ALIoT

Internet of Things
for Industry and Human Applications

Development and Implementation of Internet of Things Based Systems

PRACTICUM

Funded by the Erasmus+ Programme of the European Union

Internet of Things for Industry and Human Applications
Development and Implementation of Internet of Things Based Systems

Ministry of Education and Science of Ukraine
Petro Mohyla Black Sea National University
Volodymyr Dahl East Ukrainian National University
National Aerospace University "Kharkiv Aviation Institute"

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Internet of Things for Industry and Human Applications

Development and Implementation of Internet of Things based Systems

Practicum

Edited by Yu.P. Kondratenko and I.S. Skarga-Bandurova

Project
ERASMUS+ ALIOT "Internet of Things: Emerging Curriculum for Industry and Human Applications"
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The structure of work on verification of residual knowledge in the discipline, the corresponding practical material, examples of tasks and criteria of evaluation are given. In the learning process, the theoretical aspects of development and implementation of IoT-based systems are presented. The basic concepts and approaches to development and implementation of IoT systems, models for IoT-based devices and technologies for data processing and transfer, and intelligent methods and approaches for management and learning of IoT-based systems are examined.

It is intended for engineers, developers and scientists engaged in the development and implementation of IoT-based systems, for postgraduate students of universities studying in areas of IoT, cybersecurity in networks, computer science, computer and software engineering, as well as for teachers of relevant courses.

Ref. – 106 items, figures – 48, tables – 20.

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Розробка та впровадження систем Інтернету речей

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Викладено матеріали практичної частини курсу PC4 “Розробка та впровадження IoT систем”, підготовленого в рамках проекту ERASMUS+ ALIOT “Internet of Things: Emerging Curriculum for Industry and Human Applications” (573818-EPP-1-2016-1-UK-EPPKA2-CBHE-JP).

Наведена структура робіт з перевірки рівня засвоєння знань з курсу, відповідний практичний матеріал, приклади виконання завдань та критерії оцінювання. В процесі навчання наводяться теоретичні аспекти розробки та впровадження IoT систем. Матеріали охоплюють основні концепції та підходи до розробки і імплементації IoT систем, моделі для IoT пристроїв і технології для обробки та передачі даних, та інтелектуальні методи і підходи для управління та навчання IoT систем.

Призначено для інженерів, розробників та науковців, які займаються розробкою та впровадженням IoT систем, для аспірантів університетів, які навчаються за напрямами IoT, кібербезпеки в мережах, комп'ютерних наук, комп'ютерної та програмної інженерії, а також для викладачів відповідних курсів.

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ABBREVIATIONS

CoAP – Constrained Application Protocol

CPU – Central Process Unit

DM – Decision Maker

FNIS –Fuzzy Negative Ideal Solution

FPGA – Field-Programmable Gate Array

FPIS – Fuzzy Positive Ideal Solution

GPU – Graphics Processing Unit

IoT – Internet of Things

JSON – JavaScript Object Notation

LCM – Linear Convolution Method

MAS – Multi-Agent System

MCDM – Multi-Criteria Decision Making

MCM – Multiplicative Convolution Method

MEMS – Micro Electromechanical System

MQTT – Message Queuing Telemetry Transport

OT – Operational Technology

PCB – Printed Circuit Board

RB – Rules Base

RFID – Radio Frequency Identifier

TCP – Transmission Control Protocol

TOPSIS – Technique for Order Preference by Similarity to Ideal Situation

UDP – User Datagram Protocol

UML – Unified Modeling Language

UoM – Unit of Measurement

XMPP – Extensible Messaging and Presence Protocol

INTRODUCTION

The materials of the practical part of the study course PC4 “Development and Implementation of IoT-based Systems”, developed in the framework of the ERASMUS+ ALIOT project “Internet of Things: Emerging Curriculum for Industry and Human Applications” (573818-EPP-1-2016-1-UK-EPPKA2-CBHE-JP)[1].

The structure of work on verification of residual knowledge in the discipline, the corresponding practical material, examples of tasks and criteria of evaluation are given. In the learning process, the theoretical aspects of development and implementation of IoT-based systems are presented. The basic concepts and approaches to development and implementation of IoT systems, models for IoT-based devices and technologies for data processing and transfer, and intelligent methods and approaches for management and learning of IoT-based systems are examined.

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

The module PCM4.1 “Basic concepts and approaches to development and implementation of IoT systems” includes two seminars and one training.

The first seminar dedicated to methodologies and approaches for comprehensive design and prototyping IoT-based systems.

The second seminar aimed on evaluation and choosing IoT device management platforms for different areas of application.

The training covers basic principles for adding cellular connectivity to IoT projects, in particular working with GSM-modules.

The module PCM4.2 “Models for IoT-based devices and technologies for data processing and transfer” contains one seminar, one training and two laboratory works.

The seminar provides a data collection and cybersecurity of IoT-based devices with possibility of processing of received data and further analysis of results.

The training covers analysis of monitoring and forecasting methods

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[1] *The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.*

in IoT systems for track, process and analyze relevant data.

The first laboratory work is about building information models of IoT-based devices and acquiring skills of work with code generator to modify and implement information models with the “Eclipse Vorto”.

The second laboratory work is about methodology for comparing and choosing rational protocols and standards for data processing and transfer in IoT systems.

The module PCM4.3 “Intelligent methods and approaches for management and learning of IoT-based systems” contains one seminar, one training and one laboratory work.

The seminar provides multi-agent systems and technologies for development of IoT-based systems taking into account modern concepts of information technology development.

The training covers multi-criteria approach for choosing the IoT platform, for analyze and compare the results of applying the appropriate multi-criteria decision making methods.

The laboratory work is about soft computing and neural networks for the selection of specialized IoT platform using fuzzy inference engine of the Mamdani type.

The course is intended for engineers, developers and scientists engaged in the development and implementation of IoT-based systems, for postgraduate students of universities studying in areas of IoT, cybersecurity in networks, computer science, computer and software engineering, as well as for teachers of relevant courses.

Practicum prepared by Professor, DrS. Yu.P. Kondratenko, Associate Professor, Dr. G.V. Kondratenko, Associate Professor, Dr. Ie.V. Sidenko and Ph.D. Student M.O. Taranov (Petro Mohyla Black Sea National University); Professor, DrS. I.S. Skarga-Bandurova, Ph.D. Student A.Y. Velykzhanin, and Senior Lecturer L.V. Barbaruk (Volodymyr Dahl East Ukrainian National University). General editing was performed by Professor, Head of Intelligent Information Systems Department of Petro Mohyla Black Sea National University, DrS. Yu.P. Kondratenko and Professor, Head of Computer Science and Engineering Department of Volodymyr Dahl East Ukrainian National University, DrS. I.S. Skarga-Bandurova.

The authors are grateful to the reviewers, project colleagues, staff of the departments of academic universities, industrial partners for valuable information, methodological assistance and constructive suggestions that were made during the course program discussion and assistance materials.

PCM4.1. Basic concepts and approaches to the development and implementation of IoT systems

Prof., DrS. I.S. Skarga-Bandurova, Ph.D. Student A.Y. Velykzhanin, Senior Lect. L.V. Barbaruk (V. Dahl EUNU)

Seminar 1

IOT-BASED SYSTEMS DESIGH METHODOLOGIES

The aim of the seminar: study of basic concepts and approaches to development and implementation of IoT systems. The main focus here is on design methodologies and high-performance platforms in order to meet computational needs of data-intensive applications moving intelligence into edge devices.

Learning tasks:

– analysis of the current state and issues in fundamental knowledge about proper design and development. IoT systems;

– analysis of core components of IoT-based systems;

– analysis of the new IoT hardware development platforms for different applications;

– study of existing methodologies and approaches for comprehensive design and prototyping IoT-based systems.

Preparation for the seminar.

Preparation for the seminar includes the following steps.

1. Receiving (determining) the topic of the essay (analytical review) and clarifying the tasks of individual work.

Topics of essays can be formed by students independently based on the IoT system development life-cycle (Fig. 1.1). It is assumed that development of IoT system intends the use of different hardware and software components, languages, execution on external devices as well as active interaction with third-party APIs. In general case, IoT design methodology includes:

1. IoT system maintenance and planning;

2. Purpose and requirements specification, including specification following components, namely process, domain model, information model, services, IoT level, functional view and operational view;
3. System design, device and component integration, application development;
4. System implementation
5. System testing.

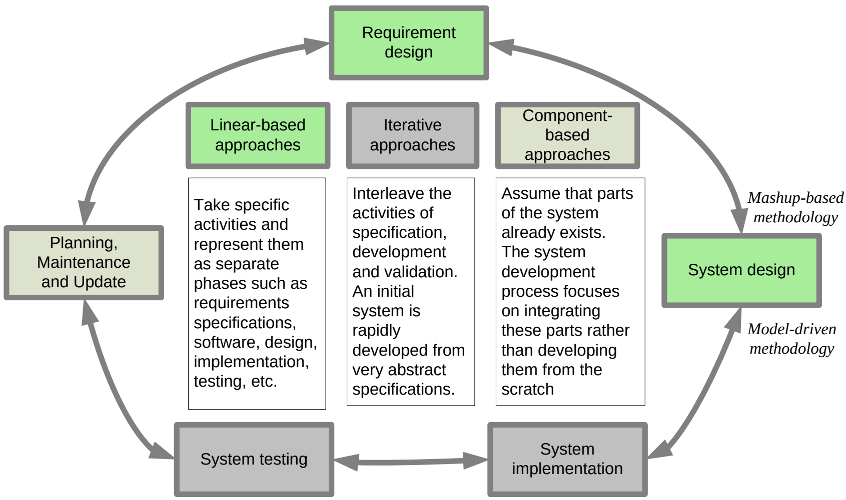

Fig. 1.1 – IoT system development life-cycle

In this seminar, we will focus mostly on the design steps 2, 3 and 4.

On step 2 system specification and infrastructure should be determined. To do this it is necessary to evaluate the potential proliferation of personal connected devices within different stakeholder communities; and decide on a common approach to development and deployment across multiple devices, including but not limited to data processing and visualization, device support protocols and integration with third-party data (Web services, APIs, etc.).

Design step 3 aimed at rapid deployment, monitoring and modification planning and includes agile and flexible deployment with small, step-by-step implementations. The key is to get started with IoT and achieve incremental benefits.

Design step 4 utilizes developing product features and embedded sensors. On this stage the base component of the IoT system is ready and we can exploit the potential with additional sensors and start enhancing IoT infrastructure, building alliances and partnerships.

Topics of the essays can also be formed by students on their own based on the following chain of keywords that are somehow related to the proper design and development of IoT systems:

– methods, tools, techniques, principles, technologies of the IoT system design;

– IoT hardware development platform landscape;

– features of IoT development platforms, namely, processing and memory/storage capacity; power consumption, size, and cost; Operating Systems and programming languages; connectivity and flexibility/customizability of peripherals of hardware platforms; and onboard sensors and hardware security features.

Examples of essays topics:

1. Design principles for IoT;
2. The cycle of the development IoT prototypes;
3. Main components of IoT system;
4. IoT architectures;
5. Phases and deliverables of an IoT technical strategy;
6. IoT system development for industrial and manufacturing applications;
7. The IoT development strategies;
8. IoT hardware development platforms;
9. Platform choices and design demands for IoT;
10. Main features of IoT hardware development platforms;
11. Key features of Arduino hardware development platforms;
12. Arduino hardware development platforms;
13. Raspberry Pi hardware platforms;
14. Onboard sensors and hardware security features of Raspberry Pi;
15. Embedded IoT design;
16. IoT design and prototyping using Arduino boards;
17. IoT design and prototyping using Raspberry Pi platforms;
18. Projects on IoT applications;
19. IoT and smart home: setting up the hardware;
20. Setting up the hardware for a home automation system;

21. Setting up the hardware for a industrial automation system;
22. IoT product design services available to assist engineering development cycle;
23. Designing custom platforms: pros and cons.

Topics of the essays should be coordinated with the lecturer and fully comply with the subject area of the course.

Theoretical issues for "Development of IoT-based systems" are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

2. Development of a plan of the work on the essay.

The work is carried out individually. Typical work involves the preparation by each student the essay and presentation on issues and a solution to the problem highlighted in the task.

3. Development of the essay plan.

Before to start writing an essay, it is necessary to clearly formulate the task of finding information according to the required essay plan.

The essay plan includes:

– introduction (relevance, brief analysis of the state of the question). In the introduction of the essay, it is necessary to justify the choice of the topic;

– systematic presentation of the main parts of the essay (structures, models, methods, tools, comparative analysis);

– conclusions (ascertaining the achievement of the goal, the main theoretical and practical results, their significance, directions for further work);

– references (paper and digital sources);

– appendix (presentation slides).

4. Writing an essay.

Writing and design of the essay (including the title page, references) should be literate. Use only the material that reflects the essence of the topic.

The essay has a volume of 12-15 pages of A4 format (font 14, 1.5 interval, 2cm margins), including the title page, content, main text, references, appendix.

At the preparation of the essay, it is necessary to use materials of modern publications not older than 7 years. The presentation of the essay should be consistent. Ambiguous language, speech and spelling errors are not allowed. Particular attention should be paid to the conclusion. In the conclusion, the answers to the tasks set in the introduction should be presented. The general conclusion should be formulated and the goal achievement of the essay should be given. The conclusion should be concise, clear and should follow from the content of the main part.

A mandatory attachment to the abstract is the presentation slides and the electronic version of all materials.

5. Preparation of the presentation.

The presentation is developed in PowerPoint and corresponds to the plan of the essay (12-16 slides) based on the time for the report – 7 min.

The presentation should include the following slides:

– title slide (indicating organization, department, discipline, topic of the report, author, date of presentation);

– content (structure) of the report;

– the relevance of the issues under consideration, the purpose and objectives of the report;

– slides with the disclosure of the content of the objectives;

– report conclusions;

– list of references.

Each of the slides should contain the footer with the title and author of the report.

The content of the slides should not contain parts of the text from the essay, but include keywords, pictures, formulas.

Submission of information can be dynamic.

6. Presentation (report).

The presentation (report) is carried out at the seminar, takes 12 minutes and includes the report itself (7 minutes) and discussion (5 minutes). Presentation and essay language is English.

7. Evaluation.

Evaluation for this work takes into account:

– quality of the essay text (form and content);

– presentation quality (content and design);

– report quality (content, logical structure, division of time, conclusions);

– completeness and correctness of answers to questions.

The grade for the essay and presentation is set for each participant of the seminar individually in accordance with the results.

8. References for seminar preparation.

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Software and Applications Conference, pp. 499-504, September 2015. DOI: 10.1109/COMPSAC.2015.263.

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13. D. Guinard, V. Trifa, and E. Wilde, "A resource oriented architecture for the web of things," *Internet of Things (IOT)*, pp. 212-220, November-December 2010. DOI: 10.1109/IOT.2010.5678452.

Seminar 2

EVALUATION OF IOT DEVICE MANAGEMENT TOOLS

The aim of the seminar: study and evaluation of IoT device management tools and applications. Today, there is no technical paper with a comprehensive list of requirement and related best practice of IoT cloud platform. This fact makes the process of choosing IoT platforms a challenging task. This seminar is aimed at filling up this gap in knowledge.

Learning tasks:

– analysis of the current state and issues in the device management and maintenance of IoT systems;

– analysis of IoT device management tools for different applications;

– study of existing methodologies and approaches for comprehensive device management in IoT-projects.

Preparation for the seminar.

Preparation for the seminar includes the following steps.

1. Receiving (determining) the topic of the essay (analytical review) and clarifying the tasks of individual work.

Themes for future research can be formed by students independently based on the device management cycle (Fig. 2.1).

There is a wide area for research. Many IoT device management platforms are focusing horizontally to make complete coverage, some others are very specific. For example, Zentri cloud focuses only on Thing management, and Paraimpu aims at social integration.

A few smart platforms like ThingsWorx offer drag-and-drop based IoT application builder tool which reduces the effort of developers to integrate admin APIs.

While most of the market solutions today are paid PaaS, there are a few ope-source options like Kaa, DeviceHive, OpenIoT, and ThingSpeak.

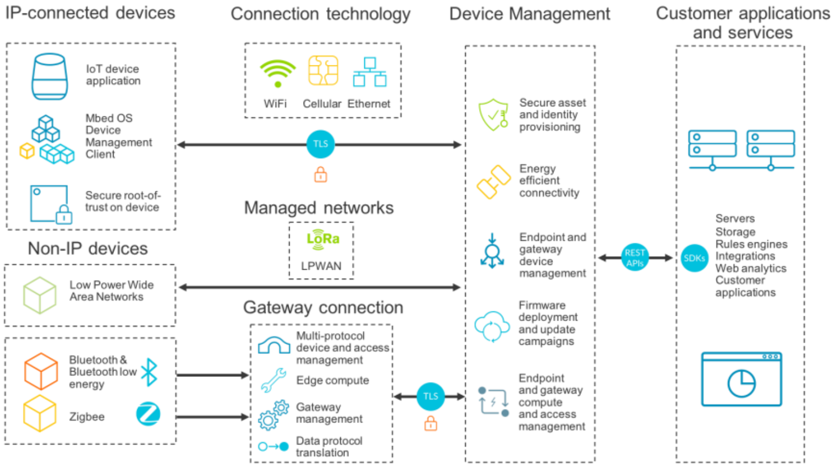

Fig. 2.1 – Device management diagramme [1]

One of the major challenges faced by IoT solutions providers is the supervision and management of the large number of deployed sensors/devices. There are at least four fundamental device management requirements for any IoT device deployment, namely provisioning and authentication, configuration and control, monitoring and diagnostics, and software updates and maintenance. Today, many DMT claims to support all these requirements. While most of them support the basic features of device management, remote monitoring, product lifecycle, scalability and integration to IoT platforms, some other vital features as the protocols supported, localization and mapping, troubleshooting and maintenance, security and access control features are available in a limited number of these tools.

For this reason, the question about what to keep into account when looking at IoT device management solutions and when looking at the IoT device management possibilities of IoT platforms is on demand.

In this seminar, we will try to answer the question how to choose IoT device management platform.

Topics of the essays can also be formed by students on their own based on the following chain of keywords that are somehow related to the choosing proper IoT device management system.

The problem of choosing appropriate IoT device management tool presents the basic and fundamental requirements of an IoT management and supervision solution based on the generalized architecture of an IoT implementation and covers the following topics:

1. IoT system architecture (types, organization, communication protocols; sensor layer, communication layer, cloud layer, management layers, services and application layer);
2. IoT device management features and challenges (connectivity of heterogeneous IoT devices, device management challenges; security limitations, next generation of IoT management tools);
3. Evaluation strategies and features to perform comparative analysis (device management, protocols supported, product lifecycle management, troubleshooting and maintenance, security and access control, localization and mapping, scalability, device monitoring, integration).
4. IoT device management solutions, platforms and trends.

Research topics comprise an analytical review of IoT device management frameworks for the following subject areas:

1. Smart home;
2. Smart grid;
3. Intelligence transportation system;
4. Research projects;
5. Internet of Drones;
6. Industrial and manufacturing applications;
7. IoT connected product management;
8. Healthcare;
9. Environmental monitoring;
10. Smart agriculture.

Theoretical issues for "Development of IoT-based systems" are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

<u>2. Development of a plan of the work on the analytical review.</u>

The work is carried out individually. Typical work involves the preparation by each student the analytical review and presentation on issues and a solution to the problem choosing IoT device management framework for subject area highlighted in the task.

In preparation for this seminar it is necessary to perform next steps:

– clarify the goals and mission of the research;

– formulate the essential challenges of IoT device management and supervision;

– review the actual state-of-the-art IoT device management and supervision techniques and tools available on the market applicable to your particular topic;

– evaluate their features and typical use cases.

The basis set for analysis is presented in Table 2.1 and includes four factors – technical offerings, strategy, market presence, and certification and recommendation. You can choose the weight percentage of each factor in accordance with your specific project need as it varies mostly from project to project.

For example, if a project refers to security certified solution, a platform with sound functional offerings but without security certification does not equal to the project goals.

Table 2.1 – Set of Selection criteria

Factors	**Sub-factors**
Technical offerings	Functionalities and non-funcational aspects are discussed in details below
Strategy	Vision, Faster time to market, Customer satisfaction, Partnerships
Market presence	Revenue, Client base, Geographical presence
Compliance and recommendations	Award won, Recognized by market research firms like Gartner/Forrester, ISO/IEC 27001/27002:2013 security certified, TR-69 compliant or similar, Patents

For best results, compare the up to ten IoT management tools/platforms taking into consideration that due to their continuous development some requirements will be met by the products in the nearest future.

The following tables will be useful as a result of your survey for presentation:

1. Key features and typical use cases of the evaluated IoT management tools (Table 2.2);
2. Comparison of the evaluated IoT management tools/platforms (Table 2.3);
3. Comparison of platforms for selected factors.
4. Discussion of results and conclusions.

Table 2.2 – Key features and typical use cases of the evaluated IoT management tools

Platform	Link	Vendor	Key features	Open source or paid	Recognition	Typical use case

Table 2.3 – Comparison of the evaluated IoT management tools/platforms

Tool	Device management	Protocols supported	Product lifecycle management	Troubleshooting and maintenance	Security and access control	Localization and mapping	Scalability	Device monitoring	Integration

You can add a legend for determine the compliance level:
● – supported;
/ – partially supported;
○ – not supported.

<u>3. Development of the essay plan.</u>

Before to start preparing an analytical review, it is necessary to clearly formulate the task of finding information according to the required essay plan.

The essay plan includes:

– introduction (relevance, brief analysis of the state of the question). In the introduction of the essay, it is necessary to justify the choice of the topic;

– systematic presentation of the main parts of the essay (structures, models, methods, tools, comparative analysis);

– conclusions (ascertaining the achievement of the goal, the main theoretical and practical results, their significance, directions for further work);

– references (paper and digital sources);

– appendix (presentation slides).

4. Writing an essay.

Writing and design of the essay (including the title page, references) should be literate. Use only the material that reflects the essence of the topic.

The essay has a volume of 12-15 pages of A4 format (font 14, 1.5 interval, 2cm margins), including the title page, content, main text, references, appendix.

At the preparation of the essay, it is necessary to use materials of modern publications not older than 7 years. The presentation of the essay should be consistent. Ambiguous language, speech and spelling errors are not allowed. Particular attention should be paid to the conclusion. In the conclusion, the answers to the tasks set in the introduction should be presented. The general conclusion should be formulated and the goal achievement of the essay should be given. The conclusion should be concise, clear and should follow from the content of the main part.

A mandatory attachment to the abstract is the presentation slides and the electronic version of all materials.

5. Preparation of the presentation.

The presentation is developed in PowerPoint and corresponds to the plan of the essay (12-16 slides) based on the time for the report – 7 min.

