

UDC 004.738.5

## THE METHOD OF SELECTING A HARDWARE-SOFTWARE IoT-PLATFORM TAKING TO ACCOUNT THE FACTORS OF FUNCTIONALITY AND COST

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## МЕТОД ВИБОРУ АПАРАТНО-ПРОГРАМНОЇ ІОТ-ПЛАТФОРМИ З УРАХУВАННЯМ ФАКТОРІВ ФУНКЦІОНАЛЬНОСТІ ТА ВАРТОСТІ

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## МЕТОД ВЫБОРА АПАРАТНО-ПРОГРАММНОЙ ІОТ-ПЛАТФОРМЫ С УЧЕТОМ ФАКТОРОВ ФУНКЦИОНАЛЬНОСТИ И СТОИМОСТИ

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**Abstract.** In the paper proposes a method for increasing the efficiency of the decision-making process for the selection of software and hardware platforms for the implementation of projects in the IoT-sphere that taking into account maximum functionality and acceptable cost. The efficiency of the process of selecting an appropriate platform can be achieved by minimizing the time it takes to select an IoT platform. The implementation of the method involves the creation of an automated system for selecting IoT-platforms that interacts with the classification database. The procedure for creation of a database of classification characteristic of IoT-platforms, which represented on the market, is formalized. For creation database is using the facet classification method. There is developed the procedure for creation facet formulas that is taking into account the functional features of IoT-platforms. As a criterion for selecting IoT-platforms there is used a set of user-defined parameters. The principle of work the automated system is formalized in the form of an algorithm.

**Key words:** Internet of things, IoT-platform, universal classification model, faset, automated selection system of IoT-platform.

**Анотація.** У статті пропонується метод підвищення ефективності процесу ухвалення рішення щодо вибору апаратно-програмної платформи для реалізації проектів у сфері Internet of Things (IoT) з урахуванням забезпечення максимальної функціональності та прийнятної вартості. Зростання популярності концепції IoT призвів до появи значної кількості різноманітних апаратно-програмних IoT платформ, які суттєво відрізняються одна від одної. Вибір відповідної апаратно-програмної платформи базується на комплексному аналізі багатьох факторів, а саме: область застосування, бажаний рівень безпеки, які методи роботи з даними підтримуються, наявність фахівців для роботи з платформою тощо. Проведення подібного аналізу вимагає відповідної кваліфікації та певних витрат часу, що, у свою чергу, призводить до збільшення часових витрат на реалізацію всього проекту. Ефективність процесу вибору оптимальної апаратно-програмної платформи може бути досягнута за рахунок мінімізації часу, необхідного для вибору IoT-платформи. Реалізація методу передбачає створення автоматизованої системи вибору платформи IoT. Формалізована процедура створення бази даних класифікаційних ознак IoT-платформ, які представлені на ринку. Для створення бази даних пропонується застосувати метод фасетної класифікації. Формалізована процедура створення фасетних формул, яка враховує функціональні особливості IoT-платформ. Надано схему алгоритму

формування бази даних. В якості критерію вибору IoT-платформи використовується набір показників, які задаються користувачем. Принцип роботи системи формалізовано у вигляді алгоритму. Надана структурна схема автоматизованої системи вибору IoT платформ, описана її функціональна структура.

**Ключові слова:** Інтернет речей, IoT-платформа, класифікаційна модель, фасет, автоматизована система вибору IoT-платформ.

**Аннотація.** В статье, предлагается метод повышения эффективности процесса принятия решения относительно выбора аппаратно-программной платформы для реализации проектов в области IoT, с учетом обеспечения максимальной функциональности и приемлемой стоимости. Эффективность процесса выбора подходящей платформы может быть достигнута путем минимизации времени, необходимого для выбора платформы IoT. Реализация метода предполагает создание автоматизированной системы для выбора IoT-платформ, которая взаимодействует с классификационной базой данных. Формализована процедура создания базы данных классификационных признаков IoT-платформ представленных на рынке. Для создания базы данных предлагается использовать метод фасетной классификации. Формализована процедура создания фасетных формул, учитывающая функциональные особенности IoT-платформ. В качестве критерия для выбора IoT-платформ используется набор параметров задаваемых пользователем. Принцип работы системы формализован в виде алгоритма, описана функциональная структура системы

**Ключевые слова:** Интернет вещей, IoT-платформа, классификационная модель, фасета, автоматизированная система выбора IoT-платформа.

