code from the Cayenne with library implements interface used for communication with Cayenne cloud. Once the code is uploaded or installed to IoT board and connection with board established, all further settings and changes are made in cloud at dashboard, without changes to uploaded code at IoT device. Cayenne API specifies more sophisticated programming interface.

Besides covering and dealing with the fundamentals of the IoT, the course can also be used as the basis for establishing web-accessible remote laboratories for the improvement of teaching Physics. Some of the topics of seminar papers for the IoT course can be defined by experiments prepared by the students of Physics acting in the capacity of customers ordering the software with the required characteristics

While reconsidering the content of the IoT course after exams, an important topic was spotted as an appropriate to be added to the course in future, for a more general view of IoT. The new topic to be added is the IoT Architectural Reference Model (ARM), IoT-A [48] introducing the abstract IoT Reference Model and IoT Reference Architecture. A wide variety of IoT supported systems, IoT technologies and architectures require a unified approach to the development process for abstract modeling of a supported system and software architecture, with methodologies for creation of those abstract models, and for deriving specific system model and architecture for implementation. This is considered as important not only for the IoT design, but also as contributing to a wider picture of design in the IT, which is an important part of the IT education.

IT and IoT will certainly change in the future and become more advanced. One of the important indirect outcomes of this IoT course is to prepare and enable students to follow, learn and create the IoT technology of the future.

7 Students projects

The group of 20 students selected the IoT course on the 4th year of general IT bachelor study group, which was almost a 100% of students on that study group, as only one student did not choose the IoT course. The evaluation consisted of usual 2 pre-exam tests, seminary work and a final exam, which was quite similar to evaluation of other subjects. Students were given a list of project titles to choose from, for their seminary work. Each topic for the seminary work was to be collaboratively done by the team of 4 students. Evaluation of the seminary work was on the individual basis. Each student had to describe his work and role on the project, and to answer some specific questions regarding project details and coding, as a proof and measure of real engagement on the project. Two projects were selected as an illustration of student's creative engagement in IoT.

The first project was "Weather station" with the tasks of assembling required hardware and software development for automatic measurement of air temperature and relative humidity. Assembled weather station hardware on proto board is displayed in Fig 4.

Software development included three different pieces of software for Arduino UNO board in C language, JavaScript for NodeJS server programming, and user interface as a client web page. Although the Arduino UNO board was used, the C language application implemented extended serial interface specification at level 3, as the used digital sensor DHT22 [49] for relative humidity required software library for measured data reading. Fig. 5 shows the web page for weather station. Besides current readings of temperature, humidity and light intensities from two opposite directions, recorded readings over a time period in the chart form are available for selected measured quantity.

Second project was implementation of web user interface for remote control of the Arduino Esplora board [50], which is a small compact lab having various sensors and actuators, displayed in Fig. 6.

Esplora board is an example of specific non-general-purpose boards that requires use of the library for easy program access to all board sensors. Moving of sensors like joystick and potentiometer slider, pressing buttons, changes of light intensity and temperature immediately send data from Esplora to server, and from server using socketIO to client browser, actually pushing data to client which uses animated controls for proper intuitive display. Implemented functionality is bidirectional allowing also the control of actuators on Esplora board from the web page. Virtual keyboard in Fig. 7 plays notes on small piezo loudspeaker on Esplora board, while RGB sliders set intensities of red, green and blue light component of RGB LED diode on Esplora board.

