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OPTIMIZATION OF GENE EXPRESSION WITH A GENETIC ALGORITHM

Angel Castellanos, Rafael Lahoz–Beltra

Abstract: *The central dogma of biology, in the simplest version, comprises two stages, transduction and translation, translating non-functional DNA information into an operational form represented by a protein. In this paper we simulated the optimization of the parameters that regulate genetic expression being the main contribution the proposal of the evolutionary surface of the parameters space. In particular we are referring to the production and degradation rates of mRNA and proteins. In addition, some methodological suggestions are made on how to study the regulation of genetic expression and on the different ways of reporting the results, either through bacterial agents or via differential equations. This work may be relevant in synthetic biology, bioinformatics or artificial life, as well as other areas of research.*

Keywords: *Optimization of space parameters, bacterial agents, genetic algorithms, gene expression regulation.*

ITHEA Keywords: *J.3 Life and Medical Sciences.*

Introduction

The regulation of gene expression is one of the fundamental evolutionary milestones for the maintenance of life. In broad terms, the expression of a gene comprises the translation of information from a gene (or DNA) into a functional molecule (protein or RNA). This translation is a process that must be subject to fine adjustment, since a lack of adjustment is usually related to pathological states, e.g. cancer [Lakatos et al., 2017]. Genetic regulation requires that in the course of evolution the cells adjust certain rates appropriately, the optimization of which is fundamental for the proper operation of the central dogma of biology (Figure 1). This dogma [Lahoz-Beltra, 2012] explains how non-functional DNA information is translated into a functional and operational molecule in the form of protein. The flow of information from DNA to proteins takes place at the 'hardware level' through a mechanism known as protein biosynthesis which includes two stages. A first stage is called transcription by which DNA information is translated into an intermediate molecule known as messenger RNA or mRNA. This step is followed by a second stage known as translation in which the information carried by the mRNA is translated into a final molecule, i.e. a protein. At the molecular level, and in a very simplified way, transcription and translation both require complex molecular machines, specifically RNA polymerase

and ribosomes, respectively. In the course of the transcription RNA polymerase, a class of proteins called enzyme, separates the two strands of DNA by exposing them as a template for mRNA synthesis. At this stage there are two fundamental parameters, the mRNA production or α_{mRNA} , i.e. the mRNA synthesis (mRNA/min) and the mRNA degradation or β_{mRNA} , i.e. a process whose duration (minutes) depends on the half-life of mRNA. In addition, and during the translation stage, the ribosomes will guide, in the order specified by the mRNA, the binding one after the other of the amino acids, i.e. the binding of the subunits from which will result the final protein. In this step there are two fundamental parameters. On one side, the protein production rate or $\alpha_{protein}$ (number of molecules per minute and per mRNA molecule) and on the other side, the protein degradation rate or $\beta_{protein}$. Therefore, an elementary model of genetic regulation will require the calibration of the four parameters described above. By optimizing these values the cells will control the amount of synthesized proteins. However, how did the cells optimize the value of these parameters during evolution? Assuming that the 'hardware' represented in Figure 1 is a 'molecular machine', and adopting an evolutionary computing approach, what would be the general appearance of the evolutionary surface of the parameter space? This work is a theoretical speculation about the evolutionary surface of the parameter space that regulates protein biosynthesis in the bacterium *E. coli*. The methodology introduced by us in this paper could be useful in the study of the optimization of gene regulation, one of the most relevant topics in molecular evolution. Aiming to facilitate the present study we model transcription and translation as two independent optimization problems, although coupled together. The classical models of genetic expression regulation are based on the use of differential equations [Alves and Dilao, 2005]:

$$\begin{cases} \dfrac{d[mRNA]}{dt} = \alpha_{mRNA} - \beta_{mRNA}[mRNA] \\ \dfrac{d[protein]}{dt} = \alpha_{protein}[mRNA] - \beta_{protein}[protein] \end{cases} \quad (1)$$

We will refer [mRNA] to the concentration of mRNA and [protein] to the concentration of the protein.

Methodology and modeling

In this paper gene expression regulation model adopts an elementary model, as it does not include details about RNA polymerase, cofactors or the role of synthesized protein in the repression of transcription. The model also does not include a sub-model that simulates the function performed by the ribosome. Therefore, it is a phenomenological model of genetic expression, simulating the optimization

of the genetic expression of a green fluorescent protein (GFP). We assume that transcription and translation are studied in a simple organism such as *E. coli* bacterium.

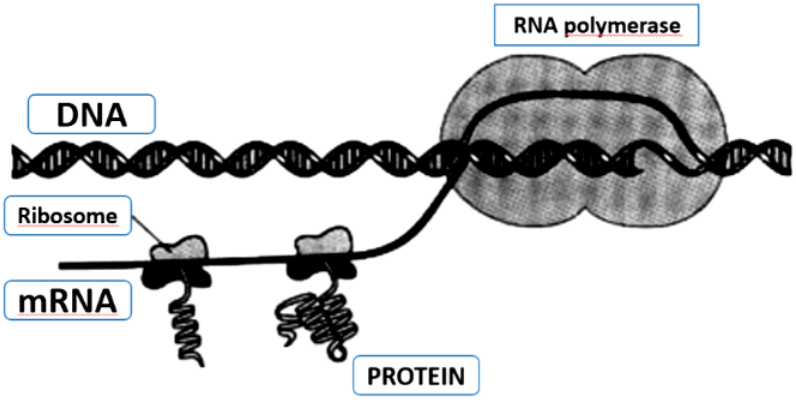

Figure 1. Central dogma of biology describes a flow of information DNA → mRNA → proteins (for an explanation see text).

GFP is a protein that is commonly used in synthetic biology projects, composed of 238 amino acids and with the feature that it emits green fluorescence when exposed to light. In 2012 [Klavins, 2012] simulated the central dogma of molecular biology using as an example the gene expression of the GFP protein. For this purpose the model of the central dogma was coded in Gro 4.0 cellular programming language (see Appendix), a language introduced by Klavins and co-workers [Jang et al., 2012]. In the aforementioned simulation the optimum rates or parameters (Figure 2) were set by the authors of the model with the following values: transcription rates were $\alpha_{mRNA} = 69.4$ mRNA/min, $\beta_{mRNA} = 3.69$ /min and translation rates $\alpha_{protein} = 3.0$ proteins per minute per mRNA, $\beta_{protein} = 0.01$ /min.

The purpose of our model was to study the genetic expression of the GFP protein using evolutionary computational methods. Our goal is to understand how natural selection was able to find the optimal transcription [Perez-Ortin et al., 2013] and translation rate values on which depends the regulation of protein biosynthesis. In this paper we question about the general appearance of the evolutionary surfaces of both production rates and degradation rates of mRNA and GFP. For this purpose, we take inspiration from models in which the optimization of some parameter plays an essential role in the dynamics of the phenomenon studied, such is the case of Max-Min quadratic equations in optimization problems. For example, in ecological informatics the DaisyWorld model [Nuño et al., 2010] simulates a planet whose inhabitants, two species of daisies, regulate the temperature of the planet. The model uses quadratic equations to simulate the optimal growth rate of daisies as a function of temperature. In theoretical genetics, quadratic expressions have been used previously to model the fitness landscape of gene-expression level [Bedford and Hartl, 2009]. In these examples, is generally used the vertex form of

a quadratic equation, i.e. $y = a(x-p)^2 + q$. The vertex has coordinates (p, q) being y a maximum (a<0) or minimum (a>0) when x = -p.

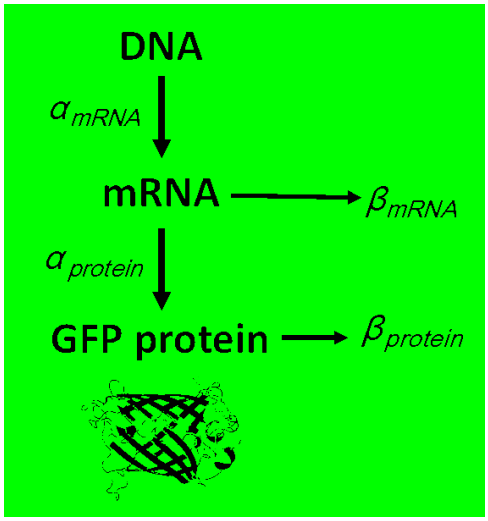

Figure 2. Diagram depicting the expression model of the GFP protein gene. The optimum parameter values were set in accordance with [Klavins, 2012]. At the bottom is shown the protein molecule in black and white (Retrieved May 21, 2018, from European Bioinformatics Institute, http://www.ebi.ac.uk/pdbe/entry/pdb/1ema).

On the basis of theoretical reasoning and simulation experiments previously conducted, we propose the following evolutionary surfaces. In the transcription step, the optimization of mRNA production and degradation rates was simulated in three different evolutionary scenarios (Figure 3):

$$F_1(x_1x_2) = \frac{2 - (0.00025(x_1 - \alpha_{mRNA})^2) - (0.1(x_2 - \beta_{mRNA})^2)}{2} \quad (2)$$

$$F_2(x_1x_2) = \frac{2 - (0.00025(x_1 - \alpha_{mRNA})^2) + (0.1(x_2 - \beta_{mRNA})^2)}{2} \quad (3)$$

$$F_3(x_1x_2) = \frac{2 + (0.00025(x_1 - \alpha_{mRNA})^2) + (0.1(x_2 - \beta_{mRNA})^2)}{2} \quad (4)$$

with the search domain represented in Table 1.

Table 1. **F(x_1,x_2) search domain**

	α_{mRNA}	β_{mRNA}
lower	5	0.50
upper	133	6.88

Notice how $F_1(x_1,x_2)$, $F_2(x_1,x_2)$ and $F_3(x_1,x_2)$ functions represent different optimization problems. In the first and second functions the optimal fitness search is a maximization problem, while for the third function the optimal fitness search is a minimization problem. In a similar way we simulate for the translation step the optimization of the production and degradation rates of the GFP protein. However, simulations were conducted only in two optimization environments, in one case as a maximization problem, in the other case as a minimization problem (Figure 4).

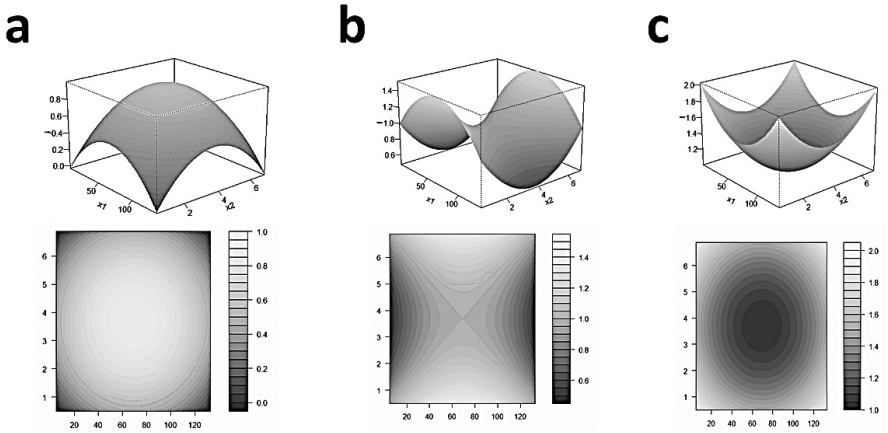

Figure 3. Evolutionary surfaces for the transcription parameters. Landscapes (a) $F_1(x_1,x_2)$, (b) $F_2(x_1,x_2)$ and (c) $F_3(x_1,x_2)$.

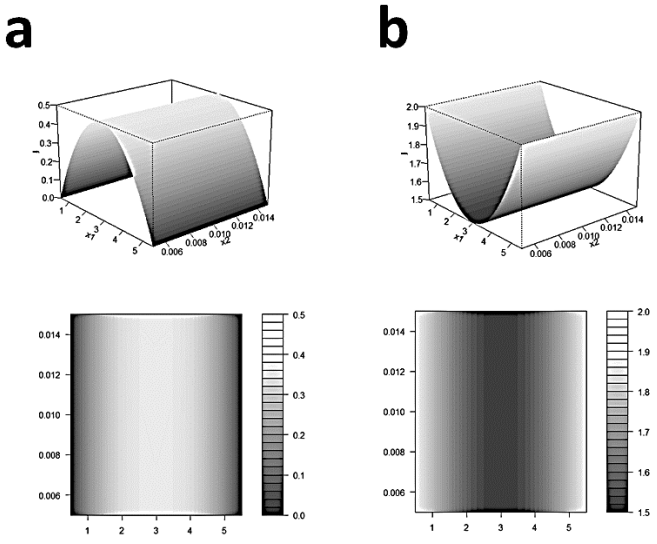

Figure 4. Evolutionary surfaces for the translation parameters. Landscapes (a) $F_4(x_1,x_2)$ and (b) $F_5(x_1,x_2)$.

The functions of the evolutionary surfaces and their search domain (Table 2) were as follows:

$$F_4(x_1x_2) = \frac{2-(0.16(x_1-\alpha_{protein})^2)-(40000(x_2-\beta_{protein})^2)}{2} \quad (5)$$

$$F_5(x_1x_2) = \frac{2+(0.16(x_1-\alpha_{protein})^2)+(40000(x_2-\beta_{protein})^2)}{2} \quad (6)$$

Table 2. **$F(x_1,x_2)$** ***search domain***

	$\alpha_{protein}$	$\beta_{protein}$
lower	0.5	0.005
upper	5.5	0.015

The optimization was conducted by means of a genetic algorithm, using the GA R-package v3.0.2 [Scrucca, 2013, 2017] with the following GA settings: type = real-valued, population size = 50, number of generations = 1000, elitism = 2, crossover probability = 0.8 and mutation probability = 0.1.

MMOGE: A method to study the optimization of genetic expression

The estimation of the parameters of a model, e.g. in this study, is one of the most common tasks in many disciplines, whether in synthetic biology, bioinformatics or in some models of artificial life. In the case we study in this paper the problem is simplified since the degradation rates can be easily estimated. This is because the values are known since they are the half-life of the molecules, e.g. the values of β_{mRNA} and $\beta_{protein}$ are sufficiently well known in the laboratories. Therefore, in the expressions (2), (3), (4) and (5) the problem is simplified to estimating the value of the production rates, i.e. α_{mRNA} and $\alpha_{protein}$, which doesn't mean it's a trivial problem. In this work, and taking into account the previous comments, we propose a methodology that we have referred to as MMOGE (*Max-Min Optimization Gene Expression*) and which comprises the following steps:

1. Consider the transcription and translation separately. We will assume that the optimal value of the production α and degradation β rates is fitted to a parabolic or Max-Min quadratic function which vertex is the maximum of the function (a<0 and x=-p).

2. By using some computer algebra system (CAS), we can tentatively set the width of the parabolic function, i.e. the search domain. For instance, in the problem discussed in this paper we use wxMaxima 16.04.2, adjusting the width of the quadratic function for the production rate of mRNA:

```
(%i2)   k:0.00025; x_opt:69.4;
-->     plot2d ([f(x), (1-k*(x-x_opt)^2)], [x,5,133], [y,0,1]);
```

Created with wxMaxima.

3. Based on the mathematical expressions of the parabolic function of each of the rates, the production rate and the degradation rate, we can combine them in a 3D function. The function obtained will have a single maximum that represents the optimum of both rates, e.g. expressions (2), (3), (4) and (5).

4. On the basis of the expressions of the previous step (3) and with a genetic algorithm, we can simulate the optimization of the genetic expression by natural selection.

5. We can finally 'test' the effect on the biological level of the optimized parameter values. The test can be conducted by simulation experiments, either by means of differential equations, or bacterial agents (e.g. Gro, Figure 6), etc.

Simulation results

In this paper we have shown how it is possible to simulate the evolution of the parameter values that regulate genetic expression in *E. coli* (Figure 6). The study uses a well-known example, such as the case of the gene of the GFP protein. Figure 5 shows one of the characteristic performance graphs of this type of evolutionary simulation experiments.

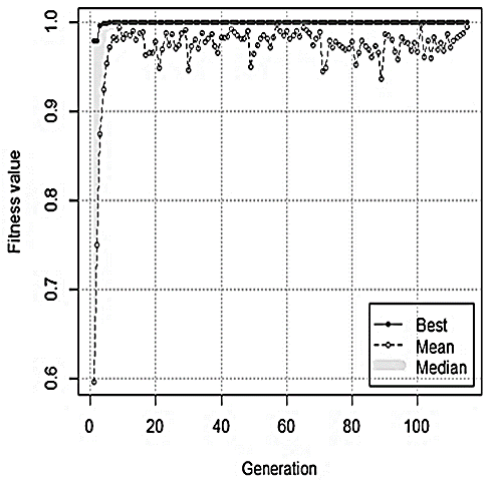

Figure 5. Performace graph for $F_1(x_1,x_2)$.

