Educational Robots for Internet-of-Things Supported Collaborative Learning

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Abstract. We present a vision of using educational robots as smart mobile components ("things") of Internet-of-Things. Such robots, beside their primary mission to facilitate learning, are able to communicate; have computing capabilities; as well as have sensors and actuators to sense and change their physical context. The robot serves both as the educational service that allows to visualize knowledge through explicit actions and behaviour as well as the enabler of learning and providing student engagement through immersion and instant feedback. The vision is based on the principles of contextualization, physicality and immersion. The pedagogical background is the proposed Internet-of-Things Supported Collaborative Learning (IoTSCL) paradigm based on constructivism, which provides a highly motivating learning environment in university, promoting collaboration among students, and achieving the creation of new knowledge in a reflexive process directed by the teacher. We demonstrate the implementation of the paradigm in the project-based setting at the university course and evaluate it using the Four-Phased Model of Interest Development.

Keywords: Internet-Of-Things, educational robotics, collaborative project-based learning.

1 Introduction

Recent achievements in educational technologies,such as educational robotics, augmented reality or semantic web, open new opportunities for increasing attractiveness of technological specialties and stimulating engagement of students in the learning process. However, new technologies require additional efforts (both methodological and technological) to integrate and construct teaching and learning environments to enhance delivery of subject material [1]. In this paper we analyse the potential of the Internet-of-Things (IoT) [2] technologies for supporting education. IoT is a vision of a world penetrated by embedded smart devices, which have identities, sensing and actuation capabilities, are connected via Internet, can communicate with each other and with humans, and can provide some useful services (definition based on [3]).

Currently IoT is emerging as one of the major trends shaping the development of technologies in the ICT sector [4]. IoT has connections with Ambient Intelligence [5],

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which refers to digital environments that are sensitive and responsive to the presence of people; Augmented Reality [6], where physical users and virtual reality are merged together, Semantic Web [7], which enables human knowledge to be machine-readable, Ubiquitous Computing [8], which allows Web services to serve anything, forming a bridge between virtual world and real world; Cloud Robotics [9], where cloud computing is used to augment the capabilities of robots by off-loading computation and providing services on demand; Wireless Sensor Networks [10], which connect spatially distributed autonomous sensors to monitor physical or environmental conditions and to cooperatively send their data through the network, Web mashups [11], where users can create applications mixing real-world devices, such as home appliances, with virtual services on the Web; and Web-Squared [12], which is an extension of Web 2.0 [13] aimed at integrating web and sensing technologies.

The theoretical background for the application of IoT for education is Norman's foundational theory of action [14], which states seven stages of activity from its conception to formation: 1) establish a goal, 2) form an intention, 3) specify an action sequence, 4) execute an action, 5) perceive the system state, 6) interpret the state, and 7) evaluate the system state with respect to the goals and intentions. Another theoretical concept is immersive learning, whichsimilarly to IoT is based around networking and could be combined with IoT in an educational setting [15].

Conceptually, IoT is similar to Object-Oriented Programming (OOP): the "things" have a state and represent real-world entities, which can be accessed only via interfaces ("services"). Currently, OOP dominates the field of software programming. However, students often face difficulties when trying to assimilate the concepts of OOP. Several approaches tried to assist student understanding of programming concepts by moving towards visualization of learning content, tools and materials, which includes, e.g., programming environments in which the structure of program code is visualized [16], or using highly abstract visual programming languages (VPLs), which use visual elements rather than machine instructions [17]. VPLs are more attractive to non-professional or novice programmers because ofsimpler description of domain [18], and immediate visual feedback [19] instead of textual languages.

On the other hand, there is a strong trend towards increasing the role of robotics in the education [1, 20, 21]. Robotics is a complex domain that includes both hardware and software parts and requires deep knowledge of embedded systems, real-time systems, artificial intelligence, mechanics, kinematics, navigation, sensors, communication and control protocols and robot programming languages.