The presentation should include the following slides:

– title slide (indicating organization, department, discipline, topic of the report, author, date of presentation);

– content (structure) of the report;

– the relevance of the issues under consideration, the purpose and objectives of the report;

– slides with the disclosure of the content of the objectives;

– report conclusions;

– list of references.

Each of the slides should contain the footer with the title and author of the report.

The content of the slides should not contain parts of the text from the essay, but include keywords, pictures, formulas.

Submission of information can be dynamic.

6. Presentation (report).

The presentation (report) is carried out at the seminar, takes 12 minutes and includes the report itself (7 minutes) and discussion (5 minutes). Presentation and essay language is English.

7. Evaluation.

Evaluation for this work takes into account:

– quality of the essay text (form and content);

– presentation quality (content and design);

– report quality (content, logical structure, division of time, conclusions);

– completeness and correctness of answers to questions.

The grade for the essay and presentation is set for each participant of the seminar individually in accordance with the results.

8. References for seminar preparation.

1. A. Ltd., "IoT Device Management", *Arm | The Architecture for the Digital World*, 2019. [Online]. Available: https://www.arm.com/products/iot/pelion-iot-platform/device-management.

2. P. Ganguly, "Selecting the right IoT cloud platform," *International Conference on Internet of Things and Applications (IOTA)*, pp. 316-320, January 2016. DOI: 10.1109/iota.2016.7562744.

3. K. Vandikas and V. Tsiatsis, "Performance Evaluation of an IoT Platform", *Eighth International Conference on Next Generation Mobile Applications, Services and Technolo*gies, pp. 141-146, September 2014.

4. B. Umar, H. Hejazi, L. Lengyel, and K. Farkas, "Evaluation of IoT Device Management Tools," *ACCSE 2018: The Third International Conference on Advances in Computation, Communications and Services*, pp. 15-21, December 2018.

5. C. Perera, C. Liu, S. Jayawardena, and M. Chen, "Survey on Internet of Things From Industrial Market Perspective," in *IEEE Access*, vol. 2, 2014, pp. 1660-1679.

6. L. Xu, W. He, and S. Li, "Internet of Things in Industries: A Survey," in *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, 2014, pp. 2233-2243.

7. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," in *IEEE Commun. Surv. Tutorials*, vol. 17, no. 4, 2015, pp. 2347-2376.

8. J. Guth, U. Breitenbücher, M. Falkenthal, F. Leymann, and L. Reinfurt, "Comparison of IoT platform architectures: A field study based on a reference architecture," *2016 Cloudification of the Internet of Things (CIoT)*, pp. 50-55, November 2016.

9. B. Varghese and R. Buyya, "Next Generation Cloud Computing: New Trends and Research Directions," in *Future Generation Computer Systems*, vol. 79(3), 2018, pp. 849-861.

10. M. Elkhodr, S. Shahrestani, and H. Cheung, "The Internet of Things: New Interoperability, Management and Security Challenges," in *International Journal of Network Security & Its Applications*, vol. 8, 2016, pp. 82-102.

11. J. Lin et al., "A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications," in *IEEE Internet of Things Journal*, vol. 4, no. 5, 2017 pp. 1125-1142. DOI: 10.1109/JIOT.2017.2683200.

12. "What makes device management a core compatibility of an IoT platform," *Softweb Solutions*, [online], Available: https://www.softwebsolutions.com/resources/IoT-devicemanagement-platform.html.

Training

BASIC PRINCIPLES FOR ADDING CELLULAR CONNECTIVITY TO IOT PROJECTS: WORKING WITH GSM-MODULES

The aim of the training: studying and understanding the basic principles of working with cellular modules, interface specifications, electrical and mechanical details, AT commands. Designing a variety of applications based on the SIM800L module.

Training participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Recommended hardware and software

Name	**Link**
Arduino UNO R3	https://store.arduino.cc/arduino-uno-rev3
SIM800L EVB v2	http://irishelectronics.ie/SIM800L-V20-5V-Wireless-GSM-GPRS-MODULE
Arduino IDE	https://www.arduino.cc/en/main/software
USB 2.0 cable type A/B	https://store.arduino.cc/usb-2-0-cable-type-a-b
Half breadboard PCB module	https://store.arduino.cc/half-breadboard-pcb-module
10 Jumper wires 150mm male	https://store.arduino.cc/10-jumper-wires-150mm-male
Micro SIM card	*On your choice.*

Theoretical information

Cellular modules provide a “plug-in” solution for a project that requires connection to an IoT, regardless of where the project is located (provided the project is within range of the cellular base station). There are a number of mature 2G, 2.5G, and 3G cellular modules ideal for single board computers (SBC) from popular manufacturers, and hardware considerations apply only to the selection and installation of an appropriate antenna, mechanical connector, and battery. Since the network is licensed, you will also need a SIM card and a data contract. To date, low-energy Bluetooth and Wi-Fi technology do not support direct IoT connectivity. In contrast, the smartphone is compatible with low power consumption of Bluetooth, Wi-Fi and IoT. Therefore, it can be used as a gateway between wireless connected devices such as the SBC project manufacturer and the cloud. Similarly, a router and a Wi-Fi cable modem can form a gateway to an SBC with Wi-Fi support Wireless technologies such as low-energy Bluetooth and Wi-Fi require routers or gateways to access the Internet, limiting the mobility and range of sensors. Cellular modules eliminate the router or gateway by directly connecting to other IP-enabled devices (Fig. 3.1).

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

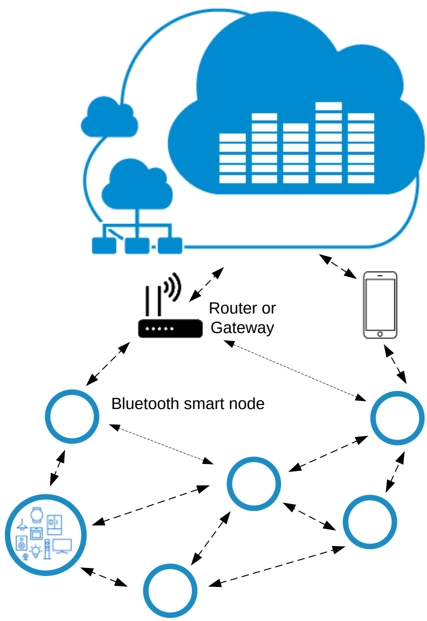

Fig. 3.1 – Wireless connectivity in IoT environments [1]

For many application vendors, connecting an IoT through a gateway is a satisfactory solution. However, if the sensor comes out of the wireless gateway range (over 30 to 100 meters for both low-energy Bluetooth and Wi-Fi), the connection is lost. This constraint prevents developers from developing projects based in remote locations or those that are constantly moving. In such cases, the cellular modules are capable of addressing this issue. Moreover, there are several mobile technologies (such as GSM, GPRS and CDMA), several generations of each commercial use technology (2G, 2.5G, 3G and 4G) and dozens of cellular bands around the world. As a result, the selection of a cellular module for a particular location requires careful consideration.

In this tutorial we will study and discover technology of adding cellular connectivity to IoT projects with GSM/GPRS modules based on the chip Mediatek ARM MT6261. As a case, SIM800L series will be used.

SIM800L is a quad-band GSM/GPRS module that works on frequencies GSM850MHz, EGSM900MHz, DCS1800MHz and PCS1900MHz. SIM800L features GPRS multi-slot class 12/class 10 (optional) and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4. It based on Mediatek ARM MT6261 chip [2]. The SIM800L uses the serial communication method that enables to interface with the UART of almost all popular microcontrollers.

SIM800L functional diagram and pinout of the chip is presented in Fig. 3.2 and Fig. 3.3 respectively.

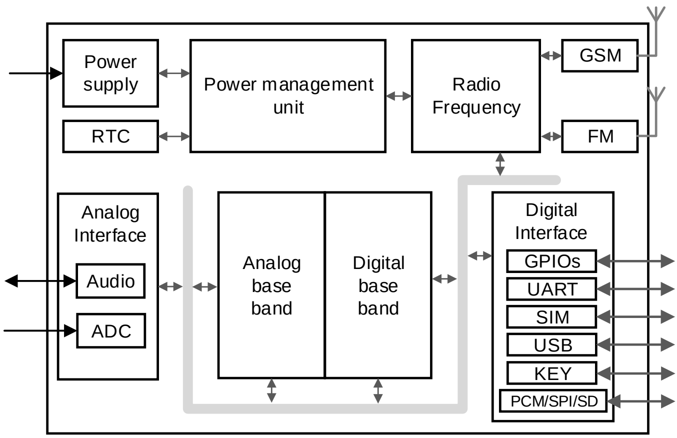

Fig. 3.2 – SIM800L functional diagram [3]

There are 12 connections in total (6×2 rows) on the SIM800L module, one row contains all of the connections required to interface with a microcontroller.

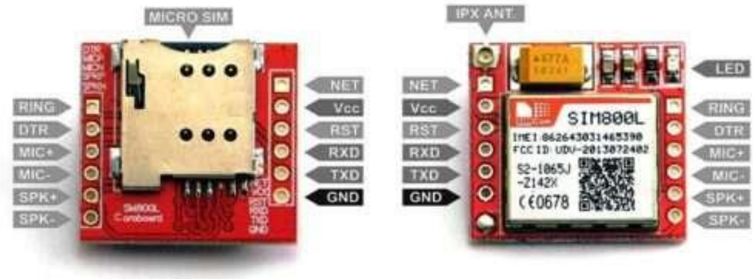

Fig. 3.3 – SIM800L pin out diagram [4]

There are various modifications to the SIM800. Some information about their capabilities is resented in summary Table 3.1.

Table 3.1 – Comparison modules based on the chip Mediatek ARM MT6261

Function	SIM 800	SIM 800C	SIM 800H	SIM 800L	SIM 800F	SIM 868	SIM 808
Voice Calls	+	+	+	+	+		
GNSS						+	+
Bluetooth 3.0	+	+	+				
Built-in FM receiver: (76-109 MHz) in 50 kHz steps			+	+			
CSD	+		+	+			+

For beginning, you need only a power supply and a serial port. Because the breakout board comes without an integrated voltage regulator, be prepared to set up an external 3.4- to 4.4-V power supply for that purpose.

While most sellers claim their SIM800L modules to be 5-V-logic-tolerant, the official datasheet defines the maximum high level to be 2.8 V. This calls for a special logic-level converter to work with 5-V logic circuits. You can follow the scheme shown in Fig. 3.4 to use the SIM800L module in real-world projects. The hardware includes an onboard fixed voltage controller and a simple logic-level handler to make the setup suitable for most training projects.

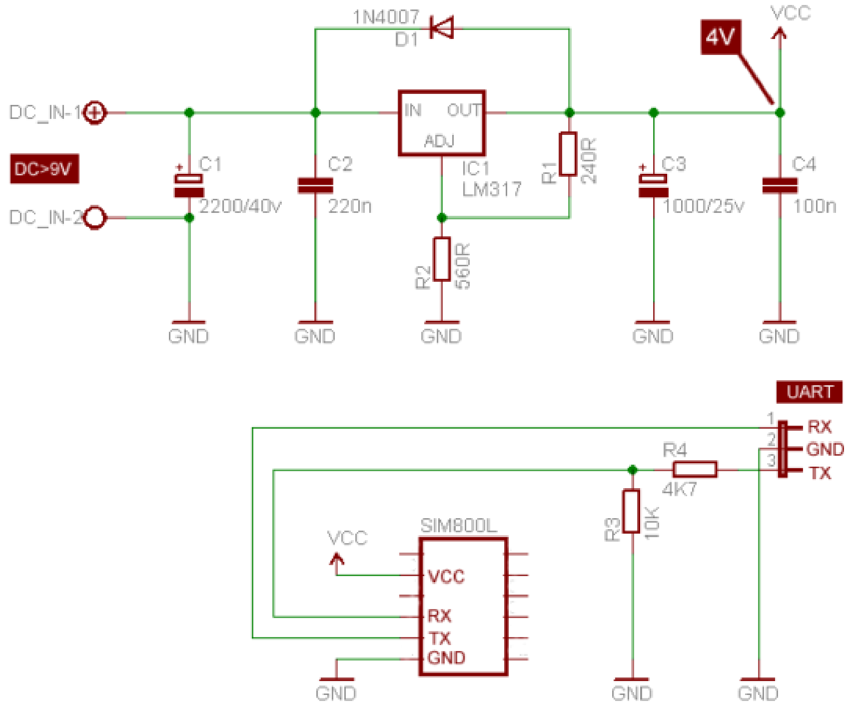

Fig. 3.4 – The basic setup scheme to work with 5-V logic circuits [5]

The interaction with the module is carried out on the UART interface (Serial port) with special AT-commands. To implement data exchange via a UART-interface, on pins other than the standard RX (0) / TX (1), you will need a standard Arduino-library SoftwareSerial.h.

Each AT command must begin with two AT letters typed in any case: AT , aT , At , at. The command must begin on a new line (the Newline parameter in the Serial window).

All AT commands are syntactically divided into 3 main groups: basic commands, commands with the S parameter and extended commands.

The basic commands have the following syntax: AT <x> <n> or AT & <x> <n>, where <x> is a command and <n> is a passed parameter (s). The parameter (s) <n> is optional and in case of its absence the default value will be used. Examples include the ATI command that was sent earlier, which returns the identification data of the module, or the AT & V command that returns the current configuration of the module.

Commands with the S parameter look like this: ATS <i> = <m>, where <i> is the index of the S-register and <m> is the value that must be assigned to it. If there is no <m> value, the default value will be assigned. For example, the AT S0 register is responsible for the number of beeps before automatically answering an incoming call, and, accordingly, the ATS0 command sets the default value to 0 (not answering the call), and the ATS0 = 2 command will cause the module to answer automatically after 2 beeps.

There is a set of commands whereby you can determine the state / readiness of the GSM module to perform specific actions, as well as obtain other useful diagnostic information. The list of AT commands is presented in the Appendix B. Extended commands can be called in several modes as it defined in Table 3.2.

Table 3.2 – List of extended commands

Mode	**Syntax**	**Description**
reference	**AT + <x> =?**	The module returns a list of possible parameters and the range of values they take.
State reading	**AT + <x>?**	The module returns the current state of the parameter (s).
Write command	**AT + <x> = <...>**	The command sets the values of user-defined parameters.
Command execution	**AT + <x>**	Command execution

For a complete list of AT commands, you can download the SIM800 Series AT Command Manual from [6].

Training preparation

In preparation for this practical training it is necessary:

– to clarify the goals and mission of the research;

– to study theoretical material contained in this manual, and [1-5];

– to familiarize oneself with the main procedures and specify the program according to defined task.

In this tutorial, we will use a ready-made SIM800 EVB v2 module.

1. Install Arduino IDE.
2. Insert SIM card to module.
3. Connect SIM800L to Arduino. Connecting the module is performed according to the Fig. 3.5:

SIM800L RX → Arduino UNO D9 (TX)
SIM800L TX → Arduino UNO D8 (RX)
SIM800L 5V → Arduino UNO 5V
SIM800L GND → Arduino UNO GND

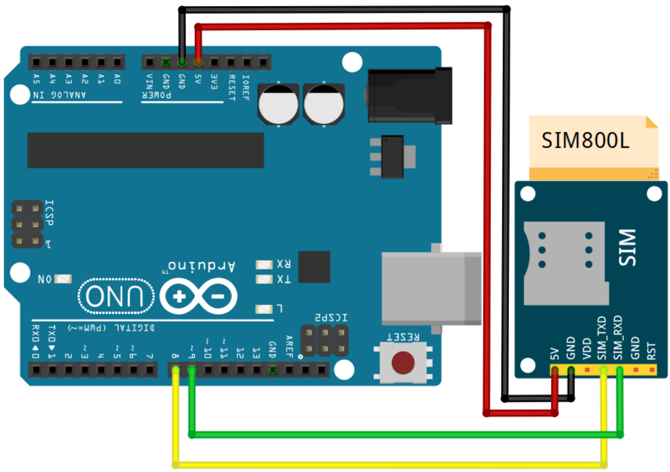

Fig. 3.5 – Connection diagram

4. Upload an example code.
5. Perform a series of tests on the connectivity given below.

AT command tester software tools, useful for testing AT commands (and other functionalities) of popular GSM modems, are now available everywhere on the web, for some well-tried and tested GSM projects refer to [7]. This project deals with the design and development of a theft control system for home, which is being used to prevent/control any theft attempt. The developed system is based on an embedded system (comprises an open hardware microcontroller and a GSM modem). In [9], a GSM based e-notice board is discussed. It has various applications used in several domains including banks, stock exchanges, traffic control, public advertisements, and educational sectors.

Training implementation

1. Connect Arduino to your computer and run Arduino IDE.
2. Update firmware on Arduino.
3. Click ”board”. Select “Arduino/Genuino UNO” (Fig. 3.6).

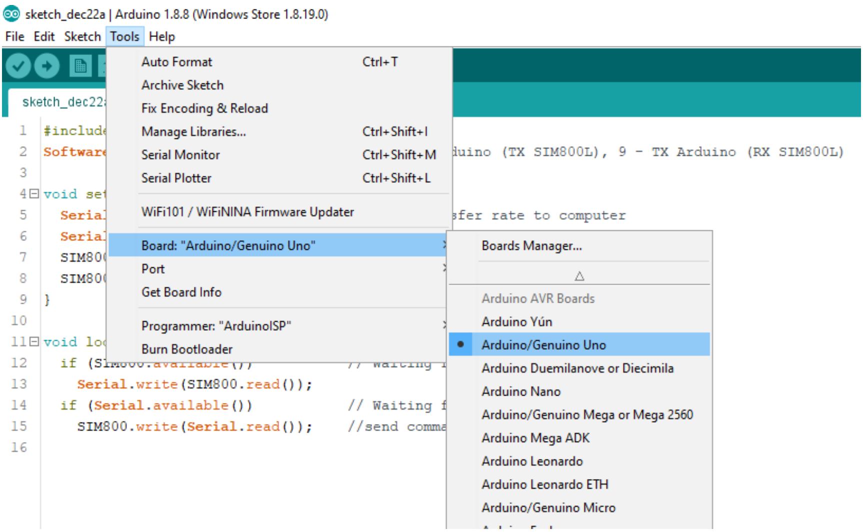

Fig. 3.6 – Update firmware by using Arduino IDE

Select port as it depicted in Fig. 3.7.

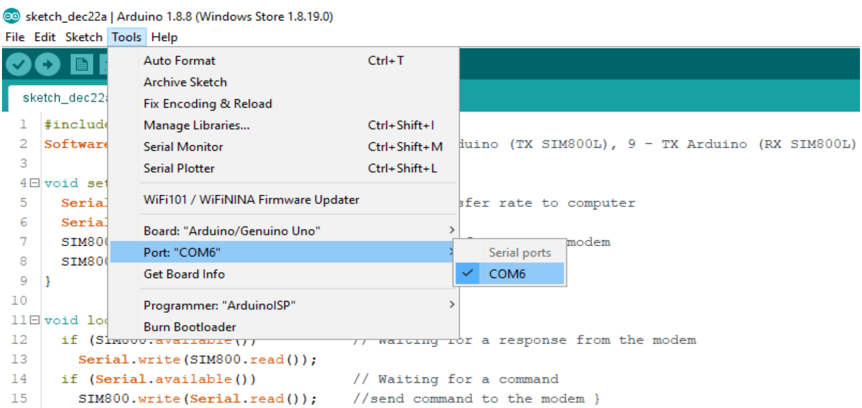

Fig. 3.7 – Selecting port

4. Copy sketch for using Arduino as USB-to-TTL converter

```
#include <SoftwareSerial.h>
SoftwareSerial SIM800(8, 9);
// 8 - RX Arduino (TX SIM800L), 9 - TX Arduino (RX SIM800L)
void setup() {
  Serial.begin(9600);        // data transfer rate to computer
  Serial.println("Start!");
  SIM800.begin(9600);           // data transfer rate to modem
  SIM800.println("AT");
}
void loop() {
  if (SIM800.available())// Waiting for a response from the
modem
    Serial.write(SIM800.read());
  if (Serial.available())           // Waiting for a command
    SIM800.write(Serial.read());        //send command to the
modem
}
```

5. Click “Upload”
6. In menu Tools open a serial monitor (Fig. 3.8)

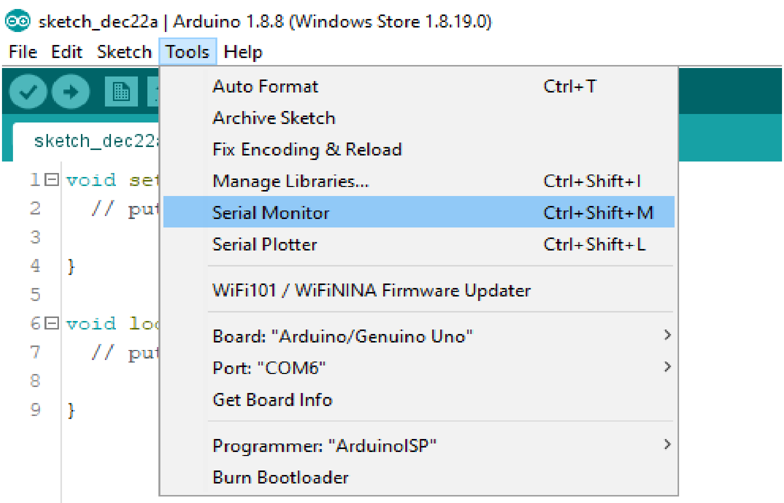

Fig. 3.8 – Opening serial monitor

7. Check baud rate. Select “9600 baud” from the bottom menu (see Fig. 3.9).

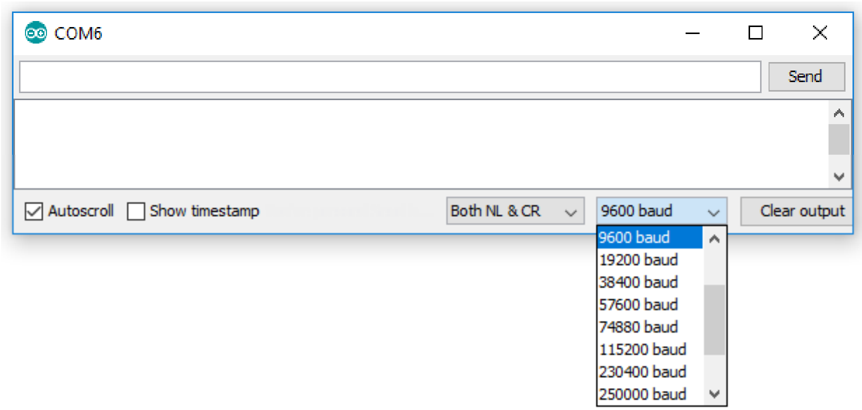

Fig. 3.9 – Change settings

8. Select “Both NL & CR” as it shown in Fig. 3.10.

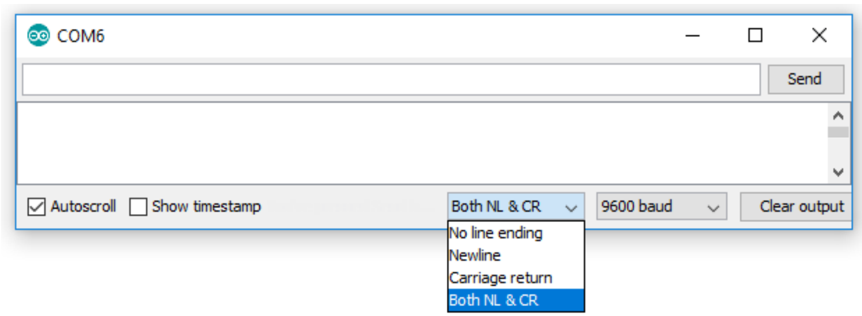

Fig. 3.10 – Serial port setting

9. To perform readiness check, enter AT in the main window (Fig. 3.11).

10. Test basic functionality and way of operation of the SIM800L module:

To request for installed software version enter AT+GMR

Call quality request: AT+CSQ;

For supply voltage information enter AT+CBC;

Operator information AT+COPS?;

Getting a list of all operators: AT+COPN (Fig. 3.12).