Tables 3 and 4 show the optimized values of the rates according to the genetic algorithm. In the case of transcription, $F_1(x_1,x_2)$ and $F_3(x_1,x_2)$ evolutionary surfaces reflect plausible environments, except for $F_2(x_1,x_2)$, where one parameter is not correctly optimized. By using this evolutionary surface we simulate a lower rate of mRNA degradation. It is at present known [Lakatos et al., 2017] that protein abundance due to poor genetic regulation, e.g. an excess of p53 protein, has a high correlation with the development of cancerous tumors. This situation is successfully simulated in our model, with the genetic expression evolving to a lower than normal mRNA degradation value. Moreover, the role of RNA today goes beyond protein biosynthesis by changing the classical paradigm of the central dogma of biology: RNA regulates gene expression, and can influence genome instability, e.g. by participating in the

survival of a cancerous tumor [Amirkhah et al., 2016]. One of the features of the model is the possibility that the results, the output, can be displayed in different formats. Figure 6 shows the output in a colony of bacterial agents (see Appendix) while Figure 7 shows the results through a system of differential equations.

Using the model described in this paper it is possible to perform more sophisticated experiments. In fact, there are several factors with an effect on transcription and translation that could be simulated [Milo and Phillips, 2015]. For instance, the antibiotic rinfampin has an effect on the beginning of the transcription, effect that could be simulated via α_{mRNA} parameter. For example, we could also simulate errors in the folding of a protein, increasing the translation speed or $\alpha_{protein}$.

Also, setting the values $\alpha_{mRNA} < \alpha_{protein}$ it is possible to simulate a 'collision' between the ribosome and RNA polymerase, resulting in a failure of the protein synthesis.Therefore, the optimal operation of the molecular machinery takes place if $\alpha_{mRNA} > \alpha_{protein}$. In summary, the proposed model opens up many possibilities for simulating genetic expression and the central dogma of biology.

Table 3. mRNA transcription rates obtained with the genetic algorithm

Evolutionary surface	mRNA production (α_{mRNA})	mRNA degradation (β_{mRNA})
$F_1(x_1,x_2)$	69.4001	3.6900
$F_2(x_1,x_2)$	70.5802	0.5007
$F_3(x_1,x_2)$	69.4008	3.6900

Table 4. Protein translation rates obtained with the genetic algorithm

Evolutionary surface	Protein production ($\alpha_{protein}$)	Protein degradation ($\beta_{protein}$)
$F_4(x_1,x_2)$	3.0000	0.0099
$F_5(x_1,x_2)$	3.0006	0.0099

Figure 6. Model of a bacterial agents colony simulated in Gro language (see Appendix, program written by [Klavins, 2012]).

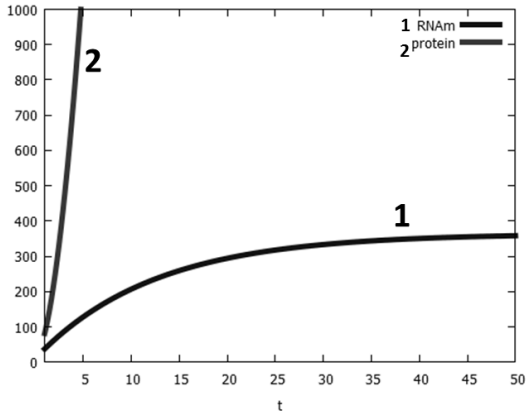

Figure 7. Simulation with differential equations (1) using the optimized values of the parameters according to the experiment described in this paper.

Appendix

The following program [Klavins, 2012] simulates in a colony of *E. coli* (Figure 6) the central dogma applied to the expression of the gene responsible for the GFP protein:

```
include gro

set ( "dt", 0.01 );
alpha_r := 69.4 / 2.35;              // mRNA / min / fL
beta_r := - log ( 0.5 ) / 3.69;      // 1/min
alpha_p := 3.0;                      // protein/min/fL/RNA
beta_p := 0.01;                      // 1/min

program gfp() := {
  mRNA := 0;
  gfp := 0;

  rate ( alpha_r * volume ) : { mRNA := mRNA + 1 };
  rate ( beta_r * mRNA ) :    { mRNA := mRNA - 1 };
  rate ( alpha_p * mRNA ) :   { gfp := gfp + 1 };
  rate ( beta_p * gfp ) :     { gfp := gfp - 1 };

};
```

```
set ( "gfp_saturation_max", 1000 );
set ( "gfp_saturation_min", 800 );

ecoli ( [ x := 0, y := 0 ], program gfp() );
```

Another possibility to show the output is the classic simulation with differential equations (Figure 7):

```
Model parameters
(%i4)   a11:29.53; a12:0.081; a21:3.0; a22:0.01;
Initial conditions
(%i5)   y0_RNAm: 10;
(%i6)   y0_protein: 10;
System of differential equations
(%i7)   EDO_RNAm: -a12*RNAm + a11;
(%i8)   EDO_protein: -a22*protein + a21* RNAm;
(%i10)  fll(x) := [first(x),last(x),length(x)]$ declare(fll,evfun)$
4-order Runge-Kutta method
(%i11)  puntos: rk([EDO_RNAm,EDO_protein ],[RNAm, protein], [y0_RNAm, y0_protein], [t, 0, 100, 0.1])$
(%i12)  %, fll;
(%i13)  AL: makelist([puntos[i][1], puntos[i][2]], i, 1, length(puntos))$
(%i14)  %,fll;
(%i15)  BL: makelist([puntos[i][1], puntos[i][3]], i, 1, length(puntos))$
(%i16)  %, fll;
Numerical solution curves
(%i17)  plot2d( [[discrete, AL],[discrete, BL]], [x, 1, 50],[style, [lines, 5]], [y, 1, 1000], [ylabel, " "], [xlabel, "t"], [legend, "RNAm", "protein"])$
```

Created with wxMaxima.

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A STUDY ON PATTERN DISCOVERY OF SMART METER DATA FOR ENERGY EFFICIENCY

Sarah Osama, Marco Alfonse, Abdel-Badeeh M. Salem

Abstract*: Infinite massive amount of data are being generated from smart meters. Precious information can be obtained by analyzing these data for efficient use of energy. Data mining algorithms are extensively used for extracting these valuable information. Researchers have been focusing on developing energy management solutions for a cleaner environment. Recognizing residents behavior and provisioning a feedback continuously about their usage is one of the effective ways to save energy in residential sector. It is assumed that the more they know and understand their consumption, the more they can track their behavior and save energy. This paper presents a study on the recent research covered for understanding behavior of household energy consumption using pattern mining algorithms as well as applications developed for reducing energy consumption and achieving a much better and efficient use of energy. The pattern discovery techniques applied during the recent 5 years are also presented.*

Keywords*: Smart Grid, Smart Meters, Pattern Mining, Smart Home, Energy Management.*

ACM Classification Keywords*: Smart Grid, Smart Metering.*

Introduction

WITH the evolution of new technologies, energy demand is increasing expeditiously. According to the US energy information administration annual report for 2017, residential and commercial sectors are contributing by 40% of the total power in US [EIA, Online]. Mining consumption data at increased level of granularity has attracted the keen interest of industrial and governmental sectors. Governments such as Australia, Canada, Europe, Korea, Ireland, Japan, UK and USA are investing in smart meters deployment although it is very costly and requires huge IT and communication infrastructure [Smart Grid, Online]. Smart meters are considered as a key component for initializing smart grid environment. Smart grid [Hassan, Radman, 2010] is a network of utilities, smart meters, transmission lines and power plants integrated together. The grid is called smart for being able to communicate in bidirectional way and making real time decisions. The current power electric grid is facing a lot of challenges and the smart grid, considered as its next generation, has emerged for tackling these challenges such as system stress and blackouts [Fang et al, 2012].

The advent of sensors era has promoted the task of collecting appliance usage data. Each home appliance can log its usage time and consumed power to smart meters. Infinite stream of log data are being generated on frequent time intervals. For an effective use of energy and developing a better distribution of power plans, it is crucial to mine and analyze these consumption data. However, the enormous amount of data generated at a constant rate makes the mining task a very challenging one. Academic researchers are making a great effort and studies to extract all possible analyzed information from these data. It is believed that residential sector has a great impact on energy saving and understanding its behavior is one of the key factors to achieve this. Residents can adjust their behavior if they are provided with a continuous feedback about their usage. Real time notifications can get them into a deep understanding and awareness of energy saving methods. Thus, helping them to respond to Demand Response (DR) programs. DR [Siano, 2014] is the change in energy demand in response to changes in electricity price. Thereby, notifying residents to postpone operating scheduled appliances like washing machine, dishwasher and dryer during peak hours. In this regard, a great benefit could be achieved for both consumers and producers. For consumers by lowering their electricity bills and for producers by preventing system stress and supply shortage.

As far to our study, researchers observe that consumption data follows a frequent pattern to some extent. Revealing that most of the residents follow a daily routine in their lives which is reflected on the appliances usage behavior. For example, the alarm is on and waking up at 7:00 am, taking the breakfast so coffee machine and microwave are turned on at 7:30 am. However, This daily routine can be influenced by some other factors like working days or weekends, holidays and environmental changes such as weather. The smart meter consumption log data is considered as a great data treasure where a lot of significant studies, analysis and information can be extracted to reduce energy consumption and achieve an efficient use of energy.

Data mining techniques such as clustering, prediction and pattern discovery have been applied on smart meter data to achieve energy efficiency. Clustering techniques have been very useful in promoting Demand Side Management (DSM) [Abdulaal et al, 2015]. Load profile is first extracted and then clustering algorithms are applied to group residents of similar consumption behavior together. Utility companies design demand response programs that are tailored based on residents preferences to satisfy their needed demand and gain their trust. Prediction techniques are applied to develop power distribution plans [Zeifman, 2014]. Pattern discovery techniques are applied to study appliances usage behavior of residents.

This paper is organized as follows: Section 2 covers pattern discovery techniques, then applications of smart meter data are covered in section 3, and finally conclusion and future work are derived in section 4.

Pattern Discovery Techniques

With the emergence of smart meters and the availability of such rich data, academic studies such as pattern mining, associations, prediction and clustering techniques are applied on smart meters data to achieve energy efficiency and provide a cleaner environment.

Pattern discovery, aka pattern mining, is a sub-field of data mining that intends to discover some sort of items pattern in a large dataset. Pattern discovery is very useful for studying residents behavior, extracting their preferences and predicting their actions and energy demands. This pattern could be periodic, frequent, sequential or usage pattern.

A. Periodic Pattern Mining

Periodic pattern mining discovers the occurrence of a specific pattern at constant time interval. It refers to appliance-time association. For example, the coffee machine works every day at 7 am. It is not necessary to occur at the exact time. However, it occurs in the same time interval.

Shailendra and Abdulsalam [Singh, Yassine, 2017] considered the appliance-time association as a clustering problem where appliances that operate at the same time interval will belong to the same cluster. He divides the day into 48 intervals where each interval equals to 30 minutes. He considered each interval as a cluster and developed a new algorithm that extends the k-means algorithm to cluster appliances with associated intervals.

Yi-Cheng et al. [Chen et al, 2012] also divides the day into intervals and develops Time-slot Probability Usage Pattern (TPUP) algorithm which estimates the probability that an appliance is on in a specific interval.

B. Frequent Pattern Mining

Frequent pattern mining discovers the occurrence of a specific pattern with frequency higher than a predefined threshold. It refers to appliance-appliance association where items appear together in the same time interval frequently. For example, the occurrence of printer and computer together. The main challenge in extracting frequent patterns is the reduction of search space. Hash tables data structure are used to improve performance where the key is the pattern itself and the value is its supported count.

Yi-Cheng et al. [Chen et al, 2013] introduced a new notation for representing appliances usage called usage representation. This representation is used as an initial step in developing Correlation Pattern Mining algorithm (CoPMiner). Later in [Chen et al, 2014], Yi-Cheng et al. modified the CoPMiner algorithm by including the probability concept. Then in [Chen et al, 2015], Yi-Cheng et al. developed

Dynamic Correlation Miner (DCMiner) where an incremental pattern mining is introduced. In general, pattern mining in dynamic databases is much more complex than the static ones. In the real case, smart meters log data regularly generating massive infinite amount of data. Thus, approaches are expected to mine the new logged data in real time without mining the whole database each time.

Shailendra and Abdulsalam [Singh, Yassine, 2017] extend pattern growth approach to generate Frequent Pattern tree (FP-tree). They achieve the progressive manner by mining data at the end of each day in chunks of 24-hours then updates the support count for repeated patterns.

C. Sequential Pattern Mining

Sequential pattern mining discovers the occurrence of sub-sequences items in a sequence dataset. It refers to the usage of appliances in sequence to perform specific activity. Sequential pattern mining is derived from frequent pattern mining where items sequence is considered. The word sequence implies the order of appliances usage. For example, the dryer is turned on after the washing machine. Some studies extract sequential frequent patterns where it discovers the sequence of interested frequent patterns. Ali and Ashkan [Honarvar, Sami, 2016] extracted sequential patterns using PrefixSpan extending pattern growth approach.

Marwan et al. [Hassani et al, 2015] proposed an algorithm that mines input streams without dividing them into batches. They extend Pattern Builder (PBuilder) by developing Streaming Pattern Miner (StrPMiner) algorithm to mine only one item at a time whenever it is arrived. The proposed algorithm was evaluated by comparing its performance and accuracy against SS-BE algorithm. It achieves a better accuracy but slower in performance.

In other studies, it is stated that residential activities are related to the usage of appliances where extracted information is in the form of activities instead of appliances. For example, using a microwave indicates cooking activity. Residents understand their power usage in terms of their activities. As far to our knowledge, the users have to state the activities related to each appliance by themselves as there is no automatic detection approach.

Yong et al. [Ding et al, 2015] gathered data by asking residents to submit their activities at the end of each day. SPADE algorithm is used in his approach to extract sequential activities. They found that different sequence implies different activities with different power consumption. Giving the following example S= {cooking, eating, out} implies breakfast activity while S={out, cooking, eating} implies dinner activity. Thereby, the power used in breakfast preparation is different from the power used in dinner preparation.

D. Usage Pattern Mining

Usage pattern mining discovers behavioral pattern. It aims to extract information that is useful to understand residents lifestyle and preferences which may vary with different context. The context may be temporal such as time, day and season or may be activity such as studying, cooking and watching TV. Context-based devices are appliances that are used frequently in a specific context.

Yu-Shan et al. [Liao et al, 2015] developed a framework extending Apriori algorithm for extracting context-based devices based on temporal patterns. The framework sets a power consumption constraint calculated based on previous historical usage and verify that power consumption will not exceed a certain level and if happens the system will schedule appliances based on their context-based priorities.

Sami and Nilanjan [Rollins, Banerjee, 2014] suggested annotation activity for devices usage. First, They gathered data from residents when using appliances for the first time to identify which activity this appliance belongs to. Then, they developed rule mining algorithm using JMeasure metric to extract associations between appliances and activities. Revealing that an appliance will be probably used during a specific activity. Moreover, extracting associations between appliances having common features such as an hour of a day or a day of a week. This approach can raise home residents awareness about their power usage related to activities and appliances associations.

Xinpeng et al. [Zhang et al, 2014] extracted appliances priority based on activity context. For example, the oven has higher priority than television while cooking. They gathered data by connecting every appliance to smart tap. Then, they extends Latent Dirichlet Allocation (LDA) algorithm which is used initially for text analysis to develop Activity - Power model (APmodel). The extended algorithm is used to estimate activities and appliances priority from power consumption.

Teruhisa [Miura, 2013] developed a system that controls appliances turning on/off by infrared sockets. The system logs appliances usage records with each system command. The drawback of this system is that there will be no log record if appliances are controlled from the device itself. The system aims to extract appliances priorities by calculating the frequency of turning on/off of appliances. The system is trained by users feedback through proposing recommendations for appliances controlling and then the user can agree or disagree with these recommendations.

Yi-Cheng et al. [Chen et al, 2012] developed a system where sensors are installed for each home appliance. These sensors gather usage data and send it to a cloud server every 5 seconds. Daily Behavior-based Usage Pattern (DBUP) algorithm was developed to cluster similar daily usage. The system calculates power usage for each appliance and presents analytic dashboards revealing appliances frequent usage time.

Below in table 1, a summary of pattern discovery techniques applied on smart meter data is presented.

