The 9th IEEE International Conference on Dependable Systems, Services and Technologies, DESSERT'2018
24-27 May, 2018, Kyiv, Ukraine

Polygon for smart machine application

Anatolii Kargin [1], Oleksandr Ivaniuk [2], Georgii Galych [3], Artem Panchenko [4]
[1,2] Ukrainian State University of Railway Transport, 7 Feierbakh Sq., Kharkiv 61050, Ukraine,
{kargin, ivaniuk}@kart.edu.ua
[3] Vasyl Stus Donetsk National University, 21 600-richya Str., Vinnytsia, 21021, Ukraine, g.galych@donnu.edu.ua
[4] V. N. Karazin Kharkiv National University, 4 Svobody Sq., Kharkiv, 61022, Ukraine, panchenko074@ukr.net

***Abstract*—The article deals with the implementation of the paradigm "a dependable and safe system out of undependable and not entirely safe components" using the example of application of complex situation monitoring, where global situation model is required. The description of the situation is based on sensory data from various locations. When it is difficult to identify the situation on the basis of incomplete and unreliable sensor systems, additional information is obtained about the state of these locations using a small group of mobile smart machines. Increasing the reliability of the situation description is achieved by generalizing, abstracting and reasoning based on heterogeneous sensory data, but not because of their duplication. The article deals with the training and research polygon of intelligent information technologies for approbation of such applications of intelligent machines. The architecture of the polygon, components of sensory systems, organized in the form of IoT locations, and smart machines are presented. It deals with the organization of the software supporting, also. A description of two projects implemented at the polygon is provided: monitoring of fire-dangerous situations and monitoring of dangerous situations related to the violation of order in the campus auditoriums. In both applications, smart machines are implemented on the basis of training wheeled robots, equipped with heterogeneous sensor systems. Software and hardware implementation is performed on Raspberry Pi, Arduino and ESP8266 platforms.**

Keywords—Smart machines; polygon of intelligent information technologies; internet of things; processing of sensory data; monitoring of dangerous situations.

I. INTRODUCTION

Industry 4.0 is bound with the implementation of Internet of Things (IoT) and Smart Machines (SM) [1] – [4]. There are IoT applications with increased reliability requirements. These are tasks of monitoring complex situations in which information comes from a large number of insufficiently reliable sensor systems [5] – [8]. To provide the dependability of these applications is a multifaceted task. The dependability and completeness of the data obtained is greatly depends on models and methods of data processing, software and hardware [9]. One of the ways how to increase the dependability is based on additional clarifying information obtained with mobile autonomous SM [7], [10], [11]. In this case, the IoT application is organized as follows. The basic IoT components (IoTC) are stationary distributed in the object space, and SM are realized as mobile devices (robot, drone), moving in the space [12], [13]. The sensory data received from SM does not duplicate IoT information, but complements the description of the situation, which increases its reliability. The railway engineering application is an example of how to implement the approach when both IoT components and a SM group are used to obtain additional specifying information in order to increase the reliability of situation descriptions [14], [15]. Intelligent train control relies on the Global Situation Model (GSM) of different levels of detail [15], which is formed on the basis of data coming from both SM and IoT locations. Another example is fire-protection systems which obtain information from both stationary indoor sensors (the indoor environment is controlled by smoke, heat, flame and other sensors) and mobile robots specifying the situation. It increases the identification reliability for the fire-safe situation and decreases the level of false alarm signals. More information from the emergency location greatly decreases the number of false signals which occur due to the environmental influence.

Industrial IoT with SM (IIoTwSM) are both highly reliable and economical. Additional heterogeneous information from various locations can be obtained by a small SM group which is more economically as compared to the variant when all locations are stationary equipped with a complete set of sensors.

Operation of IIoTwSM is based on GSM which describes the states and changes in all locations at arbitrary point of time. Increasing the dependability of the GSM is reached by generalization and reasoning of the sensory data rather than their duplication [6], [7], [16], [17].

There are some problems in designing GSM [17]. The situation model, built directly on the initial sensory data, is difficult for decision-making. Actual IIoTwSM applications cannot be parameterized therefore a great number of situation prototypes, build on specific sets of sensory data, are taken into account. The dimension is considerably reduced thanks to usage of the fuzzy system instrument – linguistic variables [18]. Studies [6], [7], [16], [17] consider formalization of GSM on the base of abstracting and categorization [19], [20]. It significantly reduces the number of potential situation prototypes. In

978-1-5386-5903-8/18/$31.00 ©2018 IEEE

this paper, we consider a GSM represented in the form of a Granularly Structure (GS), consisting of information granules (IG) [17]. IG is an abstract model of the situation representation by some set of sensory data.