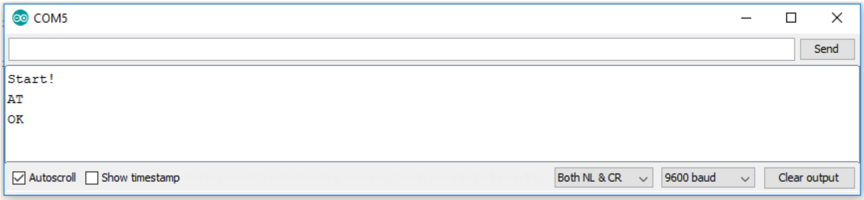

Fig. 3.11 – Readiness check

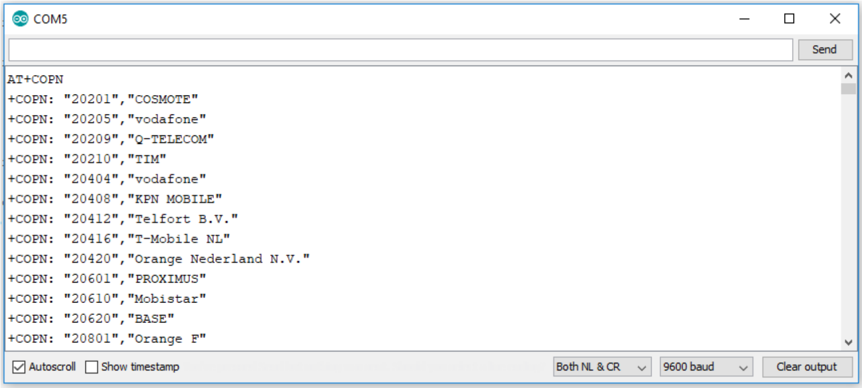

Fig. 3.12 – List of operators

GSM module phone status can be checked by AT+CPAS (Fig. 1.13).

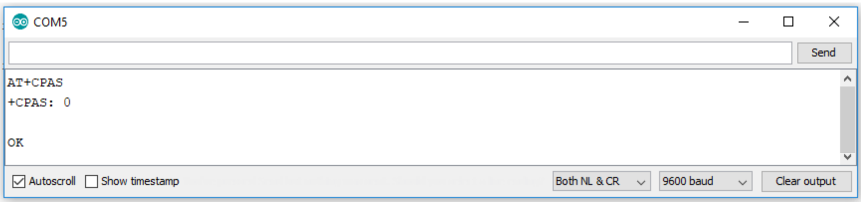

Fig. 3.13 – GSM module phone status

To make an outgoing call, type the command: ATD <phonenumber>; where <phonenumber> is you phone number (ex. ATD + 380XXXXX-XXXX;).

To send an SMS, type the following command (change to your number). Next, enter the message text. After sending, press Ctrl-z or ESC.

```
AT+CMGS="+380XXXXX-XXXX"
>
test (SMS text)
(after sending, press ESC or Ctrl-z)
```

Tasks for individual work

1. Follow all the steps described in the sections “Training preparation” and “Training implementation”
2. Assemble the proposed circuit.
3. Conduct a series of experiments using AT commands
4. To better understand the basic principles of working with cellular modules and interfaces, gain an insight into the basic functionality and way of operation of the SIM800L module. Together with the AT command reference, find, discover and explore other promising features.
5. Make an analytical review of basic principles of adding cellular connectivity to IoT projects. Draw up a report, answer the questions.

Report

The report should contain:

– title page with the title of the training work;
– aim of the work;
– problem statement according to the task;
– the progress and results of the study in graphical form;
– analysis of the results and conclusions.

All materials of the report should be printed, billed, the pages should be numbered.

Test questions

1. What are the main purposes to add cellular connectivity to IoT projects?
2. What are the main advantages of using a cellular module for maker project wireless connectivity?
3. What are the disadvantages of using GSM in IoT systems?
4. How to determine the state / availability of the GSM module?

5. What technology enables connecting to the Internet using the smartphone as a gateway?

6. How to o get a cellular module to connect and receive/transmit data?

7. For what IoT applications wireless communication is crucial? Explain why.

Recommended literature

1. "IPv6 over Bluetooth Smart takes wearables from smartphone to standalone," *Embedded Computing Design*, 05-Sep-2018. [Online]. Available: https://www.embedded-computing.com/embedded-computing-design/ipv6-over-bluetooth-smart-takes-wearables-from-smartphone-to-standalone.

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3. "SIM800L Hardware Design V1 - img.filipeflop.com," [Online]. Available: https://img.filipeflop.com/files/download/Datasheet_ SIM800L.pdf.

4. "Mikrocontroller.net," *SIM800L Parameter werden nicht übernommen - Mikrocontroller.net*. [Online]. Available: https://www.mikrocontroller.net/topic/445224.

5. "How To Play with SIM800L: Part 1," *ElectroSchematics.com*, 14-Dec-2017. [Online]. Available: https://ac-electroschematics. azurewebsites.net/13548/introducingsim800l/.

6. "SIM800 Series AT Command Manual," [Online]. Available: https://www.waveshare.com/w/upload/2/20/SIM800_Series_AT_Comm and_Manual_V1.09.pdf.

7. "Arduino GSM Home Security Alarm System Project," *ElectroSchematics.com*, 08-Sep-2014. [Online]. Available: https://www.electroschematics.com/10760/arduino-gsm-home-security-alarm-system/.

8. "Wireless Electronic Notice Board using GSM," *ElectroSchematics.com*, 26-May-2015. [Online]. Available: https://www.electroschematics.com/11965/wireless-electronic-notice-board-using-gsm/.

PCM4.2. Models for IoT-based devices and technologies for data processing and transfer

Prof., DrS. Yu.P. Kondratenko, Ass. Prof., Dr. G.V. Kondratenko, Ass. Prof., Dr. Ie.V. Sidenko, Ph.D. Student M.O. Taranov (PMBSNU)

Seminar

DATA COLLECTION AND CYBERSECURITY OF IOT-BASED DEVICES

The aim of the seminar: study of methods and technologies of cybersecurity in networks of IoT-based devices with possibility of processing of received data and further analysis of results.

Learning tasks:

– analysis of the current state of the problem of cybersecurity in networks of IoT-based devices;

– analysis of technologies of data collection and processing in networks of IoT-based devices;

– studying of existing methods and approaches for data security in IoT.

Preparation for the seminar.

Preparation for the seminar includes the following steps.

1. Receiving (determining) the topic of the essay (analytical review) and clarifying the tasks of individual work.

Topics of essays can be formed by students independently based on the general structure of the IoT cybersecurity (Fig. 1.1) and IoT data collection (Fig. 1.2). Cybersecurity architecture can be consists of 7 security levels: random number generator; trust boot zone; key management; encryption; authentication and authorization; anti-virus; network firewall. Data can be collected in real-time from a wide breadth of sensors. This data is then analyzed and aggregated into useful information.

Fig. 1.1 – General structure of the IoT cybersecurity

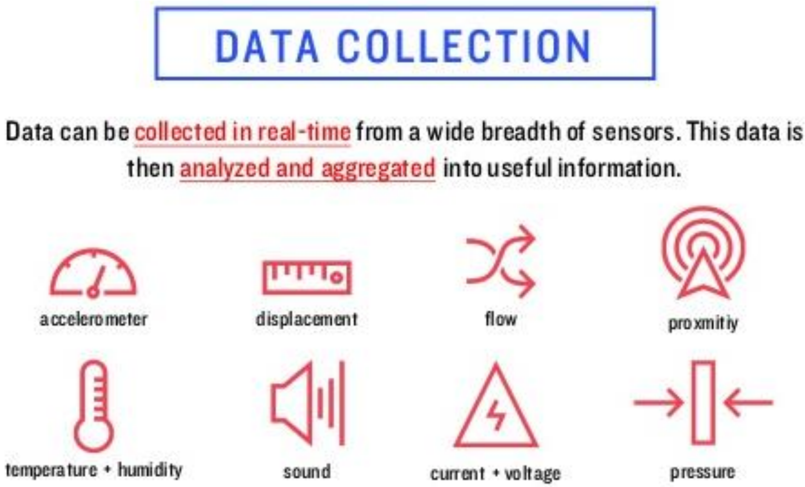

Fig. 1.2 – General structure of the IoT data collection

Topics of the essays can also be formed by students on their own based on the following chain of keywords that are somehow related to the IoT cybersecurity and IoT data collection:

– protocols, standards, methods of the IoT cybersecurity…;

– methods, tools, techniques, principles, technologies of the IoT data collection…;

– cloud computing, data processing, system analysis during data collection in IoT-based networks…;

– types of attacks, security levels, types of networks during the IoT cybersecurity…

Examples of essays topics:

– standard protocols for data transmission with wireless and wired networks at different levels;

– new protocols of IoT interactions designed to provide data transmission in low-speed wireless communications, examples of which are: MQTT, ZeroMQ, ZigBee, WirelessHART, CoAP;

– vulnerability of wired and wireless networks;

– encrypt data transmitted on many devices;

– interfaces for "smart" devices for an external user;

– antivirus software on IoT-devices;

– ports for remote administration of IoT-based devices;

– mechanisms of counteracting passwords;

– the confidentiality of information by "smart" devices in the open source (for example, fitness trackers storing information about the movement of the user);

– accuracy and reliability of "smart" sensors IoT-based devices;

– resistance to attacks;

– authentication of data;

– control of access to the data provided;

– confidentiality of the client in IoT-based networks;

– virtual private networks for cyber (information) security;

– DNS Security Extensions in IoT-based networks;

– scheduled check of hardware device functionalities;

– verification and use of security systems and anti-virus;

– encrypt the data with the most advanced standards and technologies;

– ensuring privacy and data security in Firebase;

– cross-origin resource sharing for cybersecurity IoT-based networks;

– password-based key derivation function.

Topics of the essays should be coordinated with the lecturer and fully comply with the subject area of the course.

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

2. Development of a plan of the work on the essay.

The work is carried out individually. Typical work involves the preparation by each student the essay and presentation on issues of modern and prospective technologies and methods of data collection and cybersecurity of IoT-based devices.

3. Development of the essay plan.

Before to start writing an essay, it is necessary to clearly formulate the task of finding information according to the required essay plan.

The essay plan includes:

– introduction (relevance, brief analysis of the state of the question). In the introduction of the essay, it is necessary to justify the choice of the topic;

– systematic presentation of the main parts of the essay (structures, models, methods, tools, comparative analysis);

– conclusions (ascertaining the achievement of the goal, the main theoretical and practical results, their significance, directions for further work);

– references (paper and digital sources);

– appendix (presentation slides).

4. Writing an essay.

Writing and design of the essay (including the title page, references) should be literate. Use only the material that reflects the essence of the topic.

The essay has a volume of 12-15 pages of A4 format (font 14, 1.5 interval, 2cm margins), including the title page, content, main text, references, appendix.

At the preparation of the essay, it is necessary to use materials of modern publications not older than 7 years. The presentation of the essay should be consistent. Ambiguous language, speech and spelling errors are not allowed. Particular attention should be paid to the conclusion. In the conclusion, the answers to the tasks set in the introduction should be presented. The general conclusion should be formulated and the goal achievement of the essay should be given. The conclusion should be concise, clear and should follow from the content of the main part.

A mandatory attachment to the abstract is the presentation slides and the electronic version of all materials.

5. Preparation of the presentation.

The presentation is developed in PowerPoint and corresponds to the plan of the essay (12-16 slides) based on the time for the report – 7 min.

The presentation should include the following slides:

– title slide (indicating organization, department, discipline, topic of the report, author, date of presentation);
– content (structure) of the report;
– the relevance of the issues under consideration, the purpose and objectives of the report;
– slides with the disclosure of the content of the objectives;
– report conclusions;
– list of references.

Each of the slides should contain the footer with the title and author of the report.

The content of the slides should not contain parts of the text from the essay, but include keywords, pictures, formulas.

Submission of information can be dynamic.

6. Presentation (report).

The presentation (report) is carried out at the seminar, takes 12 minutes and includes the report itself (7 minutes) and discussion (5 minutes). Presentation and essay Language is English.

7. Evaluation.

Evaluation for this work takes into account:

– quality of the essay text (form and content);
– presentation quality (content and design);
– report quality (content, logical structure, division of time, conclusions);
– completeness and correctness of answers to questions.

The grade for the essay and presentation is set for each participant of the seminar individually in accordance with the results.

8. References for seminar preparation.

1. K. Saghar, W. Henderson, D. Kendall, and A. Bouridane, "Applying formal modelling to detect DoS attacks in wireless medium," *The 7th International Symposium on Communication Systems, Networks & Digital Signal Processing*, pp. 896-900, July 2010.

2. M. Chenine, J. Ullberg, L. Nordstrom, Y. Wu, and G. Ericsson, "A Framework for Wide-Area Monitoring and Control Systems Interoperability and Cybersecurity Analysis," in *IEEE Transactions on Power Delivery*, vol. 29, no. 2, 2014, pp. 633-641.

3. T. Cruz, L. Rosa, J. Proenca, L. Maglaras, M. Aubigny, L. Lev, J. Jiang, and P. Simoes, "A Cybersecurity Detection Framework for Supervisory Control and Data Acquisition Systems," in *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, 2016, pp. 2236-2246.

4. M. Razzaque, M. Milojevic-Jevric, A. Palade, and S. Clarke, "Middleware for Internet of Things: A Survey," in *IEEE Internet of Things Journal*, vol. 3, no. 1, 2016, pp. 70-95.

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6. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies Protocols and Applications," in *IEEE Commun. Surv. Tutorials*, vol. 17, iss. 4, 2015, pp. 2347-2376. DOI: 10.1109/COMST.2015.2444095.

7. Z. Sheng, K. Leung, and Z. Ding, "Cooperative wireless networks: from radio to network protocol designs," in *IEEE Communications Magazine*, vol. 49, no. 5, 2011, pp. 64-69.

8. L. Thames and D. Schaefer, *Cybersecurity for Industry 4.0*. Cham: Springer, 2017.

9. O. Illiashenko, V. Kharchenko, and A. Kor, "Gap-analysis of assurance case-based cybersecurity assessment: technique and case study," in *Advanced Information Systems*, vol. 2, no. 1, 2018, pp. 64-68. DOI: 10.20998/2522-9052.2018.1.12.

10. Y. Lu and L. Xu, "Internet of Things (IoT) Cybersecurity Research: A Review of Current Research Topics," in *IEEE Internet of Things Journal*, vol. 6, no. 2, 2019 pp. 2103-2115.

11. G. Falco, C. Caldera, and H. Shrobe, "IIoT Cybersecurity Risk Modeling for SCADA Systems," in *IEEE Internet of Things Journal*, vol. 5, no. 6, 2018, pp. 4486-4495. DOI: 10.1109/jiot.2018.2822842.

Training

ANALYSIS OF MONITORING AND FORECASTING METHODS IN IOT SYSTEMS

The aim of the training: research tools and technologies for modeling IoT devices, integrating them into a holistic system for integrated monitoring, using a developed web application that will track, process and analyze relevant data on product rules and forecasting methods.

Training participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Theoretical information

Existing systems of intelligent IoT-based devices consist of the following main components [1]: sensors placed on real physical devices; local network of sensors; gateway to transfer data to the general network and transport them to the server; remote server that processes and stores data. In paper [2] authors offer an architecture for constructing an IoT platform using the data mining tools presented in Fig. 2.1.

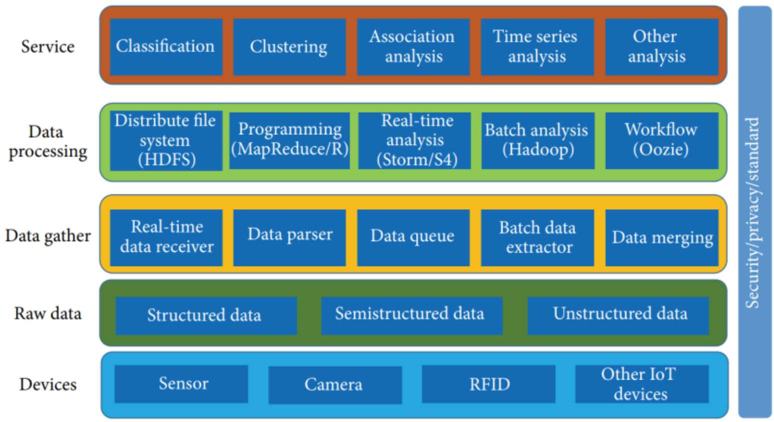

Fig. 2.1 – An architecture for constructing an IoT platform

Data sets of different volumes and types are collected from devices, and then aggregated, which opens the possibilities for visualization, monitoring, data mining, and the use of other analytical tools. The architecture allows you to filter, extract, and transform structured data from existing databases and unstructured data from sensors for equipment and create log files on the IoT platform. Then data can be visualized and analyzed using high-level applications. Real-time systems are used to aggregate data sets and securely transfer them to a server for analytics of large data. The process of transmission is accompanied by validation, filtering and reformatting of data so that it will be easier to work with them later [3, 4].

The main task of forecasting is not to provide accurate information about the state of the subject, but rather to reduce the level of uncertainty about it. Forecasts are then decoded by people who have additional information in a particular industry and after processing can be valuable to the user [3].

Prediction in IoT should be an integral part of management decision-making, as it can provide critical information. According to the purpose, goals and scale of forecasting, different types of forecasts are distinguished by the duration of the projected period [4].

Depending on the duration of the forecast, they are divided into the following [5-7]:

– short-term forecasts. Projections from 1 day to 3 months. Necessary for personnel planning, production and transportation. In the planning process, demand forecasts are sometimes needed;

– medium-term forecasts. Forecasts lasting from 3 months to 2 years. Necessary to determine the need for resources in the future in order to procure raw materials, hire personnel, or buy machinery;

– long-term forecasts. Forecasts lasting 2 years. Used in strategic planning. Such solutions should take into account market opportunities, environmental factors and internal resources.

Once the forecast has been generated, the system should analyze the data and determine if the threshold is approaching. If detected, the monitoring system sends a command to the appropriate device with some actions. To set the threshold and behavior of the system, the production rules of the type “IF – THEN” are used [8].

Production rules are a form of representation of human knowledge in the form of a sentence of type: If (condition), then (action). The rules provide a formal way to present recommendations, guidelines or strategies. They are ideally suited in cases where knowledge of the subject area emanates from empirical associations accumulated over the years of work to solve problems in one or another field. Production rules are used in systems of artificial intelligence (as an example, expert systems), as one of the most common forms of knowledge representation, along with logical models, frames, and networks [9].

To conduct a logical conclusion regarding the establishment of system behavior, it is necessary to have a sample of data in the form of rules of the type “IF – THEN”. That is, the value of the parameters that determine the state of the system, in their totality give one or another single result of the required action of the system [10].

A set of rules that are necessary for output are formed by a pre-expert, or made by the person who uses this system, based on his own assessment of the normal values of the parameters.

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

Training implementation

Let's consider the principle of the proposed architecture on the example of a complex monitoring and control system for cooling the premises.

For the above example, the set of such rules will have approximately the following appearance:

1) IF the *temperature* is above *30*, set the *switch* to the value *"true"*;

2) IF the *humidity* is below *30*, set the switch to *"false"*.

Where the switch can turn on or roll the device, such as a fan, by command from the system.

In this case, when new data is received, their prediction is carried out, provided that for this type of data restrictions are established. Based on the rules of the rules, prediction data is analyzed and, according to a certain rule, the required command is sent to the operator (Fig. 2.2).

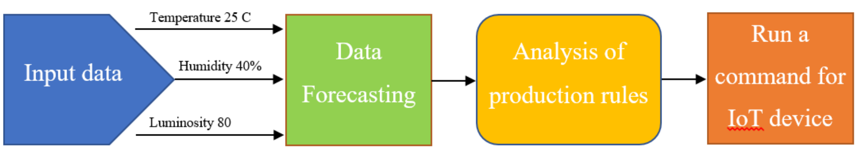

Fig. 2.2 – The order of data processing in the system

As a result, on the example of forecasting of the temperature parameter data, a graph is shown in Fig. 2.3, where the red line indicates the threshold set by the user in the production rule.

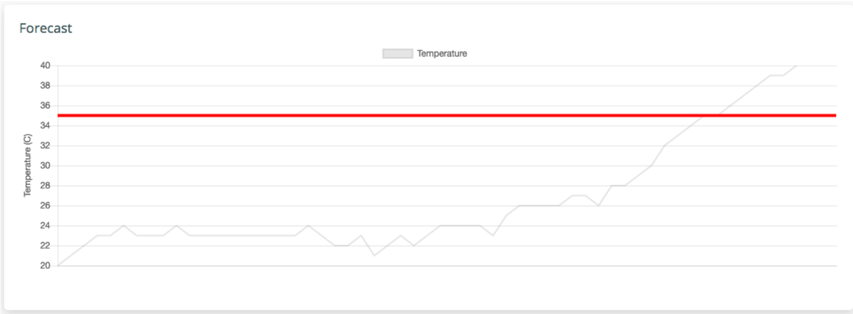

Fig. 2.3 – Forecasting of temperature by exponential smoothing method

Device models are a separate software product developed using the Java programming language. To implement the MQTT transmission protocol, a special library was developed by Eclipse-Paho. The data is transmitted to a broker in the format of JSON and processed by the monitoring system.

