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A METHOD FOR COMPUTER AIDED COMMUNICATION TECHNOLOGY COMPARISON

METODOLOĢIJA KOMUNIKĀCIJU TEHNOLOĢIJU SALĪDZINĀŠANAI AR DATORU PALĪDZĪBU

Dmitry Mikoyelov, *Riga Technical University,*
Meza 1/3, Riga, LV 1048, Latvia, Mg.sc.ing.,
dmitry.mikoyelov@gmail.com

Analytical model, communication technology, comparison

1. Introduction

The paper presents a set of factors for a mathematical analytical model intended for evaluation of communication technologies in distributed embedded systems. The paper introduces a final stage of the main research of the author within the PhD study domain. A mathematical model for analysis of communication technology implementation in distributed embedded systems and an algorithm for choosing a set of appropriate factors for the model are introduced. The developed model task is to aid the technology decision process of system architects and sales engineers, which are designing new or improved distributed systems based on embedded nodes and communication links between them.

The first part of the paper describes the general definitions and a set of selected factors. The second part presents an algorithm for choosing a set of factors, and the third part of the paper is dedicated to the description of the introduced model and a demonstration of its implementation on a test use case. The paper is based on previous research [1-6], assisting in completion of the mathematical model.

The target solution in this case is a method for an automated selection of the most appropriate technology (or a set of close technologies) in a given environment (distributed embedded system description and additional specific customer requirements), implementing an analytical mathematical model with a target function. The target function is intended to be based on values of a number of unique factors. In turn, every factor is based on a set of coefficients specific to each factor individually. The values of coefficient variables are calculated by processing the measurement data basing on [7-12].

There are numerous more or less independent critical attributes of embedded telecommunication systems, which should be implemented in a distributed embedded system. The choice of appropriate communication technologies affects the integrity of the system the most. Even when the hardware and software part work properly, if there is no way to timely communicate or convert the communication between nodes, the system is useless.

Speaking of industrial process automation, these attributes immediately become much more critical comparing to home or office communication requirements. Downtime on a factory floor will affect in a way of enormous financial expenses. In some processes, which are related to substances with low viscosity (oil fractions, diesel or black oil, for example), the heating of the sub-product must be constant, as well as its transportation though the processing line. Otherwise, the valuable equipment will malfunction for a long time or become unusable at all until replacement. Distributed network sites operate at a downtime cost of $20000 to $80000 per hour, with companies like stock firms impacted at rates of $6 million per hour. Even at $80K per hour, an average downtime of 88,6 hours calculates to $7,1 million (Strategic Research Corporation.) Some distributed embedded systems may operate unattended and be used to control hazardous devices or systems, which through either normal or flawed operation could lead to significant human, economic, or mission losses. Unfortunately, similar problems were encountered earlier in manufacturing automation [6, 12]. But now modern systems are potentially larger, more distributed for sure, and operate in much less controlled environments. The constraints cast on distributed embedded systems, including long life time periods, changes in structural parts, and resource limitations tend to strain existing methods for evaluating and ensuring system safety.

2. General definitions

In this chapter, the list of general attributes and rules for the model is defined. The list consists of clear theses, where each next thesis follow the essence of the previous one.

- All the case studies involve *distributed embedded systems*, which consist of **nodes** (subsystems). Here, communication links (contiguous or intermittent) are created between nodes and data exchange takes place.
- In an abstract meaning, a **node** is defined as an any set of equipment designated for gathering (acquiring), processing and visualization of data, and, most important in the problem domain, communication equipment, which allows to connect such remote **node** with other **nodes** belonging to the overall distributed system. In this case, the designation and operational characteristics of the measurement and processing equipment are not taken in an account and do not influence the course of calculations. It was defined that only the main communication equipment will be mentioned as a **node** in the fore coming calculations and analysis [1].
- It is defined that each **node** is enforcing the ability of wired (connected) equipment to speak (communicate) with other remote equipment in the environment of the distributed embedded system.
- Each **technology** [3, 4] taken into account in the research has a defined set of **case studies**, which are investigated and estimated with the help of factors, of which importance (and relevance) is based on **coefficients**.