Table 1. Pattern Discovery Techniques Summary

Technique	Authors	Objective	Algorithm	Dataset
Periodic Pattern Mining	Shailendra and Abdulsalam [Singh, Yassine, 2017]	Extracting appliance-time association	K-means extended by dynamic programming	UK-DALE [Kelly, Knottenbelt, 2015]
	Yi-Cheng et al. [Chen et al, 2012]	Extracting time slot probability usage pattern	TPUP Algorithm	Home of 6 appliances [Chen et al, 2012]
Frequent Pattern Mining	Yi-Cheng et al. [Chen et al, 2013]	Extracting associations between appliances	CoPMiner extending UPrefixSpan	REDD [Kolter, Johnson, 2011]
	Yi-Cheng et al. [Chen et al, 2014]	Extracting appliances associations probabilistically	CoPMiner extending UPrefixSpan	REDD [Kolter, Johnson, 2011]
	Yi-Cheng et al. [Chen et al, 2015]	Extracting appliances associations progressively	DCMiner extending UPrefixSpan	REDD [Kolter, Johnson, 2011]
	Shailendra and Abdulsalam [Singh, Yassine, 2017]	Extracting appliances associations progressively	FP-Growth	UK-DALE [Kelly, Knottenbelt, 2015]
Sequential Pattern Mining	Ali and Ashkan [Honarvar, Sami, 2016]	Extracting appliances sequence pattern	PrefixSpan on Spark platform	SGSC [Honarvar, Sami, 2016]
	Marwan et al. [Hassani et al, 2015]	Extracting appliances sequence pattern using batch-free approach	StrPMiner extending Pbuilder	REDD [Kolter, Johnson, 2011]
	Yong et al. [Ding et al, 2015]	Extracting appliances sequence pattern	SPADE algorithm	23 households in Japan [Ding et al, 2015]
Usage Pattern Mining	Yu-Shan et al. [Liao et al, 2015]	Extracting context-based devices based on temporal patterns	Extending apriori algorithm	Smart meter data [Liao et al, 2015]
	Sami and Nilanjan [Rollins, Banerjee, 2014]	Extracting association rules between context and device usage	Rule mining algorithm using JMeasure metric	6 households in US [Rollins, Banerjee, 2014]
	Xinpeng et al. [Zhang et al, 2014]	Extracting appliances priority	Extending LDA algorithm	14 households [Zhang et al, 2014]
	Teruhisa [Miura, 2013]	Extracting residents preferences	Learning preferences by user feedback	Home for 7 appliances [Miura, 2013]
	Yi-Cheng et al. [Chen et al, 2012]	Extracting daily behavior usage pattern	DBUP Algorithm	Home of 6 appliances [Chen et al, 2012]

From this summary table we can observe that FP-Growth, Apriori, PrefixSpan and SPADE are the mostly used algorithms for pattern mining. UK-DALE [Kelly, Knottenbelt, 2015] and REDD [Kolter, Johnson, 2011] are the mostly used datasets for developing pattern mining techniques.

Smart Meter Data Applications

Smart meter data has a great potential to develop applications that manage energy efficiently. Below are some of these applications:

- Demand response programs; energy providers are developing and designing demand response programs that are tailored based on user preferences. In such programs, it is very important to gain customers trust by respecting their preferences and without lowering their level of comfort. Clustering techniques are applied to group similar residents with similar load profiles together. Demand response programs are developed for each cluster to guide residents in this cluster for an effective use of energy, i.e. changing in their demand in response to changes in electricity price [Vardakas et al, 2015].
- Integrating with renewable energy resources; with the rapid increase in energy demand, it is essential to find other renewable and clean energy resources such as solar panels and windmills. With the benefit of bidirectional communication of smart grids, the excess demand can be transmitted to other areas having shortage in power supply [Bhalshankar, Thorat, 2016].
- Billing system; the transmission of real time data can be used to develop a billing system. Since the smart meter sends these data every predefined time interval, the readings are obtained in an updated manner instead of a meter reader that passes by and takes the readings every month. In addition to, developing an analytical tool for home residents by which they can view their bills in an itemized form [Weiss et al, 2012]. This tool is supposed to get them into deep understanding about the amount of energy used for each appliance and the cost corresponding to this usage.
- Prediction; energy providers are paying much attention to reach a good accuracy of predictive models. It is very important to have a future estimate about the needed demand in each area. In case of any failure, power redistribution decisions can be easily taken if there is a predicted demand in each region [Zeifman, 2014].
- Utilities applications; with the availability of smart meter data in real time, several applications can be developed such as decision making, network monitoring, power distribution, risks reduction, faults detection and handling [Wang et al, 2018].
- Estimating household characteristics; smart meters data are not only used to save energy but also can be used to reveal social characteristics such as estimating number of appliances in a home and the standard of living [Beckel et al, 2014]. This information can be used for any socio-economic statistics.
- Home Energy Management System (HEMS); it is a system connecting home appliances and smart meter together through home area network [Niyato et al, 2011]. HEMS is responsible for

visualizing appliances consumption in real time and controlling appliances remotely. In addition to, notifying residents about any abnormal usage or responding to demand response programs if needed.

- Recommendation systems; recommending to residents methods to save energy. For example, when a resident operates scheduled appliances like washing machine at peak time, a notification is send to the resident suggesting another time to operate this appliance. Some recommendation systems learns from user feedback. Daniel et al. [Schweizer et al, 2015] propose a recommendation system that is trained from user feedback. The system asks the user for each recommendation whether it was useful or not.
- Theft detection; pattern discovery techniques are applied to study the behavior of residents. Electricity theft crimes could be detected when any abnormal usage is noticed [Sahoo et al, 2015].

Conclusion and Future Work

This paper presents a study on the techniques proposed to achieve energy efficiency in residential sector. Our study focuses on pattern mining methods applied to discover periodic, frequent, sequential and usage patterns. Periodic patterns discover appliance-time association. Frequent patterns discover appliance-appliance association. Sequential patterns discover sequence of appliances usage and finally usage patterns discover appliances priority related to context-based. As far to our study, we observe that FP-Growth and Apriori algorithms are mostly used when mining frequent patterns while PrefixSpan and SPADE are mostly used when mining sequential patterns.

Key challenges are still observed when mining smart meter data and developing solutions are needed to tackle these challenges. Massive infinite streams of data are being generated from smart meters. It is impossible to mine the whole database whenever a new record is generated so an incremental progressive approach should be used instead. Moreover, studies are applied on the hypothesis that residents behavior follow some sort of usage pattern and it is reflected on appliances usage but this behavior can be changed easily with time. For example, the air conditioner is extensively used in summer and not used at all in winter. Also, some patterns may be obsolete at any time and new patterns may need to be detected. Thus, an automatic fast learner approach is needed to detect these behavioral changes, learn and extract new mined data. In our future work, we will develop an incremental progressive pattern discovery method considering temporal changes and focusing on performance enhancement. In addition to, considering residents feedback about analyzed usage data and its effectiveness for saving energy.

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OBTAINING INITIAL INFORMATION FOR BEHAVIORAL SOFTWARE MODELS' PROCESSING

Olena Chebanyuk, Oleksii Dyshlevy, Valentyna Skalova

Abstract: *In software development process, following AGILE approach, operations with software models take a great role. The paper is devoted to important aspect of software modeling process, namely to analysis of XMI representation of UML diagram. Preparing quality information for different software models processing operations is an important step for effective software development processes performing.*

Paper is devoted to improvement of an approach of text to model transformation. The essence of the proposed approach is to decompose data stream into chains and mark conditional and cycle operations. Pointing of such operations is a necessary condition for preparing quality initial information for software models refinement and comparison.

A notation for an analytical representation of behavioral operations, namely conditional and cycle ones is proposed in this paper.

The example of representing of different types of behavioral software models according to the proposed notation is shown.

Keywords *XMI, UML, behavioral software model, graph representation,*

ITHEA classification keywords*: D2 software engineering, D 2.0 Tools.*

Introduction

According to definition from UML standard, software models are UML diagrams [OMG, 2015]. Analytical representation of behavioral software models is the ground for the successful performing of different Model-Driven Architecture operations. The set of these operations are: software models' comparison, reusing, refactoring, and merging. These operations are performed in different processes in software development lifecycle activities.

Obtaining detailed information about data streams, represented in behavioral software models, allows providing a comparison considering semantic aspects and refinement, based on operations with algorithms.

Well-designed notation for behavioral software models representation provides a background for comparing, transformation or refinement of software diagrams considering semantic aspects.

This paper is a continuation of papers [Chebanyuk] and [Chebanyuk, 2018]. In the paper [Chebanyuk, 2018] an approach to restore software model structure from UML diagram stored in modeling environment is represented. The concept of different types of behavioral software models representation is proposed in the paper [Chebanyuk, 2015].

Used terminology

Let's introduce main concepts of used terminology for describe the proposed approach

Table 1 Analytical denotations for restoring software model structure

Concept	Explanation and analytical representation of concept
Software model (SM)	According to the UML 2.5 standard SM is an UML diagram. Denote it as SM and SM of some type as SM_{type} where type=use case, type=class, etc.
Software model representation	The graph representation is chosen. $SM_{type} = (O_{type}, L_{type})$ (1) where O_{type} – a set of SM objects that are used in SM_{type} notation. Objects are the elements of SM notations that can be expressed as graph vertexes. L_{type} – a set of software model links that are used in SM_{type} notation. Links are elements of SM notation that can be expressed as graph edges. Common definitions for behavioral SM representation are presented in the paper [Chebanyuk, 2015].
Elementary sub-graph	It is a part of a graph, consisting of two linked vertexes. Denote an elementary sub-graph as: $e = (o_1, l, o_2)$ (2) where $o_1, o_2 \in O$ are software model objects linked by link $l \in L$.

Concept	Explanation and analytical representation of concept
Set of elementary sub-graphs	All elementary sub-graphs of SM. Denote this set as *A*.
Linked Elementary Sub-Graphs (LESG)	Consider two elementary sub-graphs $e_1 = (o_1, l_1, o_2)$ and $e_2 = (o_2, l_2, o_3)$ If two elementary sub-graphs are interconnected through an object $o_2 \in O$ these two sub-graphs are considered linked. Consider a pair of elementary sub-graphs e_1 and e_2 Determine e_1 as the first linked elementary sub-graph, e_2 respectively as the seconds.
Starting border elementary sub-graph	Elementary sub-graph that has no first linked elementary sub-graph. Consider $e_1 = (o_1, l_1, o_2)$ · Usually $o_1 \in O$ is an object from which streams of UML diagram are started. These objects are actors or objects that have no incoming links.
A set of starting border elementary sub-graphs	A set that contains all starting border elementary sub-graphs of software model. Denote this set as START. $START = \{e_{start,1}, e_{start,2}, ..., e_{start,k}\}, k = \mid START \mid$ (3)
Switching elementary sub-graphs	Consider two linked elementary sub-graphs. $e_1 = (o_1, l_1, o_2)$ and $e_2 = (o_1, l_2, o_3)$. They are started from the $o_1 \in O$. An elementary graph located on SM before $e_1 \, and \, e_2$, $e_0 = (o_0, l_0, o_1)$ is determined as a switching elementary sub-graph.
A set of switching border elementary sub-graphs	A set that contains all switching elementary sub-graphs of a SM. Denote this set as *SWITCH*. $SWITCH = \{e_{switch,1}, e_{switch,2}, ..., e_{switch,p}\}, p = \mid SWITCH \mid$ (4)
Finishing border elementary sub-graphs	An elementary sub-graph that has no second linked elementary sub-graphs. Consider $e_1 = (o_1, l_1, o_2)$ · Usually $o_2 \in O$ is an object to which streams of UML diagram are ended. Other words these objects have no outcoming links.
A set of finishing border elementary sub-graphs	A set that contains all finishing border elementary sub-graphs of a SM. Denote this set as *FINISH*. $FINISH = \{e_{finish,1}, e_{finish,2}, ..., e_{finish,t}\}, t = \mid FINISH \mid$ (5)
A set MIDDLE	All elementary sub-graphs that are not included to sets *START, SWITCH*, and *FINISH* are included to the set *MIDDLE.*

Concept	Explanation and analytical representation of concept
Software model sub-path	A part of software model, consisting from chain of linked elementary sub-graphs. Denote a sub-path of a SM as *chain.* Using (2) *chain* is denoted by the following: $chain = ((o_1, l_1, o_2), (o_2, l_2, o_3), ..., (o_{n-1}, l_{n-1}, o_n)), n = \mid chain \mid$ $chain = (e_1, e_2, ..., e_n)$ (6) where *n* is a number of elementary sub-graphs in sub-path. There are several variants of forming chains: — starting from a border elementary sub-graph and ending on a switching elementary sub-graph; — starting from a next elementary sub-graph to switching one (the second elementary sub-graph in pair of linked elementary sub-graph) and ending on other switching elementary sub-graph; — starting from a next elementary sub-graph to switching one (the second elementary sub-graph in pair of linked elementary sub-graph) and ending on the finishing border elementary sub-graph; — starting from a starting border elementary sub-graph and ending on finishing border elementary sub-graph.

The contribution of this paper: is a modification of the text to model transformation approach for restoring behavioral software model structure decomposing models into chains considering main operations of algorithms represented on them.

Such decomposition simplifies the further data stream analysis as well as comparison and refinement operations. In order to compare software models it is possible to analyze combination of processes represented in reference software models and ones used in development of concrete projects. From the other hand obtaining information about operations represented in behavioral software models provides a background for their processing considering semantic aspects.

Investigation of the existing approaches drawbacks

In order to ground the necessity of the existing approaches improvement, it is necessary to illustrate the drawbacks of the previous methods. Doing this, consider two examples for different type of software models, namely UML Use Case and Communication Diagrams.

Let's remember that the process forming of elementary sub-graphs chains uses graph representation of software models. Such a representation considers software model as a graph that consists from a set of objects and links.

In the beginning graph objects are divided into several types [Chebanyuk, 2018].

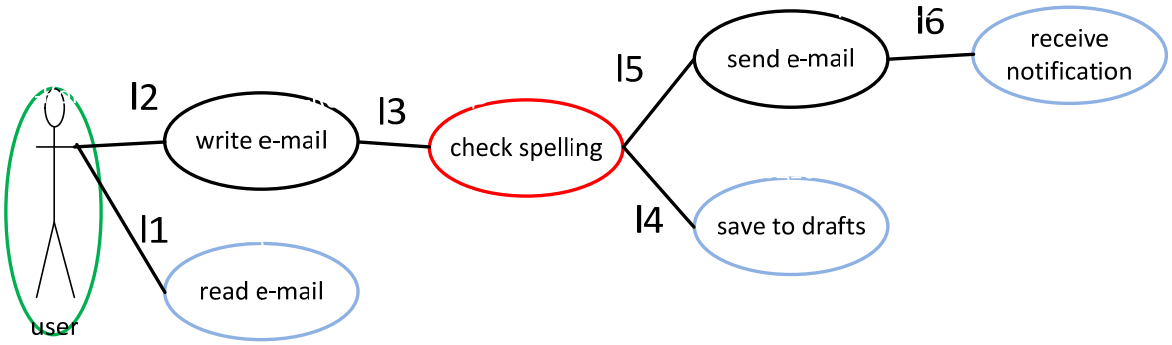


Figure 1 Different types of UML diagram objects.

Let's remember the classification of UML diagram objects. It is proposed to divide software model elements into groups:

- Starting border element. Such element has no incoming links. In the figure 1 it is "user" (marked by green).
- Switching element. Such element has several outgoing links and at least one incoming link. In other words several linked objects can start from it. In the figure 1 it is "check spelling". (This element is marked by red).
- Finishing border element. Such element has no outgoing links. In the figure 1 they are "receive notification", "save to draft", and "read e-mail". (Elements are marked by blue).

Such representation of elements help to compose rules to form chains of software model elements that are linked directly [Chebanyuk, 2018].

An example of forming the set A for small Use-Case Diagram (Figure 2) is represented in the Table 2.

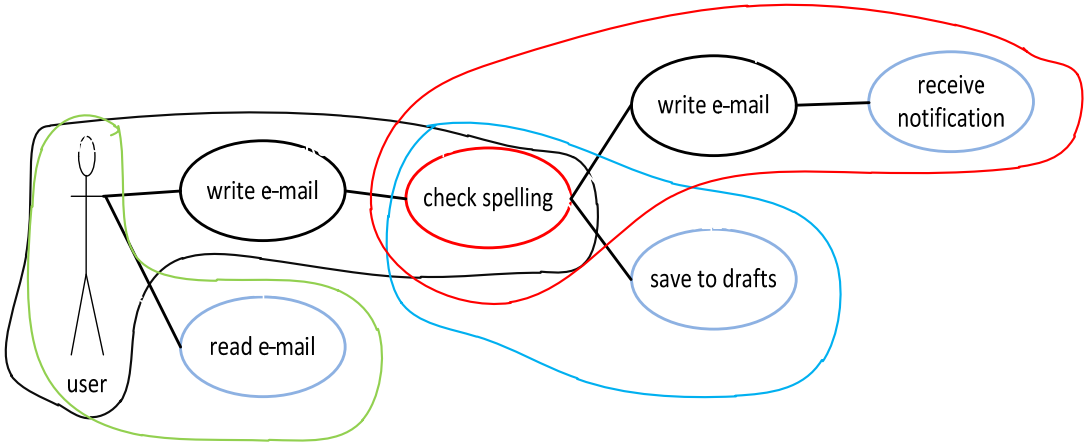


Figure 2. Illustration decomposition of software model to linked chains

Table 2. Description of forming CHAIN process from UML Use-Case diagram, shown in the figure 2

Use Case diagram sets	Explanation
$START = \{(el_1, l_1, el_2), (el_1, l_2, el_3)\}$ $SWITCH = \{(el_3, l_3, el_4)\}$ $FINISH = \{(el_4, l_4, el_7), (el_5, l_6, el_6)\}$ $MIDDLE = \{(el_4, l_5, el_5)\}$	$chain_1 = (el_1, l_1, el_2)$ There is no elementary sub-graph starting from el_2. That's why the forming of the $chain_1$ is finished on the first step. Elementary sub-graph (el_1, l_1, el_2) is deleted from the set START. In the figure 2 this chain is marked by green.
$START = \{(el_1, l_1, el_2), (el_1, l_2, \boxed{el_3})\}$ $SWITCH = \{(\boxed{el_3}, l_3, el_4)\}$ $FINISH = \{(el_4, l_4, el_7), (el_5, l_6, el_6)\}$ $MIDDLE = \{(el_4, l_5, el_5)\}$ In the figure 2 this chain is marked by black	el_3 is a common element for (el_1, l_1, el_3) and (el_3, l_3, el_4). According to the proposed approach if $ref \in SWITCH$ Forming of $chain_2$ is finished. $chain_2 = ((el_1, l_2, el_3), (el_3, l_3, el_4))$ Elementary sub-graphs (el_1, l_1, el_3) and (el_3, l_3, el_4) are deleted from the sets START and SWITCH.