In order to research performance of various implementations of IIoTwSM, being based on GSM, the Polygon IIoTwSM (PII) was developed. The training and research PII was organized on the base of the Department of Information Technologies of Ukrainian State University of Railway Transport. Among the tasks for PII are to provide hardware and software support for the research of various variants of IIoTwSM architecture, influence of characteristics of some IoTC and SM on the system characteristics of IIoTwSM. In the organization of the PII, the main principles proposed in the works devoted to the creation of similar platforms [21] – [26] are laid. This is an open platform, modularity, wireless sensor network and others. A description of two projects implemented at the polygon is discusses: monitoring of fire-dangerous situations and monitoring of dangerous situations related to the violation of order in the campus auditoriums. In both applications SM implemented on the basis of training wheeled robots are used to obtain additional clarifying information.

II. THE IIOTWSM POLYGON COMPOSITION

Fig. 1 presents the polygon structure. It has two types of the elements: IoTC (stationary systems) and SM (mobile systems). Interaction among the elements is conformed with the standard Industry 4.0 for projects M2M and IoT. Limits of computing power, which should be taken into account for embedded systems [12], defined the Constrained Application Protocol (CoAP).

Function distribution between IoTC and SM is as follows.

SM realizes:

- Spatial motion to a specified location along the route dynamically synthesized by SM. SM control is fulfilled under disturbance.
- Observation of the location environment, where it arrived. Observation is made with a system of sensors SM equipped with. The observation process can be long in time, which is necessary to calculate the dynamic properties of the environment and is associated with search space maneuvers. This process is not pre-programmed.
- The real-time processing of sensory data and formation of a GSM fragment stored in SM memory. This fragment presents GS lower levels.
- Wireless transfer of a GSM fragment which presents a fuzzy description of location properties at a certain abstraction level. Subsequently, this fragment is intended for GSM updating with cloud computing technology.

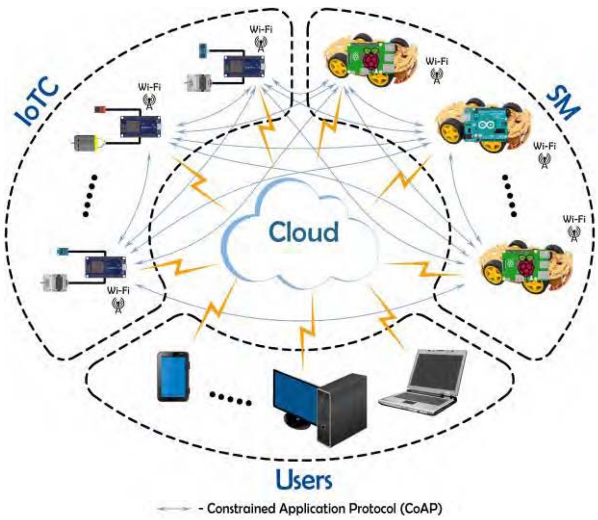

Figure 1. The IIoTwSM Architecture

IoTC fulfills:

- The real-time processing of sensory data and formation of a GSM fragment stored in IoT local memory.
- Formation and implementation of control decisions based on recommendations from a local network and analysis of its GSM fragment.
- Wireless transfer of its GSM fragment to a local network for subsequent GSM updating.

The cloud computing fulfills the following functions:

- Upon IoTC and SM requests, integration of the transmitted GSM fragments into the global model of the situation (GSM update) is performed. It is implemented by granular computing algorithms [17] supported by cloud computing technologies.
- Intellectual analysis of GSM data by granular computing algorithms in order to form control decisions. Under incomplete information the decision on the method of obtaining additional information on the state of the environment of a certain location is taken. The task for SM (location, list of environmental properties to be controlled and the method to obtain these properties) is formed.
- Keeping GSM history in cloud storages.

SM included in the polygon structure are autonomous wheel robots equipped with various sensor systems. Content and structure of SM hardware are chosen so that to support the above-mentioned functions. According to the complexity of a SM task the required computing power is supported by two hardware variants: on the base of a single-board Raspberry Pi [27] and on the platform of microcontroller Arduino [28]. Microcontroller platforms Arduino are intended for processing a small volume of sensory data. The first platform has computing power to support granular structures processing of several generalization levels. The second platform only supports processing granules of the lower zero level.