During the development it was determined that each device should have the fields shown in Table 2.1.

Table 2.1 – Common fields of the IoT device model

Field	Description
DeviceId	Unique Device ID. For example: TS-229177, where the first letters indicate the type of device Temperature Sensor.
DeviceType	Type of device, which is given by the listing with fixed values.
Parameters	Parameters passed by the device. Set as a key-value collection. For example: for the temperature sensor, the parameter temperature and its current value. For the accelerometer you need to set three parameters.
UoM (Unit of Measurement)	Not a required field, which indicates the measure of the sensor parameter.

At present, the following types of IoT devices are implemented in the system:

– TEMPERATURE - temperature sensor;
– HUMIDITY - humidity sensor;
– SWITCH - switch;
– BULB - smart controlled light bulb;
– BRIGHTNESS - light sensor;
– PRESURE - pressure sensor.

MQTT protocol implements the publisher-follower principle, each model of the device can mimic an abstract class with the logic of the publisher or the subscriber, depending on the type of device (Fig. 2.4). The monitoring system implements both the logic of the subscriber and the publisher at the same time, since it collects data from all devices and sends commands.

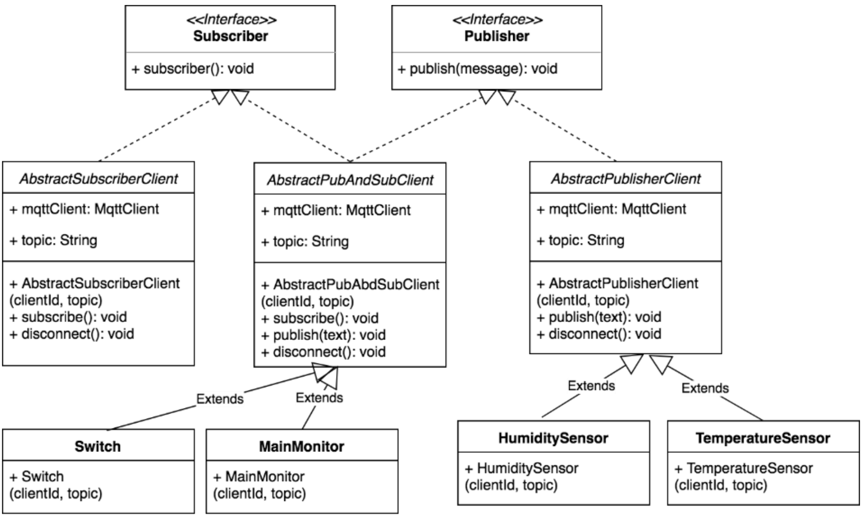

Fig. 2.4 – UML class diagram for software implementation of IoT-device models

When you start the web application, the main page opens, where all the devices stored in the database are displayed. The left side displays a menu that contains four items: dashboard, forecasting, rules and settings.

By default, the dashboard is displayed. In the form of charts, you can observe the receipt of data from active devices in real time. Each device has its own identifier and the corresponding type (Fig. 2.5).

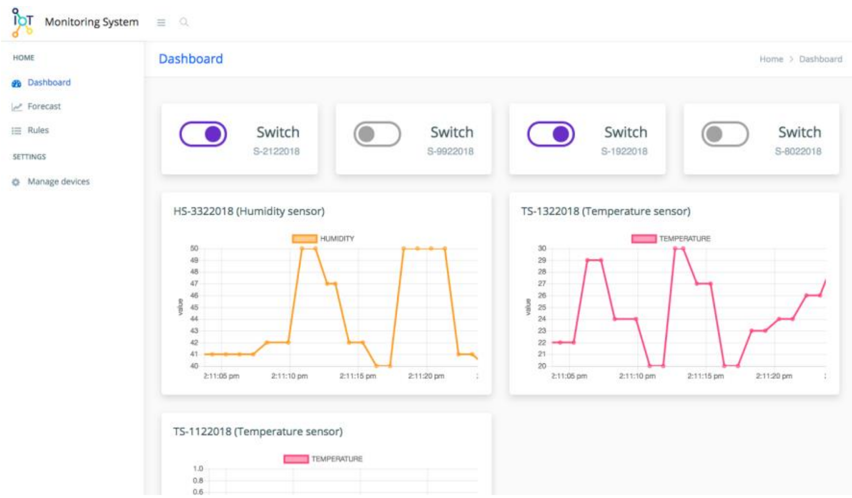

Fig. 2.5 – The "Dashboard" page of the web application for monitoring and forecasting results of IoT-based devices

By going to the “Rules” page (Fig. 2.6), the user can set a threshold for any device that is stored in the database.

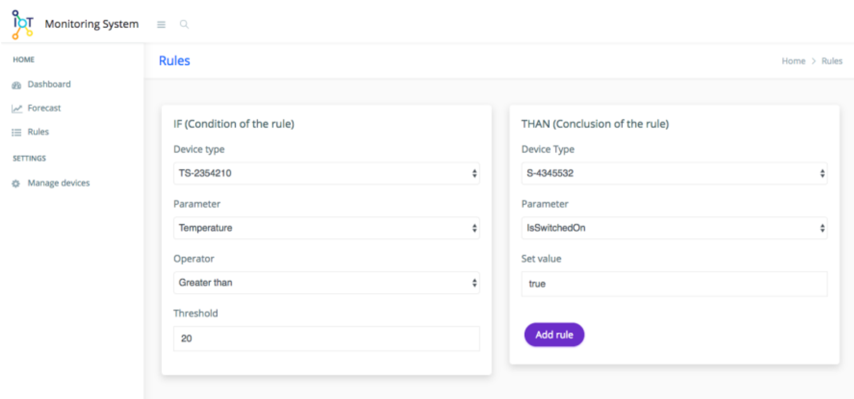

Fig. 2.6 – The "Rules" page of the web application for monitoring and forecasting results of IoT-based devices

The user interface is represented by two forms. One is to establish a production rule condition and the other to establish a conclusion or action to control. When setting the conditions, the user selects from the drop-down list the device for which the restriction, device parameter, operator and threshold value are set. To determine the output, you also have to select the device to which the command will be sent, the device parameter and the value to be set.

On the “Settings” page (Fig. 2.7), you can view all saved devices (Saved devices) as well as devices that have been recognized by the system, but have not yet been saved (Current devices). These devices can also be saved to the database.

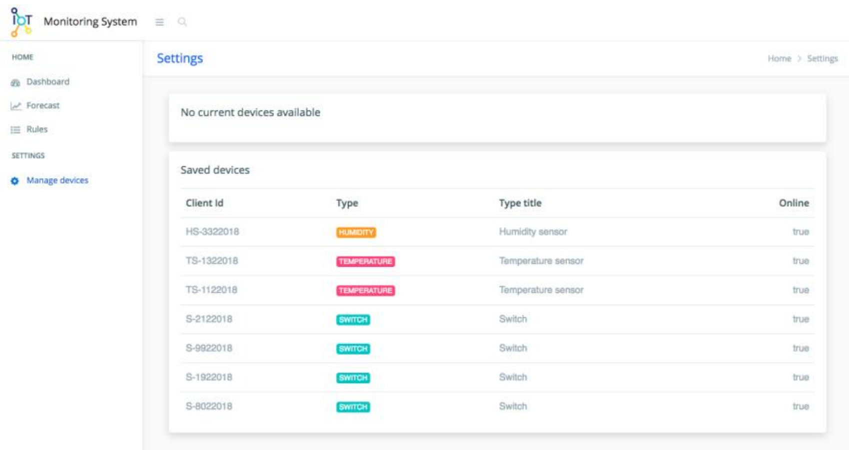

Fig. 2.7 – The "Settings" page of the web application for monitoring and forecasting results of IoT-based devices

When switching to the “Prediction” page (Fig. 2.8), the user must select the device for which the time series will be constructed and the period for which the predicted values will be performed. After that the forecast will be displayed in the form of a diagram, with the axes: the time and sensor parameter (for example, for the temperature sensor - temperature).

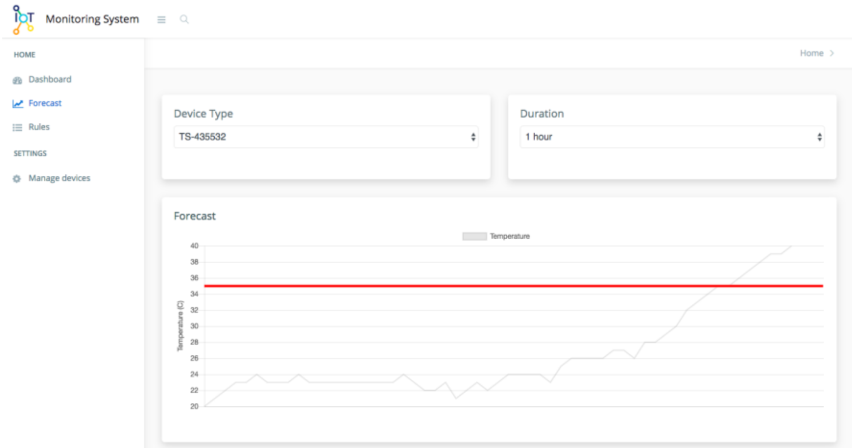

Fig. 2.8 – The "Prediction" page of the web application for monitoring and forecasting results of IoT-based devices

<u>Tasks for individual work</u>

Analyze the work of the system for monitoring and forecasting results of IoT-based devices on various sensors. Add 2 own sensors and to form their models. Produce sensor forecasting using exponential smoothing method and production rules.

<u>Report</u>

The report should contain:

– title page with the name of the training work;
– aim of the work;
– problem statement according to the task;
– the progress and results of the study in graphical form;
– analysis of the results and conclusions.

All materials of the report should be printed, billed, the pages should be numbered.

<u>Test questions</u>

8. What is a production rule and from what parts it is composed?
9. What types of forecasting in IoT do you know?
10. What are the IoT sensor parameters?
11. What are the tools for creating models of IoT-based devices?

Recommended literature

1. R. Ranjan, O. Rana, S. Nepal, M. Yousif, P. James, Z. Wen, S. Barr, P. Watson, P. Jayaraman, D. Georgakopoulos, M. Villari, M. Fazio, S. Garg, R. Buyya, L. Wang, A. Zomaya, and S. Dustdar, "The Next Grand Challenges: Integrating the Internet of Things and Data Science," in *IEEE Cloud Computing*, vol. 5, no. 3, 2018, pp. 12-26.

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9. Y. P. Kondratenko, S. B. Encheva, and E. V. Sidenko, "Synthesis of intelligent decision support systems for transport logistic," *IEEE Intern. Conf. IDAACS-2011*, pp. 642-646, September 2011.

10. V. Shebanin, I. Atamanyuk, Y. Kondratenko, and Y. Volosyuk, "Application of Fuzzy Predicates and Quantifiers by Matrix Presentation in Informational Resources Modeling," *Perspective Technologies and Methods in MEMS Design: Proceedings of the International Conference MEMSTECH-2016*, pp. 146-149, April 2016.

Laboratory work 1

BUILDING INFORMATION MODELS OF IOT-BASED DEVICES

The aim of the laboratory work: consolidation of knowledge about information models, software products and tools for creating information models for different types of IoT devices, types of IoT platforms for connecting devices to the network; acquiring skills of work with code generator to modify and implement information models of the device on specific platforms. Acquiring skills with the Eclipse Vorto Software.

Laboratory work participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Theoretical information

There is a large number of software tools for creating information model devices. Information model is a model of an object presented in the form of information describing the parameters and variables essential for the given consideration of the object, the relationship between them, the inputs and outputs of the object, and allows it to be inputted to the model of input variables to simulate the possible states of an object [20]. Also, the term “Informational model” can be regarded as a collection of information that characterizes the essential properties and states of the object, process, phenomenon, as well as the relationship with the outside world. The existence of IoT technology is not possible without the existence of information models of devices that need to be connected to the network [1].

One of the open source software that can be used to create information models is "Eclipse Vorto" (Fig. 3.1).

“Eclipse Vorto” is an open source software tool that allows you to create and manage technologies that are compatible with other systems as well as information models. Information models, in the context of software for their creation, are understood as description of the attributes and capabilities of a real device. These models can be managed into Vorto Information Model Repository [2].

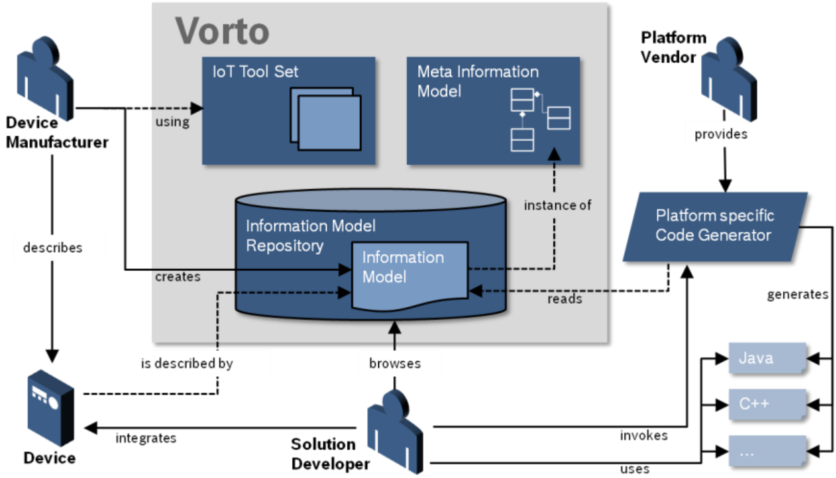

Fig. 3.1 – “Eclipse Vorto” structure and its components

The benefits of the “Eclipse Vorto” software are that it can be solved by the following tasks [3, 4]:

1. Development of information models of IoT devices (description of devices and their use).
2. Creating platforms.
3. Develop solutions.

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

Example of work execution

Download “Eclipse Vorto” software using one of three sources:

– download from the official page - eclipse.org/vorto/downloads;

– download from the manufacturer's official website - www.eclipse.org/vorto/documentation/installation/installation.html#installing-from-the-eclipse-marketplace;

– download via specially designed resource - www.eclipse.org/vorto/documentation/installation/installation.html#installing-from-the-vorto-toolset-upadte-site.

For an example, let's setup “Eclipse Vorto” with the first source.

Step 1. Launch the Eclipse environment.

Step 2. In the new browser tab, go to the page - https://eclipse.org/vorto/downloads. The following window is loading (Fig. 3.2).

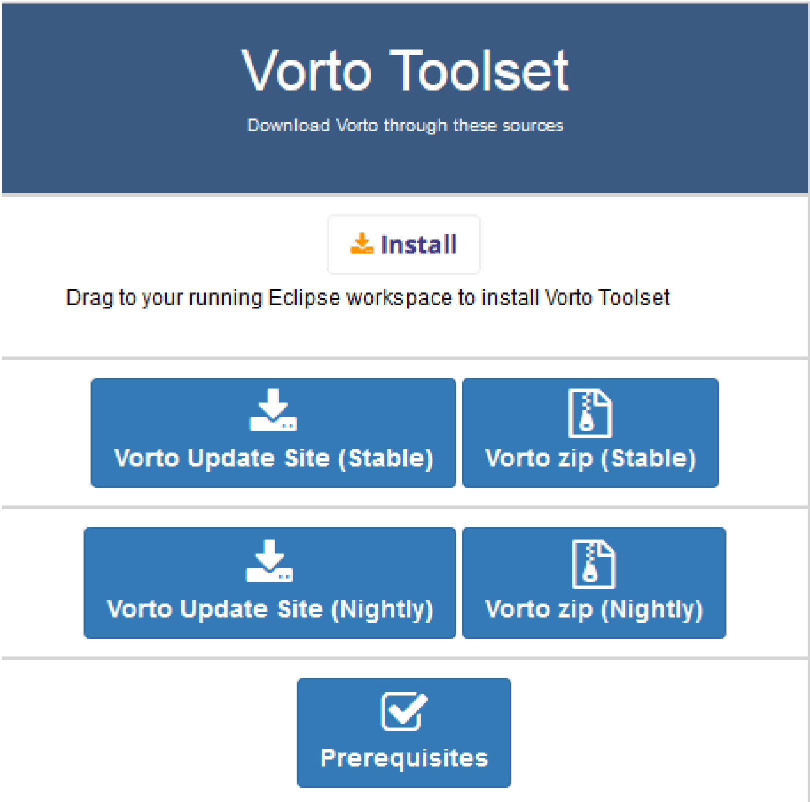

Fig. 3.2 – Download window

Step 3. Click the Install button. The Marketplace Eclipse features confirmation dialog will open (Fig. 3.3).

Step 4. Click the Confirm button and then click on the "License Agreement" window.

Step 5. Click the Vorto Update Site ((Stable) or (Nightly) button according to your needs). The standard Eclipse page opens with instructions for using the download link in Eclipse (Fig. 3.4). Follow the instructions on the page.

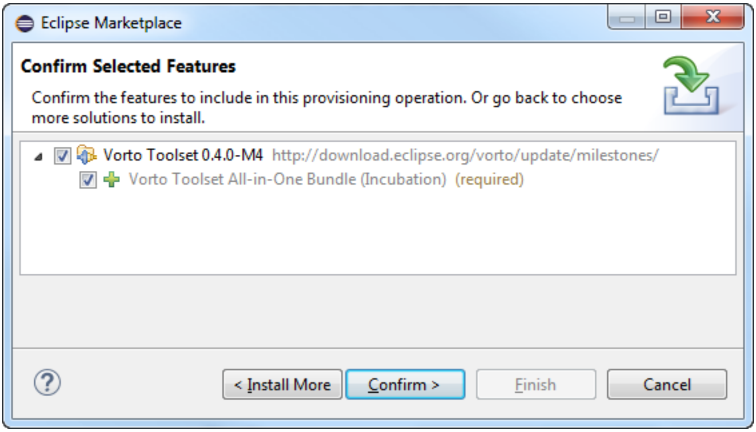

Fig. 3.3 – Confirmation window

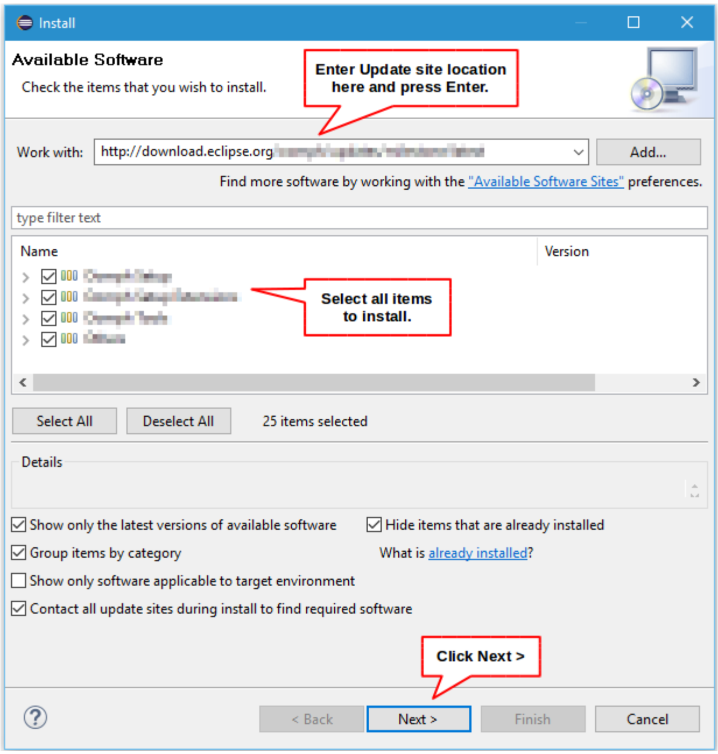

Fig. 3.4 – Instructions page

In order to create your own information model, you first need to create a project in which you will work in the future.

Create a new project.

The Eclipse environment must be running.

Step 1. In the Vorto Model Browser, click the “+” button. The Create new Vorto Project dialog box opens (Fig. 3.5).

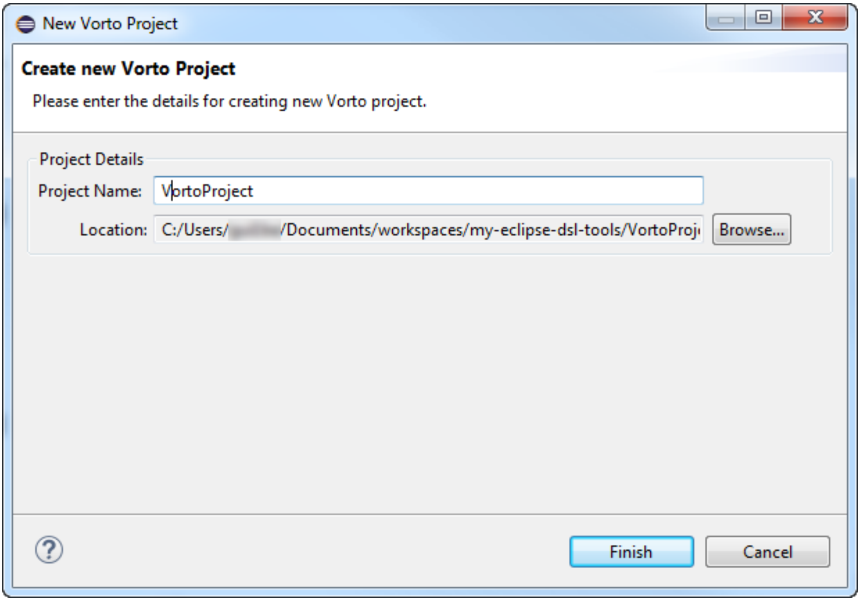

Fig. 3.5 – Create a new project

Step 2. Enter the name as the Project Name, such as MyVortoProject. Click the "Finish" button. The new project was created (Fig. 3.6).

Creation of functional blocks of the information model.

Information models represent the capabilities of a specific type of IoT device (Fig. 3.7). An information model contains one or more functional blocks.