Use Case diagram sets	Explanation
$START = \varnothing, SWITCH = \varnothing$ $FINISH = \{(el_4, l_4, el_7), (el_5, l_6, el_6)\}$ $MIDDLE = \{(el_4, l_5, el_5)\}$ In the figure 2 this chain is marked by red	According to the proposed approach forming of $chain_2$ in this case is started from the set MIDDLE because $START = \varnothing$ and $SWITCH = \varnothing$ el_5 is a common element for (el_4, l_5, el_5) and (el_5, l_6, el_6). $chain_3 = ((el_4, l_5, el_5), (el_5, l_6, el_6))$ Elementary sub-graphs (el_4, l_5, el_5) and (el_5, l_6, el_6) are deleted from the sets MIDDLE and FINISH.
$START = \varnothing, SWITCH = \varnothing$ $FINISH = \{(el_4, l_4, el_7)\}, MIDDLE = \varnothing$ In the figure 2 this chain is marked by blue	$chain_4 = ((el_4, l_4, el_7))$

Similar steps are used to compose the chains from UML communication diagram that is represented in the Figure 3.

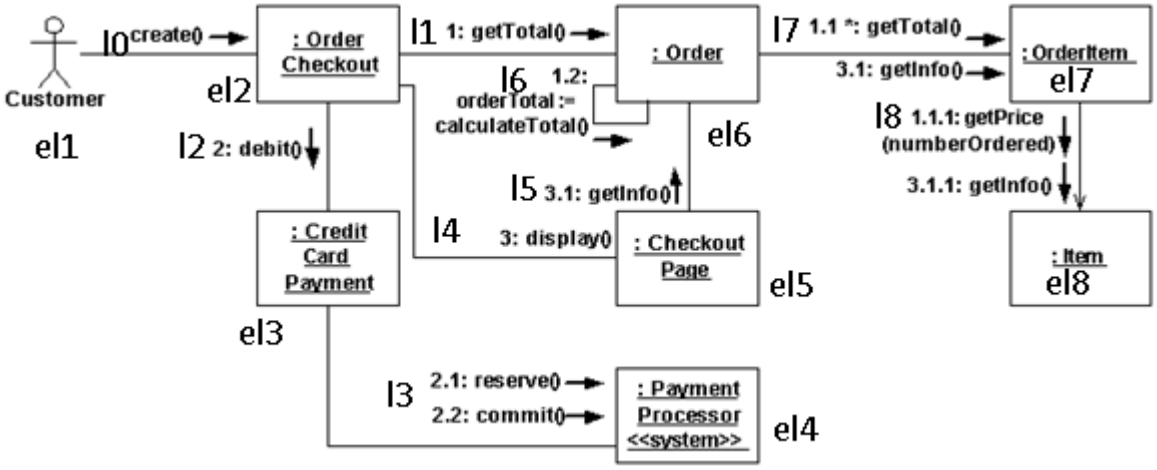


Figure 3 Communication diagram of performing order in internet shop

The figure is taken from AgileModeling site http://agilemodeling.com/style/communicationDiagram.htm

An analytical representation according to proposed approach is prepared

1. Form a graph representation of communication diagram

$$\begin{aligned}
&el_1 = customer, el_2 = order : checkout, el_3 = order, el_4 = checkoutpage, el_5 = creditcardpayment,\\
&el_6 = orderitem, el_7 = item, = el_8 = payment\\
&l_0 = create : l_1 = 1 : gettotal, l_2 = 2 : debit, l_3 = 2.1 reserve(2.2 commit), l_4 = display, l_5 = 3.1 get\,\mathrm{inf}\, o,\\
&l_6 = 1.1 ordertotal(calculateTotal), l_7 = 1.1 GetTotal(3.1 GetInfo), l_8 = 1.1.1 getprice(3.1.1 get\,\mathrm{inf}\, o)
\end{aligned} \quad (7)$$

2. Compose different sets of UML communication diagram sub-graphs.

$$\begin{aligned}
&START = \{(el_1, l_0, el_2)\}\, SWITCH = \{(el_2, l_1, el_6)\}\\
&FINISH = \{(el_3, l_3, el_4), (el_7, l_8, el_8)\}\\
&MIDDLE = \{(el_2, l_2, el_3), (el_2, l_4, el_5), (el_5, l_5, el_6), (el_6, l_6, el_6), (el_6, l_7, el_7)\}
\end{aligned} \quad (8)$$

3. Let's form the chains of elementary sub-graphs following the algorithms, described above.

$$\begin{aligned}
&chain_1 = ((el_1, l_0, el_2))\\
&chain_2 = ((el_2, l_1, el_6), (el_6, l_6, el_6), (el_6, l_7, el_7), (el_7, l_8, el_8))\\
&chain_3 = ((el_2, l_2, el_3), (el_3, l_3, el_4))\\
&chain_4 = ((el_2, l_4, el_5), (el_5, l_5, el_6))
\end{aligned} \quad (9)$$

Analyzing communication diagram, chains it is pointed that element el_2 is a switch object, but does not appeared in the SWITCH objects set. It appears in the START set. As START set is formed before SWITCH element el_2 was not recognized as SWITCH element.

Research question 1: Why it is important to consider all SWITCH objects?

SWITCH objects have important meaning in defining the type of operations. For example: in considering the conditional operation. It becomes a motivation for authors to improve the algorithm of decomposing software model elements into the chains. The essence of the proposed algorithm is to provide a preparation of initial information for the further analysis after decomposing behavioral software models into chains.

Task: to propose an approach for decomposition of UML diagram chains into operations.

Challenges to prepare initial information for semantic comparison and merging of UML diagrams in convenient form for the further analysis

In order to perform this task the next Research Problems (RPs) should be solved:

- RP1: To define key features of conditional and cycle operations in UML diagrams.
- RP2:To provide changes to algorithm restoring software model structure to define conditional and cycle operations.
- RP3: To propose an analytical form of conditional and cycle operation recording.

Application of the proposed approach is to provide a background for software model comparison, refinement, and transformation considering semantic aspect.

Grounding of the necessity of designing algorithm for decomposing elementary sub-graphs into the chains marking operations

The notation of behavioral software models analytical representation is given in the paper [Chebanyuk, 2015]. In this paper the concept of all operations performed in behavioral software models processing is introduced. We consider two types of operations, namely conditional and cycle ones. These types of operations are defined directly only in sequence diagrams from all behavioral software models. But other types of UML diagrams have more common notations and no notation tool on UML diagrams, except comments, to define operations performed in algorithm in precise form (figure 4).

Description of the proposed approach

Solutions of the research problems given above:

RP1: define key properties to cycle and conditional operations.

In order to define key features of behavioral software models consider communication diagrams as diagrams that are designed to show data streams.

Table 2 illustrates examples of communication diagrams fragments that match to different operations with their elements.

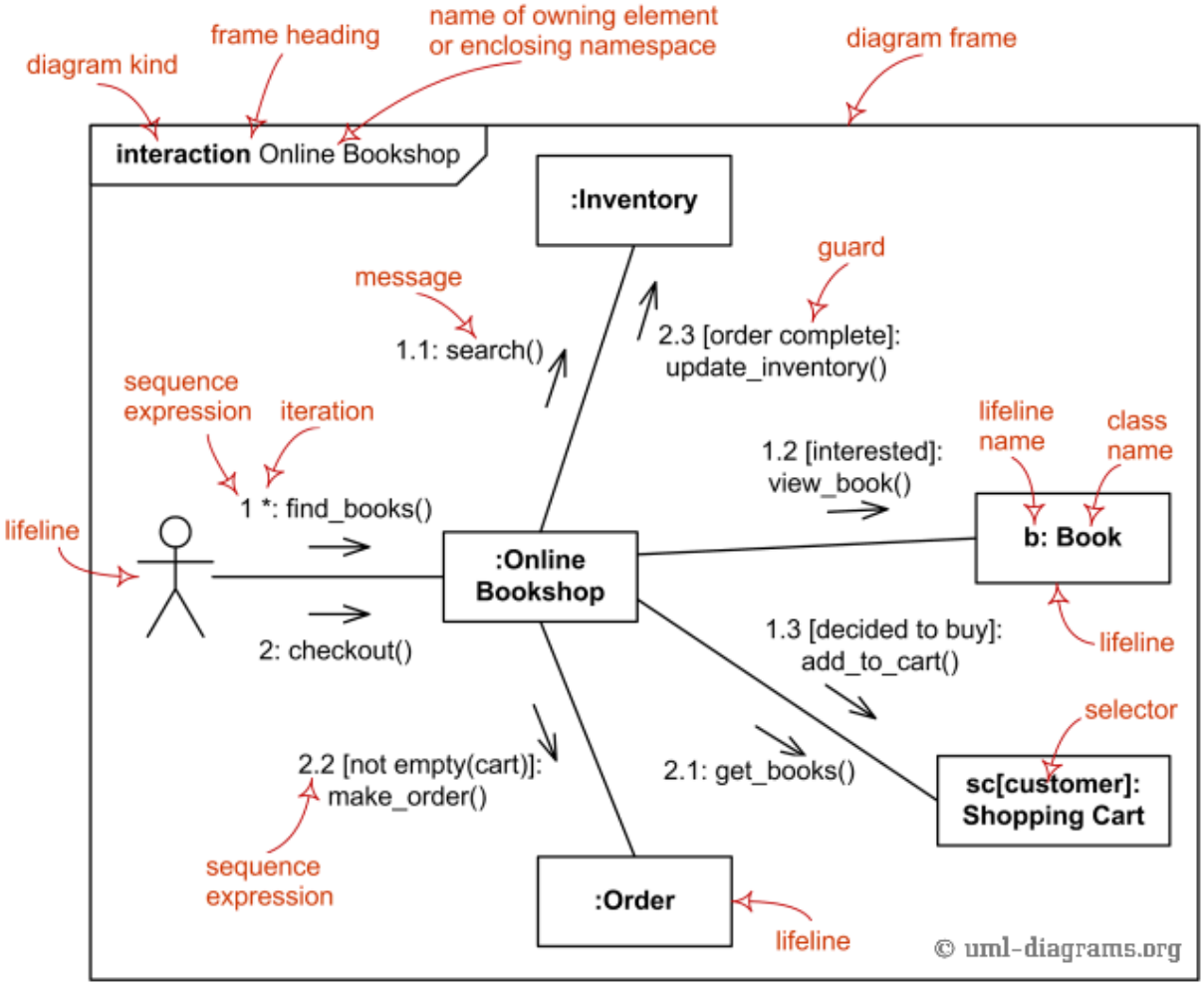
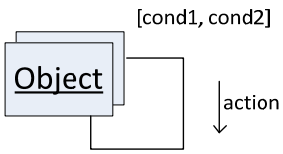
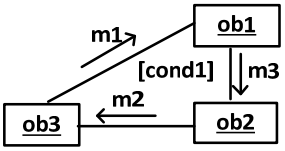
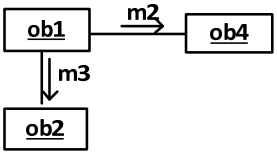


Figure 4 An example of operations description in behavioral software models

https://www.uml-diagrams.org/communication-diagrams.html

Table 2 Examples of behavioral software models fragments

Communication diagram fragment	Analytical representation
 Explanation: simple action that is executed under all elements of some collection	The first example of cycle construction $chain = (Object^*, action, Object^*)$ Where $Object^*$ - is a collection of objects

Communication diagram fragment	Analytical representation
 Explanation while cond1 is true actions m_3 and m_2 are executed under objects ob_2 and ob_3 respectively.	The second example of cycle construction $chain = ((ob_1, m_3, ob_2), (ob_2, m_2, ob_3), (ob_3, m_1, ob_1))$ Also such communication diagram fragment can match to conditional statement Pay attention to collision the same communication diagram fragment may point both to conditional and cycle statement.
 Explanation when cond1 is true conditional operation is performed with ob_2 otherwise this operation is executed with ob_4	Another example of conditional construction $chain_1 = \{ob_1, m_2, ob_4\}$ $chain_2 = \{ob_1, m_3, ob_2\}$ Where: ob_1 is a switching object.

Firstly we can assume that switching object points to conditional operation. In order to detect cycle operation let's pay attention to several variants of cycle operation organization.

1. Consider a loop, recorded in one chain. The cycle condition is formulated as follows: chain must starts and ends with the same object (see the first example in the table 2).

2. Consider a loop, represented in two chains, namely $chain_2$ and $chain_2$ The cycle condition is formulated as follows: $chain_1$ starts from the object ob_1 . This object should be the last one in the $chain_2$. The second condition is the next: $chain_1$ ends with the object ob_1 $chain_2$ must starts from the same object.

$$chain_1 = ((ob_1, m_2, ob_4), (ob_4, m_3, ob_6))$$
$$chain_2 = ((ob_1, m_3, ob_2), (ob_1, m_3, ob_2))$$

3. We can extend this condition for representing loop recorded in several chains, $CHAIN = (chain_1, chain_2 ..., chain_n)$. ob_1 is the first object in $chain_2$ and the last one in the

$chain_2$. In general ob_i is the first object in the $chain_{i+1}$ and the last one in the. The object ob_0 is the last in the $chain_n$ and the first one in the $chain_1$.

It is necessary to point that even when it is possible to combine a cycle from chains it is not always cycle operation. Consider the situation shown in the figure 3. Combination of arrows directions illustrates that only one cycle is represented in the figure 3. (It is started and finished in object el_6) Also we can notice that the object el_2 is a switch one but according to algorithm proposed in paper [Chebanyuk, 2018] elementary sub-graph (el_1, l_0, el_2) participates in forming START set. Repeating actions that are based on proposed algorithm we can skip switch objects from the START set. But definition of them is a very important thing because switching objects point to conditional and probably cycle operations.

RP2: Provide changes to algorithm restoring software model structure to define conditional and cycle operations

It is proposed to take three changes into algorithm of decomposing UML diagram into the chains.

First: additional point is added after elementary sub-graphs are divided into sets START, FINISH, MIDDLE, and SWITCH.

All switching elementary sub-graphs are marked as conditional ones. Conditional elementary sub-graphs are the first sub-graphs in the chain representing conditional operations. The form to consider conditional operations will be introduced later.

Second: in order to avoid situations when elementary sub-graph is not considered as a conditional one (9). It is proposed to perform review of chains after their forming. This review should calculate the number of chains that are started from some object obj. If there is more than one chain starting from the "obj" then "obj" is considered as switching object.(in considering communication diagram in the figure 3 we can define one more switch object. It is object el2).

"Switch record" is formed.

Third: the analysis of chains is performed in order to define linked chains. Linked chains are those that have common element. This element should be the last in the first chain and the first in the second one. In order to organize cycle the first chain should start and the last chain should finish from the same element.

RP3: Propose an analytical representation of recording conditional and cycle operations.

Analytical representation of "Switching record" to represent conditional operation

$$\Xi = \left[el_1, l_1, el_2 \left[\begin{array}{l} el_2, l_3, el_3 \\ el_2, l_4, el_5 \\ \cdot \\ \cdot \\ \cdot \\ el_2, l_n, el_k \end{array} \right. \right. \quad (10)$$

Where: Ξ - denotation of the conditional operation

Analytical representation of cycle operation

$$O = ((el_1, l_1, el_2), ..., (el_n, l_m, el_k), (el_k, l_1, el_p), ...(el_t, l_r, el_w), (el_w, l_s, el_1)) \quad (11)$$

where: O is a denotation of cycle operation.