A. SM based on Raspberry Pi

As an example of the first type SM designed by PII project give a robotic explorer for the video monitoring of the situation. The robot is able to make a remote observation of the situation and real-time Internet transmission of the video bitstream. The platform supporting the sensory data processing is given in Fig. 2. This is microcomputer Raspberry Pi 3 B with embedded Wi-Fi transceiver and standard operational system Raspbian. The software application is developed in Python 3.

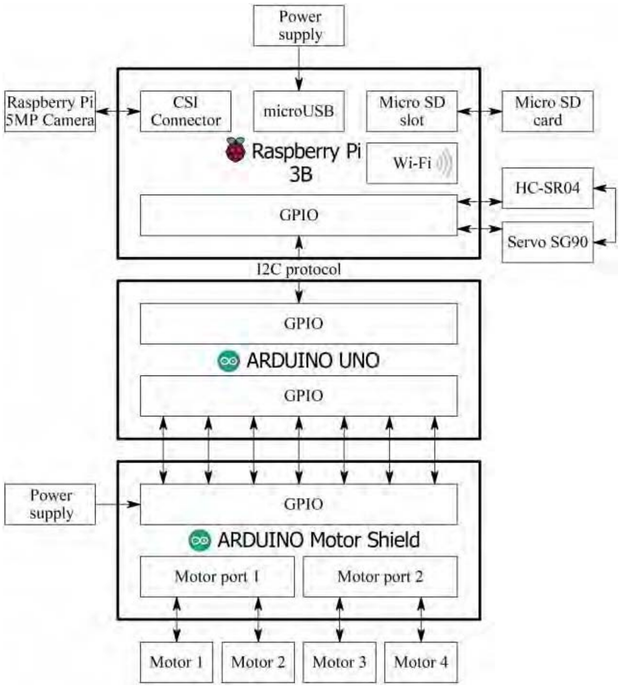

Figure 2. The SM block diagram based on Raspberry Pi

Robots are assembled on the budget platform of four-wheel ZK-4WD chassis equipped with reducer-motors. The robot motion control implemented on the microcontroller platform Arduino UNO, supplemented by the engine controller Arduino Motor Shield (based on the microcontroller L293D). This architecture has its advantages allowing use of standard and well optimized for Arduino Motor Shield library of reducer-motor control. Commands to the motors are relayed from Raspberry Pi to Arduino UNO according to I2C protocol. Video surveillance is realized by Raspberry Pi 5MP Camera with the aid of CSI interface.

The robot motion control is realized using the situational control method based on sensory data (ultrasonic sensors HC-SR04). The sensor installed on the servomotor SG90 is applied for one of the variants. It provides to explore the area in different directions.

B. SM on Arduino basis

SM on Arduino basis is intended to monitor fire-hazardous situations. Robot explorer is equipped with a number of sensors necessary for the analysis of risk of fire situation. The hardware structure of data processing system is shown in Fig. 3.

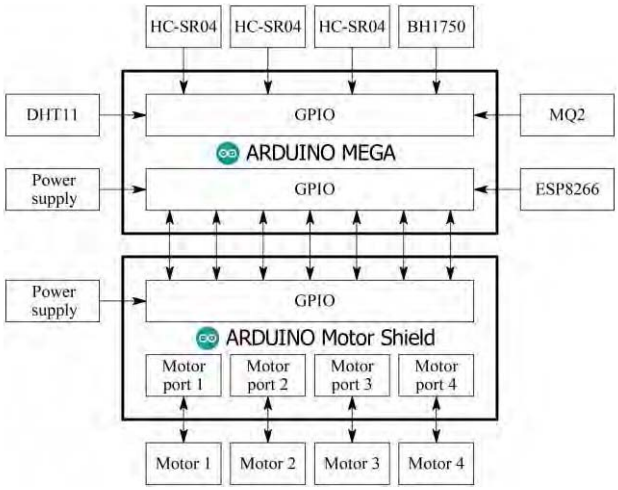

Figure 3. The structure chart of SM on Arduino basis

There is a microcontroller platform Arduino MEGA at the basis of it. Application programs are developed in C/C++. Arduino Motor Shield is directly connected to Arduino MEGA. Microcontroller with built-in Wi-Fi transceiver ESP8266 [29] is connected to the system by I2C protocol. The robot is equipped with three ultrasonic sensors HC-SR04 for distance detection installed perpendicularly to each other. The location characteristics data come from the sensors of temperature, humidity (DHT11), illumination (BH1750), and gas pollution (MQ-2).