- Each **factor** (high-level definitions in [2-6]) is designed basing on **coefficients** (the scale of an estimation for all factors is uniform - *[0..9]*; that is made for an opportunity of construction of a universal mathematical model.)
- Here, each **factor** corresponds to the set of **coefficients** for creation of an analytical model.
- The more **coefficients** of a **factor** are equal to 0 (or maximally close, aspiring to 0), the higher is the probability of exception of a **factor** in each researched **case study**.
- *A statement, which has no direct relation to the end model* - values of **coefficients** directly depend on conditions (environment) of each **case study**:
    - the topology of the distributed system,
    - the general requirements to the system and its functionality,
    - the customer's requirements to the system and to its relative parameters (for example: cost of the equipment, charges for communication services.)

3. A list of analyzed technologies

Here, it is specified that each investigated **technology** has a set of **case studies**. Measurements of these case studies result in values for coefficients for each factor.

The relativeness (an estimation of importance or relevance) of each factor is estimated and achieved by analyzing the values of measured attributes.

The list of **technologies** with corresponding **case studies** is presented in Tables 1 and 2. In the tables situated below, each column presents a title of the technology followed by its use cases.

Table 1. A list of analyzed technologies

Wired Networks	WLAN	Bluetooth
RS-232	Point-to-Point	Point-to-Multipoint
RS-422	Point-to-Multipoint	Hub-to-Hub
RS-485	Peer-to-Peer	
CAN		
DeviceNet		
Modbus		
Profibus		
Foundation Fieldbus		

Table 2. A list of analyzed technologies (continued)

GSM	GSM/GPRS	Radio Modems
GSM DATA	GPRS	Transparent
GSM DATA-HSCSD	GPRS (corporate)	Peer-to-peer
GSM SMS	GPRS SMS	Multi-repeater

4. A list of factors and coefficients for the analytical model

In the main research, there is a set of various situations (case studies) defined for each of the given technologies. The measurements are performed in these case studies. Measurements are involved in the analytical model as influencing factors. Each measurement is not obligatory to be represented in exact numbers, having these replaced with their corresponding value - an equivalent on a scale [0..9].

The maximal and minimal value is applied on each type of "measurement", where 0 is always "an impossibility of performance" (aspires to zero), and 9 is always "unlimited opportunities" (aspires to infinity). Other entered values *[1..8]* correspond to the exact numerical values of measurements broken into 8 phases.

- **Availability** [16-19] is a factor that specifies several crucial characteristics of the system, including fault tolerance, performance and similar, including integrity and privacy of communication links:
  - *Fault-Tolerance*: the quality of the transferred data remains within the limits of norm even with failures of a communication link
  - *High or continuous availability*: an opportunity of restoration of connection after failures at the absence of necessity of intervention of a master-repairman
  - *Performance*: provides the desirable ready response
  - *Recoverability*: can restart (resend) unsuccessfully sent portions of data
  - *Consistency*: an opportunity of automatic co-ordination of actions between several units that allows them to operate as a single entity.
- **Adaptability** [16, 17, 19] is a factor that specifies the possibility to modify or change (also improve) the configuration of the distributed subsystem network according to the new demands of the system:
  - An opportunity of redeploying the nodes in space (dependence of quality and an opportunity of data transmission in overall after redeployment)
  - A necessity of additional adjustment of the node in case of redeployment
  - An opportunity of changing of topology or configuration of the network constructed on given technology.
- **Scalability** [16, 17, 19, 20] is a factor that specifies the possibility to enlarge the quantity of subsystem in the distributed system without significant changes of the system structure, configuration or additional expenses:
  - An opportunity of addition of new nodes without the need of serious interventions of the system administrator and/or serious charges
  - An opportunity of addition of the whole new subsystems consisting of numerous nodes without the need of serious intervention of the system administrator and/or serious charges.
- **Complexity** [17, 20] is a factor that specifies the overall complexity of the system implementing the selected technology: how hard is to implement each layer of technology, including middleware communicating devices and similar:
  - A degree of complexity of addition of new nodes (or groups of nodes)
  - A degree of complexity of adjustment of communication links between the nodes
  - A degree of complexity of installation of the communication equipment of on each node
  - A degree of complexity of installation of all equipment of the node/nodes necessary for building the communication links (modems, antennae, amplifiers, repeaters, etc.)
- **Costs** [17, 19, 20, 21] is a factor that specifies the cost of implementation of the system using the selected technology, which consists of two main components: installation costs, including all the hardware, software and middleware, and running costs (per-message, per-megabyte, per-minute) if applicable:
  - Charges on implementation of the given **technology** in a context of a considered **case study**:

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  -
    - charges on installation of the necessary communication equipment (direction of antennae, search of an appropriate place without obstacles)
    - charges on the software
    - charges on the communication equipment
    - charges on adjustment of the equipment
  - Charges on the maintenance (support) of the system:
    - periodic (monthly, annual, etc.) payments for the used data link (lease of the line)
    - expenses for data transmission (constant charges on data packages, time on-line charge or for charges for the volume of the transferred data).
- **Range** [17, 19, 21] is a factor that specifies how far can a distributed system span in space, if it is based on the selected technology. This factor is working with the natural ranges of service for the devices implementing the selected technology:
  - The maximal distance between the **nodes** of the system implementing given **technology**, allowing to work in a nominal mode, without interference (after characteristics of the implemented **technology**)
  - The maximal distance between the **nodes** of the system implementing given **technology**, allowing to work in a nominal mode, without interference (in conditions of a current **case study**: interferences and other adverse conditions)
  - A *collateral coefficient*: distance (spatial borders) on which it is possible to redeploy the **node** without changes in the configuration of the system.
- **Speed** [17, 19, 21] is a factor that specifies the width of the band provided by the selected technology:
  - The maximal throughput (in bits per second) of the communication link implementing given technology between the nodes of the system, allowing to work in a nominal mode, without interference (after characteristics of the implemented technology).

5. A method for choosing a set of appropriate factors (measurements)

The adequacy/appropriateness/conformity/correspondence of the criterion was checked in the following way:

1. Similar estimations of the criterion according to each technology were calculated (the calculation results are given in Table 3, example for 3 groups of technologies).
2. The estimation scatter D_i was calculated based on the results presented in Table 3.
3. The scatter D_i was compared with the quantity D_{krit}, which was chosen arbitrarily, thus providing the required accuracy of the criterion adequacy/appropriateness/conformity/correspondence: $\frac{\sum(x-\bar{x})^2}{(n-1)}$
   - if $D_i < D_{krit}$, the "YES" code is displayed (the criterion corresponds to the given level of D_{krit});
   - if $D_i > D_{krit}$, the "NO" code is displayed (the criterion is not optimal for the given level of D_{krit}).
4. The level of D_i expressed in percentage of the maximum possible value of $D_{max} = 106.8$ is determined. Such a value of D_{max} is obtained at a total insensitivity of the criterion to the technologies examined (all the technologies have got the same estimate

X = 0, …, 9. We should note that the estimate can acquire any value, e.g., all "1" or "9").