Case study and evaluation of the proposed approach

Let's analyze the communication diagram represented in the figure 3. From the first view it seems to have two cycles. One of them is started from the object order:checkout another one from the object :order But the analysis of data stream shows that after object order:checkout two separate stream are started. That why this diagram is interesting to investigate and to prove formulated conditions. Modified algorithm of analysis of linked chains allows defining one mode switching object.

Review of related papers

Nowadays there are many investigations directed to analysis of information getting from the UML diagrams, designed in modeling environments. They are divided into two large directions, namely analysis of software development artifacts to get initial information for software model designing (requirement based engineering area). The second area of investigation is aimed to is to extract information from software model XMI for the further analysis.

Let us consider papers taking information about software model from requirement specification.

Paper [Sneed, 2018] introduces tool to extract logical test cases or test conditions from requirement specification as they are referred to in the ISO Standard-29119. To archive this goal authors introduce the next terminology base: test condition, action, state, and rule.

A test condition defines a particular feature of the system. This can be an action, a state or a rule. An action would be "to place an order". A state is "the ordered article is available". A rule would be "the

customer can only place an order if the ordered article is available". A rule is as shown here actually a combination of a state with an action.

Information about logical test cases and centrally sequence of them, gathered into logical test cases, serves to expose some domain process in compact view. This information is initial for the analysis of problem domain algorithms and operations. It is possible for example to verify obtained logical test cases with reference ones and to define whether conditional operation was skipped or extra one is added.

Then consider papers proposing approaches that are based on extracting information from software models.

There are investigations related to processing the information about UML diagrams stored in modeling environment. Many researches are concentrated on using ready tools for software analysis. One of them is project SMartyParser. It is aimed to parse UML diagrams stored in XMI formats. Authors of this project [L. A. Lanceloti at el., 2013] use SD Metrics tool for the analysis of XMI. This tool allows performing the next operations:

- **Comprehensive design measurement**

  SDMetrics ships with a rich set of object-oriented (OO) design measures covering structural properties of design elements from all UML1.x/2.x diagram types. Investigator may measure all the import design attributes - size, coupling, complexity and more - at all levels of detail, from the model, subsystem, package level down to classes and operations [SDMetrix, 2014].

- **Design rule checking**

  Design rules and heuristics automatically check UML design for completeness, consistency, correctness, design style issues such as dependency cycles, and more [SDMetrix, 2014].

- **Early quality feedback**

  SDMetrics finds arthitectural problems at the design stage, before they are committed to source code [SDMetrix, 2014].

- **Extensible set of design measures and design rules**

  SDMetrics has a flexible and powerful mechanism to define and calculate new design rules and measures of your own, tailored to your development practices [SDMetrix, 2014].

- **Compare designs**

  Calculate size metrics deltas to quantify the growth in size between two versions of a design, identify parts of the system design that have undergone much change, or evaluate alternative solutions to a design problem [SDMetrix, 2014].

The aim of investigation represented in paper [L. A. Lanceloti at el., 2013] is to define differences UML diagrams in software Product Line approach. In order to parse them class XMIReader is used. Then SDMetrics allows representing statistic values about software model. Analyzing these values it is possible to make a conclusion how much UML diagrams are differ.

There are authors [Chebanyuk and Mironov, 2017] taking efforts to design own tools for extracting information about software models elements. The proposed approach implies working with a machine-readable representation of a software model used by modeling environments. XMI is considered as a fitting option due to rich set of features allowing to effortlessly recognizing entities and relations between them. Moreover, XMI is used by notorious modeling environments like IBM Rational Software Architect (RSA) and Eclipse Papyrus and suggests various ways to process and analyze models.

Introduced idea and approach has been expressed as a simplistic framework that works with different types of UML diagrams. It is implemented as a core library and a set of frontends to it. .NET Core is used as a basis for realization because of a powerful XML-parsing features (XDocument, LINQ) and availability on multiple platforms.

The library itself is able to recognize diagrams in XMI format and provide additional data for Class and Use-Case diagrams. It is open to extension and may easily accept new functionality like custom business logic, new frontends, and new kinds of diagram to parse and new metrics to calculate for already implemented ones.

Proposed tool become a start point to design application for analyzing a class diagram in accordance to SOLID design principles [Chebanyuk and Povalyaev, 2017]. The first point of such an analysis is to extract class diagram elements by means of special LINQ requests. Then LINQ requests matching to expression of predicate logic proposed in paper [Chebanyuk and Markov, 2016] were composed.

Summarizing the review

The next conclusion is performed: there is a series of Investigations to analyze xmi representation of UML diagram but extracting information about UML diagram entities does not provide possibility to perform other operation with software model such as transformation, comparing, merging because it is necessary to involve additional information to include semantic aspects in some operation performing. Such semantic aspect is decomposing software model chains into operations.

Conclusion

The proposed approach for software models representation allows decomposing data streams in behavioral software models into chains. Modification of the proposed algorithm lets to consider

conditional and cycle operations that are used in algorithm. Such operations are “skeletons” for analyzing data streams and providing further software models comparison and refinement operations.

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METHODS OF IMPROVING THE PROCESS APPROACH IN ASSESSING THE EFFICIENCY OF UNIVERSITY QUALITY MANAGEMENT SYSTEMS

Plamen Pavlov

Abstract: The article discusses the problems with the implementation of the process method of quality control in higher education, the necessity to develop process cards for assessment of processes and assessment of the maturity of the quality control processes.

Keywords: *quality, process method, process cards, maturity of processes*

ITHEA Keywords: *Please use keywords from http://idr.ithea.org/tiki-browse_categories.php .*

Introduction

One of the most important achievements of the contemporary doctrine for achieving a high quality educational product offered by higher education institutions is the implementation of the principles of the process approach in the versions of the ISO 9001 standard. This governs the use of the "process approach" principle in the development, implementation and improvement of the performance of the quality management system, with the aim of increasing consumer satisfaction with the educational product by meeting consumer requirements.

For the successful operation of the organization, its senior management must identify and manage multiple interconnected activities.

An activity that uses resources and is run in order to convert inputs into outputs can be viewed as a process. Very often, the output of a process is an immediate input to the next process.

The implementation of a system of processes in the organization, their identification and the definition of their interaction, as well as their management can be considered as a "process approach".

The advantage of the process approach lies in the fact that it provides continuity of management at the boundary of the individual processes within their common system framework, as well as in their combination and interaction.

Using this approach within the quality management system highlights the importance of:

- understanding the requirements and their compliance;
- The need to consider the process in terms of increasing the efficiency of the activity (adding value);
- Achieving the set criteria (results) in the functional characteristics of the processes;
- Continuous improvement of the processes based on objective measurements.

Nature of the Problem

On the basis of practical experience, the following problems in the implementation of the process can be identified:

1. Managerial misunderstanding of the necessity of mandatory implementation of the process approach as an ideology.

The difficulty lies mainly in the lack of leadership on the part of mid-level management to engage staff. Changes are needed above all in the minds of lecturers and assistants. They need to be ready and to be trying to use the new management methods, and this should by all means be encouraged by management. Management should refer to the process approach primarily as an ideology.

2. Unwillingness to make major changes to the organizational management structure.

Often, management is not ready for serious changes that will inevitably affect the organization's management system in a deliberate and non-perfunctory implementation of the process approach (as everyone wants to get a quick result on relatively small investments). When embarking on the implementation, it is often underappreciated how much effort needs to be put in, in order to achieve meaningful results. An in-depth analysis needs to be carried out on what changes can objectively be implemented and the relevant priorities need to be set. Otherwise, these changes will not actually be managed, which will lead to only perfunctory implementation.

3. Building a system of processes that is not adequate to the specifics of the educational activity.

The activity of each organization is in its essence the implementation of processes. Leaders and collaborators intuitively understand this but as a rule they have difficulty in defining processes adequately. Building the system of processes in the organization and its further development is determined by the requirements for the management tools that may be used by managers.

Sometimes the implementation of the process approach does not have the desired effect when the processes in organizations are not defined objectively and the process system is built only perfunctory and does not match the specifics of the activity. Processes are not tied to other processes. Interconnections are complex and difficult to manage. The designation of the owner of the individual processes is determined without taking account of these complex relationships and without giving the owner the appropriate rights and obligations.

4. Misunderstanding as to why detailed process governance is needed and how it can be properly implemented.

If processes in the organization are not properly defined and regulated, this means that the activities are carried out on the basis of accepted rules and norms, which have traditionally been accepted and adhered to by the lecturers and collaborators. They know how to carry out the processes and get the results expected from the management. When work is organized this way, the losses of different types

of resources (financial, material and human) are inevitable. There is no governance and analysis to modify existing processes in the organization.

Processes should be defined and documented with the aim of:

- analysis of the problems, the "bottlenecks", the losses in the implementation of the processes with subsequent development and enactment of the improvement activities;
- standardization of activities, ensuring repeatability of the processes and the possibilities for their management;
- dissemination of experience in other structural units in the organization (affiliates);
- comparing results with competitors and improving processes (benchmarking);
- defining the new processes when new activities emerge in the organization;
- Accumulation of knowledge and experience in carrying out the processes and passing them on to new associates (training, entry into work);
- conducting internal audits.

5. Errors in creating a system of indicators, the linking of processes and indicators.

The implementation of the process approach is often mistakenly interpreted to be only a detailed description and reorganization of processes. Even if a one-off improvement has been achieved initially, performance will start decreasing over time. Processes need to be continuously improved, increasing or retaining the achieved level of efficiency. It is impossible to do this without an adequate system of objectives and indicators for managing and evaluating the processes. Sometimes organizations define high-level processes, and later not quite correctly (without taking into account the specifics and various interconnections, without analyzing material and information flows, etc.), they detail them by creating the relevant organization charts and schedules. Then, indicators are defined for all the detailed processes, looking at each of them in turn and defining relevant indicators. In applying this approach, often, the system built is fragmented (i.e. it is missing a number of important indicators that are needed for management); part of their indicators contradict (achieving one of them excludes the achievement of another); indicators are not geared towards achieving the organization's strategic goals, its overall effectiveness.

6. Absence of the patience, desire and resources necessary for the real optimization of the processes.

Leaders may indeed want to fully and conscientiously implement the process approach to quality management and even adopt the relevant decisions, but that is not enough. It is necessary to provide the required resources and to set up a working group of qualified specialists who have experience in using methodologies for implementation of the process approach that have been tested in practice. Methods can also be obtained from consultancy organizations that provide relevant training and advice.

7. Difficulties in organizing process management.

A process approach can be considered to be implemented only when the organization also carries out process management. In some organizations, the implementation of the process approach ends at the description stage and subsequent process governance. Other organizations set up a system of indicators. However, only in very few organizations has management systematically approached the organization and management of processes.

For process management, it is not enough to write in the governance documents that the processes should be managed by the owners. It is necessary to create the relevant effective management mechanisms.

8. Difficulties in creating and maintaining a continuous process improvement system (PDCA cycle).

There are difficulties in implementing the PDCA cycle. The system of continuous improvement of the quality management system does not arise in the organization by itself. It is necessary to implement the relevant mechanisms that will motivate the staff. Organizations often create a situation where management does not want to and cannot deal with improvements other than those that would contribute to raising the most important deliverables or lowering costs, because of too much workload. In particular, top management is unwilling to deal with minor improvements. For that reason, the management of the organizations is not able to develop and implement a system of improvement that uses the time and intellectual resources of middle management and specialists. The implementation of the process approach in this case is incomplete.

9. Difficulties in evaluating the processes themselves.

HEIs experience serious difficulties in the objective assessment of the defined quality management processes.

As a good practice we should point out the definition of a System of Processes and Criteria that directly affect Quality Management according to the International Standard ISO 9001: 2015.

Identifying, understanding and managing inter-linked processes as a system contributes to the organization's efficiency and effectiveness in achieving its goals.

Within this system, processes are defined by the management as strategic ones that directly determine and influence the quality of the educational product offered, and the basic ones that govern specific activities for the implementation of the strategic ones.

For the evaluation of each of the basic processes a set of basic and additional criteria are defined. To these criteria, specific and measurable quantitative indicators are developed to allow benchmarking and comparability of the evaluation results.

On this basis, process cards are developed and adopted to assess the effectiveness of the process (Table 1)

Table 1. Example process card to evaluate process efficiency

<table>
<tr><td>LEVEL AND TYPE OF PROCESS</td><td>PROCESS NAME</td><td colspan="2">PROCESS CONTROLLER
Rector</td></tr>
<tr><td rowspan="3">Basic process</td><td>Educational process. Lifelong learning</td><td colspan="2" rowspan="2">PROCESS MANAGER
Deputy Rector of Education</td></tr>
<tr><td>PROCESS GOVERNANCE DOCUMENTS</td></tr>
<tr><td>Process Management, Regulations for the Structure and Activities of the HS, Educational Activities Code, Student Admissions Code, Academic Staff Code, Administrative Staff Code, Code for Organization of the PhD Students' Training Activity, etc.</td><td colspan="2">PROCESS EXECUTION
Deans of Faculties, Head of Departments, Lecturers, Head of Front Office</td></tr>
<tr><td colspan="2">PROCESS INPUTS</td><td colspan="2">PROCESS OUTPUTS</td></tr>
<tr><td colspan="2">1. Student admission.
2. Student contracts signed.
3. Curricula.
4. Syllabuses.
5. Planning the learning process.
6. Results of educational process control and the status of the students’ academic progress.</td><td colspan="2">1. Implementation of the curriculum.
2. Documentation of test results and ongoing control.
3. Monthly reports of lecturers on curriculum implementation.
4. Assessment of students' knowledge.</td></tr>
<tr><td colspan="2">RELATED PROCESSES WITH DATA:</td><td colspan="2">POSSIBLE RISKS, DEFICIENCIES AND NON-CONFORMITY</td></tr>
<tr><td colspan="2">Improving the organization of the learning process</td><td colspan="2">Decreased entry level requirement control (student admissions)</td></tr>
<tr><td colspan="2">Manage interaction with customers and users</td><td colspan="2">Teaching on inappropriate syllabuses</td></tr>
<tr><td colspan="2">Management of curricula and syllabuses</td><td colspan="2">Errors in planning the learning process</td></tr>
<tr><td colspan="2">Control and assessment of results</td><td colspan="2">Shortage of qualified lecturers</td></tr>
</table>

Evaluating the level of expertise of the trained staff and the possibilities for their career development.	Lack of motivation among students
Managing discrepancies	Lowering of criteria during current and final control

CRITERIA FOR MEASURING PROCESS EFFECTIVENESS:	**TARGET VALUE**	**REALIZED VALUE**
Number of new Bachelor degree courses introduced	…..	…..
Number of new Master degree courses introduced	…..	…..
Attitude of permanent academic staff to non-permanent academic staff in the university	…..	…..
Number of improvements / changes introduced in curricula (development and adaptation of curricula and syllabusees)	…..	…..
Number of newly introduced learning activities / services. (lifelong learning, certification courses, others)	…..	…..

The process cards define:

1. The level and type of the process, its name, the documents governing the process (external and internal governance framework).

The individuals involved in process management: Process Controller, Process Manager (Process Owner) and Process Execution.

One of the biggest problems that arise is the appointment of a process manager (owner) and the definition of their rights and obligations. Often, the basic processes are related to or intertwined with other basic processes (e.g. teaching, research and publishing) involving different structural and core units with different managers. Who can be appointed process owner in this case? The one who conveys the end product to the consumer or the one who carries out the essential part of the activity. It all depends on the specific situation. The ideal owner:

- receives the assignment from the management and bears the responsibility for the product quality (outcome) of the process to the next level;
- oversees (/ can direct) resources and process information, and manages them;
- is responsible for the organization of the activity (technology, algorithm);
- organizes a system for gathering information on the progress of the process;
- conducts monitoring (control and analysis) on the progress of the process;
- is responsible for increasing the efficiency of the process.

In practice, finding a person who has all the above-mentioned powers (and resources) is rather complicated, whilst it must also be consistent with the established tradition of the organization.

2. Process inputs - basic data and results from the preceding process.
3. Outputs of the process - basic data and results of the managed process that are suitable for processing in subsequent processes.
4. Other processes related to the specific process - other processes that interact with the defined process or are intertwined with it, and that cannot be isolated or carved-out from it.
5. Possible risk factors influencing the process - defined risks to process quality based on in-depth analysis of the impact of input data, impact of management on the process, the presence or absence of resources, the impact of related processes.
6. Criteria for measuring the efficiency of the process - target values are determined on the basis of an analysis of the availability of the relevant resources, a satisfactory level of the input data, an adequate organizational structure and governance framework.
   (A) target value - a specific and measurable value allowing for comparability and repeatability and subject to statistical processing and analysis
   (B) actual measured value which is accounted for on the basis of:
      - analyzes of statistical information from conducted evaluations of different activities;
      - self-assessment (including process maturity assessment) by the process manager and the heads of the individual units involved in managing the process;
      - Results of internal and external supervisory audits;
      - analyzes of the effectiveness of corrective actions taken as a result of registered inconsistencies or recommendations for improvement of the activity in the respective area;
      - analyzes of the effectiveness of implemented preventive actions on the recommendation of the process controller or on the initiative of those involved in the management of the process.