C. IoTC

IoTC has its location (territorial appliance). It is created on the basis of microcontrollers with built-in Wi-Fi transceiver ESP8266. Each microcontroller measures several physical parameters of location where it is installed as well as controls some actuators. IoTC applications are developed in MicroPython language [30].

III. INTELLIGENT PROCESSING OF SENSORY DATA

Intelligent processing of sensory data is based on the granular computing model [17]. GSM presents the situation by means of notion of different abstraction and generalization levels. Knowledge portions are represented as IG. At different levels generalized description of the situation are granules representing knowledge of a different level of abstraction. Notions of all possible situations are represented by multilevel GS. The GS sensory data processing is as follows. The data from sensors are directly granulated in discrete time moments. The situation on this zero GS level is represented by a variety of fuzzy IG characteristics. Then, on the basis of these fuzzy characteristics the description of sensory data as a set of different level categories is found. As a result, there is a mapping of the set of fuzzy characteristics IG of the zero level to the set of fuzzy characteristics IG of all overlying GS levels. Each portion of fresh sensory data is generalized by Granular Computing (GC) and complements the description of the situation at the upper levels of the GS. The allocation of informativeness index IG in GS demonstrates the description of current situation on different generalization levels.

Sensor data processing according to GC model is graphically illustrated in Fig. 4. A four system component is demonstrated, two SM and two IoTC. GSM is represented by five fragments. The four fragments – lower GSM levels – are supported by SM and IoTC hardware and software. The fifth component – upper GSM levels – is supported by cloud technologies. As shown in the figure, the GSM fragments of different tonality reflect the results of granular computing for sensory data concrete values. More shaded areas correspond to higher values of informativeness level granule.

For example, for the robot shown in the upper right corner, the GS fragment describes possible situations at the intersection in the form of the following categories: "dangerous for turning to the right", "safe for turning to the right" and others. At zero level there is granular presentation of “object distance” sensory data received from ultrasonic sensors. For the design of IIoTwSM applications, the Automated Application Development Systems GC (GC AADS) are used. GC AADS is developed at the IT department of UkrSURT. GC AADS includes GS editor and the package of GC libraries. The processing of sensory data software is designed for real-time. To support processing of fragmented GS the editor is supplied with fragmentation function. The library supports processing on distributed hardware architecture.

IV. Example of IIoTwSM application implementation

Two applications implemented at the polygon is: monitoring of fire-dangerous situations and monitoring of situations related to the violation of order in the campus auditoriums. In both applications, the task of monitoring the situation in five classrooms on the same floor was decided. Locations are equipped with various IoTC (table 1). They comprise locations controlling vibration level (desks are provided with sensors registering minor bangs on the table, for instance, a dropped book or a cuff), noise level, movement, illumination level. IIoTwSM receives data from sensors of fire-prevention signaling. IIoTwSM includes four SMs: two robot-explorer of video-audio situation and two robot-explorer of fire-hazardous situation. The first are equipped with video-audio sensors (Fig. 2).

The latter – with a collection of sensors for measuring fire-hazardous situation characteristics (Fig. 3). GSM is represented by eight fragments of nine-level GS.

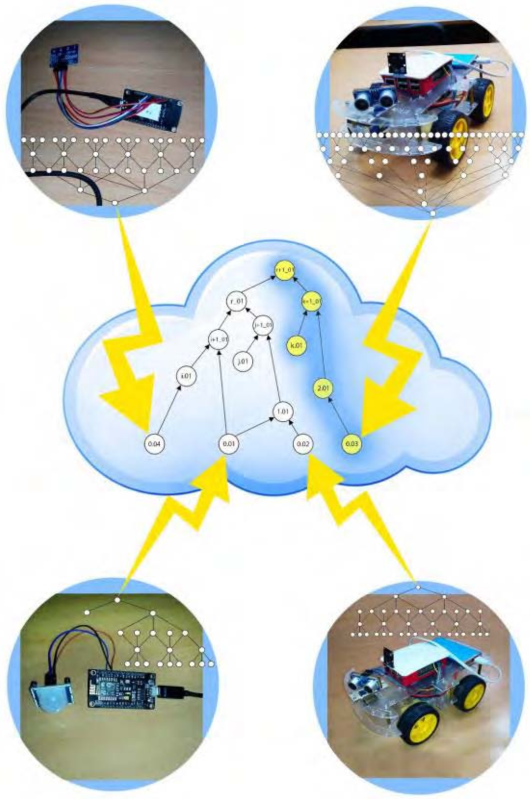

Figure 4. The graphic illustration of sensor data processing by granular computing model

The fragment stored in the cloud (Fig. 4) is represented by the prototypes of hazardous situations. Here is a description of various types of fire-hazardous situations; disturbance situations; situations related to comfort disruption and situations dangerous in terms of disorder, uproar and panic. GS fragments stored in SM memory are represented by prototypes of safe situations for moving robots along the route and prototypes for estimating the values of measured parameters, as well as motion control prototypes for situational control by the robot. Some quantitative criteria that assess the capabilities of the polygon are shown in Table 1.