Table 3. Factor estimation example

Method	**Availability**	**Adaptability**	**Scalability**	**Complexity**	**Costs**	**Range**	**Speed**	**Upgradable**	**Geography focus**	**Modularity**	**Manufacturer**
WLAN											
Point-to-Point	4	2	0	2	2	1	3	6	2	1	2
Point-to-Mpoint	2	2	3	3	2	1	3	5	2	1	2
Peer-to-Peer	4	4	5	4	4	1	3	5	2	1	2
Point-to-Mpoint	2	2	0	3	2	1	3	5	2	1	2
Bluetooth											
Hub-to-Hub	4	3	5	4	2	1	3	5	1	1	3
GSM											
GSM DATA	4	4	3	2	3	6	1	1	1	1	3
GSM SMS	5	4	5	2	3	6	0	0	1	1	3
GPRS	4	4	5	2	3	6	2	3	1	1	3
GPRS (corp)	5	5	5	2	4	6	2	3	1	1	3
GPRS SMS	5	4	5	2	3	6	0	0	1	1	3
1	0	0	0	0	1	5	3	3	13	22	0
2	2	7	2	8	6	1	4	1	9	0	9
3	3	4	8	9	7	5	7	3	0	0	13
4	14	10	0	5	7	5	1	2	0	0	0
5	3	1	9	0	1	1	3	5	0	0	0
6	0	0	0	0	0	5	2	1	0	0	0
7	0	0	0	0	0	0	0	3	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0

Dispersion	20,5	14,0	13,6	14,5	10,3	6,0	5,4	1,9	24,5	53,8	24,5
Satisfaction	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO
Error %	19,2	13,1	12,7	13,6	9,6	5,6	5,1	1,8	23,0	50,4	23,0
Level	21										

Level (%) from MAX	19,7	MAX level	106,778

6. The principle of the algorithm

For a qualitative expression of the degree of similarity of the client inquiry and the adequate technology, the author used the square of Euclidean space.

The Euclidean space is the *geometric distance* in a multidimensional space and is calculated as follows:

$$(x,y) = \{\Sigma_i (x_i - y_i)^2\}^{1/2}$$ [13-15].

The square of Euclidean space is calculated by the initial data, instead of standardized ones.

The author used the weight coefficient (0-1), allowing us to lower the contribution into the error of one or several parameters defined by the client. In other words, the client has a possibility to choose a series of inessential parameters and endow it with the weight coefficient (up to the complete exclusion of the factor): 1 – the parameter is accounted for 100% and 0 – the parameter is disregarded. By default, the weight coefficients are equal to unity. The data are given in absolute magnitudes and percentage of the squared maximum possible distance.

The maximum possible squared distance between the technology and the inquiry is:

$$(x,y)_{max} = \{N * (9 - 0)^2\},$$

where N is the number of estimated parameters. In our case (seven technologies),

$$(x,y)_{max} = 7 * 81 = 567.$$

The percent of the maximum possible squared distance is:

$$((x,y) / 567) * 100.$$

The method described in this paper allows the calculated data are shown graphically in the form of histograms:

- the squares of Euclidean spaces (not exceeding the value specified by the client),
- percentage of the maximum possible squared distance (not exceeding the value specified by the client), and
- absolute values of the squared distance according to all the technologies.

7. The structure of the calculations

The preliminary calculations based on [4-6] are performed in Microsoft Excel. Each technology was evaluated by 7 parameters: Availability, Adaptability, Scalability, Complexity, Costs, Range, and Speed [4-6]. The evaluation was carried out by a 10-grade scale (0-9), where 0 and 9 are the lower and upper levels, respectively. In the cases where it was impossible to estimate the technology by the parameter, it was estimated by an expert method (in continuation of [6]).

The estimates of all the technologies are visualized in the table. The client inquiry contains the combination of estimates according to all the parameters. If necessary, the client can introduce the weight coefficient for one or several parameters (by default, all the weight coefficients are equal to unity).

The error is calculated automatically, after the introduction of the parameters and the weight coefficients specified by the client.