The novelty of this paper is an approach that combines robotics, IoT and Computer Supported Collaborative Learning (CSCL) for project-based learning based on a vision of robots as *mobile smart learning objects*.The aim of the paper is to discuss the proposed concept of IoT Supported Collaborative Learning (IoTSCL) and describe its application in the university course using educational robots.

The structure of the remaining parts of the paper is as follows. Section 2 discusses the role and model of using IoT for educational purposes. Section 3 proposes the concept of IoTSCL and discusses its advantages for education. Section 4 presents a case study application of the proposed ideas in the university course. Section 5 evaluates and discusses results and Section 6 presents conclusions.

2 Role and Model of Internet of Things for Education

IoT is based on the concept of “smart objects”, or “things”. Miorandi et al. [4] define smart objects as entities that are *physical*; can communicate (accept incoming messages and reply to them); have a unique identifier and are associated to at least one name and one address; have some computing capabilities; and have means to sense physical phenomena (sensors) or to trigger actions having an effect on the physical reality (actuators). These properties allow smart objects to be *context-aware*, i.e., smart object can analyse the data received from its sensors and can use recognition algorithms to detect activities and events [22], as well as to be *social*, i.e., share their data, learn about each other and perform intelligent behaviours based upon each other's states [23], and provide services to both humans and robots in real-world environments [24].

Structurally, IoT consists of three major layers of abstraction:

1) *Hardware* (sensors, actuators and communication devices), which is built upon the existing global Internet communication infrastructure that links physical and virtual services [25]. Sensors allow users to get information about their environment, enable new forms of user interaction, and connect the real world with information.

2) *Middleware* (computing tools), which is used for data capture, aggregation and analysis. Secondary information inferred from sensor data also can be used for synchronizing learning activities with the physical environment and user feedback about their interaction with objects [26].

3) *Presentation* (or web service) *layer*, which allows Things to participate in business processes and provide capabilities to query things and change their state as well as support visibility (therefore, abstract concepts to be learned can be made visible and hence more understandable).

The main challenge in developing educational IoT systems is integration of functionalities and/or resources provided by smart things into educational services [27]. This requires the definition of the educational IoT architectures and models for seamlessly integrating and composing the resources/services of smart objects into educational services for learners.

For educational purposes, the IoT Reference Model [3] can be adopted. The IoT Reference Model identifies the generic IoT scenario in which a User (a human person or a software agent) needs to interact with a Physical Entity (a discrete, identifiable part of the physical world). A Physical Entity can be represented in the electronic world by a uniquely identifiable Digital Entity such as avatars, or even a social network account. Smart Object is the extension of a Physical Entity with its associated Digital Proxy. For Smart Object to be represented in both physical and digital world, it has embedded or attached Devices such as Sensors or Actuators that allow for interacting with or gaining information about the Physical Entity. Users can interact with Smart Objects through the use of Resources which provide services to Users.

In the next Section, we discuss how IoT can be used to support collaborative learning using mobile physical robots as Smart Objects as defined by the IoT Reference Model.

3 The Concept of IoT Supported Collaborative Learning

Computer supported collaborative learning (CSCL) refers to a technological environment in which students interact actively, share experiences and build knowledge [28]. Face-to-face CSCL provides a highly motivating learning environment, changing the classroom dynamics and promoting collaboration among students for achieving good results [29]. The inclusion of educational robotics to CSCL as Mobile Robotic Supported Collaborative Learning (MRSCL) [30] has added a new dimension to this learning environment. While maintaining the face-to-face interactions, collaboration, and the underlying technological assistance, Educational Robotics provides a way to embrace real-world capabilities [30]. This real environment (as opposed to virtual learning environments common in e-learning [31]) provides students with a common resolution space where mobility enables world exploration and immersion. On the other hand, the robot, empowered with mobility and autonomous navigation, becomes a new actor capable of interacting with both, the physical world and a group of students. Moreover, MCSCL introduces a space that favours constructivism to achieve creation of new knowledge in a reflexive process directed by the teacher [32].Conceptually, the role of robots in the educational IoT-based environment is threefold:

1) **Robot as a mobile smart "thing**". Knowledge is created, enhanced, and rebuilt through interaction between smart objects. Learning materials and processes can be self-organized and adapted according to students' real-time interest and psychological statuses [33]. Things are implemented as Mobile Robots, which can move and interact with their environments [34].