One of the trends in the development of modern information technology is realized in the concept of "Internet of Things" (IoT). In general, IoT is a further development of complex automation concept that was transferred from the industrial sphere to all aspects of human life [1].

Global analytical agency McKinsey based on the results of 2015 estimated that the amount of investments in IoT till the 2025 will be \$11 trillion (11% of Global GDP). The market for IoT hardware components (for example, sensors) and IoT connectivity solutions has existed for a long time, whereas the IoT platform market is a new segment for which the annual growth rate is projected to be 33% for the next 6 years. In 2021 it is expected that the market of IoT-platforms will grow up to \$ 1.6 billion [2].

The key concept in IoT is the so-called IoT platform. The IoT platform is the central object in the concept of the Internet of Things, which unites the real and virtual components and consists of four main components - hardware, software, telecommunications and information security [2].

The growth of IoT concept popularity leded a huge amount of IoT-platforms appearance, which differs significantly from each other [3]. This circumstance sets a new task before users – the task of the most suitable from the technical and economic point of view IoT-platform selection for each specific situation.

The choice of the most suitable IoT platform is based on a variety of factors complex analysis, such as: range of use, presence of specialists who work with the platform, supported methods of data processing, the desired level of security, etc. Obviously, carrying out such an analysis requires appropriate qualification and a certain amount of time, which reduces the effectiveness of interaction between suppliers and potential users of IoT-technologies, and the time spent on a platform selection significantly increases the overall development time of projects.

The efficiency of the process of selecting an appropriate platform can be achieved by minimizing the time it takes to select an IoT platform. This time depends on the size of the PF set available for selecting the IoT platforms and the time taken to evaluate the capabilities of each solution. It is also advisable to take into account the limitation on the cost of the IoT platform.

This task can be presented in the following general form [4]:

$$\begin{aligned} T_S = f(PF, \overline{t_{ES}}) &\rightarrow \min, \\ C_i &\rightarrow \min, \end{aligned} \tag{1}$$

where  $T_s$  is a time spent on selection of the most suitable for particular situation IoT-platform;  $C_i$  is a cost of  $i$ -th IoT-platform;  $PF$  is a set of IoT-platform, power  $pf$ ;  $\overline{t_{ES}}$  is an average time spent on assessment of  $i$ -th IoT-platform characteristics, that is defined as:

$$\overline{t_{ES i}} = \sum_k t_{ESk} \cdot m_k, \quad (2)$$

$$i = \overline{1, n}, k = \overline{1, p},$$

where  $t_{ESk}$  is time spent on assessment of  $k$ -th characteristic of  $i$ -th IoT-platform;  $m_k$  is an element of set  $M = \{m_{(k)}\}$ ;  $k = \overline{1, p}$  that describes characteristics of  $i$ -th IoT-platform.

The solution of this problem can be achieved by creating an automated selection system of the IoT platform, in accordance with the stated requirements of the customer.

**The goal of this work** is proposes a method for increasing the efficiency of the decision-making process for the selection of software and hardware platforms for the implementation of projects in the IoT-sphere that taking into account maximum functionality and acceptable cost.

The work of the automated system assumes the existence of a database  $B$  of IoT platforms. For forming database  $B$ , it is necessary to classify IoT platforms, which are present on the market. Obviously, in this case there will be no rigid classification structure, since one and the same IoT platform can fall into different classes. In addition, we cannot define a finite number of classes in the classification system - new classes can appear in the process of analyzing the characteristics of different IoT-platforms. Taking into account the above, to create a classification model it is advisable to apply the facet classification method [5].

The facet method involves creating a classification system from a set of independent subsets - facets. Each facet contains a collection of values that a classification attribute can take. Values of different facets should not be repeated. The classification system is described by a faceted formula of the form  $KS = (FS_1, FS_2, \dots, FS_n)$  and the same object can be part of different facets.