Further, the correspondence between the parameters of the technology and the parameters of the inquiry is calculated. The parameters of the inquiry are subtracted from the parameter of the technology, and the resulting value is squared, $R=(x_i - y_i)^2$. This procedure is carried out for all seven parameters for each technology. The resulting value (the squared difference between the technology and inquiry parameters) is multiplied by the weight coefficient of the respective parameter:

$$R_v = v_i * (x_i - y_i)^2.$$

The products of the squared differences and weight coefficients are summed up separately for each technology. This is exactly the measure of discrepancy between the inquiry and particular technology, or, in other words, the square of the Euclidean space in a multidimensional space of parameters [17]. The dimensionality of the space is equal to the number of parameters (seven in our case) [4]. To each inquiry and technology, in a 7-dimensional space, there corresponds a separate point in the space. The square of Euclidean space yields the measure of the similarity between the inquiry and each technology:

$$T = \Sigma_i \{v_i * (x_i - y_i)^2\}.$$

The error for an *i-th* technology T_i (the sum of squares of Euclidean spaces multiplied by weight coefficients) is deduced in two forms: absolute value (T_i) and a percent of the maximum possible error ($T_{max} = 567$; $T\% = (T_i / 567) * 100$).

The client chooses the admissible error T_d between the technology and inquiry. Only the values not exceeding the mentioned admissible error T_d are displayed in the corresponding cells. At $T_d \geq T_i$, the absolute and percent value of the error is displayed; at $T_d < T_i$, the code "no" meaning the discrepancy between the *i-th* technology and inquiry (with a current admissible error T_i).

The use of weight coefficients and/or admissible error can transform the position of the technology in the 7-dimensional space from the point to a region. In this case, we take into account all the totality of solutions (technologies [17, 21]) adequate for the inquiry within the limits of the admissible error T_i.

Thus, the author realized a flexible system of calculating the error, which takes into account the importance of parameters from the viewpoint of the client. It is also possible to reduce the contribution to the error by describing the secondary (for the client) parameters.

The secondary parameters are described by assigning them the weight coefficients v_i.

The weight coefficients in the range $0 \leq v_i \leq 1$ are assigned to the parameters at any step (for example, 0.1, 0.01, 0.001, 0.0001, etc.) and in any combination (for example, 0.9, 1, 1, ….1, 0.3, 0.3).

The error can also be understood alternatively. In this case, the error is the use of the technology not corresponding to the inquiry. Or, more literally, the improper selection of the respective technology.

8. The results

Let us overview the graphical representation of the results, which contains three histograms. The final form of the inquiry of the client based on his target use case is depicted in table 4.

Table 4. The form of the client inquiry

	Availability	Adaptability	Scalability	Complexity	Costs	Range	Speed
Inquiry:	3	2	2	3	2	5	2
Weight:	1	1	1	1	1	1	1

The **weight** coefficient determines whether the desired factor is irrelevant or not. This approach allows to quickly filter the results of calculations by "switching off" one or more factors and seeing if the result is still in the acceptable range.

The diagrams are constructed automatically upon the change of the inquiry, weight coefficients v_i, or the admissible error T_d, and the new diagrams are generated. This makes it possible to choose the most appropriate technology and to model the merits and demerits of different technologies, varying them within the inquiry.

8.1. The admissible absolute values of the error

The admissible absolute values of the error (for technologies with $T_d \geq T_i$), i.e., the errors do not exceed the mentioned admissible error T_d. At $T_d < T_i$, the code of discrepancy to particular technology "no" is not displayed on the histogram. The results of the calculations are shown in Figure 1 (error is set to 5, corresponding percent error is calculated as 0.881834).