2) **Robot as a Service (RaaS)** [35] enables an agent to enlist a robotic entity to perform actions. The robot becomes a service end point for a user to command.

3) **Robot as Learning Object (RaLO),** which extends the notion of an LO beyond the virtual domain (learning content) to a physical domain (robot hardware and physical processes that are demonstrated by the hardware) [36, 37].

Connecting learning services and materials to physical objects enriched with sensors is a next step in the evolution of Learning Objects and e-learning environments. As noted by Specht [38],"*the connection between digital and physical objects builds a new landscape for learning of the future*." The vision of robot as "smart thing" allows to extend the MRSCL into the IoT domain as the IoT Supported Collaborative Learning (IoTSCL). The main contribution of IoT for education is as follows:

1) Providing a technological background for c*ontextualised* learning by embedding technology (gadgets, devices, sensors, etc.) in the natural environment in which learning takes place. It enriches the learning experience by contextualising learning activities and synchronizing learning content with the learner's context and reflection [38]. Contextualization is an essential step towards personalization of delivery of learning services, i.e., IoT comes forward as a technological platform for such personalization.

2) Achieving immersion of learners, where the learner rather than interacting with the outside learning environment, actually is inside of the learning environment, with smart physical mobile robotic learning objects surrounding him. A core component of

the efficient learning is the instant feedback in these rich and interactive environments. In a real-time environment each action of the robot programmer and user may trigger instant feedback and subsequent reflective thought processes [38]. Such learning through immersion can contribute to the construction of new knowledge which is based on the pre-existing knowledge of students.

3) Increasing student engagement by using *physical* rather than virtual things. This engagement plays a fundamental role in skill development, because behaviour of the physical thing provides immediate feedback that helps the student to gain knowledge and correct the errors[39],and has positive influence on algorithmic thinking [40].

4 Case Study

The use of educational robotics and IoT technologies combined with project-based collaborative learning was explored during the laboratory works of "Robot Programming Technologies", a course delivered at Faculty of Informatics, Kaunas University of Technology (Lithuania)to the 4th year bachelor students [41]. The course was attended by 34 students in 2012 and by 22 students in 2013. The course aims to teach students of the basic principles of robot control and robot programming. The main concepts to learn are state (property of the robot), action/reaction (change of the state of the robot due to external or internal factors), behaviour (specific sequence of actions aimed to achieve a pre-set objective), decision (ability to undertake a specific sequence of actions from a set of alternatives), autonomity (ability to function independently), communication (ability to send/receive messages from external devices).

This case study describes the development of one project in the group project-based educational setting.Following the Norman's foundational theory of action [14], the goal of the project has been formulated as the development of the mobile webcam for home security applications and its evaluation. The functions of the robot to be implemented is home patrolling (free roaming with obstacle avoidance as well line following in room environment), image capturing and sending to the server computer, as well as fire detection and user warning using the temperature sensor.

The robot has been assembled using .NET Gadgeteer components and programmed using object-oriented language C#. For data transmission wireless internet is used. Robot control commands are sent to robot using UDP and images from robot camera