In general, the following functional modules can be distinguished as distinctive features in the logical structure of the IoT platform (Fig 1):

1. Connection and translation module. There are miss unified standards in the field of IoT, devices (things) can use different protocols of interaction, as well as generate data in different formats. This module provides the conversion of different protocols and different data formats into an internal, unified, universal virtual format.

2. Device management module. The tasks of this module are provision of preparation and configuration of devices (things), remote control, monitoring of work and detection of failures, updating of the software component of devices.

3. Data management module. The process of data collection and processing is one of the main processes in the IoT concept. The speed of data acquisition, their reliability, affects the ultimate effectiveness of the functioning of devices (things) within the framework of the IoT concept. This module should provide: the ability to store big data size in various formats and forms, high speed of processing and access to data; reliability of data.

4. The module of actions management. The tasks of this module are to perform certain actions. The actions are performed in accordance with the result obtained after processing the data transferred by the device (thing). This level uses the IFTTT model (If-this-then-that rule) - "if this happened, then do this."

5. The analysis module. This module provides a comprehensive analysis of data, aimed at achieving the optimal result. For example, when analyzing data from the sensors of the smart house

system, you can find a combination in which the optimal level of illumination and heating in the house will be realized while minimizing energy costs. This level involves the use of all available analysis algorithms - from dynamic computation and prediction to neural networks and machine learning.

6. Reporting module. This module can also be called a data visualization module. The main task of this level is the transformation of data into a form that is convenient for human perception, for example, in the form of various diagrams or in the form of 2D or 3D models / layouts.

7. Integration module. The ecosystem of the IoT platform cannot exist separately; it must integrate with other similar platforms or with external systems (for example, ERP or CRM systems). The task of this module is to provide integration with the external environment through the use of standardized interfaces.

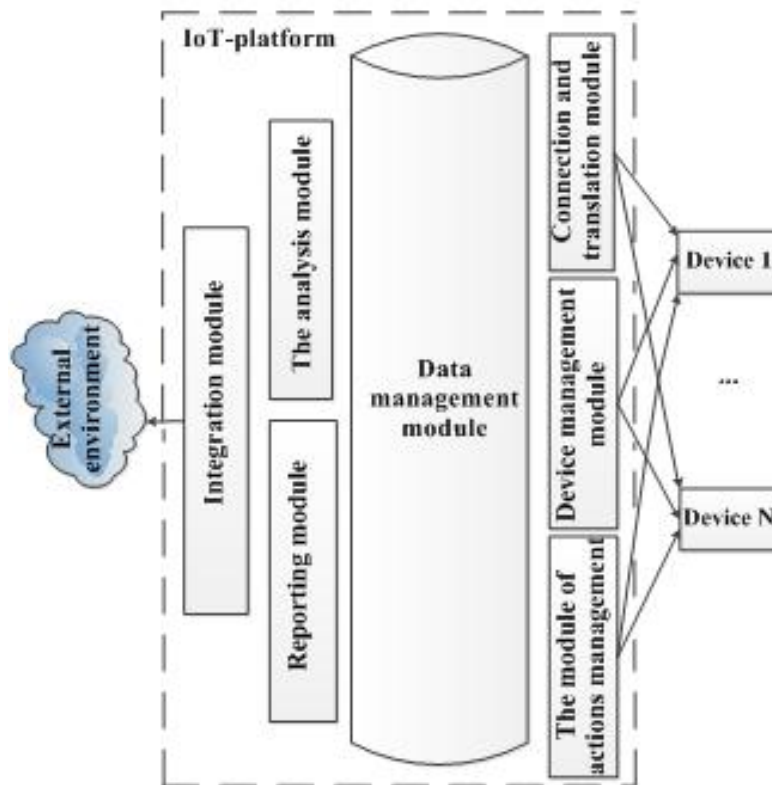


Figure 1 – The logical structure of IoT-platforms

The construction of facet formulas should be performed taking into account the above-mentioned functional features of IoT-platforms. This procedure can be formalized as follows.

Let  $PF$  is a set of available for selection of IoT-platforms:

$$U_{PF} = \{u_{PF_i} \mid i = 1, \dots, t\}, \quad (3)$$

where  $u_{PF_i}$  is the element of the set  $PF$  (IoT -platform).