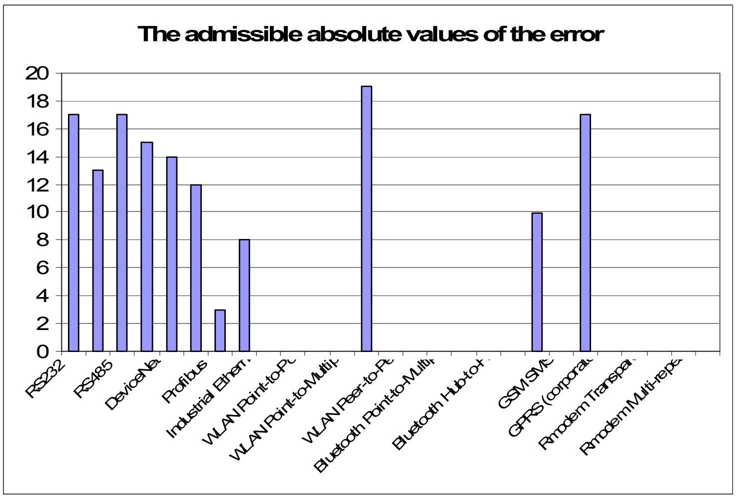

Figure 1. The admissible absolute values of the error (5/0.881834)

It is possible to change the absolute error to a higher value for this particular use case to see the different results. The results of the calculations are shown in Figure 2 (error is set to 25, corresponding percent error is calculated as 3.527337).

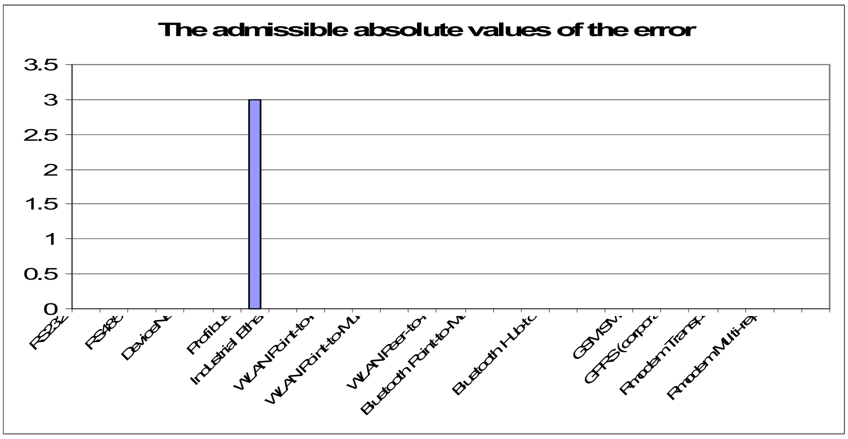

Figure 2. The admissible absolute values of the error (25/3.527337)

8.2. The admissible percent values of the error

The admissible percent values of the error for technologies with $T_d \geq T_i$, i.e., the errors do not exceed the mentioned admissible error T_d. The percentage error is the same as before: ((x,y) / 567) * 100. At $T_d < T_i$, the code of discrepancy to particular technology “no” is not displayed on the histogram.

The results of the calculations are shown in Figure 3 (error is set to 5; corresponding percent error is calculated as 0.881834).

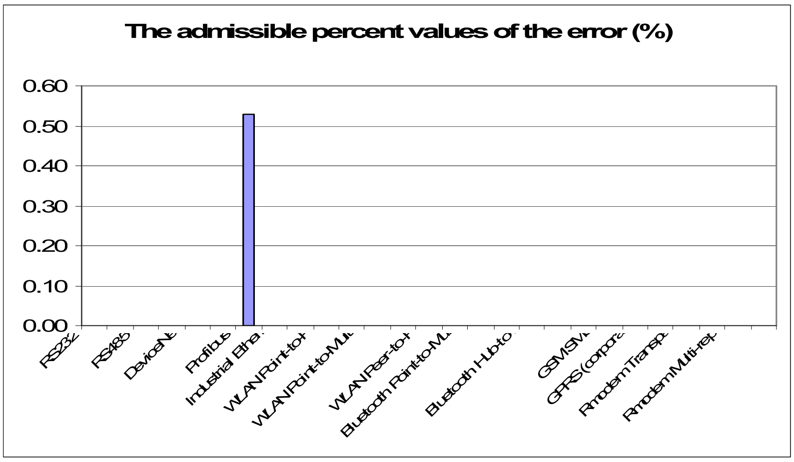

Fig.3. The admissible percent values of the error (5/0.881834)

It is possible to change the absolute error to a higher value for this particular use case to see the different results. The results of the calculations are shown in Figure 4 (error is set to 25, corresponding percent error is calculated as 3.527337).