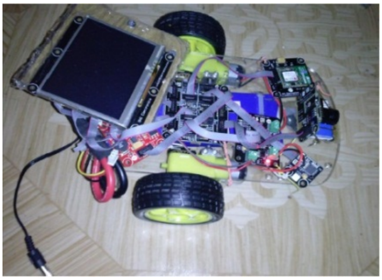

Fig. 1. Implementation of robot

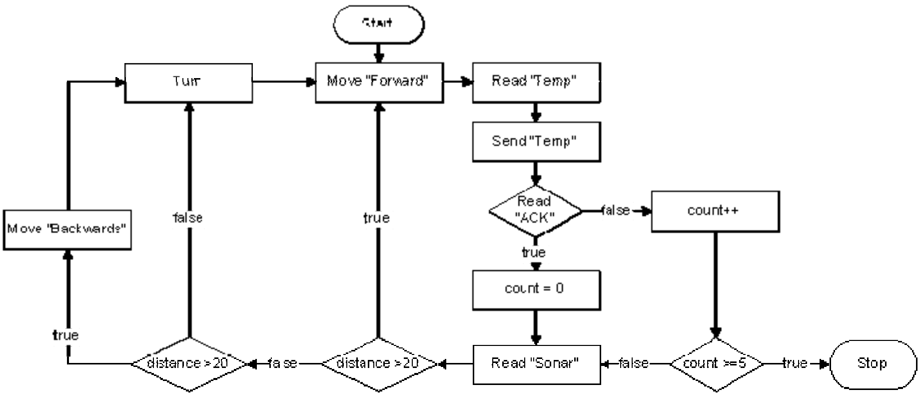

Fig. 2. Flowchart of the robot algorithm

are sent using TCP (TCP ensures faster data transmission). The hardware implementation of the robot can be seen in Fig. 1, while a fragment of the behaviour algorithm is shown in Fig. 2. The fragment demonstrates obstacle avoidance of the robot.

The line following algorithm modelled using Microsoft Visual Programming Language, a part of the Microsoft Robotics Developer Studio, is presented in Fig. 3.Using a high-level visual language rather than code-level textual programming language such as C# for description of algorithms is positively rated by students as it allows to deal with complexity of robotics and IoT domains more effectively [41].

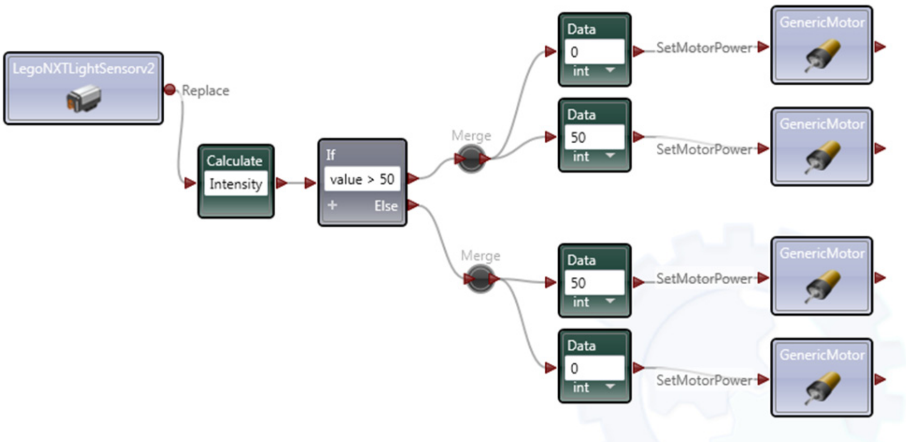

Fig. 3. Line following algorithm in Microsoft Visual Programming Language

The constructed robot is also able to measure temperature of its environment (see Fig. 4), to send values to the server for storage and further analysis (if needed), and to send SMS to the user, if the temperature value exceeds a predefined value. This service allows to demonstrate the communication capabilities of the robot as a mobile sensor platform in the context of Internet-of-Things.

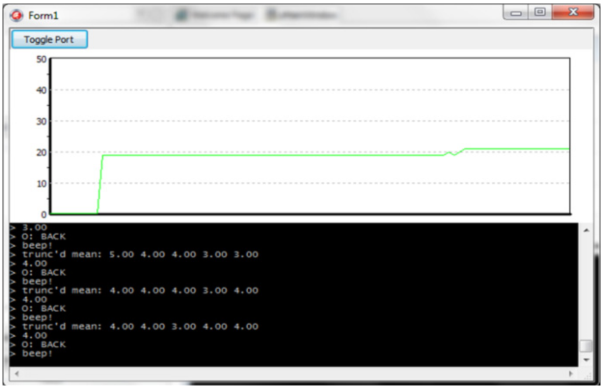

Fig. 4. Example of temperature measurement results

In the research part of the project, the student group was asked to experimenttally evaluate different strategies for turning a robot, i.e., to change the direction of its movement using different values of motor power applied to its wheels, in terms of their speed and accuracy. Three variants of turning a robot were devised (see Fig. 5).