Then the set of facets  $FS$  on the set  $U$  is defined as:

$$FS(U) = \{FS_k \mid k = 1, \dots, s\}, \quad (4)$$

where  $FS_k$  is the facet that defines the  $k$ -th classification feature of the IoT platform.

Each facet can take a certain set of valid values:

$$\phi^{FS_k} = \{\phi_{k1}, \dots, \phi_{km}\}, \quad (5)$$

where  $m$  is the set of admissible values within the  $i$ -th facet

For each element of the set  $PF$ , we must specify at least one value of the facet attribute:

$$\phi_j(u_{PFi}) = \{\phi_{ks}(u_{PFp}), p \in \{1, \dots, k\}\} \subset \phi^{FS_k}. \quad (6)$$

The set of values of all facet attributes is defined as:

$$\phi_j(u_{PFi}) = \left\{ \begin{array}{l} \phi_{ks}(u_{PFp}), \\ \forall p : p \in \{1, \dots, k\}, \phi_j(u_{PFi}) \neq \emptyset \end{array} \right\} \quad (7)$$

then the facet formula  $Ff$  for the IoT platform is defined as:

$$Ff(u_{PFi}) = \left\{ \begin{array}{l} [FS_j : \phi_j(u_{PFi})] | FS_j \in FS(U), \\ \phi_j(u_{PFi}) \in \phi^{FS_k} \forall j \in \{1, \dots, k\}, \\ \phi_j(u_{PFi}) \neq \emptyset. \end{array} \right\} \quad (8)$$

In paper [6] there is offer the basic universal classification model of IoT-platforms which allows defining set of classification signs  $U$  necessary for creation of the data base (Fig. 2).

For the formation of database  $B$ , a procedure is proposed that is carried out in several stages:

1. Analysis of the set of IoT-platforms  $PF$ , power  $pf$ . It is necessary to find characteristics that correspond to the set of facets  $FS$ , the power of  $fs$ . As a result, for each IoT platform is formed a vector  $\bar{A}$ , whose elements take values:

$$a_i = \begin{cases} 1, & \text{if the platform belongs to the } i\text{-th class,} \\ 0, & \text{otherwise.} \end{cases} \quad (9)$$

$$i \in [1, fs].$$

2. Determine the functionality of the IoT platform. According to the standard ISO 25010: 2011, functionality is the ability of an object, under certain conditions, to solve the tasks that users need. To estimate functionality, it needs to define the following parameters [7]:

- Functional suitability. It is ability to solve the required set of tasks;
- Accuracy. It is ability to produce the desired results;
- Ability to interact with other systems;
- Conformity of the object with industrial standards, regulatory and legislative acts, other regulatory standards.

Plane of basic characteristics		Plane of specific characteristics	
Classification feature	Class of IoT platform	Classification feature	Class of IoT platform
Type of realization	Unidirectional	Application area	Industrial
	Universal		Medical
Type of support	Fully supported		Consumer
	Partly supported		Multi-purpose
	Non-supported		
Type of compatibility with operation systems	Mobile		Visualization opportunity
	Stationary		With visualization
	Cross-platformed		
Type of compatibility with databases	Relational	Data processing methods	Real time
	Non-relational		Serial
Type of architecture	Open		
	Closed		
Type of supported network protocols	Basic	Devices management methods	Centralized
	Specialized		Decentralized
	Combined		
Type of development strategy	Vertically integrated up	Type of information security	Authorization platform
	Vertically integrated down		Encryption platform
	Affiliate		

Figure 2 – Universal classification model of IoT-platforms

Each of the listed parameters in the IoT-platform, according to the manufacturer's description, corresponds to a certain set of functions. The task is to confirm the compliance of the declared functions for each IoT platform in the process of its testing and determine its functionality:

$$OF_i = \frac{F_i^T}{F_i^0}, i \in [1, n], \quad (10)$$

where  $F_i^T$  is the number of functions corresponding to the claimed;  $F_i^0$  is total number of declared functions.