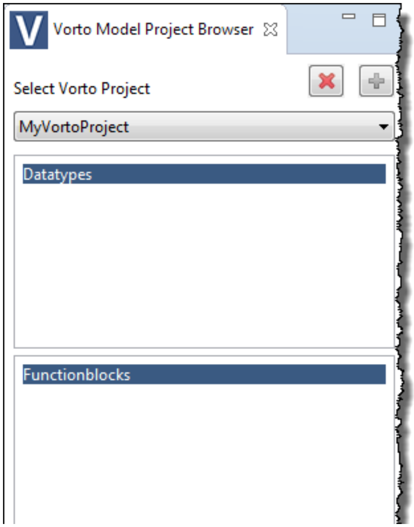

Fig. 3.6 – View of the created project in the environment

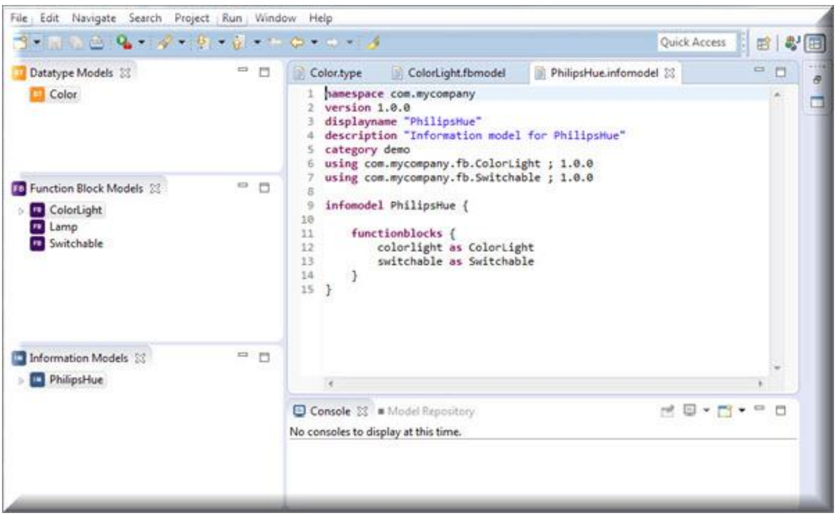

Fig. 3.7 – An example of an information model

Step 1. In the Vorto Model Project Browser, select the project from the Select Vorto Project drop-down list (Fig. 3.8).

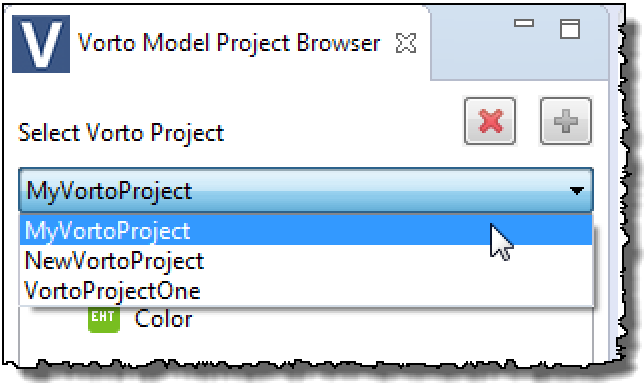

Fig. 3.8 – Project selection

Step 2. Right-click on the function blocks area and select "New Functionblock" in the context menu. The "Create Function Block Model" dialog box opens (Fig. 3.9).

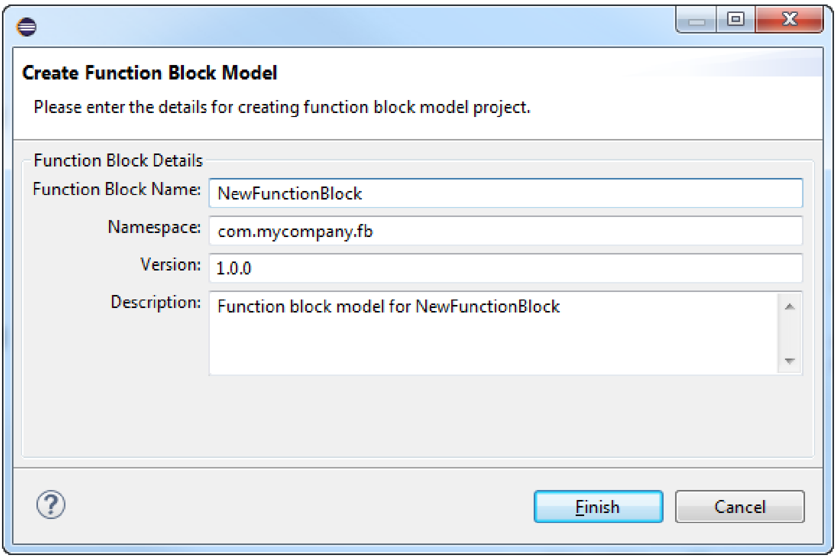

Fig. 3.9 – The "Create Function Block Model" dialog box

Step 3. Enter a name as Function Block Name, for example, ColorLight.

Step 4. Adjust the entries for the Namespace and Version if necessary.

Step 5. Enter the description in the "Description" field if desired.

Step 6. Click "Finish."

New function block (ColorLight) created. In addition, the editor of the model displayed the output file block of the function blocks (.fbmodel). The file contains the complete structure according to the DSL syntax with the values given in the previous steps (Fig. 3.10).

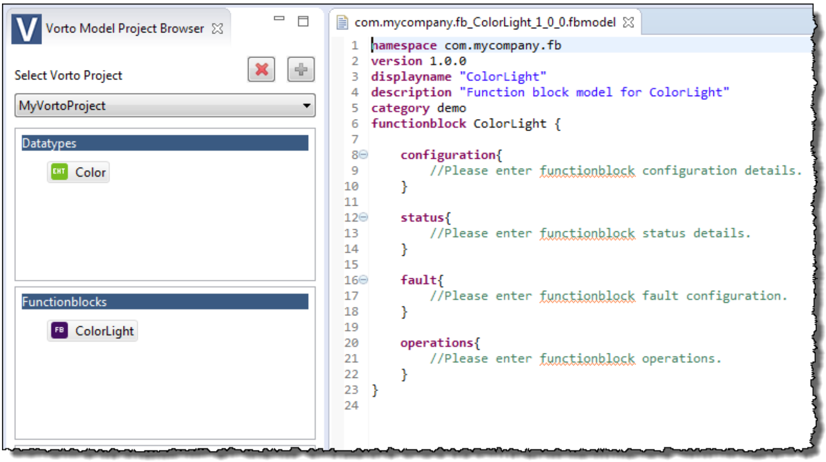

Fig. 3.10 – Functional block

Creating an information model.

You need to create the required functional blocks. The process of creating an information model is very similar to the process of creating functional blocks. Let's take a quick look at it.

Step 1. In the Vorto Model Project Browser, select the project from the Select Vorto Project drop-down list.

Step 2. Right-click on the "Information Models" area and select the "New Information Model" context menu.

Step 3. Enter the name as the Name of the information model, for example, PhilipsHue.

Step 4. Adjust the entries for the Namespace and Version if necessary. If desired, enter a description in the Description field. Click Done.

The new information model (PhilipsHue) has been created. In addition, the source file DSL of information model (.infomodel) displayed in the editor of the model. The file contains the complete structure according to the DSL syntax with the values given in the previous steps (Fig. 3.11).

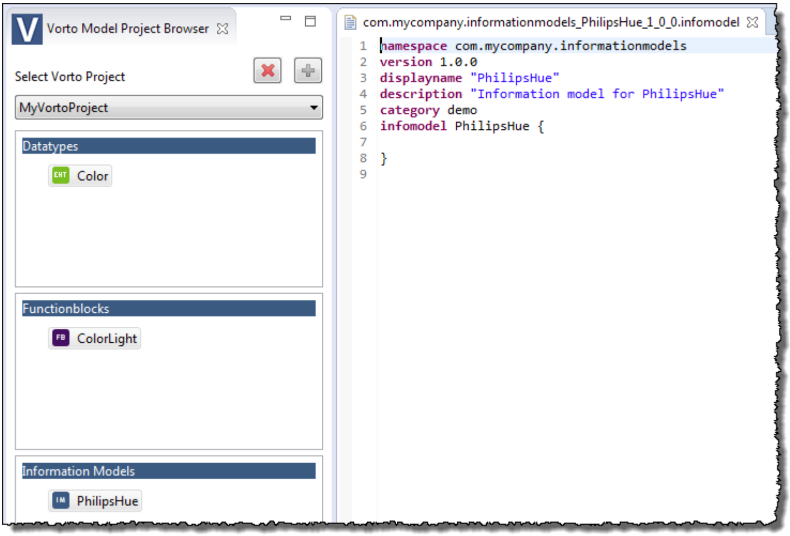

Fig. 3.11 – Information model

Tasks for individual execution

1. Download and install the "Eclipse Vorto" environment.
2. Select the IoT device whose information model it will be necessary to create (the device is selected from the Table 3.1, starting from the 9 variants the IoT devices are repeated).
3. Identify the required functional blocks and add them.
4. Create an information model.

Table 3.1 – IoT device variants

Variants	IoT device	Variants	IoT device
1-4	TV	14-17	Boiler
5-8	Monitor	18-21	Router
9-12	Air conditioning	22-25	Microwave
10-13	Refrigerator	26-29	Washing machine

Report

The report should contain: title page with the name of the laboratory work; aim of the work; problem statement according to the task; the progress and results of the study in graphical form; analysis of the results and conclusions.

Task for the raised ball

Get acquainted and create your own Information Model Mapping. To do this, in your project, right-click on the information model that you want to create for comparison, and select New Mapping Model. If desired, enter a description in the Description field. Click Done. Switch to the Java perspective. New mapping file created (*.mapping). It is located in the <project> / mappings folder (Fig. 3.12).

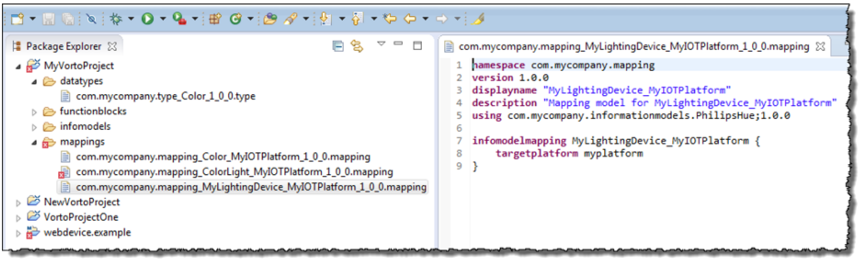

Fig. 3.12 – Information Model Mapping

Example of Information Model Mapping file:

```
namespace com.mycompany
version 1.0.0
displayname "MyLightingDevice_MyIOTPlatform"
description "MyLightingDevice to MyIOTPlatform mapping"
```

```
using com.mycompany.MyLightingDevice ; 1.0.0
using com.mycompany.ColorLight_MyIOTPlatform ; 1.0.0
infomodelmapping MyLightingDevice_MyIOTPlatform {
    targetplatform MyIOTPlatform
    from MyLightingDevice.displayname
    to TargetDisplayName
    from MyLightingDevice.switchable
    to MySwitch with { Icon : "switch.png" }
```

```
        from MyLightingDevice.colorlight
        to reference ColorLight_MyIOTPlatform
}
```

Test questions

1. What is an information model?
2. What is a functional block?
3. What are the benefits of the “Eclipse Vorto” software?
4. What is needed to create a new project in “Eclipse Vorto”?

Recommended literature

1. M. Wagner, J. Laverman, D. Grewe, and S. Schildt, "Introducing a harmonized and generic cross-platform interface between a Vehicle and the Cloud," *IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, pp. 48-56, June 2016.

2. V. M. Tayur and R. Suchithra, "Review of interoperability approaches in application layer of Internet of Things," *International Conference on Innovative Mechanisms for Industry Applications (ICIMIA)*, pp. 32-40, February2017.

3. "Eclipse Vorto - IoT Toolset for standardized device descriptions," [online] Available: http://www.eclipse.org/vorto/documentation/overview/introduction.html.

4. "Eclipse SmartHome - A Flexible Framework for the Smart Home," Eclipse Foundation, [online] Available: http://www.eclipse.org/smarthome/.

Laboratory work 2

PROTOCOLS AND STANDARDS FOR DATA PROCESSING AND TRANSFER IN IOT SYSTEMS

The aim of the laboratory work: learn to rate and select protocols and standards for data processing and transfer for your own IoT system and network using Fuzzy TOPSIS method.

Laboratory work participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Theoretical information

Protocols and standards for IoT data transmission are rules that define how data is exchanged between objects of the IoT systems and networks [1].

With the rapid development of the IoT and the exceptional features of this network (for example, low-power devices, low transmission speeds, etc.), it has become necessary to create protocols that will meet these requirements [2].

So the replacement of the well-known HTTP protocol in the IoT network is the CoAP protocol, which is intended for use by devices with low speed, high loss, and multicast on the network. In 1999, Message Queuing Telemetry Transport (MQTT) protocol was introduced, but it became widespread only after 2010. MQTT specializes in low-speed, high-latency environments, and is therefore well suited for data exchange between machines (M2M). In 2002, an XMPP working group was formed to develop a Jabber-based protocol for instant messaging. The working group formed four specifications that were issued as standards in 2004 [3-5].

There are many data transfer protocols (standards), as an example are the most popular [6]:

1. MQTT (Message Queue Telemetry Transport) - collects data from multiple nodes and sends it to the server. It is based on the publisher-subscriber model using an intermediate broker server (prioritization of messages, queuing, etc.). As a transport - TCP.

2. CoAP (Constrained Application Protocol) - from the user's point of view is similar to the HTTP protocol, but differs in the small size of headers, which is suitable for networks with limited capabilities. Uses

client-server architecture and is suitable for transmitting node status information to a server (GET, PUT, HEAD, POST, DELETE, CONNECT messages). As a transport - UDP.

3. XMPP (Extensible Messaging and Presence Protocol) - has long been used on the Internet to send messages in real time, thanks to the XML format, suitable for use in IoT networks. Works on top of publisher-subscriber and client-server architectures. Also used to address devices in small networks (addressing "name@domain.com").

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

Let’s rate and select current protocols and standards for data processing and transfer using Fuzzy TOPSIS method [7].

The method called Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) can be used to evaluate multiple alternatives against the selected criteria. In the Fuzzy TOPSIS approach an alternative that is nearest to the Fuzzy Positive Ideal Solution (FPIS) and farthest from the Fuzzy Negative Ideal Solution (FNIS) is chosen as optimal. An FPIS is composed of the best performance values for each alternative whereas the FNIS consists of the worst performance values. Here, presented relevant steps of fuzzy TOPSIS for the current task – choosing the best protocol (standard) for data processing and transfer among 3 alternatives $A=\{A_1,A_2,A_3\}$, where A_1 is MQTT, A_2 is CoAP, A_3 is XMPP according to 5 criteria $C=\{C_1,C_2,C_3,C_4,C_5\}$, where C_1 is messaging, C_2 is authentication, C_3 is encryption, C_4 is security, C_5 is success stories, as below. Four experts (Exps) $Exps=\{Exp_1,Exp_2,Exp_3,Exp_4\}$ were involved for evaluation of alternatives and criteria [8-10].

Example of work execution

Step 1. Assessment of criteria and alternatives.

To convert linguistic terms into fuzzy numbers, a conversion scale is used. Usually a scale of 1 to 9 is used to determine criteria and alternatives estimates. The intervals between terms are chosen in such a way as to have a homogeneous density of estimates for fuzzy triangular numbers. As a rule, five linguistic assessments are used (Table 4.1).

Table 4.1 – Conversion scale for assessment criteria and alternatives

Fuzzy number	**Alternative evaluation**	**Criterion evaluation**
(1, 1, 3)	Very Poor (VP)	Very Low (VL)
(1, 3, 5)	Poor (P)	Low (L)
(3, 5, 7)	Fair (F)	Medium (M)
(5, 7, 9)	Good (G)	High (H)
(7, 9, 9)	Very Good (VG)	Very High (VH)

The results of the evaluation of the criteria and alternatives in the linguistic form (c_j^k and a_{ij}^k , where *I* is an alternative, *j* is the criterion, *k* is an expert) conducted in the Microsoft Excel environment are presented in Fig. 4.1.

	Ci				A1				A2				A3			
	Exp1	Exp2	Exp3	Exp4	Exp1	Exp2	Exp3	Exp4	Exp1	Exp2	Exp3	Exp4	Exp1	Exp2	Exp3	Exp4
C1	H	M	L	VH	G	F	G	G	P	G	VG	VG	G	F	P	G
C2	M	M	H	M	P	P	F	F	G	F	F	P	P	G	VG	P
C3	L	H	M	H	F	P	G	P	F	VG	P	G	VG	P	F	VG
C4	H	VH	M	VL	G	VG	F	G	VG	P	G	VP	F	G	G	F
C5	VH	VH	H	M	G	F	G	F	VP	G	VP	F	F	VP	P	VP

Fig. 4.1 – Results of evaluation of criteria and alternatives in linguistic form

According to the conversion scale (Table 4.1), the results of the evaluation of the criteria and alternatives presented in the linguistic form (Fig. 1) are transformed into numerical evaluation of criteria and alternatives in the form of fuzzy triangular numbers (Fig. 4.2). For example, the estimation of the first expert Exp_1 of the second criterion C_2 (c_2^1) corresponds to the linguistic term "M" (Fig. 1), which is transformed into a fuzzy triangular number by the conversion scale $c_2^1 = (3,5,7)$ (Fig. 4.2). Also the estimation of the first expert Exp_1 of the first alternative A_1 by the first criterion C_1 (a_{11}^1) corresponds to the linguistic term "G" (Fig. 4.1), which is transformed into an estimation in the form of a fuzzy triangular number on the conversion scale $a_{11}^1 = (5,7,9)$.

	Ci											
	Exp1			Exp2			Exp3			Exp4		
C1	5	7	9	3	5	7	1	3	5	7	7	9
C2	3	5	7	3	5	7	5	7	9	3	5	7
C3	1	3	5	5	7	9	3	5	7	5	7	9
C4	5	7	9	7	7	9	3	5	7	1	1	3
C5	7	7	9	7	7	9	5	7	9	3	5	7

	A1											
	Exp1			Exp2			Exp3			Exp4		
C1	5	7	9	3	5	7	5	7	9	5	7	9
C2	1	3	5	1	3	5	3	5	7	3	5	7
C3	3	5	7	1	3	5	5	7	9	1	3	5
C4	5	7	9	7	7	9	3	5	7	5	7	9
C5	5	7	9	3	5	7	5	7	9	3	5	7

	A2											
	Exp1			Exp2			Exp3			Exp4		
C1	1	3	5	5	7	9	7	7	9	7	7	9
C2	5	7	9	3	5	7	3	5	7	1	3	5
C3	3	5	7	7	7	9	1	3	5	5	7	9
C4	7	7	9	1	3	5	5	7	9	1	1	3
C5	1	1	3	5	7	9	1	1	3	3	5	7

	A3											
	Exp1			Exp2			Exp3			Exp4		
C1	5	7	9	3	5	7	1	3	5	5	7	9
C2	1	3	5	5	7	9	7	7	9	1	3	5
C3	7	7	9	1	3	5	3	5	7	7	7	9
C4	3	5	7	5	7	9	5	7	9	3	5	7
C5	3	5	7	1	1	3	1	3	5	1	1	3

Fig. 4.2 – Results of evaluation of criteria and alternatives in numerical form

Step 2. Averaging evaluations of criteria AVc_i and alternatives AVa_{ij} [7]. For example, averaging estimates for the first criterion C_1 (Fig. 4.2 and Fig. 4.3):

$$AVc_1 = \frac{c_1^1 \oplus c_1^2 \oplus c_1^3 \oplus c_1^4}{4} = \frac{(5,7,9)\oplus \ldots \oplus (7,7,9)}{4} = \frac{(16,22,30)}{4} = (4,5.5,7.5).$$

Ci			A1			A2			A3		
averaged ci			averaged ai1			averaged ai2			averaged ai3		
4	5,5	7,5	4,5	6,5	8,5	5	6	8	3,5	5,5	7,5
3,5	5,5	7,5	2	4	6	3	5	7	3,5	5	7
3,5	5,5	7,5	2,5	4,5	6,5	4	5,5	7,5	4,5	5,5	7,5
4	5	7	5	6,5	8,5	3,5	4,5	6,5	4	6	8
5,5	6,5	8,5	4	6	8	2,5	3,5	5,5	1,5	2,5	4,5

Fig. 4.3 – Averaged evaluations of criteria AVc_i and alternatives AVa_{ij}

Step 3. Normalization of estimations of alternatives $NAVa_{ij} = AV\,a_{ij} / \max_i AVa_{ij}$ and formation of the matrix of weighted normalized alternatives $WNAVa_{ij} = NAVa_{ij} \otimes AVc_i$. For example, a normalized assessment of the first alternative A_1 (Fig. 4.3 and Fig. 4.4):

$$NAVa_{11} = (4.5,6.5,8.5) / \max\left[(4.5,6.5,8.5),(5,6,8),(3.5,5.5,7.5)\right] = \\ = (4.5,6.5,8.5)/8 = (0.53,0.76,1).$$

A1			A2			A3		
normalized ai1			normalized ai2			normalized ai3		
0,53	0,76	1	0,59	0,71	0,94	0,41	0,65	0,88
0,29	0,57	0,86	0,43	0,71	1	0,5	0,71	1
0,33	0,6	0,87	0,53	0,73	1	0,6	0,73	1
0,59	0,76	1	0,41	0,53	0,76	0,47	0,71	0,94
0,5	0,75	1	0,31	0,44	0,69	0,19	0,31	0,56

Fig. 4.4 – Normalized alternatives estimates $NAVa_{ij}$

For example, weighted normalized estimation of the first alternative A_1 (Fig 4.3, Fig. 4.4 and Fig. 4.5):

$$WNAVa_{11} = (0.53, 0.76, 1) \otimes (4, 5.5, 7.5) = (2.12, 4.21, 7.5).$$

A1			A2			A3		
wn ai1			wn ai2			wn ai3		
2,12	4,21	7,5	2,35	3,88	7,06	1,65	3,56	6,62
1	3,14	6,43	1,5	3,93	7,5	1,75	3,93	7,5
1,17	3,3	6,5	1,87	4,03	7,5	2,1	4,03	7,5
2,35	3,82	7	1,65	2,65	5,35	1,88	3,53	6,59
2,75	4,88	8,5	1,72	2,84	5,84	1,03	2,03	4,78

Fig. 4.5 – The matrix of weighted normalized alternatives $WNAVa_{ij}$

Step 4. Define FPIS (A^+) and FNIS (A^-) [8].