The analysis and evaluation of the effectiveness of the main processes is carried out with periodicity defined in the Quality Management System (Quality Manual or System Procedures) during the Annual Management Reviews in accordance with the requirements of ISO 9001: 2015.

The assessment of the main processes must be carried out by assessing their degree of maturity on annual basis. The evaluation criteria are presented in Table 2.

Table. 2 Assessment scale

Level of maturity	Level of implementation	Instructions
1.	No documented approach	There is no systematic approach; no results, bad or unpredictable results.
2.	Reaction approach	Reactive / problem-centric or corrective approach; minimum data on the improvement results.
3.	Stable, documented system approach	Process-oriented system approach, system-level improvements in the early stages, availability of performance data, availability of improvement trends.
4.	Marked continuous improvement	Implemented improvement process; good results and obvious improvement trends.
5.	Best Performance	Documented and optimal results from the comparison with the best

To achieve system certification, the processes evaluated by standard elements need to achieve a maturity level 3.

In order to prove an effective quality management system it is necessary that the processes evaluated are stable at level 4 and 5.

Possible applications at the level of maturity.

The Standard does not specify a methodology for conducting and shaping the organization's overall assessment. Self-assessment or assessment can be used in a flexible manner, depending on its objectives. The main direction in which assessment is oriented is an adequate review and analysis in order to achieve a consensus in setting priorities for improvement and action plans.

The approach used for performance maturity assessment is used to achieve a steady development and improvement of the quality management system. Compliance with relatively simple principles may lead to the formation of clear objectives for system development and criteria for assessing their accomplishment.

The deconstruction of the system into basic processes in terms of the quality management system and / or the processes that make up the main objective of the organization, allows to uniquely identify the processes that are lagging or overtaking the common development. Risk analysis for the process that are lagging behind or overtaking the common development may set priorities for the development of

elements of the quality management system as well as their importance for achieving the goals and strategic development of the organization.

The stability of a system implies an equal level of maturity of the processes that build it. In the case of related sequential processes with different maturity levels, it is reasonable to assume that the level of implementation of the integrating process cannot exceed the maturity level of the process with lowest maturity. Adhering to the principle of harmonious development of the system implies new opportunities for discovering areas for improvement. It is logical to seek to achieve a balanced model of the quality management system, i.e. if possible, all constituent processes are at one level or overtaking / lagging at no more than one level. Otherwise, it is difficult to predict the future behavior and development of the system as a whole. The observations of the author are that significant differences in the level of maturity in successive processes most often poses significant problems among the teams involved in their realization. This is largely due to the different and constantly changing value system, different and characteristic of each of the maturity levels.

The results of the self-assessment of process maturity can be presented in the form of radar diagrams (Figure 1).

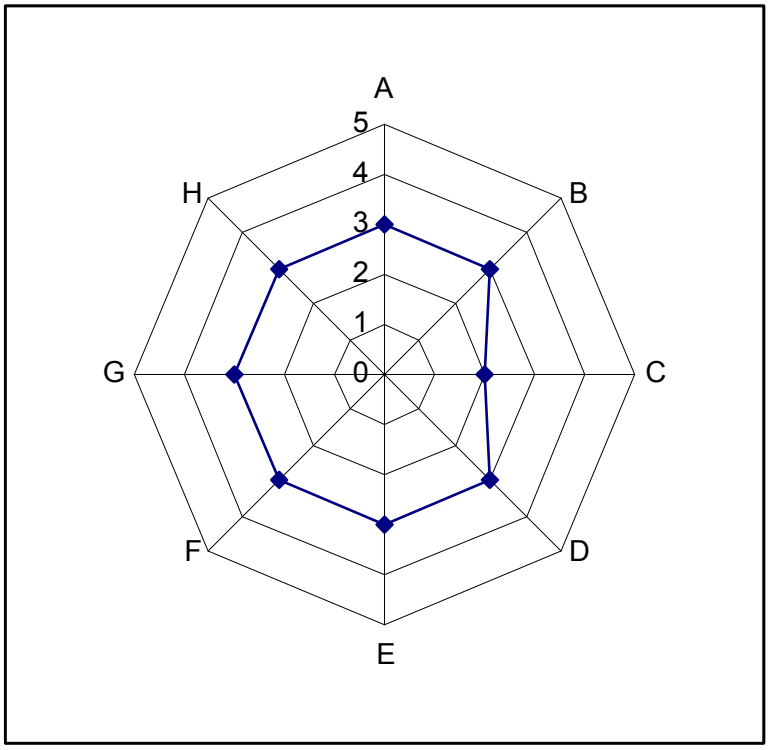

Fig.1 Level of maturity for the implementation of basic principles of BDS EN ISO 9001: 2015

Conclusion

The University Council, based on a Result Analysis, assesses the maturity of each of the strategic processes and defines new target values to be pursued in the next period to achieve the requirement of continuous improvement. Process maps can be improved by adding new criteria, adding new related processes, new governance documents, and more.

The proposed improvement of the process approach is expressed in:

- Creation of an evaluation and improvement toolbox;
- Creation of a system of criteria for evaluation of the results by process;
- Creation of methodologies for evaluation of the results by process;
- Definition of key indicators by activity and process;
- Linking the development strategy to the key indicators;
- Planning and providing the necessary resources for the implementation of the strategy.

Self-assessment is a comprehensive and systematic review of the organization's activities and results are benchmarked against the requirements of the quality management system or model of excellence.

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THE INVERSE RANKING PROBLEM AND THE ALGORITHM FOR SOLVING IT

Viacheslav Gorborukov, Oleg Franchuk

***Abstract**: After solving the classical problem of ranking of alternatives for the aggregate of criteria may occur another problem: what the minimum values of changes could improve the ratings of the selected alternative. The desired result of solving this problem is determination of minimum deviation of the initial criterial values which can allow to get the rating which is not below than the pre-set value. In this article the inverse problem of ranking alternatives, which is formalized in the class of discrete programming models, has been considered. The algorithm for solution this problem, based on the ideology of the method of dynamic programming, has been proposed.*

***Keywords**: decision-making, ranking alternatives, multi-criteria optimization, discrete programming, dynamic programming*

***ACM Classification Keywords**: H. Information Systems*

Introduction

Among tasks of the theory of decision-making, which often occur in practice, tasks of selecting (ranking) alternatives are actual [Ishizaka, 2013; Odu, Charles-Owaba, 2013; Emel'janov, 1985; Larichev, 2003]. Mathematically, these tasks are described by a set of alternatives $x \in X = \{A_1, ..., A_n\}$, for each of which the values of m indicator are given. The solution of this task is considered to be the alternative, which has the best (in aggregate) value of the criteria, which differ in different importance (weighting coefficients) [Emel'janov, 1985; Larichev, 2003]

In practice, there may be a task that is reversed to the specified one, when it is necessary to determine the values of the indicators for the chosen alternative, in which it would receive a given place in the overall rating, and the deviation of the obtained values from the initial ones would be optimal (the minimum of possible). A similar task may be actual when analyzing the results of a rating assessment of the development of certain objects (entities), for example, ranking regions of the country in terms of economic, innovation, industrial activities. In this case, we can talk about developing reasoned recommendations for those ranking participants who failed to occupy the places.

To date, a significant number of methods have been developed for solving the direct task of ranking alternatives in multiple criteria [Ishizaka, 2013; Odu, Charles-Owaba, 2013; Emel'janov, 1985; Larichev, 2003]. The most investigated and commonly used are the analytic hierarchy process (AHP) [Saati,

1993], which is actively used to solve applied problems of decision-making [Baby, 2013; Yadav, Anis, Ali, Tuladhar, 2015; Kutlu et al, 2014].

However, the literature deals with selection problems, which characterized by some specificity: multiple choice alternatives, models with fuzzy relation of advantages, decision-making under uncertainty. [Mustakerov, Borissova, Bantuto, 2012; Borzecka, 2012].

Problem statement

In the general case, the criterion can be considered a certain function $(f_j(x), j \in J = \{1 \ldots m\})$, defined on the set of alternatives. The values of this function be-long either to a predefined set or are calculated in accordance with certain mathematical rules. In the first case, variants are possible: the set of values is given by a point scale, linguistic scale [Saati, 1993] or in the form of a numerical interval $[f_j^{min}, f_j^{max}]$, which is formed from all possible values of the function (from minimum to maximum), taking into account the accuracy of its calculation. An example of the second case is the synthesis of local priorities in the AHP [Saati, 1993]. So, we can assume that the value of the j-th criterion is always a countable set, designate it as Q_j. The best one is the result that corresponds to the maximum or minimum value of the function $f_j(x)$, $j \in J$, depending on the direction of optimization of the criterion. Let J_1 and J_2 be the sets of indexes of criteria that are respectively maximized and minimized ($J_1 \cup J_2 = J$). Next, we assume that the values of each function $f_j(x)$, $j \in J$ belong to a common numerical interval $[q_{min}; q_{max}] \subset R$ of the set of real numbers. Otherwise, it is not difficult to construct a corresponding mutually unambiguous trans-formation of the initial values $f_j(x)$, $j \in J$ in a similar interval.

In general, when considering multi-criteria problems, a vector $W = (\omega_1, \omega_2, \ldots, \omega_m)$ is introduced. Each component of this vector characterizes the importance of the j-th criterion, and $\sum_{j=1}^{m} w_j = 1$, $w_j > 0$ [Emel'janov, 1985; Larichev, 2003; Kini, Rajfa, 1981].

The task of ranking alternatives $x \in X = \{A_1, \ldots, A_n\}$ in multiple criteria $f(x) = (f_1(x), \ldots, f_m(x))$ is to establish a certain order

$$A_{i_1} \succ A_{i_2} \succ \ldots \succ A_{i_n} \quad (1)$$

on the basis of computing the values of a generalized significance $G(X)$ for each element of the set:

$$G(x) = G(f(x), W) = G((f_1(x), \ldots, f_m(x)), (\omega_1, \ldots, \omega_m)),\ x \in X \quad (2)$$

where the values $G(A_i)$ are calculated according to a certain rule (algorithm), which is determined by the mathematical method, which used in each particular case, and

$$G(A_{i_1}) \geq G(A_{i_2}) \geq \ldots G(A_{i_n}). \quad (3)$$

Thus, in decision-making theory, the most known and widespread is the method of an ideal point, a linear convolution, a power-additive convolution, and some others [Lotov, Pospelova, 2008; Makarov et al., 1982; Chernoruckij, 2005; Shtojer, 1992].

In the task of ranking alternatives, the alternative A_{i_1} considered best, which in order (1) takes the first place, respectively, the worst alternative is A_{i_n}. Next we will say that the alternative in the order (1) is at k-th place. Hence, the alternative A_{i_k}, $k = \overline{1,n}$ in the order (1) is at *k*-th place.

However, in practice, after solving the problem (1) - (3) for another alternative A' might be necessary to analyze the place k' that it occupied in the order (1). Such type of analysis can be a research: "At which deviations from the existing values $f_j(A')$, $j \in J$ of the alternative A' would it take another, predetermined and different place?" A concrete illustrative example may be the problem of developing an individual plan for training a reserve sports team player in order to he would be able to get into the first team in the near future. It is about what exactly the indicators that are analyzed in the process of training should be given the most attention. Another example is to argue and to point out the shortcomings of a particular project (any sphere of human activity) that participated in a competition for a grant or funding allocation, etc.

Suppose, after the solving of problem (1) - (3), it has become necessary that the alternative A' occupies a certain place in order (1), not lower than p ($p < k'$), and the decision maker is empowered to determine the subset of the criteria $J' \in J$ for which the values $f_j(A')$, $j \in J$ are allowed to change. The set of vector-parameters $\Theta = (\Theta_1 \times \ldots \times \Theta_m,\ \Theta \subset R^m)$ is defined in the following way:

$$\Theta_j = \bigcup_{q_j \in Q_j} (q_j - f_j(A')), j \in J', \quad \Theta_j = \{0\}, j \in J \setminus J'$$

where each set $\Theta_j, j \in J'$ represents all possible deviations of values $q_j \in Q_j$ from $f_j(A')$. The mathematical model of the problem under consideration will look like this:

$$H(A', \theta, p, W) \to \min$$
$$H(A', \theta, p, W) = G(f(A', \theta), W) - G(f(A_{i_p}), W) \quad (4)$$

$$G(f(A', \theta), W) > G(f(A_{i_p}), W), \quad (5)$$

$$\theta = (\theta_1 \times \ldots \times \theta_m) \in \Theta = (\Theta_1 \times \ldots \times \Theta_m,\ \Theta \subset R^m), \quad (6)$$

where $f(A', \theta) = (f_1(A') + \theta_1, f_2(A') + \theta_2, \ldots, f_m(A') + \theta_m), \theta \in \Theta.$

If for solving of problems (1) - (3), (4) - (6) uses a linear convolution as a generalized criterion, then the function $G(\cdot)$ in (2) will have the form:

$$G(x) = G(f(x), W) = \sum_{j \in J_1} w_j(f_j(x)) - \sum_{j \in J_2} w_j(f_j(x)),$$

And the function $H(\cdot)$ in (4) –

$$H(A', \theta, p, W) = \left(\sum_{j \in J_1} w_j(f_j(A') + \theta_j) - \sum_{j \in J_2} w_j(f_j(A') + \theta_j) \right) - \left(\sum_{j \in J_1} w_j(f_j(A_{i_p})) - \sum_{j \in J_2} w_j(f_j(A_{i_p})) \right) =$$

$$= \sum_{j \in J_1} w_j(f_j(A') + \theta_j - f_j(A_{i_p})) - \sum_{j \in J_2} w_j(f_j(A') + \theta_j - f_j(A_{i_p})) \quad (7)$$

For power-additive convolution:

$$G(x) = G(f(x), W) = \sum_{j \in J_1} (f_j(x))^{w_j} - \sum_{j \in J_2} (f_j(x))^{w_j},$$

$$H(A', \theta, p, W) = \left(\sum_{j \in J_1} (f_j(A') + \theta_j)^{w_j} - \sum_{j \in J_2} (f_j(A') + \theta_j)^{w_j} \right) - \left(\sum_{j \in J_1} (f_j(A_{i_p}))^{w_j} - \sum_{j \in J_2} (f_j(A_{i_p}))^{w_j} \right) =$$

$$= \sum_{j \in J_1} w_j((f_j(A') + \theta_j)^{w_j} - (f_j(A_{i_p}))^{w_j}) - \sum_{j \in J_2} ((f_j(A') + \theta_j)_{w_j} - (f_j(A_{i_p}))^{w_j})$$

If the task (1) - (3) is solved by the method of the ideal point, and A^* – the ideal alternative (point), then

$$G(x) = G(f(x), W) = \left(\sum_{j \in J} w_j(f_j(x) - f_j(A^*))^2 \right)^{\frac{1}{2}},$$

However, in this form, the function $G(x)$ does not meet the requirements (3), since for this case the best will be not bigger but smaller values $G(x)$ (the distance to the ideal point is minimized), therefore, for correct use of the model (1) - (3) $G(x)$ could be modify in following way:

$$G(x) = \tilde{G} - \left(\sum_{j \in J} w_j(f_j(x) - f_j(A^*))^2 \right)^{\frac{1}{2}},$$

$$\text{where } \tilde{G} = \left(\sum_{j \in J_1} w_j(\min_{x \in X} f_j(x) - f_j(A^*))^2 + \sum_{j \in J_2} w_j(\max_{x \in X} f_j(x) - f_j(A^*))^2 \right)^{\frac{1}{2}},$$

$\tilde{G}$ – the distance between the ideal worst and ideal best alternatives. Then

$$H(A', \theta, p, W) = G(f(A', \theta), W) - G(f(A_{i_p}), W) = \left(\sum_{j \in J} w_j(f_j(A_{i_p}) - f_j(A^*))^2 \right)^{\frac{1}{2}} - \left(\sum_{j \in J} w_j(f_j(A') - f_j(A^*))^2 \right)^{\frac{1}{2}}$$

Algorithm

The algorithm for solving the problem (4) - (6) for the case of application of the linear convolution of the criteria in (2) is consider in detail. The cost function (7) can be rewrited int the form:

$$H(A',\theta,p,W)=\sum_{j\in J_1}w_j\theta_j-\sum_{j\in J_2}w_j\theta_j+\sum_{j\in J_1}w_j(f_j(A')-f_j(A_{i_p}))-\sum_{j\in J_2}w_j(f_j(A')-f_j(A_{i_p}))=\sum_{j\in J_1}w_j\theta_j-\sum_{j\in J_2}w_j\theta_j-$$

$$-\left(\sum_{j\in J_1}w_j(f_j(A_{i_p}))-\sum_{j\in J_2}w_j(f_j(A_{i_p}))\right)+$$

$$+\left(\sum_{j\in J_1}w_j(f_j(A'))-\sum_{j\in J_2}w_j(f_j(A'))\right)=\sum_{j\in J_1}w_j\theta_j-\sum_{j\in J_2}w_j\theta_j-\left(G(A_{i_p})-G(A')\right)=$$

$$=h(\theta_1,\theta_2,\ldots,\theta_m)-G^* \qquad (8)$$

In the resulting formula

$$h(\theta_1,\theta_2,\ldots,\theta_m)=\sum_{j\in J_1}w_j\theta_j-\sum_{j\in J_2}w_j\theta_j\ ,$$

and G^* is the constant value, which sets the initial advantage of the alternative A_{i_p} over A', so $G^*=G(A_{i_p})-G(A')$. According to (3) G^* is not a negative number.