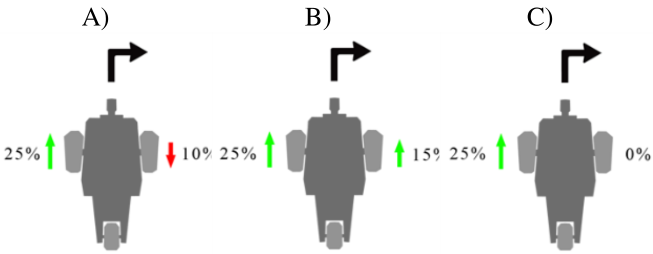

Fig. 5. Motor power and wheel turning direction in different robot turning scenario

The experiments were performed using two different line following algorithms: One Bounce and One Inside [42], and two different types of route for robot driving. One route (see Fig. 6, a) is aimed to evaluate the ability of the robot to complete rounded turns while frequently changing the direction of movement. Another route (Fig. 6, b) is made of 10 sharp angles which test the ability of the robot to complete sharp turns. The results of robot time trial are presented in Table 1.

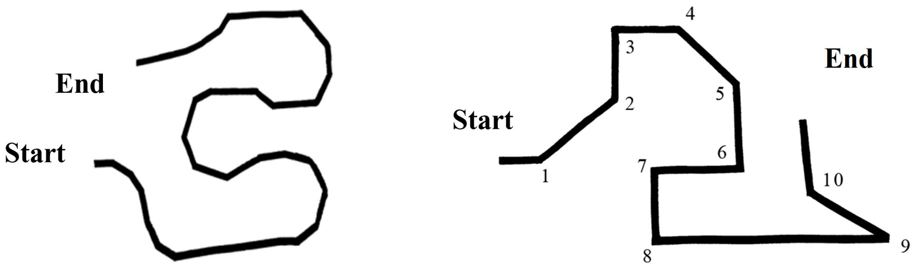

Fig. 6. Routes: a) with rounded turn angles, b) with 10 sharp turns

Table 1. Experimental results of robot driving

Route	Algorithm	Turning variant	Time (min:s.ms)	Accuracy evaluation
1	One Bounce	A	2:52.8	Completed
1	One Bounce	B	1:30.8	Completed
1	One Bounce	C	-	Failed
1	One Inside	A	2:16.7	Completed
1	One Inside	B	1:27.5	Completed
1	One Inside	C	1:09.9	Completed
2	One Bounce	A	1:35.7	Completed 8/10 turns
2	One Bounce	B	0:35.5	Completed 7/10 turns
2	One Bounce	C	0:24.7	Completed 7/10 turns
2	One Inside	A	1:26.1	Completed 10/10 turns
2	One Inside	B	0:16.3	Completed 3/10 turns
2	One Inside	C	0:21.1	Completed 6/10 turns

Project Findings. The project results were discussed during student self-evaluation sessions with a teacher as well as presented during course workshop for all course students. The students noted that the most important factor determining the accuracy of robot movement is noise in sensor data. While in theory all analysed line following algorithms should allow the robot to complete the intended route, random factors such as dust or unevenness of ground caused errors in sensor interpretation of line colour beneath the robot, which caused change or movement direction and, eventually, missing of the route. Also the students have noted that the sharpness of angles of the route could cause problems for the robot. When comparing different line following algorithms, One Bounce algorithm proved to be more reliable, but also slower and visually observed robot movement was more similar to stepping. One Inside algorithm allowed the robot to complete the route faster but sometimes also caused the robot to miss the line, especially when driving at sharp angles.

5 Evaluation and Discussion

To measure students' satisfaction we took a survey of 22 students after the lab exercise. The majority of students was satisfied with the class and expressed positive opinion. Fig. 7 shows the survey results.The students were asked three questions:

1) First question "*What is your opinion of the course?*" surveyed the emotional disposition of students towards the course.
2) Second question "*What advantages does this course have?*" surveyed the cognitive disposition of students towards the course.
3) Third question "*Would you prefer to have more practical exercises with mobile robots in the next semester?*" surveyed their disposition to reengage.