3. Adds the cost of the IoT platform  $C_i, i \in PF; i = 1, \dots, n$  into the database  $B$ . If the IoT platform is free, the cost is take equal 1.

Fig. 3 shows the algorithm of forming the base  $B$  in a graphical form.

After the process of forming the database  $B$  has been completed, the system is ready for operation.

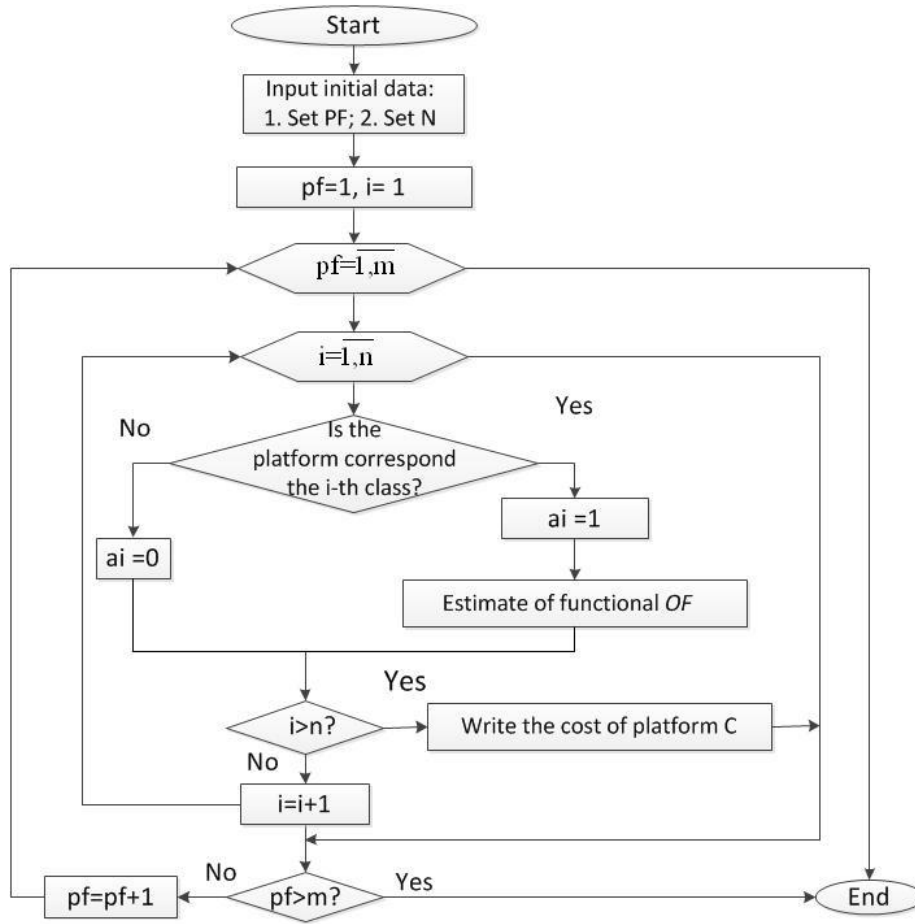


Figure 3 – The algorithm of forming the base B

The system, based on the user's request, generates a preference vector  $\bar{P}$ , whose elements take values:

$$p_i = \begin{cases} 1, & \text{if the user needs the } i\text{-th characteristic of the platform,} \\ 0, & \text{otherwise,} \end{cases} \quad (11)$$

$$i \in [1, n]$$

and defines the coefficient of cost  $\beta$ , which takes on values:

$$\beta = \begin{cases} 1, & \text{if the cost is taken into account when selecting a platform,} \\ 0, & \text{otherwise.} \end{cases} \quad (12)$$

On the next step, the system defines a set of platforms  $S$  of power  $s$ , ( $S \subset PF$ ), that corresponds the user's requirements. For each  $k$ -th element of the set  $S$  ( $k = 1, \dots, s$ ), it is formed platform selection vector  $\bar{V}$ , whose elements take the values:

$$v_i = \begin{cases} 1, & \text{if } a_i \geq p_i, \\ 0, & \text{if } a_i < p_i, \end{cases} \quad (13)$$

$$a_i \in \bar{A}, p_i \in \bar{P}.$$

The next step – it is choice of the most effective IoT platform that best meets the user's request. This is performed taking into account the maximization of IoT platform functionality and minimization of costs, which is usually included in the user of preferences. For this, the system determines the objective function that has the following view:

$$\gamma_i = \sum_i v_i \cdot OF_i + \beta \cdot \frac{1}{C_i} \rightarrow \max i \in [1, n], i \in PF. \quad (14)$$

If necessary, the user can be provided with a complete list of platforms that is sorted in descending order of corresponds to his request. If the result of the system does not satisfy the user, he is invited to change the requirements for the platform and perform the procedure anew.