At this step forming $A^+ = \{a_1^+, a_2^+, ..., a_5^+\}$ and $A^- = \{a_1^-, a_2^-, ..., a_5^-\}$, where $a_j^+ = \left(\max_i WNAVa_{ij}, \max_i WNAVa_{ij}, \max_i WNAVa_{ij}\right)$;

$$a_j^- = \left(\min_i WNAVa_{ij}, \min_i WNAVa_{ij}, \min_i WNAVa_{ij}\right).$$

For example, $a_1^+ = (7.5, 7.5, 7.5)$. Thus, we get (Fig. 4.5 and Fig. 4.6):

$$A^+ = \{(7.5, 7.5, 7.5), (7.5, 7.5, 7.5), ..., (8.5, 8.5, 8.5)\};$$

$$A^- = \{(1.65, 1.65, 1.65), (1, 1, 1), ..., (1.03, 1.03, 1.03)\}.$$

FPIS A+			FNIS A-		
7,5	7,5	7,5	1,65	1,65	1,65
7,5	7,5	7,5	1	1	1
7,5	7,5	7,5	1,17	1,17	1,17
7	7	7	1,65	1,65	1,65
8,5	8,5	8,5	1,03	1,03	1,03

Fig. 4.6 – Define FPIS (A^+) and FNIS (A^-)

Step 5. Determine the distances from each alternative to FPIS (A^+) and FNIS (A^-) for each criterion [7, 8]. For example, the distance from DFPIS ($d_1^1 A^+$) from the first alternative A_1 to FPIS (A^+) according to the first criterion C_1 is calculated as follows (Fig. 4.7):

$$d_1^1 A^+ = d\left(WNAVa_{11}, a_1^+\right) = \sqrt{1/3 \cdot \left[\left(2.12 - 7.5\right)^2 + ... + \left(7.5 - 7.5\right)^2\right]} = 3.64\,.$$

DFPIS			DFNIS		
A1	A2	A3	A1	A2	A3
3,64	3,64	4,11	3,7	3,4	3,07
4,56	4,03	3,91	3,37	4,13	4,14
4,43	3,82	3,7	3,32	4,03	4,05
3,25	4,1	3,58	3,36	2,22	3,06
3,92	5,32	6,1	4,95	3	2,24

Fig. 4.7 – Determine the distances DFPIS ($d_i^j A^+$) and DFPIS ($d_i^j A^-$)

Step 6. Determine of the closeness coefficient CC_i [7] for each alternative (Fig. 4.8):

$$CC_i = \sum DFNIS\left(d_i^j A^-\right) \Big/ \left(\sum DFNIS\left(d_i^j A^+\right) + \sum DFNIS\left(d_i^j A^-\right)\right).$$

For example, $CC_1 = 18.7/(19.8 + 18.7) = 0.49$.

DFPIS			DFNIS		
A1	A2	A3	A1	A2	A3
3,64	3,64	4,11	3,7	3,4	3,07
4,56	4,03	3,91	3,37	4,13	4,14
4,43	3,82	3,7	3,32	4,03	4,05
3,25	4,1	3,58	3,36	2,22	3,06
3,92	5,32	6,1	4,95	3	2,24
19,8	20,9	21,4	18,7	16,8	16,6
			0,49	0,45	0,44

Fig. 4.8 – Determine of the closeness coefficient for each alternative

As a result of the ranking we get $A_1 \succ A_2 \succ A_3$. Thus, the first alternative A_1 is the best – the protocol (standard) **MQTT**.

Tasks for individual execution

1. Select the protocol (standard) for data processing and transfer for your own IoT system and network using Fuzzy TOPSIS method (according to variants from the Table 4.2).
2. Analyze the results.
3. Form a report.

Table 4.2 – Variants for individual execution

Variants	Task	Variants	Task
1-5	5 experts and 3 same alternatives	16-20	3 experts and 4 alternatives (add protocol DDS)
6-10	6 experts and 3 same alternatives	21-25	2 experts and 5 alternatives (add protocols DDS and DPWS)
11-15	2 experts and 4 alternatives (add protocol DDS)	26-30	3 experts and 5 alternatives (add protocols DDS and DPWS)

Report

The report should contain:

- title page with the name of the training work;
- aim of the work;
- problem statement according to the task;
- the progress and results of the study in graphical form;
- analysis of the results and conclusions.

All materials of the report should be printed, billed, the pages should be numbered.

Test questions

1. What is the standard for data transfer in IoT network?
2. What is the conversation scale for assessments?
3. What is the normalization of assessments?
4. How is the closeness coefficient determined?

Recommended literature

1. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies Protocols and Applications," in *IEEE Commun. Surv. Tutorials*, vol. 17, iss. 4, 2015, pp. 2347-2376. DOI: 10.1109/COMST.2015.2444095.

2. I. Morns, O. Hinton, A. Adams, and B. Sharif, "Protocols for sub-sea communication networks," *Conference Proceedings on MTS/IEEE Oceans 2001*, pp. 2076-2082, November 2001.

3. D. Garcia-Carrillo and R. Marin-Lopez, "Multihop Bootstrapping With EAP Through CoAP Intermediaries for IoT," in *IEEE Internet of Things Journal*, vol. 5, no. 5, 2018, pp. 4003-4017.

4. A. Luoto and K. Systä, "Fighting network restrictions of request-response pattern with MQTT," in *IET Software*, vol. 12, no. 5, 2018, pp. 410-417. DOI: 10.1049/iet-sen.2017.0251.

5. Y. Wang, "Development of a Comprehensive Monitoring System Based on Cloud Computing and XMPP," in *International Journal of Engineering Research in Africa*, vol. 25, 2016, pp. 98-107. DOI: 10.4028/www.scientific.net/jera.25.98.

6. L. Novelli, L. Jorge, P. Melo, and A. Koscianski, "Application Protocols and Wireless Communication for IoT: A Simulation Case Study Proposal," *The 11th International Symposium on Communication*

Systems, Networks & Digital Signal Processing (CSNDSP), pp. 372-378, July 2018.

7. F. Jolai, S. A. Yazdian, K. Shahanaghi, and M. A. Khojasteh, "Integrating Fuzzy TOPSIS and Multi Period Goal Programming for Purchasing Multiple Products From Multiple Suppliers," in *Journal of Purchasing & Supply Management*, vol. 17(1), 2011, pp. 42-53.

8. C. N. Liao and H. P. Kao, "An Integrated Fuzzy TOPSIS and MCGP Approach to Supplier Selection in Supply Chain Management," in *Expert Systems with Application*, vol. 38(9), 2011, pp. 10803-10811.

9. J. Buckley, "Ranking alternatives using fuzzy numbers," in *Fuzzy sets and systems*, vol. 15(1), 1985, pp. 21-31.

10. Y. Jiang, "A method for group decision making with multigranularity linguistic assessment information," in *Information Sciences*, vol. 178(4), 2008, pp. 1098-1109.

PCM4.3. Intelligent methods and approaches for management and learning of IoT-based systems

Prof., DrS. Yu.P. Kondratenko, Ass. Prof., Dr. G.V. Kondratenko, Ass. Prof., Dr. Ie.V. Sidenko, Ph.D. Student M.O. Taranov (PMBSNU)

Seminar

MULTI-AGENT SYSTEMS AND TECHNOLOGIES FOR DEVELOPMENT OF IOT-BASED SYSTEMS

The aim of the seminar: study of methods and techniques of multi-agent systems (MAS) and technologies for development of IoT-based systems. Consider the types and characteristics of agents, the principles of agent interaction, and the types of architectures of multi-agent systems.

Learning tasks:

– analysis of the current state of the problem of multi-agent systems and technologies for development of IoT-based systems;

– analysis of types and characteristics of agents;

– studying of principles of agent interaction in IoT networks;

– analysis of the types of architectures of multi-agent systems.

Preparation for the seminar.

Preparation for the seminar includes the following steps.

1. Receiving (determining) the topic of the essay (analytical review) and clarifying the tasks of individual work.

Topics of essays can be formed by students independently based on the general structure of the MAS (Fig. 1.1). Multi-agent systems consist of agents and their environment. Typically MAS research refers to software agents. However, the agents in a MAS could equally well be robots, humans or human teams. A multi-agent system may contain combined human-agent teams.

Topics of the essays can also be formed by students on their own based on the following chain of keywords that are somehow related to the multi-agent systems and technologies:

– methods, techniques, approaches of the multi-agent systems and technologies…;

– tools, principles, types of the MAS…;

– data processing, interaction, architecture of MAS in IoT-based networks…;

– types of agents, agent environments, system paradigms in multi-agent systems for IoT…

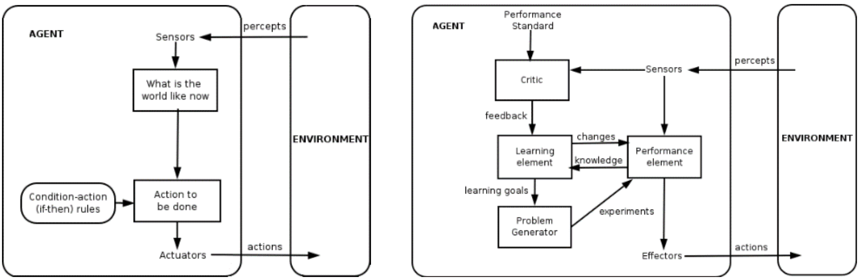

Fig. 1.1 – General structure of the multi-agent system

Examples of essays topics:

– agent platform for creating, interpreting, launching, moving, and destroying agents;

– links between agent systems in IoT;

– architectures of multi-agent systems;

– the scheme of rules processing in the multi-agent system for classification;

– collective behavior of agents for development of IoT-based systems;

– ways and causes of interaction between agents;

– simulation of interaction in multi-agent systems;

– coordination of agent behavior in a multi-agent systems for IoT concept;

– coordination of behavior based on auction model;

– multi-agent decision support system;

– technologies of designing multi-agent systems;

- instrumentation tools for building multi-agent systems;
- scheme for designing applications in the Agent Builder ToolKit;
- prospects for multi-agent technologies;
- means and methods of information protection in IoT devices using multi-agent systems;
- foundation for intelligent physical agents;
- knowledge query and manipulation language;
- agent communication language;
- advanced research projects agency;
- conflict situations as a result of the interaction of agents;
- separate modules for the development of multi-agent systems. Repast Simphony;
- separate software libraries. JADE;
- tecnomatix plant simulation system;
- concept of program agent: task, structure, properties;
- architecture of an artificial agent in IoT systems;
- characteristics of intellectual agents in IoT networks;

Topics of the essays should be coordinated with the lecturer and fully comply with the subject area of the course. In preparing for the seminar should use literary sources.

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

2. Development of a plan of the work on the essay.

The work is carried out individually. Typical work involves the preparation by each student the essay and presentation on issues of modern and prospective methods and techniques of multi-agent systems and technologies for development of IoT-based systems.

3. Development of the essay plan.

Before to start writing an essay, it is necessary to clearly formulate the task of finding information according to the required essay plan.

The essay plan includes:

– introduction (relevance, brief analysis of the state of the question). In the introduction of the essay, it is necessary to justify the choice of the topic;

– systematic presentation of the main parts of the essay (structures, models, methods, tools, comparative analysis);

– conclusions (ascertaining the achievement of the goal, the main theoretical and practical results, their significance, directions for further work);

– references (paper and digital sources);

– appendix (presentation slides).

4. Writing an essay.

Writing and design of the essay (including the title page, references) should be literate. Use only the material that reflects the essence of the topic.

The essay has a volume of 12-15 pages of A4 format (font 14, 1.5 interval, 2cm margins), including the title page, content, main text, references, appendix.

At the preparation of the essay, it is necessary to use materials of modern publications not older than 7 years. The presentation of the essay should be consistent. Ambiguous language, speech and spelling errors are not allowed. Particular attention should be paid to the conclusion. In the conclusion, the answers to the tasks set in the introduction should be presented. The general conclusion should be formulated and the goal achievement of the essay should be given. The conclusion should be concise, clear and should follow from the content of the main part.

A mandatory attachment to the abstract is the presentation slides and the electronic version of all materials.

5. Preparation of the presentation.

The presentation is developed in PowerPoint and corresponds to the plan of the essay (12-16 slides) based on the time for the report – 7 min.

The presentation should include the following slides:

– title slide (indicating organization, department, discipline, topic of the report, author, date of presentation);

– content (structure) of the report;
– the relevance of the issues under consideration, the purpose and objectives of the report;
– slides with the disclosure of the content of the objectives;
– report conclusions;
– list of references.

Each of the slides should contain the footer with the title and author of the report.

The content of the slides should not contain parts of the text from the essay, but include keywords, pictures, formulas.

Submission of information can be dynamic.

6. Presentation (report).

The presentation (report) is carried out at the seminar, takes 12 minutes and includes the report itself (7 minutes) and discussion (5 minutes). Presentation and essay Language is English.

7. Evaluation.

Evaluation for this work takes into account:
– quality of the essay text (form and content);
– presentation quality (content and design);
– report quality (content, logical structure, division of time, conclusions);
– completeness and correctness of answers to questions.

The grade for the essay and presentation is set for each participant of the seminar individually in accordance with the results.

8. References for seminar preparation.

1. R. Fagin, J, Halpern, Y. Moses, and M. Vardi, *Knowledge in Multi-Agent Systems*. Cambridge: MIT Press, 2003.

2. F. Januario, A. Cardoso, and P. Gil, "Multi-agent approach for resilience enhancement in wireless sensor and actuator networks," *Joint 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems (IFSA-SCIS)*, pp. 635-640, June 2017.

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Training

MULTI-CRITERIA APPROACH FOR CHOOSING THE IOT PLATFORM

The aim of the training: learn to apply different methods of multi-criteria approach for choosing the IoT platform for further development of own IoT system; study to analyze and compare the results of applying the appropriate multi-criteria decision making methods.

Training participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Theoretical information

The Internet of Things (IoT) describes a network of the interconnected smart devices, which are able to communicate with each other for a certain goal. But how easy is the process of realization which IoT platform is right for you? The market for the IoT platforms is rapidly evolving. With an ever-increasing number of available platforms to choose from, the authors decided it would be helpful to lay out their features and capabilities for easy comparison using different methods of multi-criteria decision making [1-4].

The development of the market of services and opportunities for information technologies leds to the emergence of the IoT concept. The IoT principle implies the interaction of familiar (for us in everyday life) things with the help of high-speed computer networks. In addition, IoT is a closer integration of physical devices and people among themselves to achieve specific goals. The desire of users to feel themselves in the role of IoT systems developers has pushed some companies to develop the special programmable platforms (IoT platforms). Such platforms allow to cope with various tasks in the field of communications, information safety during data transmission, visualization of IoT systems performance, etc. [2, 4].

Estimating and choosing a rational IoT platform is a rather complicated process for many reasons, including: multi-factor evaluation in the platform selection; complexity of preliminary consideration of all possible stages of decision making; lack of awareness of the peculiarities of modern information technology development and IoT services market; insufficient technical and material base and so on [3, 5].

The analysis of many real practical problems naturally led to the emergence of a class of multi-criteria problems. The solution of the corresponding problems is found through the use of such methods as the selection of the main criterion, the linear, multiplicative and max-min convolutions, the ideal point method, the sequential concessions methodology, the lexicographic optimization [6-8].

Most of the methods of multi-criteria decision making provide transformation of a multi-criteria problem into the one-criterion, which greatly simplifies the decision making process [7, 8].

In most cases, the choice of the IoT platform for the development of the IoT systems comes to the comparative analysis of their capabilities and taking the pricing policy for the services provided by the developers of their own IoT platforms into account. Besides, IoT developers often give preference to the well-known IoT platforms, without considering the criteria (factors) that in the future may affect the development, maintenance, updating, reliability, safety and scaling of the developed IoT systems [2]. The study [3] noted that the following features and features of platforms should be taken into account when choosing an IoT platform:

- orientation toward the hybrid application environment;
- the ability to receive data and prepare it for the analysis;
- a statement of the owner of the cloud infrastructure;
- reliability and data safety;
- peripheral processing and data control.

One of the approaches to selecting an IoT platform is based on the defining a reference platform architecture that includes the benefits and capabilities of the existing modern IoT platforms [4]. Later on, a comparative analysis of the selected platforms with the reference one is carried out and the best IoT platform is determined.

At the present time, there are several known methods of expert evaluation and selection of IoT platforms, in particular, the analytic hierarchy process, the Delphi method and the decision making methods based on fuzzy sets and fuzzy logic [6, 9-11]. At that, the considered methods and approaches have some limitations and peculiarities of application, in particular, the necessity of calculation of the consistency of expert judgments; the limited number of levels of the hierarchy and the dimension of the paired-comparison matrix; the constant contact with experts for conducting the questionnaires; the need to update the structure of the model when changing the number of criteria and alternatives, etc. [10, 11].

Training implementation

Based on several recent surveys, we have selected the following criteria as being crucial for an IoT platform:

- device management (Q_1);
- integration level (Q_2);
- level of safety and reliability (Q_3);
- protocols for data collection (Q_4);
- variety of data analytics (Q_5);
- usefulness of visualization (Q_6);
- database functionality (Q_7).

Let us consider the relevant criteria in more detail.

Device management is one of the most important criteria expected from any IoT platform. The IoT platform should maintain a list of devices connected to it and track their operation status; it should be able to handle configuration, firmware (or any other software) updates and provide device-level error reporting and error handling. At the end of the day, users of the devices should be able to get individual device level statistics [1].

Integration level is another important criterion expected from an IoT platform. The API should provide access to the important operations and data that needs to be exposed from the IoT platform [2].

The level of safety and reliability measures required to operate an IoT platform is much higher than general software applications and services. Millions of devices being connected with an IoT platform means we need to anticipate a proportional number of vulnerabilities. Generally, the network connection between the IoT devices and the IoT platform would need to be encrypted with a strong encryption mechanism [3].

Another important criterion which needs attention is the *types of protocols for data collection* used for data communication between the components of an IoT platform. An IoT platform may need to be scaled to millions or even billions of devices (nodes). Lightweight communication protocols should be used to enable low energy use as well as low network bandwidth functionality [4].

Variety of data analytics. The data collected from the sensors connected to an IoT platform needs to be analyzed in an intelligent manner in order to obtain meaningful insights. There are four main types of analytics which can be conducted on IoT data: real-time, batch, predictive, and interactive analytics [2].

Visualization enables humans to see patterns and observe trends from visualization dashboards where data is vividly portrayed through line-, stacked-, or pie charts, 2D- or even 3D-models [4].

Database functionality. Scalable storage of device data brings the requirements for hybrid cloud-based databases to a new level in terms of data volume, variety, velocity and veracity. Requirements for this criterion is an attempt to restore order in the processing and transfer of data from, for example, different platforms or even to other information systems [1-2, 4].

A careful investigation into the current IoT platform landscape reveals that each of the above-mentioned criteria has been implemented - to different extents. We've listed the relevant platforms below, with a summarized criteria comparison:

– AWS IoT Platform (E_1);

– Kaa IoT Platform (E_2);

– IBM Watson IoT Platform (E_3);

– Microsoft Azure IoT Platform (E_4);

– Bosch IoT Suite - MDM IoT Platform (E_5).

Let's consider the relevant IoT platforms in more detail.

AWS IoT Platform. According to Amazon, their IoT platform will make it a lot easier for developers to connect sensors for multiple applications ranging from automobiles to turbines to smart home light bulbs [1].

The main features of AWS IoT platform are the registry for recognizing devices; software development kit for devices; device shadows; secure device gateway; rules engine for inbound message evaluation [3].

Kaa IoT Platform. Kaa is provided with open source code, which makes it easy to integrate into projects with "smart house" technology. This allows developers to create their own intelligent IoT systems much faster. In addition, it makes it possible to configure the corresponding IoT systems, or to combine them among themselves [3].

Main features of Kaa IoT platform are perform real-time device monitoring; perform remote device provisioning and configuration; collect and analyze sensor data; analyze user behavior deliver targeted notifications; create cloud services for smart products [1].

IBM Watson IoT Platform. You can try out their sample apps to get a feel for how it all works. You can also store your data for a specified period, to get historical information from your connected devices. IBM Watson also offers some cool security possibilities based on machine learning and data science [2].

Users of IBM Watson get device management; secure communications; real-time data exchange; data storage; recently added data sensor and weather data service [4].

Microsoft Azure IoT Platform. Representatives of Microsoft have cloud storage, machine learning, IoT services, and have even developed their own operating system for IoT devices [1].

Main features of Azure IoT platform are device shadowing; a rules engine; identity registry; information monitoring [2, 4].

Bosch IoT Suite - MDM IoT Platform. Bosch cloud offers its customers complete safety and reliability while storing the data on its secure server in Germany. The company hosts the cloud in Stuttgart, Germany. Using Platform as a Service (PaaS) the company can offer its service at fairly reasonable rates [3].

The main features of Bosch IoT platform are the platform as a Service (PaaS); remote manager; analytics; cost-effective; ready to use [1, 3].

In next section, the methods of multi-criteria decision making for solving the task of selecting a rational IoT platform in special cases are considered in more detail. Abovementioned special cases deal with the situations in decision-making processes when alternatives (different IoT platforms) are included to Pareto-optimal set [7, 8] and the criteria priority depends on the judgments and personal assessments of the experts on the basis of the requirements to the functional characteristics and hardware capabilities, which put forward to the future IoT systems.

Here is a comparative table of alternative solutions (IoT platforms) based on the definite criteria for choosing a rational IoT platform (Table 1). Note that choosing a platform also takes one of the important criteria, such as the level of safety and reliability of platforms, into account [2, 3].

Let us transform (based on own expert experience and judgments) the comparative table in the linguistic form (Table 2.1) into a decision matrix in numerical form (Table II) for further processing by multi-criteria decision making methods [7, 8].

Table 2.1 – Comparison of IoT platforms by certain criteria

	E_1	E_2	E_3	E_4	E_5
Q_1	Device SDK for AWS IoT	Kaa Core, Kaa Sandbox Frame, and Kaa Sample Apps	IBM Watson IoT Platform Client Library, Watson IoT Platform Device recipes, Paho Library	Azure IoT Device SDK, ConnectTheDots.io	Bosch IoT Suite, Bosch IoT Remote Manager
Q_2	REST API	Portable SDK, REST API	IBM Watson SDK for Salesforce	Windows Azure SDK for .NET	REST API
Q_3	Link Encryption (TLS), Authen tication (SigV4, X.509)	Link Encryption (SSL), RSA key 2048 bits, AES key 256 bits	Link Encryption (TLS), Identity management (LDAP)	Link Encryption (TLS), Authentication (per-device with SAS token)	Link Encryption (TLS)
Q_4	MQTT, HTTP	MQTT, CoAP, XMPP, TCP, HTTP	MQTT	HTTP, AMQP, MQTT	MQTT, CoAP, AMQP,STOMP
Q_5	Real-time analytics (Rules Engine, Amazon Kinesis, AWS Lambda)	Real time IoT Data Analytics and Visualization with Kaa, Apache Cassandra and Apache Zappelin	IoT Real-Time Insights, IBM Streaming Analytics,	Microsoft Stream Analytics	Bosh IoT Analytics
Q_6	AWS IoT Dashboard	Yes (without additional information)	Embeddable Reporting, IBM Push Notifications	Notification Hubs, Power BI	User Interface Integrator
Q_7	Amazon DynamoDB, Amazon Redshift	MongoDB, Cassandra, Hadoop, Oracle NoSQL	MongoDB, Cloudant NoSQL, ObjectStorage Informix Time Series data, etc.	DocumentDB Storage (high-performance tables, blobs), Microsoft SQL	MongoDB

The experts evaluated alternative decisions (IoT platforms) $E_1, E_2, ..., E_5$ according to the specified criteria $Q_1, Q_2, ..., Q_7$ using the 10-point rating scale (from 0 to 9), where 9 points corresponds to the largest value of the alternative decision's evaluation according to corresponding criterion (Table 2.2).