The questionnaire allows to measure emotional/cognitive interest vs. short-time/long-time engagement.

The students' satisfaction was evaluated using the Four-Phase Model of Interest Development proposed by Hidi and Renninger [43] which introduces four types of interest as follows:

1) *Triggered Situational Interest:* short-term changes in affective (i.e. emotional) and cognitive processing sparked by content (e.g. information, tasking).
2) *Maintained Situational Interest:* a psychological state that involves focused attention and persistence over an extended period of time for content/tasks that an individual considers meaningful or relevant.
3) *Emerging Individual Interest:* the beginning of enduring predisposition for an individual to seek repeated engagement with particular content or tasks over time.
4) *Well-Developed Individual Interest:* an enduring predisposition to reengage with particular content or tasks over time characterized by positive feelings, more stored knowledge and more stored value for the content.

The answers of students are interpreted using the matrix presented in Table 2 and summarized in Fig. 7 (in percents). When analysing we assume that long-term interest subsumes short-term interest and cognitive interest subsumes emotional interest.

Table 2. Interpretation of Four-Phase Model of Interest Development [43]

Four-Phase Model of Interest Development	**Short-term engagement → Long-term engagement**	
Emotional interest	Triggered Situational Interest	Maintained Situational Interest
↓ **Cognitive interest**	Emerging Individual Interest	Well-Developed Individual Interest

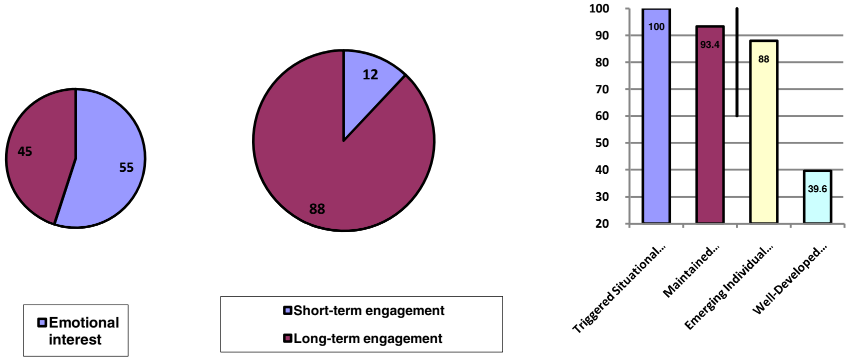

Fig. 7. Results of survey and their interpretation using four-phase interest model

6 Conclusions

This paper has studied and analysed the basic components of the Internet of Things (IoT) Supported Collaborative Learning (IoTSCL) environment defining and implementing the robot as a mobile physical smart learning object and service. Such smart learning objects and services can create contextualized learning ecosystems that enhance both learning outcomes and motivational states of students interacting with them. The paper has discussed the experience of using a mobile robot development project in the context of IoT for joining hardware and software subjects in the learning process. A case study presented an example implementation of a mobile home webcam project in which students interacted with a robot as a contextualized learning object and service within the context of IoT. The experience has been done in the 4th course of software engineering studies with the aim to motivate students. Students acquired problem-oriented skills (knowledge and competences) in software and hardware. The course experience demonstrated that mobile robots can be used as physical smart learning objects. The evaluation of the course using Four Phase model of Interest Development [43] demonstrated that a majority of students have developed long-term cognitive interest into the subject of study. The use of mobile robots as physical learning objects allowed to enrich the learning experience by providing instant feedback and subsequent reflection, and achieving full immersion of learners into the learning environment with smart physical learning objects surrounding them.

Future work will focus on the development of a learning environment that supports visual modelling language for mobile robotics as well as elements of IoT (sensors, actuators and communications). The environment will be used in the context of group-based collaborative project learning and its pedagogical efficiency will be evaluated using student and expert surveys.

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