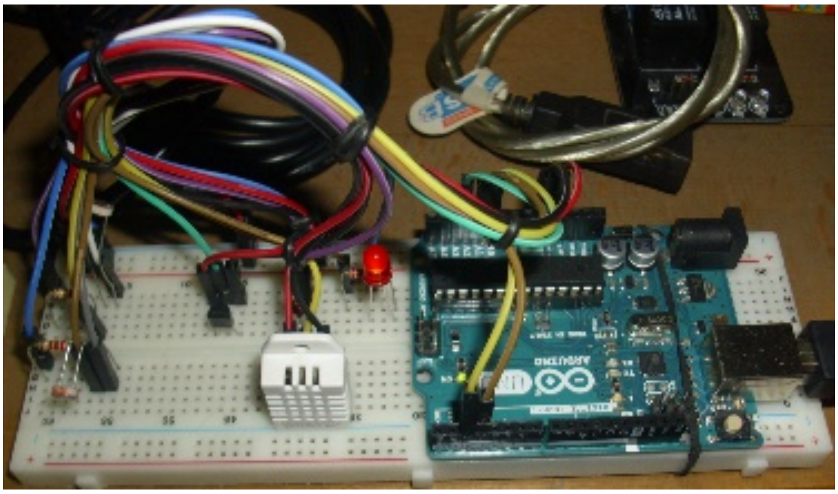

Fig. 4. Weather station hardware setup

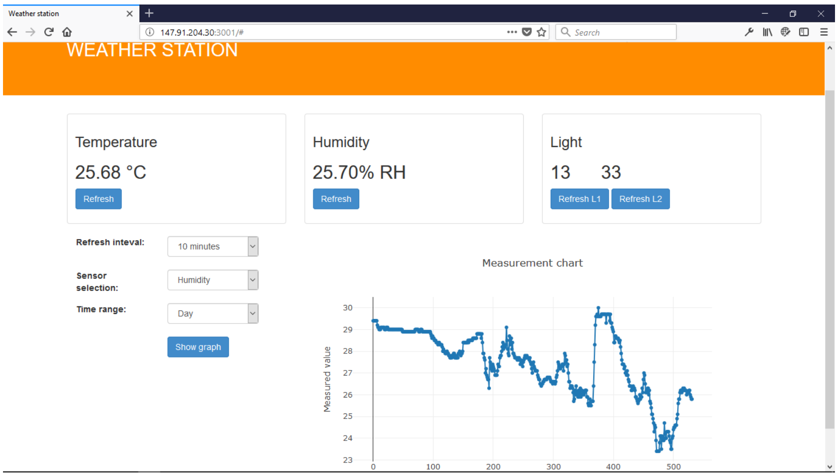

Fig. 5. Weather station web page

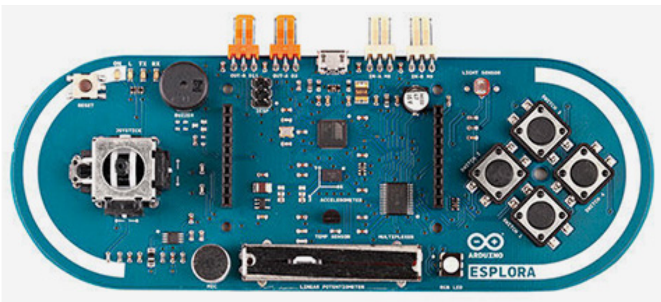

Fig. 6. Arduino Esplora board

8 Conclusion

The IoT is an important contemporary concept for connecting of physical world with virtual world of digital technologies by means of sensors and actuators immersed in the physical world media of interest for monitoring and control. IoT combines various IT technologies for obtaining and collecting of physical data and control of actuators in various industries bringing new benefits and revenues. An adequate education of the IoT professionals is required for exploiting the IoT potentials and further development. University IT departments are privileged and expected to offer the contemporary cutting-edge IT education with IoT courses built upon IT foundation. As the IoT combines IT technologies with some engineering disciplines dealing with physical world interactions which are generally not part of the IT, the IoT courses require some support from engineering, as the IoT courses for engineering students would require some support from the IT. The IoT only explicitly requires what is implicit for the IT, that development of the IT support for some real-world system always requires some knowledge of the system expressed in the system model. That implies the "T" shaped educational profile with solid basis of the main studies extended towards some more peripheral content estimated as important. Besides the necessary IT and engineering content of the IoT course, some wider view of the IoT should be provided due to the diversity of supported systems and IoT technologies in the form of the IoT ARM (IoT-A) which introduces the abstract reference model and reference architecture as common for any IoT project. The IoT-A also specifies methodologies for creation of abstract models and obtaining required specific model and architecture for implementation.

Staff competencies for the IoT teaching are seen as comprising not only the knowledge which must exceed the course content, but also the operational experience and ability to motivate students for non-constrained thinking and original solutions.

One of the goals of the IoT course should be the "education for future", enabling students to learn, use and create the IoT of tomorrow.

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Devoted to my dear IT bachelor students that elected the IoT course.

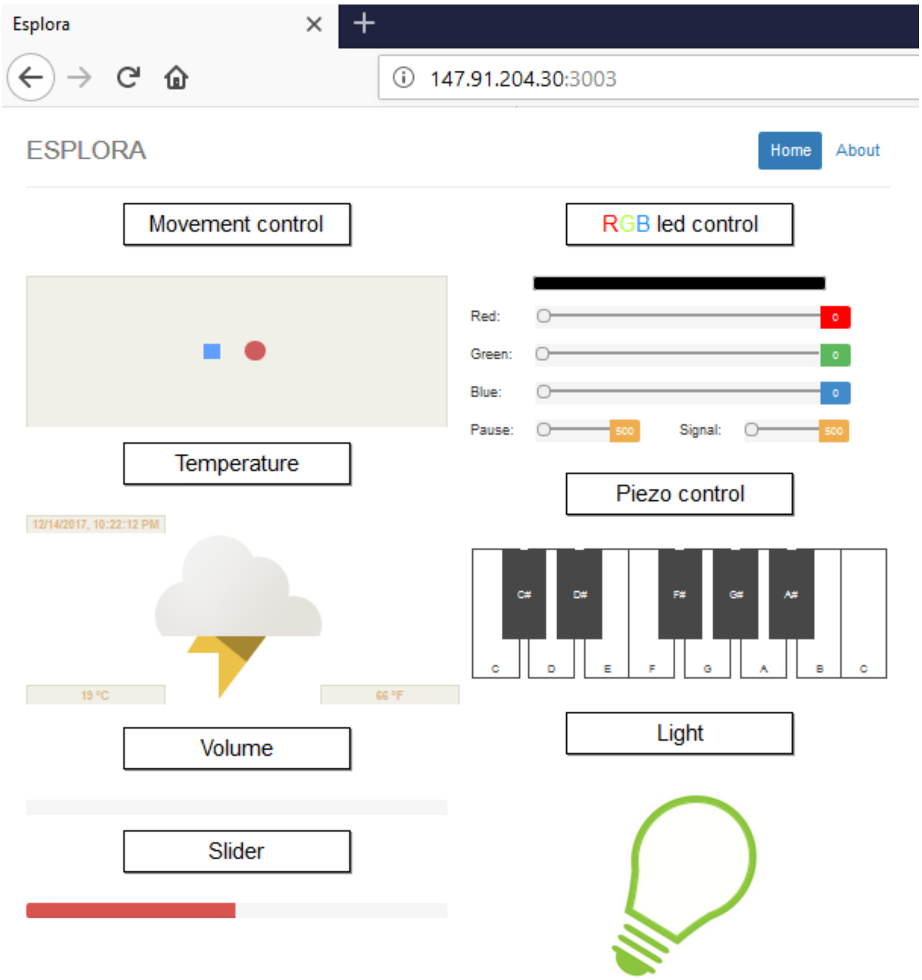

Fig. 7. Esplora web page

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