TABLE I. Quantitative Criteria That Assess The Capabilities Of The Polygon

No	Criteria	Restrictions	
		min	***max***
1	Number of locations	1	-
2	Number of sensors in one location	1	6
3	Number of SM used simultaneously	1	8
4	Number of sensors installed on one SM	1	8
5	Number of levels of GS sensory data abstraction	2	10
6	Number of sensory data portions that complement the description of the situation	1	10
7	Frequency of sensor data polling, times per second	<100	100
8	Delay interval for receiving portions of sensory data	custom model parameter	

V. SUMMARY

An approach is proposed for implementing the paradigm of dependable IIoT applications by intelligent processing of additional information obtained with the help of the SM group. The approach has been studied for monitoring complex situations where GSM construction is required. The approach is tested on the IIoTwSM polygon. Polygon components have not enough high reliability and accuracy - budget equipment used for training purposes. The experiments confirmed the possibility of using sets of not completely reliable budgetary equipment based on Raspberry Pi, Arduino MEGA and microcontrollers ESP8266 for solving the problem of creating a dependable system.

The reliability of decision making on the basis of GSM information is enhanced by applying the technology of generalization and categorization of sensory data, which are additionally obtained in the process of investigating the situation with the help of moving SM. It is shown that GC with distributed GS can be implemented on budget hardware used for creating educational SM applications.

REFERENCES

[1] B. Buntz. “An Executive’s Guide to Industry 4.0, Smart Factories and Beyond.” Internet: www.ioti.com/industrial-iot-iiot/executive-s-guide-industry-40-smart-factories-and-beyond, May 24, 2017 [Aug. 14, 2017].

[2] G. Mintchell. “Industry 4.0 Survey: Building the Digital Enterprise.” Internet: www.themanufacturingconnection.com/2016/09/industry-4-0-survey-building-digital-enterprise, Sept. 12, 2016 [Aug. 14, 2017].

[3] “Industrial Revolution 4.0. On the threshold of a new era.” Internet: www.chp.com.ua/all-news/item/46476-promyshlennaya-revolyutsiya-4-0-na-poroge-novoj-epokhi, Jan. 19, 2017 [Aug. 14, 2017].

[4] T.H. Davenport and J. Kirby. (2016, Mar.). “Just How Smart Are Smart Machines?” *MIT Sloan Management Review*. [Online]. 57(3), pp. 21-25. Available: http://ilp.mit.edu/media/newsarticles/smr/2016/57306.pdf [Aug. 14, 2017].

[5] G. P. Colucci, M. Poletti, R. Stefanelli and D. Trinchero, “Internet of Things as a means to improve agricultural sustainability,” *2017 IEEE Biomedical Circuits and Systems Conference (BioCAS)*, Torino, 2017, pp. 1-4.

[6] A. Mileo, D. Merico, S. Pinardi and R. Bisiani, “A Logical Approach to Home Healthcare with Intelligent Sensor-Network Support,” in *The Computer Journal*, vol. 53, no. 8, pp. 1257-1276, Oct. 2010.

[7] K. W. Lee, J. H. Park and R. D. Oh, “Design of active semantic middleware system to support incomplete sensor information based on ubiquitous sensor network,” *2010 4th International Conference on Application of Information and Communication Technologies*, Tashkent, 2010, pp. 1-5.

[8] D. Camilleri and T. J. Prescott, “Action recognition with unsynchronised multi-sensory data,” *2017 Joint IEEE International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)*, Lisbon, 2017, pp. 53-59.

[9] C.A. Boano, K. Römer, R. Bloem, K. Witrisal, M. Baunach. (2016, Nov.). “Dependability for the Internet of Things – from dependable networking in harsh environments to a holistic view on dependability.” *e & i Elektrotechnik und Informationstechnik*. [Online]. 133(7), pp. 304-309. Available: https://link.springer.com/article/10.1007/s00502-016-0436-4 [Aug. 14, 2017].