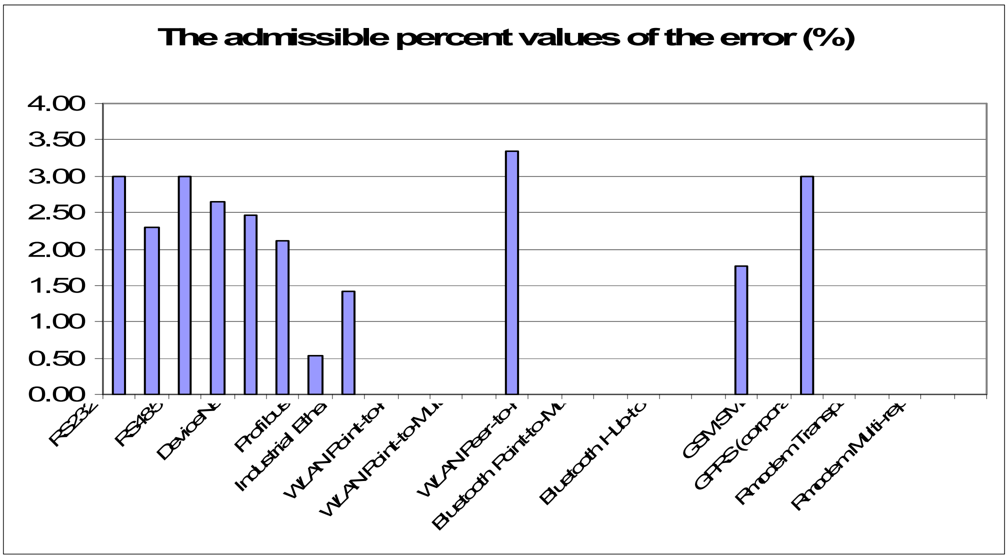

Fig.4. The admissible percent values of the error (25/3.527337)

8.3. The admissible percent errors

Let us see the results of the calculation of the admissible percent errors according to all the technologies. The percent error is the same as before: ((x,y) / 567) * 100. The values of the admissible error T_d specified by the client are not taken into account.

The results of the calculations are shown in Figure 5.