Fig. 4 shows the algorithm of work of the system in a graphical form.

Obviously, automation of the process of selecting will not only significantly reduce the time  $T_s$  that spent on choosing the IoT platform, but also improve the quality of the decision, which will avoid errors that may arise in the future due to improper selection of the IoT platform.

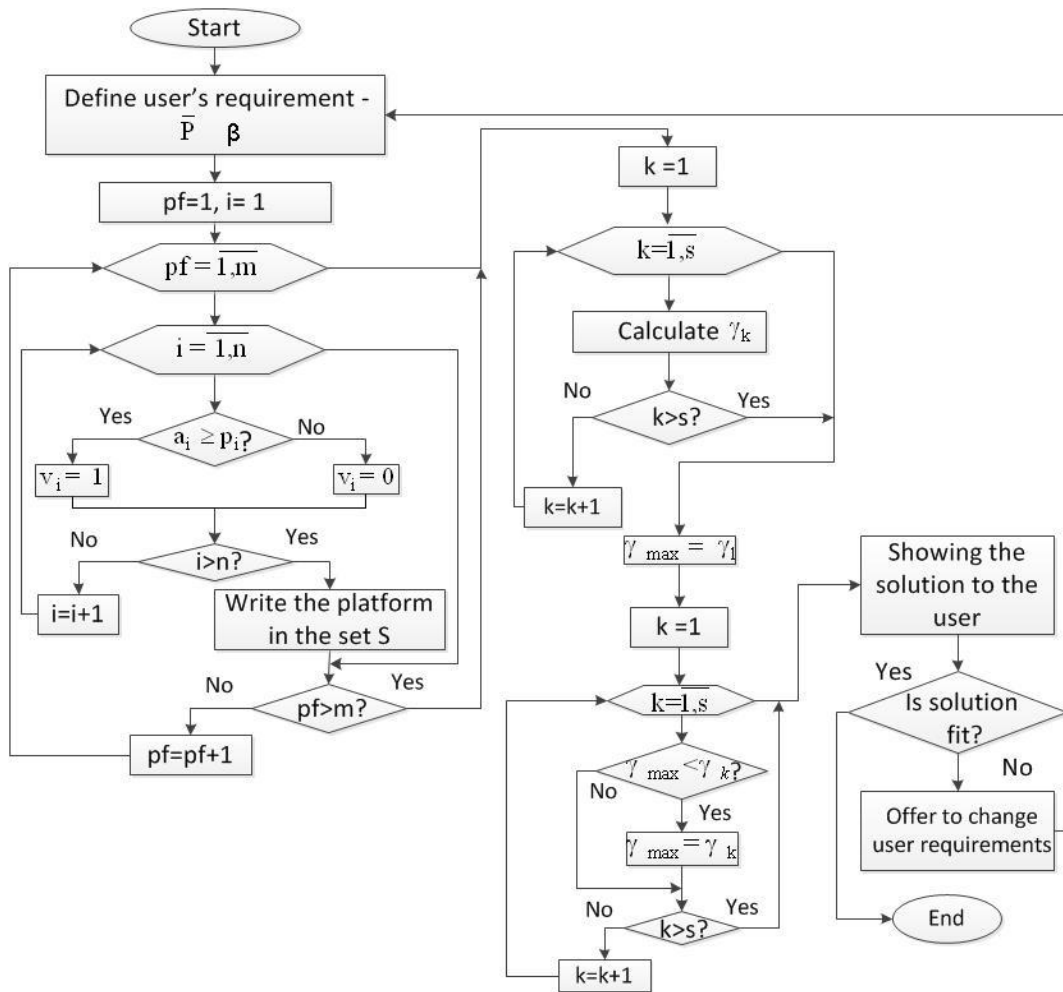


Figure 4 – The algorithm of work of the system

The overall structure of an automated selection system of IoT platform is showed Fig. 5.