Often, the set of criteria is reduced to one global and solves the classical one-criterion problem. However, the application of this approach has certain disadvantages, one of which is that some of the best Pareto decisions cannot be obtained [7].

Table 2.2 – Decision matrix in numerical form

	E_1	E_2	E_3	E_4	E_5
Q_1	7	8	9	9	6
Q_2	6	8	7	7	6
Q_3	7	7	6	8	7
Q_4	6	9	5	7	9
Q_5	8	8	7	7	6
Q_6	7	5	7	6	9
Q_7	8	8	9	8	5

The simplest and most frequently used method of bringing the multi-criteria problem to one-criterion is *linear convolution method* (LCM). We can use LCM, if the weight non-negative coefficients which denote the importance of each criterion are determined, and the linear combination of target functions is maximized [8].

With the help of LCM, the global criterion is presented as a linear combination of the vector criterion of quality with weight coefficients $\lambda_j, (j = 1,...,n)$:

$$Q(E_i) = \sum_{j=1}^{n} \lambda_j Q_j(E_i) \Rightarrow Max; E_i \in E; \lambda_j > 0; \sum_{j=1}^{n} \lambda_j = 1; (i = 1,2,...,m), \quad (2.1)$$

where $Q_j(E_i)$ is the j-th component of the vector criterion of quality $Q(E_i)$; λ_j is the weight coefficient which denote the relative importance of j-th criterion.

Simple ranking method for determining the weight coefficients λ_j [14]. Table 2.3 consists of ranking order of seven criteria $Q_j(E_i), (j = 1,...,7)$ according to (a) their priority for decision-maker (DM) and (b) the results of experts' evaluation.

The data of the priority of the criteria (Table 2.3) are formed taking into account that for the last place of the relevant criterion is given 1 point, for the penultimate place - 2, ..., for the second place - 6, and for the first place - 7 (in this case - the maximum number of points).

Proportional method for determining the weight coefficients λ_j. The criteria are arranged in the order of their priority for DM and the results of experts' evaluation. The criterion with the lowest priority has weight λ. The weights of the remaining criteria are set proportionally to their priority (Table 2.4) [8].

Table 2.3 – Simple ranking method for determining weight coefficients

Criterion	Priority of the criterion	Total number of points for the criterion	Average number of points for the criterion of the one priority	Weight λ_j (average number of points for the criterion / total number of points for all criteria)
$Q_3(E_i)$	1	7	7	$\lambda_3 = 7/28 = 0.25$
$Q_5(E_i)$	2-3	6+5=11	11/2=5.5	$\lambda_5 = 5.5/28 = 0.196429$
$Q_6(E_i)$	2-3	6+5=11	11/2=5.5	$\lambda_6 = 5.5/28 = 0.196429$
$Q_4(E_i)$	4	4	4	$\lambda_4 = 4/28 = 0.142857$
$Q_1(E_i)$	5	3	3	$\lambda_1 = 3/28 = 0.107143$
$Q_7(E_i)$	6	2	2	$\lambda_7 = 2/28 = 0.071429$
$Q_2(E_i)$	7	1	1	$\lambda_2 = 1/28 = 0.035714$
Total	28		28	$\sum_{j=1}^{7} \lambda_j = 1$

Table 2.4 – Proportional method for determining weight coefficients

Criterion	Priority of the criterion	Weight λ_j (priority for the criterion / total priorities for all criteria)
$Q_3(E_i)$	4.5λ	$\lambda_3 = 4.5\lambda / 21\lambda = 0.214286$
$Q_5(E_i)$	4λ	$\lambda_5 = 4\lambda / 21\lambda = 0.190476$
$Q_6(E_i)$	4λ	$\lambda_6 = 4\lambda / 21\lambda = 0.190476$
$Q_4(E_i)$	3.5λ	$\lambda_4 = 3.5\lambda / 21\lambda = 0.166667$
$Q_1(E_i)$	2.5λ	$\lambda_1 = 2.5\lambda / 21\lambda = 0.119048$
$Q_7(E_i)$	1.5λ	$\lambda_7 = 1.5\lambda / 21\lambda = 0.071429$
$Q_2(E_i)$	λ	$\lambda_2 = \lambda / 21\lambda = 0.047619$
Total	$\sum = 21\lambda$	$\sum_{j=1}^{7} \lambda_j = 1$

Let's choose the best decision (IoT platform) based on the LCM.

First, we shall use the global criterion constructed by the simple ranking method (Table 2.3) for evaluate of the alternatives:

$$Q(E_i) = 0.107143 Q_1(E_i) + ... + 0.071429 Q_7(E_i). \qquad (2.2)$$

Using (2.2) for the calculation of the global criterion we can get the usefulness of alternatives (Table 2.2, Table 2.3):

$$Q(E_1) = 0.107143 \cdot 7 + ... + 0.071429 \cdot 8 = 7.089286;$$
$$Q(E_2) = 0.107143 \cdot 8 + ... + 0.071429 \cdot 8 = 7.303571;$$
$$Q(E_3) = 0.107143 \cdot 9 + ... + 0.071429 \cdot 9 = 6.821429;$$
$$Q(E_4) = 0.107143 \cdot 9 + ... + 0.071429 \cdot 8 = 7.339286;$$
$$Q(E_5) = 0.107143 \cdot 6 + ... + 0.071429 \cdot 5 = 7.196429.$$

$$E_4 \succ E_2 \succ E_5 \succ E_1 \succ E_3. \qquad (2.3)$$

Therefore, the fourth alternative decision E_4 is the best (2.3). The IoT platform "Microsoft Azure IoT Platform" is the most rational from the point of DM's view in this case.

Now let's choose the best decision based on the LCM in which criteria weights are calculated using the proportional method (Table 2.4):

$$Q(E_i) = 0.119048 Q_1(E_i) + ... + 0.071429 Q_7(E_i) \qquad (2.4)$$

Using (2.4) to calculate the value of the global criterion, we can obtain the usefulness of alternatives (Table 2.2, Table 2.4):

$$Q(E_1) = 0.119048 \cdot 7 + ... + 0.071429 \cdot 8 = 7.047619;$$
$$Q(E_2) = 0.119048 \cdot 8 + ... + 0.071429 \cdot 8 = 7.380952;$$
$$Q(E_3) = 0.119048 \cdot 9 + ... + 0.071429 \cdot 9 = 6.833333;$$
$$Q(E_4) = 0.119048 \cdot 9 + ... + 0.071429 \cdot 8 = 7.333333;$$
$$Q(E_5) = 0.119048 \cdot 6 + ... + 0.071429 \cdot 5 = 7.214286.$$

$$E_2 \succ E_4 \succ E_5 \succ E_1 \succ E_3. \qquad (2.5)$$

The second alternative E_2 is the best according to (2.5) in this case. Thus, from the point of DM's view, the IoT platform "Kaa IoT Platform" is the most rational.

Linear convolution has one more disadvantage - the value of one of the criteria components can be very large due to the fact that the values of others are minimal. This situation is extremely undesirable.

To avoid such situations, *multiplicative convolution method* (MCM) is proposed [7, 8]:

$$Q(E_i) = \prod_{j=1}^{n} \left(Q_j(E_i)\right)^{\lambda_j} \Rightarrow Max; E_i \in E; \lambda_j > 0; \sum_{j=1}^{n} \lambda_j = 1; (i = 1, 2, ..., m). \quad (2.6)$$

For a such convolution, a sharp decrease of the value of at least one partial criterion $Q_j(E_i)$ sharply decreases the value of the global criterion $Q(E_i)$.

Choose the best decision (IoT platform), based on the MCM. First, we shall use the global criterion constructed by the simple ranking method (Table 2.3) for evaluate of the alternatives:

$$Q(E_i) = Q_1(E_i)^{0.107143} \cdot Q_2(E_i)^{0.035714} \cdot ... \cdot Q_7(E_i)^{0.071429}. \quad (2.7)$$

Using (2.7) to calculate the value of the global criterion, we can obtain the usefulness of alternatives (Table 2.2, Table 2.3):

$$Q(E_1) = 7^{0.107143} \cdot 6^{0.035714} \cdot ... \cdot 8^{0.071429} = 7.057921;$$
$$Q(E_2) = 8^{0.07143} \cdot 8^{0.035714} \cdot ... \cdot 8^{0.071429} = 7.174713;$$
$$Q(E_3) = 9^{0.107143} \cdot 7^{0.035714} \cdot ... \cdot 9^{0.071429} = 6.713917;$$
$$Q(E_4) = 9^{0.107143} \cdot 7^{0.035714} \cdot ... \cdot 8^{0.071429} = 7.282527;$$
$$Q(E_5) = 6^{0.107143} \cdot 6^{0.035714} \cdot ... \cdot 5^{0.071429} = 7.062808.$$

$$E_4 \succ E_2 \succ E_5 \succ E_1 \succ E_3. \quad (2.8)$$

In this case, the fourth alternative decision E_4 is the best (2.8) and the IoT platform "Microsoft Azure IoT Platform" is the most rational.

Now, let us choose the most rational alternative decision based on the MCM in which criteria weights are calculated using the proportional method (Table 2.4):

$$Q(E_i) = Q_1(E_i)^{0,119048} \cdot Q_2(E_i)^{0,047619} \cdot ... \cdot Q_7(E_i)^{0,071429}. \qquad (2.9)$$

Using (2.9) for calculation of the global criterion value $Q(E_i)$ we can obtain the usefulness of all alternatives (Table 2.2, Table 2.4):

$$Q(E_1) = 7^{0.119048} \cdot 6^{0.047619} \cdot ... \cdot 8^{0.071429} = 7.013595;$$
$$Q(E_2) = 8^{0.119048} \cdot 8^{0.047619} \cdot ... \cdot 8^{0.071429} = 7.249509;$$
$$Q(E_3) = 9^{0.119048} \cdot 7^{0.047619} \cdot ... \cdot 9^{0.071429} = 6.717181;$$
$$Q(E_4) = 9^{0.119048} \cdot 7^{0.047619} \cdot ... \cdot 8^{0.071429} = 7.27627;$$
$$Q(E_5) = 6^{0.119048} \cdot 6^{0.047619} \cdot ... \cdot 5^{0.071429} = 7.075073.$$

$$E_4 \succ E_2 \succ E_5 \succ E_1 \succ E_3. \qquad (2.10)$$

According to (2.10), the fourth alternative decision E_4 is the best and the IoT platform "Microsoft Azure IoT Platform" is the most rational in this case.

From the results of applying two methods of multi-criteria decision making (LCM and MCM) using two approaches to weight coefficients determination (simple ranking method and proportional method) to select a rational IoT platform, it is evident that the Microsoft Azure IoT Platform is the most rational from the point of view of DM. At the same time, the choice of the method for weight coefficients determination within the framework of one approach of multi-criteria decision making also influences the result of the decision-making process. The results (2.3), (2.5) of using the linear convolution with two different methods of weight coefficients determination (simple ranking method and proportional method) give the ambiguous best solution. Moreover, the application of the multiplicative convolution with various approaches to weight coefficients determination recommends one-valued best solution (2.8), (2.10).

Theoretical issues for "Development of IoT-based systems" are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

Tasks for individual work

Analyze the work of the methods of multi-criteria decision making using two approaches to weight coefficients determination (simple ranking method and proportional method) to select a rational IoT platform. Add 2 own IoT platforms (for example, (a) Google Cloud IoT Platform and (b) Samsung Artik Cloud IoT Platform) and 2 criteria (for example, (a) level of processing and action management and (b) scaling of the system). Select a rational IoT platform.

Report

The report should contain:

- title page with the name of the training work;
- aim of the work;
- problem statement according to the task;
- the progress and results of the study in graphical form;
- analysis of the results and conclusions.

All materials of the report should be printed, billed, the pages should be numbered.

Test questions

1. What is an IoT platform and why is it designed?
2. What is multi-criteria decision making?
3. What methods of multi-criteria decision making are known to you?
4. What is the difference in simple ranking method and proportional method?

Recommended literature

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Laboratory work

SOFT COMPUTING AND NEURAL NETWORKS FOR THE SELECTION OF SPECIALIZED IOT PLATFORM

The aim of the laboratory work: learn to apply soft computing, in particular, fuzzy logic approach for the selection of specialized IoT platform for further development of own IoT system; study to analyze and compare the results of applying the appropriate approach.

Training participants: lecturers, scientists, technical staff, students and post-graduate students of the department (faculty, institute) of the university; developers, engineers, trainees.

Theoretical information

IoT describes a network of the interconnected smart devices, which are able to communicate with each other for a certain goal. In simple words, the purpose of any IoT device is to connect with other IoT devices and applications (cloud-based mostly) to relay information using internet transfer protocols. The gap between the device sensors and data networks is filled by an IoT platform. At the same time, the question remains about the choice of the IoT platform when designing IoT systems [1, 2].

The aim of this work is to solve the problem for selecting the IoT platform for increasing the efficiency of decision-making processes using soft computing approach, based on Mamdani-type fuzzy logic inference engine.

Let’s consider the most popular specialized (cloud services) IoT platforms which can be used to create different IoT systems. As a matter of fact, IoT platform is not dominated by one single criteria. In most cases, IoT platforms that, for example, have the highest level of safety do not support the variability of databases and visualization tools and vice versa [3-5]. The before following IoT platforms (alternatives) it is possible to consider most suited for such description: Kaa IoT Platform (E_1) [1]; AWS IoT Platform (E_2) [2]; Microsoft Azure IoT Platform (E_3) [4]; Bosch IoT Suite - MDM IoT Platform (E_4) [3], [16]; IBM Watson IoT Platform (E_5) [3]; Google Cloud IoT Platform (E_6) [3]; Samsung Artik Cloud IoT Platform (E_7) [4].

Each platform has advantages and limitations. The examination of these IoT platforms in detail will be held in order to determine which one is best suited for specialized IoT networks [3-5].

The criteria influence the evaluation and the choice of decisions from the set of alternatives $E=\left(E_1,E_2,...,E_i,...,E_m\right), i=1,2,...,m$, where $m=7$ for above-mentioned IoT platforms. The criteria are selected by the developers based on their own experience and depend on the scope of the task. Such tasks are called multi-criteria tasks. The selection of the criteria is an important and rather complex task since it involves the formulation of a plurality of factors that influence the decision making. Properly selected criteria increase the efficiency of the decision making while solving multi-criteria problems in various types of their applications.

Some criteria are not relevant (within the scope of a special application) in selection process for the specialized IoT platform. According to the various studies and own experience, the authors proposed the use of the following important (main) criteria when selecting IoT platform [3-5]: level of safety and reliability (Q_1); device management (Q_2); integration level (Q_3); level of processing and action management (Q_4); database functionality (Q_5); protocols for data collection (Q_6); usefulness of visualization (Q_7); variety of data analytics (Q_8).

Example of work execution

Appropriate MCDM methods have some limitations: the need to take into account the weigh coefficients of the criteria, the definition of the Pareto-optimal set of alternative decisions, etc. [6-8]. The implementation of the soft computing approach based on Mamdani-type fuzzy logic inference engine looks more perspective, from authors' point of view, for selection of the specialized IoT platform [9-11]. In this case, the previously proposed criteria $Q_1,Q_2,...,Q_8$ can act as input signals (coordinates) or factors $X=\left\{x_1,x_2,...,x_8\right\}$ of the fuzzy logic inference system.

The structure $y=f\left(x_1,x_2,...,x_8\right)$ of the fuzzy logic inference system for selection of the specialized IoT platform includes 3 fuzzy subsystems and has 8 input coordinates $X=\left\{x_j\right\}, j=1,...,8$, and one output y, which are interconnected (by common properties) by the fuzzy dependencies $y_1 = f_1(x_1, x_2, x_3, x_4)$, $y_2 = f_2(x_5, x_6, x_7, x_8)$ and $y = f_3(y_1, y_2)$ of the appropriate rules bases (RBs) of the 3 subsystems [12, 13].

To estimate the input coordinates $X = \{x_j\}$, $j = 1,...,8$, three linguistic terms (LTs) with a triangular form of membership function (MF), in particular "low - L", "medium - M" and "high - H", are chosen. Five LTs $y_1, y_2 \in \{L, LM, M, HM, H\}$ are chosen for the evaluation of intermediate coordinates. The output coordinate y has 7 LTs $y \in \{VL, L, LM, M, HM, H, VH\}$. The partial sets of rules of RBs for the first $y_1 = f_1(x_1, x_2, x_3, x_4)$ and for the third $y = f_3(y_1, y_2)$ subsystems are given in Table 3.1.

Table 3.1 – The partial sets of rules of RBs for the first and for the third fuzzy subsystems

№ of rule	Subsystem $y_1 = f_1(x_1, x_2, x_3, x_4)$					№ of rule	Subsystem $y = f_3(y_1, y_2)$		
	x_1	x_2	x_3	x_4	y_1		y_1	y_2	y
1	L	L	L	L	L	1	L	L	VL
…			…		…	2	L	LM	L
37	M	M	L	L	LM	…		…	…
38	M	M	L	M	M	13	M	M	M
…			…		…	…		…	…
81	H	H	H	H	H	25	H	H	VH

In the example discussed earlier, using MCDM methods for selecting of IoT platform before the system's work, it was necessary to clearly indicate the number of alternatives and criteria, and also to form a decisions matrix with expert estimates (Table 3.1). Using the Mamdani-type algorithm to develop the fuzzy logic inference system for selection of IoT platform, we eliminate the need to form weight coefficients for the criteria. In this case, this soft computing approach allows you to get rid of the limitations on the number of alternatives [14, 15].

The software application (Fig. 3.1) allows evaluating IoT platforms based on certain input coordinates (factors) $X = \{x_1, x_2, ..., x_8\}$ with the use of the fuzzy logic inference engine. The number of IoT platforms is not limited to 7 ($E_1, E_2, ..., E_7$) as in the case of MCDM methods application

(Fig. 3.1). The corresponding software application provides a preview of the RBs in the system's real-time mode. For example, estimates have been made of 10 ($E_1, E_2, ..., E_{10}$) IoT platforms (all data stored in the system) that are ranked without the use of the threshold value (for example, $Thr = 7.2$) and with its use (Table 3.2, Fig. 3.1). The Table 3.2 contains 7 ($E_1, E_2, ..., E_7$) IoT platforms mentioned above and 3 additional IoT platforms: E_8 is the ThingWorks IoT platform, E_9 is the Cisco Cloud IoT platform, E_{10} is the Salesforce IoT platform.

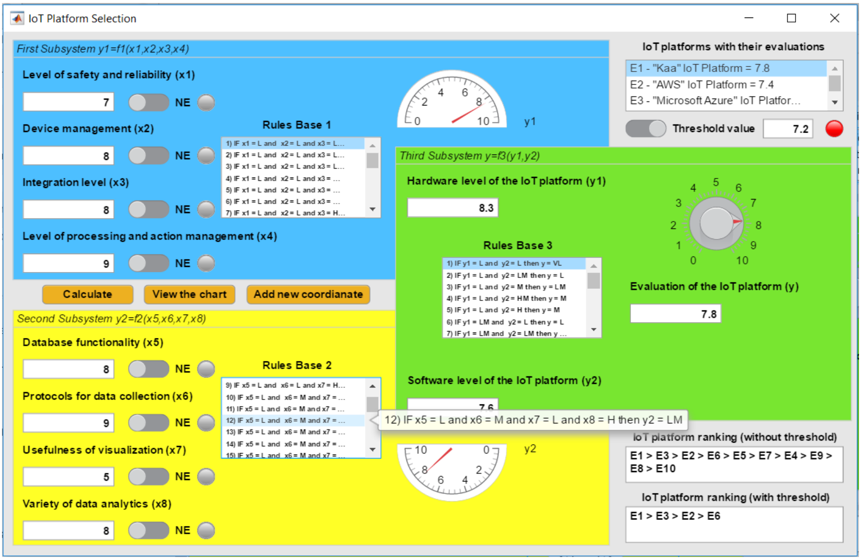

Fig. 3.1 – Fuzzy logic inference system for the selection of specialized IoT platform

Also, the software application (Fig. 3.1) provides the use of the author's proposed method of two-stage correction of fuzzy RBs [12] in case of change the dimension of the input vector (for example, if DM cannot estimate (NE) the values of the input coordinates). It allows in interactive mode to perform automatic correction of fuzzy rules without changing the structure of fuzzy system, which provides an increase in the efficiency and speed of decision-making in various situations [12], [13].

Table 3.2 – Evaluations and ranking of the IoT platforms

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Evaluations of the IoT platforms	7.8	7.4	7.5	6.6	7.15	7.25	7.0	5.9	6.5	5.3
Ranking without the threshold	$E_1 \succ E_3 \succ E_2 \succ E_6 \succ E_5 \succ E_7 \succ E_4 \succ E_9 \succ E_8 \succ E_{10}$									
Ranking with the threshold	$E_1 \succ E_3 \succ E_2 \succ E_6$									

The threshold value is determined by the expert on the basis of his experience and requirements to the necessary operating conditions of the IoT platform. Chart of the IoT platforms ranking (Fig. 3.1, Table 3.2) using the threshold value ($Thr = 7.2$) is presented in Fig. 3.2.

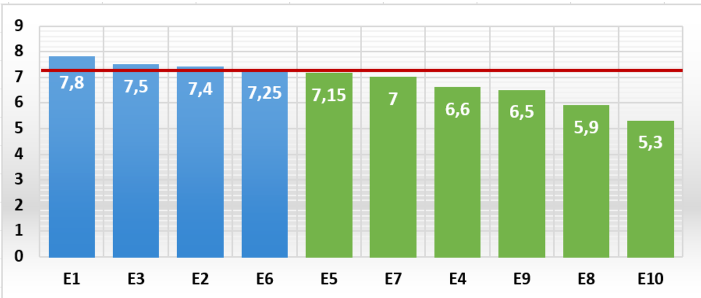

Fig. 3.2 – Chart of the IoT platforms ranking using the threshold value

The use of fuzzy inference engine of the Mamdani type allows users to choose the best specialized platform with any increase (decrease) in the number of alternative platforms without changing the model and structure of the system. This significantly simplifies the decision-making process (compared with the method of linear convolution) when changing the dimension of the set of alternatives. The considered approaches to solving described problem can be easily integrated into various tasks [14, 15].