[10] N. G. Fernández and S. Schön, “Development of a simulation tool for collaborative navigation systems,” *2017 14th Workshop on Positioning, Navigation and Communications (WPNC)*, Bremen, 2017, pp. 1-6.

[11] R. D. Oh, K. W. Lee and J. H. Park, “Construction of smart middleware system to support incomplete data based on WSN,” *2013 7th International Conference on Application of Information and Communication Technologies*, Baku, 2013, pp. 1-4.

[12] C. Alippi. *Intelligence for Embedded Systems: A Methodological Approach*. Berlin: Springer, 2014, p. 304.

[13] D. Liu, L. Wang, K.C. Tan. *Design and Control of Intelligent Robotic Systems*. Berlin: Springer, 2009, p. 480.

[14] “Unlocking The Potential Of Railways: A Railway Strategy for CAREC, 2017-2030.” Internet: https://www.adb.org/sites/default/files/institutional-document/227176/carec-railway-strategy-2017-2030.pdf, Oct. 26, 2016 [Aug. 14, 2017].

[15] “Rail Technical Strategy Capability Delivery Plan.” Internet: https://www.rssb.co.uk/rts/Documents/2017-01-27-rail-technical-strategy-capability-delivery-plan-brochure.pdf, [Aug. 14, 2017].

[16] T. Lieske, B. Pfundt, S. Vaas, M. Reichenbach and D. Fey, “System on chip generation for multi-sensor and sensor fusion applications,” *2017 International Conference on Embedded Computer Systems: Architectures, Modeling, and Simulation (SAMOS)*, Pythagorion, Greece, 2017, pp. 20-29.

[17] A.A. Kargin, T.G. Petrenko. “Abstraction and categorization in smart machines based on granular computations.” *Vestnik Natsional'nogo tekhnicheskogo universiteta “KhPI”. Seriya: Informatika i modelirovaniye*, vol. 50(1271), pp. 57-68, 2017. (in Russian)

[18] A. Piegat. *Fuzzy modelling and control*. Heidelberg: Physica-Verlag Heidelberg, 2001, p. 728.

[19] W.J. Clancey. “Heuristic classification.” *Artificial Intelligence*, vol. 27, pp. 289-350, 1985.

[20] B. Chandrasekaran. “Generic tasks in knowledge-based reasoning: high-level building blocks for expert systems design.” *IEEE Expert*, vol. 1(3), pp. 23-30, 1986.

[21] P. A. F. Rezeck, H. Azpurua and L. Chaimowicz, “HeRo: An open platform for robotics research and education,” *2017 Latin American Robotics Symposium (LARS) and 2017 Brazilian Symposium on Robotics (SBR)*, Curitiba, 2017, pp. 1 6.

[22] M. Khamphroo, N. Kwankeo, K. Kaemarungsi and K. Fukawa, “Integrating MicroPython-based educational mobile robot with wireless network,” *2017 9th International Conference on Information Technology and Electrical Engineering (ICITEE)*, Phuket, 2017, pp. 1-6.

[23] S. A. Ram, N. Siddarth, N. Manjula, K. Rogan and K. Srinivasan, “Real-time automation system using Arduino,” *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, Coimbatore, 2017, pp. 1-5.

[24] L. B. Hörmann, M. Steinberger, M. Kalcher and C. Kreiner, “Educational remote lab concept for energy harvesting enhanced wireless sensor networks,” *2012 5th European DSP Education and Research Conference (EDERC)*, Amsterdam, 2012, pp. 95-99.

[25] A. Lenskiy, H. Junho, K. Dongyun and P. Junsu, “Educational platform for learning programming via controlling mobile robots,” *2014 International Conference on Data and Software Engineering (ICODSE)*, Bandung, 2014, pp. 1-4.

[26] R. Rahimi et al., “An Industrial Robotics Application with Cloud Computing and High-Speed Networking,” *2017 First IEEE International Conference on Robotic Computing (IRC)*, Taichung, 2017, pp. 44-51.

[27] Raspberry Pi documentation.” Internet: www.raspberrypi.org/documentation, [Oct. 18, 2017].

[28] “Arduino Products.” Internet: www.arduino.cc/en/Main/Products, [Oct. 18, 2017].

[29] “ESP8266EX Datasheet.” Internet: www.espressif.com/sites/default/ files/documentation/0a-esp8266ex_datasheet_en.pdf, [Oct. 18, 2017].

[30] “MicroPython documentation.” Internet: https://docs.micropython.org/en/latest/esp8266, [Oct. 18, 2017].