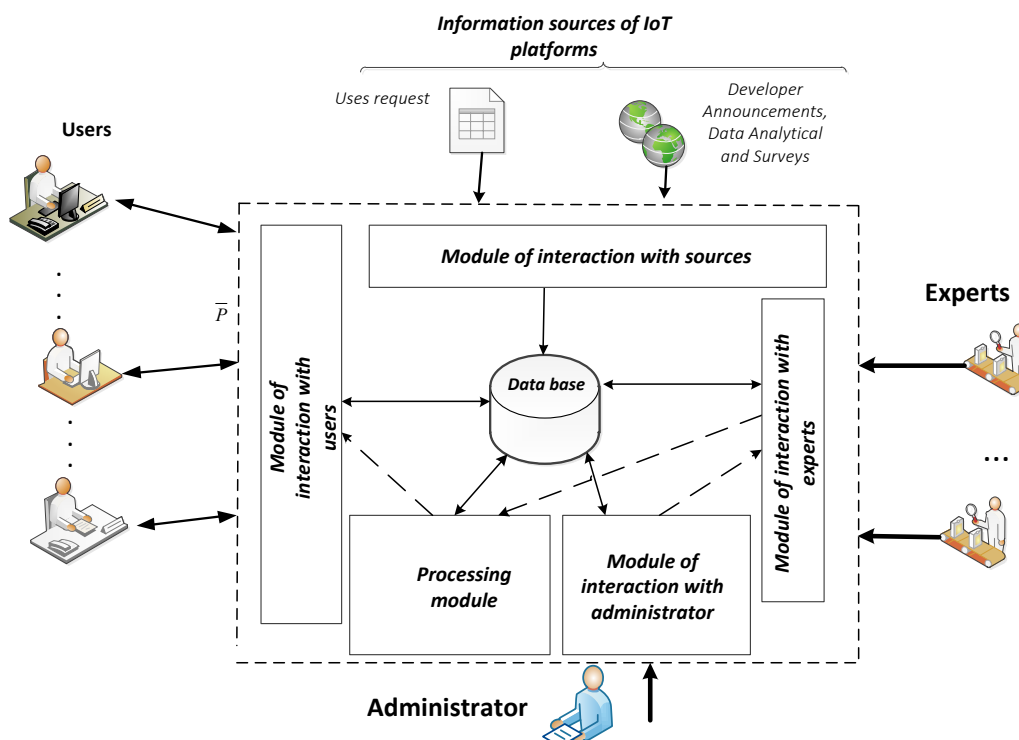


Figure 5 – The overall structure of an automated selection system of IoT platform

The module of interaction with users is the part of the system that responsible for interacting with users. The main task of the module is to provide the user opportunity to set the required platform characteristics.

The module of interaction with sources is provide to receive data about new IoT platforms and supported the database B in the actual state.

The module of interaction with administrators is responsible for the organization of the working space of the system administrator. It provides him the necessary tools to perform administrative functions (create / edit / delete user accounts, confirm / reject registration, etc.).

The module of interaction with experts is responsible for the organization of the working space of the expert, provides the necessary tools for evaluating the functionality of IoT platforms.

Database contains the classification features (characteristics) of IoT platforms.

The results of the research indicate the following.

The paper proposes a method to increase the efficiency of the decision-making process for the selection of software and hardware platforms for the implementation of projects in the IoT-sphere, taking into account maximum functionality and acceptable cost. The offered approach assumes creation of an automated selection system of IoT-platforms, that cooperating with the classification base of IoT-platforms, presented on the market. To create the database was used the facet classification method. The principles of work of the proposed automated system are formalized in the form of algorithms.

Further work will be directed to the development of software implementation of the proposed algorithm for selecting the optimal IoT platform in accordance with the stated requirements of the customer.

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DOI 10.33243/2518-7139-2018-1-2-65-74