Theoretical issues for “Development of IoT-based systems” are described in Part VIII (sections 28-30) of the book [*Internet of Things for Industry and Human Application*. In Volumes 1-3. Volume 2. Modelling and Development / V. S. Kharchenko (ed.) – Ministry of Education and Science of Ukraine, National Aerospace University KhAI, 2019].

Tasks for individual execution

1. Select the best specialized IoT platform with any increase (decrease) in the number of alternative platforms without changing the model and structure of the system using fuzzy inference engine of the Mamdani type (according to variants from the Tables 3.3-3.7).
2. Analyze the results.
3. Form a report.

Table 3.3 – Variants 1-5 for individual execution

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Q_1	7	8	8	8	6	7	8	9	6	7
Q_2	8	7	9	6	9	8	6	5	8	9
Q_3	8	6	7	6	7	6	8	8	9	8
Q_4	9	7	8	7	8	8	9	7	8	8
Q_5	8	9	8	5	9	8	7	6	8	9
Q_6	9	6	7	9	5	6	8	5	5	5
Q_7	5	7	6	9	7	7	6	9	8	6
Q_8	8	8	7	6	7	8	6	5	8	6
Threshold value ($Thr = 8.5$)										

Table 3.4 – Variants 6-10 for individual execution

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Q_1	7	9	8	7	6	7	8	6	7	8
Q_2	5	7	9	6	9	6	6	5	8	9
Q_3	8	5	7	5	7	6	8	8	9	8
Q_4	7	7	8	7	4	8	8	7	9	7
Q_5	8	9	8	5	9	6	7	5	8	9
Q_6	9	6	7	9	5	6	8	5	5	5
Q_7	8	6	6	9	7	7	5	9	8	5
Q_8	8	8	7	6	7	9	6	9	6	6
Threshold value ($Thr = 7.0$)										

Table 3.5 – Variants 11-15 for individual execution

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Q_1	9	8	6	8	6	6	7	6	8	9
Q_2	5	6	9	5	7	9	6	5	8	9
Q_3	7	5	6	5	7	6	8	7	7	7
Q_4	7	7	8	7	4	8	7	7	9	7
Q_5	8	9	8	5	9	6	7	7	8	9
Q_6	6	9	8	7	4	8	8	5	6	6
Q_7	8	6	6	9	7	7	7	8	8	5
Q_8	8	8	7	6	7	9	6	9	6	6
Threshold value ($Thr = 7.5$)										

Table 3.6 – Variants 16-20 for individual execution

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Q_1	6	7	9	7	8	9	8	5	9	6
Q_2	5	6	9	5	7	9	6	5	7	9
Q_3	5	7	5	7	6	6	8	9	9	7
Q_4	7	7	8	7	4	7	8	7	9	7
Q_5	8	9	9	5	9	6	7	5	7	9
Q_6	6	9	8	7	7	8	8	5	5	6
Q_7	8	6	6	8	7	6	9	8	7	5
Q_8	9	7	7	6	7	9	6	9	6	6
Threshold value ($Thr = 6.5$)										

Table 3.7 – Variants 21-25 for individual execution

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Q_1	5	7	8	9	7	8	7	5	8	7
Q_2	5	6	9	5	7	9	6	6	7	9
Q_3	7	7	6	8	5	5	8	9	8	7
Q_4	7	9	8	7	4	7	7	8	9	8
Q_5	8	9	9	5	9	6	7	5	7	9
Q_6	9	6	6	5	7	7	8	5	6	6
Q_7	8	6	6	8	8	6	8	7	7	5
Q_8	9	7	7	6	7	9	6	9	6	7
Threshold value ($Thr = 8.0$)										

Report

The report should contain:

– title page with the name of the training work;
– aim of the work;
– problem statement according to the task;
– the progress and results of the study in graphical form;
– analysis of the results and conclusions.

All materials of the report should be printed, billed, the pages should be numbered.

Test questions

1. What is a specialized IoT platform and why is it designed?
2. What is soft computing approach?
3. What is the fuzzy inference engine of the Mamdani type?
4. What is the rules base and what is it for?

Recommended literature

1. A. Javed, *IoT Platforms*. Berkeley: Apress, 2016. DOI: 10.1007/978-1-4842-1940-9_12.

2. G. Keramidas, N. Voros, and M. Hubner, *Components and Services for IoT Platforms*. Cham: Springer, 2017. DOI: 10.1007/978-3-319-42304-3.

3. J. Guth, U. Breitenbucher, M. Falkenthal, F. Leymann, and L. Reinfurt, "Comparison of IoT platform architectures: A field study based on a reference architecture," *Cloudification of the Internet of Things (CIoT)*, pp. 72-77, November 2016. DOI: 10.1109/CIOT.2016.7872918.

4. J. Mineraud, O. Mazhelis, X. Su, and S. Tarkoma, "A gap analysis of Internet-of-Things platforms," in *Computer Communications*, vols. 89-90, 2016, pp. 5-16.

5. M. Kim, N. Y. Lee, and J. H. Park, "Study on the generic architecture design of IoT platforms," in *Advances in Computer Science and Ubiquitous Computing*, vol. 421, 2016, pp. 1039-1045. DOI: 10.1007/978-981-10-3023-9_161.

6. M. Z. Zgurovsky and Y. P. Zaychenko, *The fundamentals of computational intelligence: system approach*. Cham: Springer, 2017. DOI: 10.1007/978-3-319-35162-9.

7. A. P. Rotshtein, "Fuzzy-algorithmic reliability analysis of complex systems," in *Cybern. Syst. Anal*, vol. 47, iss. 6, 2011, pp. 919-931. DOI: 10.1007/s10559-011-9371-x.

8. A. V. Katrenko, V. V. Pasichnyk, and V. P. Pas’ko, *Decision making theory*. Kyiv: Publ. Group BHV, 2009 (in Ukrainian).

9. G. Thomas, P. Lozovyy, and D. Simon, "Fuzzy robot controller tuning with biogeography-based optimization," *Intern. Conf. on IEA/AIE*, pp. 319-327, June 2011. DOI: 10.1007/978-3-642-21827-9.

10. Y. P. Kondratenko and N. Y. Kondratenko, "Soft computing analytic models for increasing efficiency of fuzzy information processing in decision support systems," in *Decision Making: Processes, Behavioral Influences and Role in Business Management*, R. Hudson, Ed. New York: Nova Science Publishers, pp. 41-78, 2015.

11. Y. P. Kondratenko, S. B. Encheva, and E. V. Sidenko, "Synthesis of intelligent decision support systems for transport logistic", *IEEE Intern. Conf. IDAACS-2011*, pp. 642-646, September 2011.

12. Y. P. Kondratenko and I. V. Sidenko, "Decision-Making Based on Fuzzy Estimation of Quality Level for Cargo Delivery," in *Recent Developments and New Directions in Soft Computing. Studies in Fuzziness and Soft Computing*, L. Zadeh, et al., Eds., vol. 317, 2014, pp. 331-344. DOI: 10.1007/978-3-319-06323-2_21.

13. Y. P. Kondratenko and Ie. V. Sidenko, "Method of Actual Correction of the Knowledge Database of Fuzzy Decision Support System with Flexible Hierarchical Structure," in *Journal of Computational Optimization in Economics and Finance*, 4(2/3), 2012, pp. 57-76.

14. M. Solesvik, Y. Kondratenko, G. Kondratenko, I. Sidenko, V. Kharchenko, and A. Boyarchuk, "Fuzzy decision support systems in marine practice", *IEEE Intern. Conf. on Fuzzy Systems (FUZZ-IEEE)*, July 2017. DOI: 10.1109/FUZZ-IEEE.2017.8015471.

15. G. Kondratenko, Y. Kondratenko, and I. Sidenko, "Fuzzy Decision Making System for Model-Oriented Academia/Industry Cooperation: University Preferences," in *Complex Systems: Solutions and Challenges in Economics, Management and Engineering. Studies in Systems, Decision and Control*, C. Berger-Vachon, A. Gil Lafuente, J. Kacprzyk, Y. Kondratenko, J. Merigó, and C. Morabito, Eds., vol. 125, 2018, pp. 109-124. DOI: 10.1007/978-3-319-69989-9_7.

APPENDIX A

TEACHING PROGRAMME OF THE COURSE PC4 "DEVELOPMENT AND IMPLEMENTATION OF IOT-BASED SYSTEMS"

DESCRIPTION OF THE COURSE

TITLE OF THE COURSE	Code
Development and Implementation of IoT-based Systems	**PC4**

Teacher(s)	Department
Coordinating: Prof., DrS. Yu.P. Kondratenko **Others:** Modules PCM4.2, PCM4.3: Ass. Prof., Dr. G.V. Kondratenko, Ass. Prof., Dr. Ie.V. Sidenko, Ph.D. Student M.O. Taranov. Module PCM4.1: Prof., DrS. I.S. Skarha-Bandurova, Ph.D. Student A.Y. Velykzhanin, Senior Lect. L.V. Barbaruk	Intelligent Information Systems (PMBSNU) Computer Science and Engineering (V. Dahl EUNU)

Study cycle	Level of the course	Type of the course
PhD	A	Bounden

Form of delivery	Duration	Language(s)
Full-time tuition	One semester	English

Prerequisites	
Prerequisites: Computer Networks; Information Networking Technologies; Embedded systems; Theory of Control Systems; Network security; Multi-criteria Decision Making; Fuzzy Sets and Fuzzy Logic; Artificial Intelligence Systems; Soft Computing; Digital electronics; Microcontrollers	**Co-requisites (if necessary):** Data encryption; Modelling systems; Machine Learning; Multi-agent Systems and Technologies

Credits of the course	Total student workload	Contact hours	Individual work hours
3	90	42	48

Aim of the course: competences foreseen by the study programme
The aim of the course is to give deep understanding principles of operation the platforms and tools for IoT application, acquisition skills in of operating with

IoT-cellular modules, configuring and administrating IoT-cloud, customization fleet of devices with cloud platform. In addition, the sub-aim is to deepen the knowledge of IoT-based systems for future practical use for the development of prototype systems, to acquire new knowledge and skills to configure IoT-based systems and their further learning to adapt to different operating conditions. Relevant knowledge is based on a study of the features and methods of information models formation for IoT-based devices and technologies for processing and transfer data between devices. In addition, corresponding knowledge is based on exploring and assimilation methods and technologies of machine learning, principles of construction of multi-agent interconnected IoT-based devices and methods of multi-criteria decision making for choosing the IoT platform for further development of own IoT system. Obtained knowledge will allow choosing the means and technologies for the development and implementation of IoT-based systems.

Learning outcomes of course	**Teaching/learning methods**	**Assessment methods**
At the end of course, the successful student will be able to: 1. Explain and discuss the basic criteria to choose the platform and tools to design IoT application	Interactive lectures, Learning in laboratories, Just-in-Time Teaching	Course Evaluation Questionnaire
2. Choose hardware and software platforms for prototyping and building IoT systems	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire
3. Explain main principles for adding cellular connectivity to IoT projects	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire
4. Compare IoT prototyping kits and development boards	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire
5. Define the information models of IoT-based devices and describe the functional possibilities and limitations using existing tools, means and technologies, in particular, Eclipse Vorto Software	Interactive lectures, Just-in-Time Teaching	Course Evaluation Questionnaire, Testing based on alternative method of assessment
6. Analyze methods and technologies of cybersecurity in IoT networks	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire

7. Use tools and technologies for modeling IoT devices, integrating them into an IoT system, process and analyze relevant data on product rules and forecasting methods	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire, Testing based on alternative method of assessment
8. Rate and select protocols and standards for data processing and transfer for your own IoT system and network using Fuzzy TOPSIS method	Interactive lectures, Learning in laboratories, Just-in-Time Teaching	Course Evaluation Questionnaire
9. Create and teach multi-agent IoT-based systems	Interactive lectures, Learning in laboratories	Course Evaluation Questionnaire
10. Use existing methods of multi-criteria decision making for comparing and choosing the best decision in IoT sphere	Interactive lectures, Just-in-Time Teaching	Testing based on alternative method of assessment
11. Apply soft computing, in particular, fuzzy logic approach for the selection of specialized IoT platform	Interactive lectures, Just-in-Time Teaching	Course Evaluation Questionnaire
12. Analyze features of methods and technologies of machine learning	Interactive lectures, Just-in-Time Teaching	Testing based on alternative method of assessment

Themes	**Contact work hours**							**Time and tasks for individual work**	
	Lectures	Consultations	Seminars	Practical work (training)	Laboratory work	Placements	**Total contact work**	**Individual work**	**Tasks**
1. IoT-based system development process 1.1. Phases and deliverables of an IoT technical strategy 1.2. The IoT development	2		2				**4**	**4**	1.5. IoT project application areas and business models

strategies 1.3. Strategies to planning IoT architectures 1.4 IoT-based systems design methodologies									1.6. IoT acceleration platforms
2. The base components of the IoT systems connectivity to IoT projects 2.1. Major types of technological offerings from IoT 2.2. IoT device classification 2.3. IoT device design flow 2.4. Relationship between Sensor Networks and IoT 2.5. Basic principles for adding cellular connectivity to IoT projects: working with GSM-modules	2			4			**6**	**5**	2.6. IoT system customization 2.7. Deploying modules to the edge devices 2.8. GPS/Cellular Asset tracking
3. The IoT development boards and platforms for prototyping 3.1. The IoT platforms: types and selection criteria 3.2 Evaluation of IoT device management tools 3.3. Real-time data streaming and processing	2		2				**4**	**7**	3.4. IoT device management platform vs IoT data management platform 3.5. Managing the fleet of devices
4. IoT-based devices: models and network communication protocols 4.1. Types of models for IoT-based devices 4.2. Tools and means for the development of information models 4.3. Network communication protocols for IoT-based devices	2				2		**4**	**5**	4.4. Structural and functional models of IoT-based devices 4.5. Eclipse Vorto for creating information models

5. Technologies for data processing in IoT-based systems 5.1. Technologies for data collection and analysis from IoT devices 5.2. Technologies for data processing 5.3. Methods of management and forecasting	2			2			**4**	**4**	5.4. Methods and approaches for data processing in IoT-based systems during data transfer
6. Protocols and standards for data transfer between IoT-based devices 6.1 Protocols for data transfer 6.2. Standards for data transfer 6.3. Cybersecurity of IoT-based devices	2		2		2		**6**	**7**	6.4. Methods of physical and information protection in IoT 6.5. Risks in information security
7. Management systems and IoT platforms 7.1. Types and capabilities of management systems and IoT platforms 7.2. Multi-criteria approach for choosing the IoT platform 7.3. Soft computing for the selection of specialized IoT platform	2			2	2		**6**	**6**	7.4. Platform for control and management “iRidium” 7.5. The programming environment Arduino IDE
8. Multi-agent approach for development and management of IoT systems 8.1. Types and characteristics of agents 8.2. Communication agents with the external environment 8.3. Data transfer techniques between agents in IoT systems	2		2				**4**	**4**	8.4. AnyLogic development environment. 8.5. Self-organizing IoT systems 8.6. Agent modeling

9. Methods and approaches for learning of IoT-based systems 9.1 General principles of M2M learning and self-learning systems 9.2. Technologies and applications of M2M learning 9.3. Neural networks for learning of IoT-based systems	2				2		**4**	**6**	9.4. Self-learning IoT systems 9.5. Problems and prospects of machine learning
On the whole	**18**		**8**	**8**	**8**		**42**	**48**	

Assessment strategy	**Weight in %**	**Deadlines**	**Assessment criteria**
Lecture activity, including fulfilling special self-tasks	10	7,14	85% – 100% Outstanding work, showing a full grasp of all the questions answered. 70% – 84% Perfect or near perfect answers to a high proportion of the questions answered. There should be a thorough understanding and appreciation of the material. 60% – 69% A very good knowledge of much of the important material, possibly excellent in places, but with a limited account of some significant topics. 50% – 59% There should be a good grasp of several important topics, but with only a limited understanding or ability in places. There may be significant omissions. 45% – 49% Students will show some relevant knowledge of some of the issues involved, but with a good grasp of only a minority of the material. Some topics may be answered well, but others will be either omitted or incorrect. 40% – 44% There should be some work of some merit. There may be a few topics answered partly or there may be scattered or perfunctory knowledge

			across a larger range. 20% – 39% There should be substantial deficiencies, or no answers, across large parts of the topics set, but with a little relevant and correct material in places. 0% – 19% Very little or nothing that is correct and relevant.
Learning in laboratories	30	7,14	85% – 100% An outstanding piece of work, superbly organized and presented, excellent achievement of the objectives, evidence of original thought. 70% – 84% Students will show a thorough understanding and appreciation of the material, producing work without significant error or omission. Objectives achieved well. Excellent organization and presentation. 60% – 69% Students will show a clear understanding of the issues involved and the work should be well written and well organized. Good work towards the objectives. The exercise should show evidence that the student has thought about the topic and has not simply reproduced standard solutions or arguments. 50% – 59% The work should show evidence that the student has a reasonable understanding of the basic material. There may be some signs of weakness, but overall the grasp of the topic should be sound. The presentation and organization should be reasonably clear, and the objectives should at least be partially achieved. 45% – 49% Students will show some appreciation of the issues involved. The exercise will indicate a basic understanding of the topic, but will not have gone beyond this, and there may well be signs of confusion about more complex material. There should be fair work towards the laboratory work

			objectives. 40% – 44% There should be some work towards the laboratory work objectives, but significant issues are likely to be neglected, and there will be little or no appreciation of the complexity of the problem. 20% – 39% The work may contain some correct and relevant material, but most issues are neglected or are covered incorrectly. There should be some signs of appreciation of the laboratory work requirements. 0% – 19% Very little or nothing that is correct and relevant and no real appreciation of the laboratory work requirements.
Course Evaluation Quest	60	8,16	The score corresponds to the percentage of correct answers to the test questions

Author	**Year of issue**	**Title**	**No of periodical or volume**	**Place of printing. Printing house or internet link**
Compulsory literature				
D. Uckelmann, M. Harrison, F. Michahelles	2011	Architecting the Internet of Things		Berlin, Heidelberg: Springer-Verlag
F. Hu	2016	Security and Privacy in Internet of Things (IoTs): Models, Algorithms, and Implementations		USA: CRC Press
H. Geng	2017	Internet of Things and Data Analytics Handbook		UK: Wiley
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APPENDIX B

AT COMMANDS FOR TRAINING 1 (PCM4.1)

Command	Response Structure	Example Response
Module readiness for operation		
AT	**Ok**	Ok
Request information about the device		
ATI	<***info***> **OK** <***info***> - model and module version	SIM800 R14.18 OK
Request for installed software version		
AT + CGMR	<***revision***> **OK** <***revision***> - software model and version	Revision: 1418B04SIM800L24 OK
Module readiness to make calls		
AT + CCALR?	**+ CCALR:** <***mode***> **OK** <***mode***> - readiness identifier: **0** - the module is not ready to make calls **1** - the module is ready to make calls	+ CCALR: 1 OK
Call quality request		
AT + CSQ	**+ CSQ:** <***rssi***> **,** <***ber***> **OK** <***rssi***> - signal quality (from 10 and above - normal): **0** -115 dBm and less than **1** -111 dBm **2 ... 30** -110 ... -54 dBm **31** -52 dBm and more than **99** cannot be determined <***ber***> - RXQUAL (a measure of signal quality), the value from the GSM 05.08 table - ETSI : **0 ... 7** - bit error rate (less is better) **99** cannot be determined	+ CSQ: 8.0 OK
IMEI module request		
AT + GSN	<***sn***> **OK** <***sn***> - IMEI module	864713035030892 OK

Request module identification information		
AT + GSV	Module text information	SIMCOM_Ltd SIMCOM_SIM800L Revision: 1418B04SIM800L24 OK
Supply voltage		
AT + CBC	**+ CBC: <*bcs*> , <*bcl*> , <*voltage*>** **OK** **<*bcs*>** - charging status **0** - no charge **1** - charging is **2** - charging is complete **<*bcl*>** - the amount of charge remaining in percent (1 ... 100) **<*voltage*>** - module supply voltage, in mV	+ CBC: 0.73.3988 OK
Network Registration Type		
AT + CREG?	**+ CREG: <*n*> , <*stat*>** **OK** **<*n*>** - answer parameter **0** - unsolicited network registration code disabled **1** - unsolicited network registration code enabled **2** - unsolicited network registration code included with location information **<*stat*>** - status **0** - unregistered, not looking for a new operator to register **1** - registered in the home network **2** - unregistered, but in search of a new operator for registration **3** - registration is prohibited **4** - unknown **5** - registered, in roaming	+ CREG: 0.1 OK
Operator Information		
AT + COPS?	**+ COPS: <*mode*> , [<*format*> , <*oper*>]** **OK** **<*mode*>** - registration mode **<*format*>** - display format **<*oper*>** - operator name in the specified	+ COPS: 0.0, "MegaFon" Ok

	format	
Getting a list of all operators		
AT + COPN	**+ COPN: <*numeric1*> , <*alpha1*>** **[<CR> <LF> +** **COPN: <*numeric2*> , <*alpha2*> [...]]** **OK** **<*numeric n*>** - the digital code of the operator **<*alpha n*>** - the text code of the operator	... + COPN: "24008", "vodafone" + COPN: "24010", "Swefour AB" + COPN: "24201", "TELENOR" + COPN: "24202", "NetCom" + COPN: "24403", "FINNET " + COPN:" 24405 "," Elisa Corporation " + COPN:" 24409 "," FINNET " ... ok
GSM module phone status		
AT + CPAS	**+ CPAS: <*pas*>** **OK** **<*pas*>** - status **0** - ready to execute commands from terminal **2** - unknown (command execution not guaranteed) **3** - incoming call, but the module is ready to execute commands **4** - outgoing call, but the module is ready to execute commands	+ CPAS: 4 OK

АНОТАЦІЯ

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Викладено матеріали практичної частини курсу PC4 “Розробка та впровадження IoT систем”, підготовленого в рамках проекту ERASMUS+ ALIOT “Internet of Things: Emerging Curriculum for Industry and Human Applications” (573818-EPP-1-2016-1-UK-EPPKA2-CBHE-JP).

Наведена структура робіт з перевірки рівня засвоєння знань з курсу, відповідний практичний матеріал, приклади виконання завдань та критерії оцінювання. В процесі навчання наводяться теоретичні аспекти розробки та впровадження IoT систем. Матеріали охоплюють основні концепції та підходи до розробки і імплементації IoT систем, моделі для IoT пристроїв і технології для обробки та передачі даних, та інтелектуальні методи і підходи для управління та навчання IoT систем.

Призначено для інженерів, розробників та науковців, які займаються розробкою та впровадженням IoT систем, для аспірантів університетів, які навчаються за напрямами IoT, кібербезпеки в мережах, комп'ютерних наук, комп'ютерної та програмної інженерії, а також для викладачів відповідних курсів.

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