Let $\theta_j\in\{\theta_j^1,\theta_j^2,\ldots,\theta_j^{r_j}\}\subseteq\Theta_j$, where r_j – Number of deviations given by decision-maker, and $\theta_j^1,\theta_j^2,\ldots,\theta_j^{r_j}$ is a numerical sequence, and for $j\in J_1\ \ 0<\theta_j^1<\theta_j^2<\ldots<\theta_j^{r_j}$; $j\in J_2\ \ 0>\theta_j^1>\theta_j^2>\ldots>\theta_j^{r_j}$

.

The purpose of the algorithm is to find such a vector $\theta=(\theta_1\times\ldots\times\theta_m)$, which minimizes $h(\theta_1,\theta_2,\ldots,\theta_m)$ among all possible sets θ for which (8) the positive value. For the minimized criteria, the elements of the set $\{\theta_j^1,\theta_j^2,\ldots,\theta_j^{r_j}\}$ are redefined as follows: $\theta_j^1:=-\theta_j^1,\theta_j^2:=-\theta_j^2,\ldots,\theta_j^{r_j}:=-\theta_j^{r_j}$, where "$:=$" is considered as a operation of the reassignment of the values. Then (8) can be rewritten in the form

$$H(A',\theta,p,W)=h(\theta_1,\theta_2,\ldots,\theta_m)-G^*=H(A',\theta,p,W)=\sum_{j=1}^{m}w_j\theta_j-G^* \qquad (9)$$

The algorithm is based on the ideology of the method of dynamic programming [Bellman, 1960]. In accordance with it, a recurrence relation is determined, according to which the initial problem is reduced to problems of smaller dimension. Hence, $\theta^k=(\theta_1\times\ldots\times\theta_k)$, the vector of deviations for the first *k* criteria, $k\in\{1,2,\ldots,m\}$. Consequently

$$H(A',\theta^m,p,W)=\sum_{j=1}^{m}w_j\theta_j-\left(G(A_{i_p})-G(A')\right)$$

$$H(A',\theta^m,p,W)=w_m\theta_m+H(A',\theta^m,p,W)-G^*,$$

$$H(A',\theta^{m-1},p,W)=w_{m-1}\theta_{m-1}+H(A',\theta^{m-2},p,W)-(G^*-w_m\theta_m),$$

…

$$H(A',\theta^k,p,W)=w_k\theta_k+H(A',\theta^{k-1},p,W)-(G^*-\sum_{j=k+1}^{m}w_j\theta_j), \quad (10)$$

…

$$H(A',\theta^1,p,W)=w_1\theta_1-(G^*-\sum_{j=2}^{m}w_j\theta_j).$$

Initially, G^* is a value as far as the alternative A' is "worse" from A_{i_p} when taking into account all *m* criteria.

The parts of the formula (10) for the dimension problem *k* are considered. The expression in brackets $G^*-\sum_{j=k+1}^{m}w_j\theta_j$ means how much the "lag" alternative A' from A_{i_p} is reduced by obtaining the value $\theta_{k+1},\theta_{k+2},\ldots,\theta_m$ at the initial *m-k* steps of the algorithm; $H(A',\theta^{k-1},p,W)$ is the minimum positive value of the desired advantage of the alternative A' over A_{i_p}, taking into account only *k* -1 of the first criteria.

In the part $w_k\theta_k$ the value of θ_k is selected from the set $\{\theta_k^1,\theta_k^2,\ldots,\theta_k^{r_k}\}$.

- For effectively work of the algorithm of problem solving (4) - (6), it is necessary to perform several procedures..
- For each of the m criteria, the arithmetic mean values of the weighted deviations are determined:

$$\tilde{\theta}_k=\frac{\sum_{i=1}^{r_k}w_k\theta_k^i}{r_k},\ k=\overline{1,m}.$$

- The criteria of the base task are sorted by the growth of the obtained values $\tilde{\theta}_k$, $k=\overline{1,m}$. In order to prevent the reassignment of the index of the criteria it is assumed that inequality $\tilde{\theta}_1\le\tilde{\theta}_2\le\ldots\le\tilde{\theta}_m$ is initially carried out. This does not reduce the generalization of the task.
- A sequence of hash sums S_k is created according to the following rule:

$$S_1=0,S_2=S_1+\theta_1^{r_1},\ldots,S_k=S_{k-1}+\theta_{k-1}^{r_{k-1}},\ldots,$$

$$S_m=S_{m-1}+\theta_{m-1}^{r_{m-1}}$$

Next, a table is created that will consist of m column of values (bottom-up) $0,w_k\theta_k^1,w_k\theta_k^2,\ldots,w_k\theta_k^{r_{jk}}$ for each criterion and have the row of the received hash amounts:

In table 1 $r_2 = \max(r_j), j \in \{1,\ldots,m\}$, $r_k > r_{m-1} > r_1$, Therefore, the columns have different heights, depending on the number of possible deviations of one or another criterion.

The algorithm allows to generate permissible solutions of the problem (4) - (6) without a complete overview of all possible variants and is verbally described as follows.

0. If sum $S_m + \theta_{m,r_m} * w_m$ lower than G^* , then the problem (4)-(6) have no solution.

1. Initialization. Initial values are determined $k = m, g_k = G^*, l_k = 0, \theta = (0,\ldots,0), \theta^{min} = \theta$. Here and further in the algorithm *k* is the number of the analyzed criterion, g_k is the "not overcome" advantage A_{i_p} over A', which remains at the moment of consideration of the subtask with *k*-th dimension. l_k is index of weighted deviation of the criterion under the number *k* $(0 \le l_k \le r_k)$, $\theta = (\theta_1, \theta_2, \ldots, \theta_k, \ldots, \theta_m)$ is variant of problem solution. Initially at (*k* = *m*) is laid $\theta_1 = 0, \theta_2 = 0, \ldots, \theta_m = 0$. At any time of the algorithm's work, the current resulting minimal function value $H(A', \theta, p, W)$ corresponds to the solution θ^{min} .

2. For a sub-task of *k*-th dimension, the column of weighted deviations of the *k*-th criterion is considered. The index l_k increases as long as the weighted deviation $w_k\theta_k^{l_k}$ with the hashed amount S_k does not become larger than g_k . It should be noted that S_k the maximum possible value, which may be reduced to advantage A_{i_p} over A' with already fixed deviations $\theta_{k+1} = \theta_{k+1}^{l_{k+1}}, \theta_{k+2} = \theta_{k+2}^{l_{k+2}}, \ldots, \theta_m = \theta_m^{l_m}$ in previous steps. There are three possible cases.

    2.1. The sum of the maximum possible weighted deviation $w_k\theta_k^{r_k} + S_k$ is less than g_k . Go to Step 3.

    2.2. Weighted deviation $w_k\theta_k^{l_k}$ without hash amount S_k is more than g_k . This means that the solution is obtained $\theta = (0,\ldots,0,\theta_k^{l_k}, \theta_{k+1}^{l_{k+1}},\ldots,\theta_{m-1}^{l_{m-1}}, \theta_m^{l_m})$. Go to Step 4.

    2.3. Weighted deviation $w_k\theta_k^{l_k}$ with the hash amount S_k is more than g_k . Go to Step 5.

3. If k = m, go to step 6, otherwise return to (k + 1) -th criterion; k = k + 1. Go to step 2.

4. If the value $H(A', \theta, p, W)$ for the received solution is less than $H(A', \theta^{min}, p, W)$, then $\theta^{min} = (0,\ldots,0,\theta_k^{l_k}, \theta_{k+1}^{l_{k+1}},\ldots,\theta_{m-1}^{l_{m-1}}, \theta_m^{l_m})$. Go to step 3.

5. The dimensionality of the task decreases; k = k - 1, $l_k = 0$. Go to step 2.

6. θ^{min} is optimal solution of the problem (1)-(6).

Table 1. Weighted deviations of values of the criteria of the problem (4)-(6).

	K_1	K_2	…	K_k	…	K_{m-1}	K_m
$\max\limits_{j\in\{1,\dots,m\}}(r_j)$	⋮	$w_2\theta_2^{r_2}$	…	⋮	…	⋮	⋮
⋮		⋮		$w_k\theta_k^{r_k}$		$w_{m-1}\theta_{m-1}^{r_{m-1}}$	
	$w_1\theta_1^{r_1}$			⋮		⋮	$w_m\theta_m^{r_m}$
	⋮						⋮
2	$w_1\theta_1^2$	$w_2\theta_2^2$	…	$w_k\theta_k^2$	…	$w_{m-1}\theta_{m-1}^2$	$w_m\theta_m^2$
1	$w_1\theta_1^1$	$w_2\theta_2^1$	…	$w_k\theta_k^1$	…	$w_{m-1}\theta_{m-1}^1$	$w_m\theta_m^1$
0	0	0	…	0	…	0	0
Hash	S_1	S_2	…	S_k	…	S_{m-1}	S_m

The formally described algorithm can be represented as follows. (Objects used in the algorithm are completely in line with the data structures defined above).

/* *k,m,i,j* : integer positive values,

Rez – value of the cost function: real;

G^* – Initial deviation A_{i_p} from A': real,

g, w, S, θ^{min} – array of *m*-th dimension: real numbers,

l, r – array of *m*-th: integer positive values,

θ – two-dimensional array of m columns of different heights: real numbers,

*/

$S_1 = 0$; // Calculation of hash sums S_k, $k = \overline{1,m}$

For $(i = 2; i \le m; i{+}{+})$ $S_i = S_{i-1} + \theta_{i-1,r_{i-1}} * w_{i-1}$

EndFor

$Rez := S_m = \theta_{m,r_m} * w_m - G^*$; // Initial value of the cost function

If $(Rez < 0)$ **Then Exit EndIf** // The problem has no solutions.

// Initialization

$k := m; g_k := G^*;$

For $(i = 1; i \le m; i{+}{+})$ $l_i := 0; \theta_i^{min} := 0;$ **EndFor**

Do while $(k \le m)$

$j := r_i + 1$ **;**

For $(i = l_k; i \le r_k, i{+}{+})$

If $S_k + w_k \theta_{k,i} - g_k > 0$ **Then** $j := i$ **;**

Break **EndIf**

EndFor

$l_k := j;$

If $(l_k \le r_k)$ **Then**

If $((w_k \theta_{k,l_k} - g_k > 0)$ **Then**

If ($w_k \theta_{k,l_k} - g_k < Rez$**)) Then**

For $(i = 1; i \le m; i{+}{+})$ $\theta_i^{min} := \theta_{i,l_i}$ **EndFor**

$Rez := w_k \theta_{k,l_k} - g_k;$

EndIf

$l_k := 0; k := k + 1; l_k := l_k + 1;$

Else $g_{k-1} := g_{k-1} - \theta_{k,l_k}; k := k - 1; l_k := 0;$

EndIf

Else $l_k := 0; k := k + 1; l_k := l_k + 1;$

Endif

EndDo

Conclusion

For solving the problem (1) - (3) a decision support system (DSP) Verum EST [Gorborukov, 2011] was created. The system is intended for the solution of applied problems arising in the administrative activity of collegial bodies of management, enterprises, organizations, institutions, etc... for making responsible and scientifically grounded decisions. The considered algorithm is implemented and included in the library of mathematical methods of this system.

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USING GENETIC ALGORITHM FOR SINGULARITY AVOIDANCE IN POSITIONING TASKS OF A ROBOTIC ARM

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Abstract: In this paper, the singularity problem is addressed. We studied the singularity of a real arm robot analytically and numerically. Then, using genetic algorithm techniques we present a new method to decrease the effects of the singularity. This allows the robot to avoid the failure of the positioning task when the robot is to pass near or pass through a singular configuration. In the proposed technique, to determine the alternative robot configurations parameters, a global objective function is designed to minimize both the error between the end-effector positions at the singular and the alternative configurations and the error between the robot joints values at the singular and the alternative configurations. Finally, an avoidance task function is proposed. The proposed solutions are implemented and the results obtained from genetic algorithm are validated when positioning tasks are performed the real arm robot. Also, the results of the proposed avoidance technique show that it allows the robot to avoid the singularity effects when the arm robot is to perform positioning tasks.

Keywords: Robot forward kinematics, Robot singularities, 5 Degree of freedom (DOF) robot arm singularity, Avoiding singularity, Genetic Algorithm.

Introduction

Since the invention of robots in mid 19th century, a lot of researches have been dedicated to study the robot kinematics, inverse kinematics, forces, joints dynamics and joints torques. Singularity analysis has been identified as a very important subject in robotic due to its effects on the robot because it causes robot joint velocity enlarged and tends to infinity. This can lead to instability in robot motion, reduce instantaneous mobility of the robot, can alter the path planned, may impede control algorithms, forces and torques, and damage the robot internal mechanisms causing a catastrophic situations, [De Xu, 2005; Jasour, 2009].

At singular configuration the determinant of the Jacobian matrix becomes zero causing the infinite joint velocities. Jacobian matrix is the coefficient matrix of the set of equations which relate the velocity of the end effector with the robot joints velocities. The Jacobian matrix is thus a critical element through robotics applications, especially in finding the singular points in the work space of a serial robot. Singularity issue is defined and studied by [Gosselin, 1990], where different kinds of singular

configurations are defined for various closed loops robot manipulators in [Zlatanov,1994a; Zlatanov, 1994b; Hayes, 2002]. The formulation of Jacobian presented in current work is built upon the material found in [Sciavicco, 2000; Siciliano, 2008; Craig, 2005].

Many efforts were done to find the singularity of a specific arm robot to derive the conditions which identify the properties of the singularity. Some researchers used the screw theory or coordinate transformations [Lai, 1986; Wang, 1987; Hunt, 1991; Sefrioui, 1993], other researchers used a geometrical approach which will also be used in current work, [Gosselin, 1990; Merlet, 1988; Merlet, 1989]. A six degrees of freedom robot arm manipulator from has been studied in [Vaezi, 2011] with full scope of the robot arm singularities to decompose the robot arm singularities the wrist singularities. The work presented in [Hayes, 2002] studies an analytical description and classification of the complete set of singular configurations of the KUKA KR-15/2 six-axis serial robot in particular and all wrist partitioned 6R robots in general. The analysis shows that all general singular positions are either shoulder, elbow, or wrist singularities, or any combination thereof, no others exist.

The paper is organized as following: in section two, some related works are presented then robot structure and Jacobian matrix are discussed. The problem definition of the CRS robot singularities is discussed and studied analytically and numerically in section three. The proposed solutions using genetic optimization and avoidance function are given in section four. The implementations of the proposed methods and the experimental results are presented in section six. Finally, section seven discusses the conclusions.

Related Works

Genetic algorithm (GA) is a powerful method to optimize a wide range of problems, it has been used to optimize problems in many fields such as military, industrial, biological, financial, economical, engineering, medical, and robotic fields. In the robotic field many researchers have used Genetic algorithm to optimize and find the best path and trajectories for the robot arm to move between different points, [Latombe, 1991; Chan, 1993; Bianco, 2002; Devendra, 2002; Pires, 2000].

Genetic algorithm is also used to maximize the reachable area in the work space by end effectors of the robot [Chaitanyaa, 2016; Stan, 2009; Khoshnoodi, 2017]. In [Chaitanyaa, 2016] optimization is used to maximize the work space area reached by the end effector of a revolute robotic arm. The singularities influences of the design variables variation is considered when the mathematical model used for the optimization is designed. Link lengths and Joint angle between link1 and link 2 are modeled as design variables. Nonlinear optimization model based on Genetic Algorithm employed to obtain a global optimum value of the objective function is compared with the using of semi-infinite programming technique, [Chaitanyaa, 2016]. The results showed that Genetic algorithm gives a maximum objective

function value which is considerably high compared with the value obtained using the semi-infinite programming method.