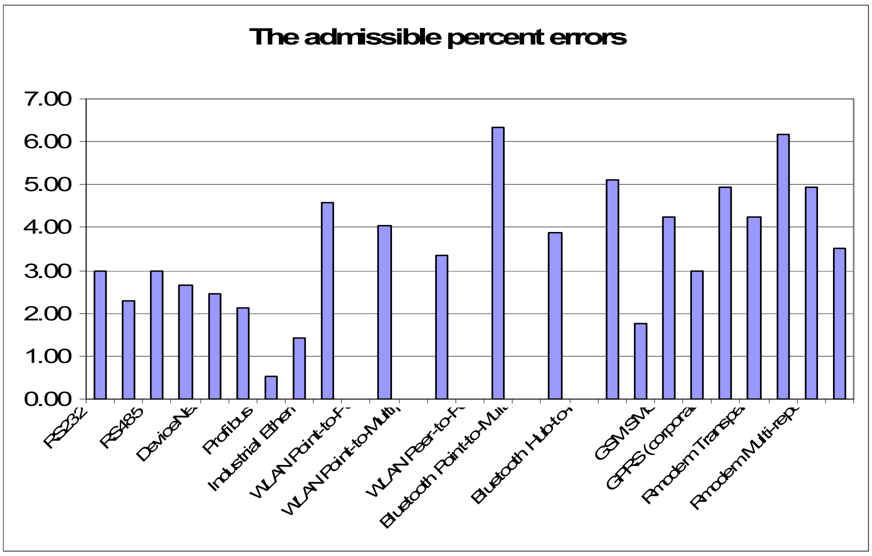

Fig.5. The admissible percent errors

9. Conclusions

The main research of the author is comparative analysis of communication technologies in industrial automation. The research results provided in the paper introduce a view on the problem domain for the main research. The current model is flexible enough to provide an engineer with an ability not only to compare different technologies in a given use case, but also exclude the desired factors from the calculation, thus evaluating the impact of each of the factors (or a group of factors) on the final result.

The choice of appropriate factors for the model is carried by an algorithm provided in chapter 5 of this paper. The algorithm allows the model to be more objective in produced results.

The method introduced in this paper is an important intermediate stage in the global research for author's PhD thesis. This stage defines the base of the analytical model and provides an opportunity to proceed to the evaluation of the empirical data already acquired from numerous experiments. The current research result has helped in choosing the right solutions for locally developed embedded distributed systems in test target use cases.

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Dmitry Mikoyelov, Riga Technical University, Meza 1/3, Riga, LV 1048, Latvia, Mg.sc.ing., dmitry.mikoyelov@gmail.com

Mikojelovs D. Metodoloģija komunikāciju tehnoloģiju salīdzināšanai ar datoru palīdzību

Raksta autors izpētīja virkni komunikāciju tehnoloģiju, kuras tiek pielietotas vai var būt pielietotas komunikāciju sakaru noorganizēšanai starp iebūvētās dalītās sistēmas apakš sistēmām. Pētījuma rezultātā tika izveidots modelis mērķa tehnoloģiju raksturīgo pielietošanas gadījumu analīzei. Arī tiek piedāvāts algoritms vispiemērotāko faktoru virknes atrāšanai izmantošanai galvenā analītiskajā modelī. Darba mērķis ir matemātiskās bāzes uzbūvēšana dažādu komunikāciju tehnoloģiju salīdzināšanas rezultātu pētīšanai. Tiek aprakstīti abu algoritmu darbības principi un piedāvāti eksperimentālo izskaitļojumu rezultāti. Praktiskā mērķa tehnoloģiju realizācija un eksperimentālie dati ir pamatoti uz praktiskās pieredzes, gūtas specifisko dalīto sistēmu konstruēšanas un pētīšanas gaitā dažādos tirgus nozarēs.

Mikoyelov D. A Method for Computer Aided Communication Technology Comparison

In this paper, the author examines a set of modern communication technologies that are or possibly can be used to build communication links between the subsystems of a distributed embedded system. An investigation of these guidelines results in a model for analysis of specific use cases of target technologies. An algorithm for choosing a precise set of factors for the main analysis model is presented too. The goal of the paper is to build a mathematical base for the author's research on comparison of communication technologies. The author describes the principles of both models and presents the results of the test calculations. Practical implementation of target technologies and empirical experiment data are based on a practical experience during the design and test of specific distributed systems in different markets.

Микоелов Д. Метод для сравнения коммуникационных технологий с помощью компьютера

Исследован ряд коммуникационных технологий, которые используются или могут быть использованы для создания коммуникационных связей между подсистемами встроенной распределенной системы. В результате исследования была создана модель для анализа характерных случаев применения целевых технологий. Также представлен алгоритм для поиска набора точных факторов для основной аналитической модели. Целью работы является построение математической базы для исследования результатов сравнения различных коммуникативных технологий. Описаны принципы обеих моделей и представлены результаты экспериментальных расчетов. Практическая реализация целевых технологий и практических экспериментальных данных основаны на практическом опыте, полученном во время конструирования и испытаний конкретных распределенных систем в различных сферах рынка.