Genetic algorithm is also used in [Stan, 2009] in workspace maximization problem of a 2-DOF parallel robot and sowed that using GA in optimization problems improves the quality of the outcome from the optimization. Genetic Algorithm is used in [Khoshnoodi, 2017] to determine the optimum manipulator dimensions when the singularity and kinematic properties are used to define the objective function. Their work show that using genetic algorithm in the optimization allows to achieve ideal design of parallel manipulator geometry with minimum singularity and good workspace. In this research work the genetic algorithm technique is used to find alternative configurations to those singular configuration of a five degrees of freedom arm robot. The structure of the CRS Robot Arm is presented and the robot Jacobian matrix are now discussed and explained.

2.1 Structure of the CRS Robot Arm

The CRS robot arm consists of five rotating joints each joint has its axis of rotation as in Figure 1.

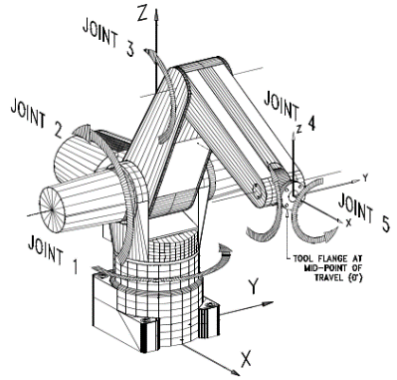

Figure 1: CRS Robot Arm

The complete system comes with a controller and a teach pendant. Robot arm is either controlled through an open or closed architecture mode. In the open architecture mode, the robot arm is controlled by Matlab, while in the closed architecture it is controlled through the teach pendant. The DH parameters representing the robot arm is shown in Table 1.

Table 1: CRS DH parameters

Link	Alpha	Angle offset	Theta	Distance
1	0	0	0	0
2	$\boldsymbol{\pi l2}$	0	$\boldsymbol{\theta_1}$	254
3	0	254	$\boldsymbol{\theta_2}$	0
4	0	254	$\boldsymbol{\theta_3}$	0
5	$\boldsymbol{-\pi l2}$	0	$\boldsymbol{\theta_4}$	0
6	0	0	$\boldsymbol{\theta_5}$	50.8

2.2 CRS Robot Jacobian Matrix:

The Jacobian matrix maps the linear and angular velocities of the end effector to the joint velocities. Singularity of the robot occurs when Jacobian matrix tends to zero. The first step in studying the singular configurations is to obtain the Jacobian matrix. The velocities v of the end effector which consists of the linear and rotational velocities is given by:

$$v = J_{CRS}\dot{Q} \tag{1}$$

where $\dot{Q}$ represents the change in every joints angle with respect to time, and J_{CRS} is the jacobian matrix to be computed. The velocity vector of the end effector is given by $v = [\dot{x}, \dot{y}, \dot{z}, \dot{w_x}, \dot{w_y}, \dot{w_z}]$ and the angular velocity vector of robot joints is given by $\dot{Q} = [\dot{\theta}_1, \dot{\theta}_2, \dot{\theta}_3, \dot{\theta}_4, \dot{\theta}_5]$.

The Jacobian matrix $\boldsymbol{J_{CRS}}$ is of size $m \times n$, where m identifies the number of degrees of freedom for the arm robot and n represents the number of joints within the arm robot. Each row in the Jacobian matrix represents the effect of each joint on the coordinate of the end-effector. The geometrical Jacobian of the robot arm can be shown in equation (2):

$$J_{CRS} = \begin{bmatrix} k_1 & k_2 & \dots & \dots & k_5 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

where $k_i = (z_i^0 \times (o_5^0 - o_{i-1}^0))$ with z_i^0 is the vector representing the axis of rotation of the joint i and o_i^0 is the origin point of frame attached to joint i.

Problem Definition

The main problem to be solved in this work is to reduces and avoid the effect of the joint singularity of the CRS robotic arm. This effects can be recognized in the instability of robot motion when it has to approach, pass through, or reach this singular configurations. A new joint singularity in the work space of the CRS arm robot is discovered. The singularity conditions of the robot are studied in order to find the singular configuration of the robot. Two approaches are used for this study analytical and numerical approaches.

3.1 Analytical Study

Singular configurations are reached when the robot configuration causes $|J_{CRS}| = 0$. Thus, the determent of Jacobian has to be obtained to find the configurations that will cause the Jacobian lose a rank or to be ill-conditioned. The determent F of the Jacobian J_{CRS} can be computed and written as:

$$F = |J_{CRS}| = kf(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5) \tag{3}$$

where k is a constant value. $k = (16387064/5)$. and $f(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5)$ is a nonlinear function of robot joint angles $\theta_1, \theta_2, \theta_3, \theta_4, \text{and } \theta_5$. When setting $F = 0$ in equation (3), we deduced that the

number of configurations satisfying this condition are two. First configuration is reached when $\theta_2 = 135$, and $\theta_4 = -45$. Such configuration is equivalent to the shoulder singularity which is not achievable in real time due to mechanical limitation in joint 2. The second singular configuration is reached when $\theta_3 = 0$ and is equivalent to elbow singularity, it can be achieved by the robot in the real time experiments and this singularity will be studied in this work.

3.2 Numerical Study

In the Numerical study, the whole workspace of the robot arm is analyzed to investigate all the possible robot arm configurations which lead to disturbance in robot operations. A simulation program was developed to study the singularities in the robot workspace by considering two different steps for each joint with step size 0.5 and 0.1. The simulation aims to observe all configurations that produce a determent value of the Jacobian less than 0.001, i. e. tends to zero value. These simulation studies show that the disturbances take place for all configurations having $\theta_3 = 0$ which is corresponding to an elbow singular configuration obtained by the analytical study.

This configuration is then analyzed in more detailed by studying the values of the determent starting at $\theta_3 = 0$, corresponding to elbow singularity, to reach $\theta_3 = 0.1$. The goal of this study is to determine when the singularity effect starts to take place and should be avoided. It is found that at $\theta_3 = 0.0001$ the determent value reaches 34.5, and at the fourth step when $\theta_3 = 0.0004$ the value of the determent jumped to 125.

Proposed Solution

Two solution approaches are proposed to avoid the singular configurations. First approach is by using genetic algorithm technique to find alternative configurations to those singular configuration. So that the robot can follow the alternative free-singularity configuration path instead of moving through a path having a singular configuration. The second approach is to design avoidance function to forbid the robot movement toward the singularity so that the robot avoid the instability behavior in its motion. This designed function aims to control the motion of the joint around its singular value.

4.1 First approach: Genetic Algorithm for Alternative Configuration

Our goal is to find the alternative configurations to the singular configurations while ensuring that the error between the two configurations (singular and alternative) is minimized, as shown in figure 2.

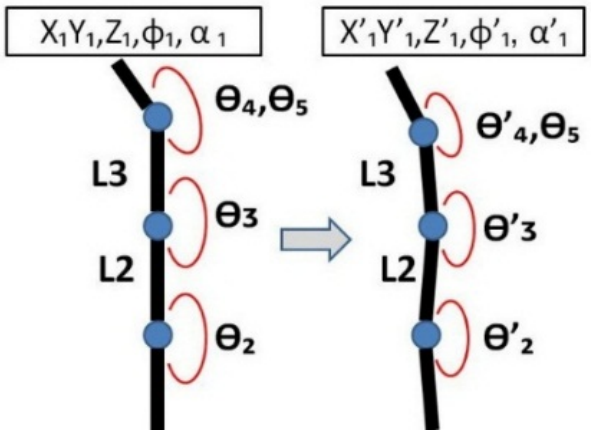

Figure 2: The alternative pose to singular pose with change in joints

By looking at any singular configuration, it is found that the joint configuration vector is $Q = (\theta_1, \theta_2, \theta_3, \theta_4, \theta_5)$, where θ_1 and θ_5 don't affect singularity, Therefore, the main concern is to control and optimize the error between the three angular joints (θ_2, θ_3 and θ_4). So, the dimension of the problem is reduced by considering the robot arm as a three degrees of freedom. As for in the Cartesian space the robot has only (x, z, α) to be controlled, where *x* and *z* are the Cartesian coordinates of the end-effector, and *α* is the pitch angle of the end-effector.

Objective Function: To design the optimization function that helps to avoid the singularity while keeping the robot end effector at the planed Cartesian position and in the same time minimize the change in the robot joint space. That is why there are two objective functions have to be optimized simultaneously. The first function considers the distance between the two configurations Q_1 and Q_1^* in the joint space where $Q_1 = [\theta_2, \theta_3, \theta_4]$ and $Q_1^* = [\theta_2^*, \theta_3 + 0.2^o, \theta_4^*]$, with the optimization function defined as:

$$f_J(\theta_2, \theta_4) = \sqrt{(\Delta\theta_2)^2 + (\Delta\theta_4)^2} \tag{5}$$

where $\Delta\theta_2 = \theta_2^* - \theta_2$ and $\Delta\theta_4 = \theta_4^* - \theta_4$.

The second function defines the error in the Cartesian space between P_1 and P_1^* where $P_1 = [X, Z, \alpha]$ and $P_1^* = [X^*, Z^*, \alpha^*]$, in this case the optimization function in Cartesian space is defined as:

$$f_C(X, Y, \alpha) = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta\alpha)^2} \tag{6}$$

where $\Delta X = X^* - X$, $\Delta Y = Y^* - Y$ and $\Delta\alpha = \alpha^* - \alpha$.

The main purpose for using GA optimization is to minimize the error in Cartesian space and also to minimize the difference in the joint space. To reach this requirement, a balancing parameter is added to

combine the least square error in joint space and in the Cartesian space between the two configurations.

$$f_{JC}(\theta_2, \theta_4, X, Y, \alpha) = \lambda\, f_J(\theta_2, \theta_4) + (1-\lambda)\, f_C(X, Y, \alpha) \quad (7)$$

The genetic algorithm parameters values are set to be: elitism = 10%, cross-over = 80%, mutation = 10%, population size = 300 and the number of generation = 500. It is found that the optimized values of θ_2 and θ_4 for each case is equal to its value in the singular configuration minus the half of the value of θ_3. This means that if the value of θ_3 is 0.2^o then θ_2 will be $(\theta_2 - 0.1)$ and θ_4 will be $(\theta_4 - 0.1)$. The effect of changing λ on the error defined by both Cartesian space and joints space is also investigated. The total Cartesian error increased proportionally with λ, which indicates that the important parameter is to control the Cartesian error while the error in the joints space declines.

4.2 Second approach: Avoidance Task Function

An avoidance task function is introduced in the control system of the robot arm based on the results of the analytical study of robot singularity. The configuration space is divided into three zones named SAFE, CARE and STOP zones. The SAFE zone is when the robotic arm is operating very far from the singularity and in that case the avoidance function do nothing, the CARE zone is when the robotic arm is approaching the singular position but not yet reaching it, the last zone is the STOP zone is when the robot has to stop completely just before reaching the singular point. The zone parameter function is given in 8:

$$\widehat{\Psi}(\theta) = \begin{cases} 0 & if\ 5 \le \theta_3 \quad SAFE\ zone \\ \dfrac{\Psi(\theta_3) - \Psi(5)}{\Psi(0.2) - \Psi(5)} & if\ 0.2 < \theta_3 < 5 \quad CARE\ zone \\ 1 & if\ \theta_3 < 0.2 \quad STOP\ zone \end{cases} \quad (8)$$

Where

$$\Psi(\theta_3) = 1/(1 + \exp^{20*\frac{\theta_3 - 0.2}{5-0.2} - 10}) \quad (9)$$

The zone parameter function is then used to adopt the avoidance task which acts as a braking speed, using equation (10):

$$\mathrm{k}_3(\theta_3) = -\dot{Q}_3 * \widehat{\Psi}(\theta_3) \quad (10)$$

where $\mathrm{k}_3(\theta_3)$ is the output variable that stabilize the velocity of joint 3, $\dot{Q}_3$ is the velocity of joint 3 and θ_3 is the value of joint angle.

Therefor the operations of the system are defined by three main stages. Stage 1 is defined when θ_3 operates between 90 and 5 where no avoidance mechanism is required, corresponding to SAFE

zone. Stage 2 is defined when θ_3 operates between 5 and 0.2 where the avoidance mechanism is activated and modify the main angular velocities to control the velocity of θ_3 to slow it down, corresponding to CARE zone. Last one is stage 3 is defined when θ_3 reaches 0.2, in this point the avoidance mechanism prevents any motion on θ_3 toward zero, corresponding to CARE zone.

Implementation of the Proposed Technique

As seen in previous sessions, the main singular configuration for CRS robot is when θ_3 tends to zero, Three experiments are performed, the first one is to study the robot behavior when the task is to move toward the singular configuration where no singularity avoidance task is considered. The second experiment is to apply the singularity avoidance task when the robot moves toward a singular configuration. The third experiment is to validate the results obtained from the genetic algorithm regarding the alternative poses corresponding to a pose at a singular configuration. Experiments one and two are planned such that the robot starts from the home position at which the joints configuration $[\theta_1, \theta_2, \theta_3, \theta_4, \theta_5] = [0, 0, 90, 0, 0]$ and moves towards the singularity at $\theta_3 = 0$.

Experiment 1: No avoidance algorithm is considered when performing this experiment. The main concern of this experiment is to test the effect on robot joints and motors when the performed task leads the robot to operate around a singular points. The robot is set to move under full joint speed, 5 deg/sec, and commanded to enforce joint θ_3 to reach its zero value. Results show an extreme motion of the robot arm especially in joints two, three and four. Joint 3 movement towards the singularity is illustrated in Figure 3, it is clear that once joint 3 reached the zero limit a huge movement is exerted on this joint so that θ_3 increased from $\theta_3 = 0^o$ to the joint limit of 130^o by moving in the opposite direction of the original movement in few milliseconds. The motor rates shows an incredible reverse motion when approaching the singular point, it is moving with almost 5 deg /sec with a steady increase till it reached almost 50 deg /sec in the neighborhood of the singular point. Then the motion is reversed in the opposite direction at a very high speed. The change in rates of motor 3 is shown in Figure 4, it is important to mention that the maximum allowed speed limit for motor 3 is 25 deg /sec and because of singularity the graph shows that for a very short period the motor rates reaches 250 deg /sec which is 10 times the allowed speed limit.

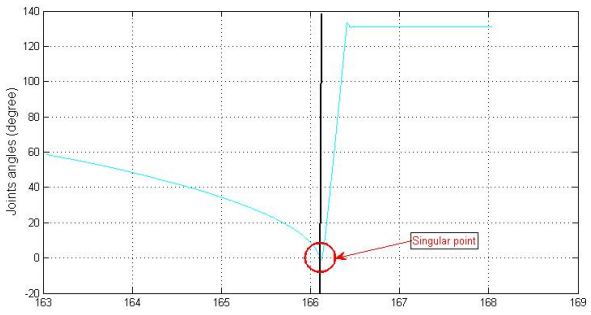

Figure 3: The motion of joint 3 towards singularity and the moment after

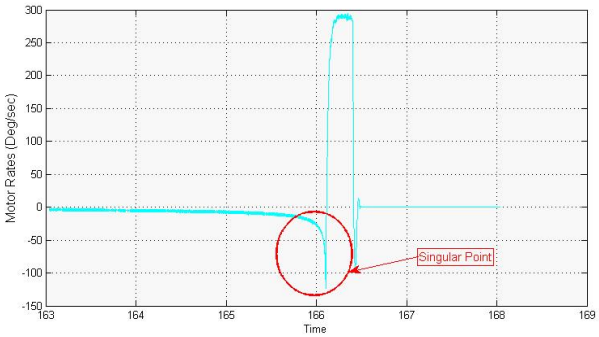

Figure 4: The rates of motor 3 responsible of the motion of the third joint.

The study of motion and the action of other joint was a necessity in this case, joints 2 and 4 have shown a more powerful reflection towards the singularity of joint 3 more than both joints 1 and 5, this may be due to an inner connection or dependence of motors of both joints 2 and 4. The behaviors of both joints are shown in Figure (5), it is clear that both joints are affected by the singularity of joint 3 which increase the sensitivity of this Arm robot toward this singularity. The motor rates for both joints show a great effect due to singularity especially in motor 2 which is illustrated in Figure (6). The effect is clear to be noticed so that it can be avoided later.

Studying joint 1 and joint 5, shows that there is no remarkable or significant effect on both joints due to the singularity whether in the value of joints nor in the motor rates. All effects occur at joint 1 and joint 5 after the singularity are illustrated in Figures (7) and (8).

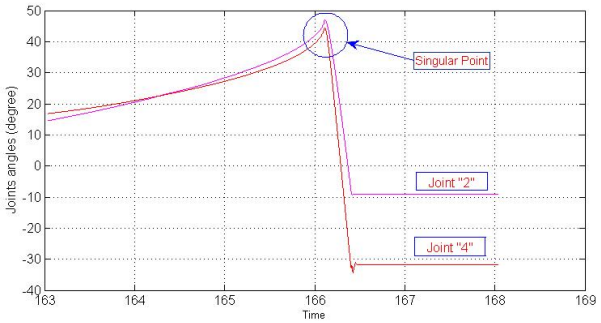

Figure 5: The joint movement of both joints 2 and 4

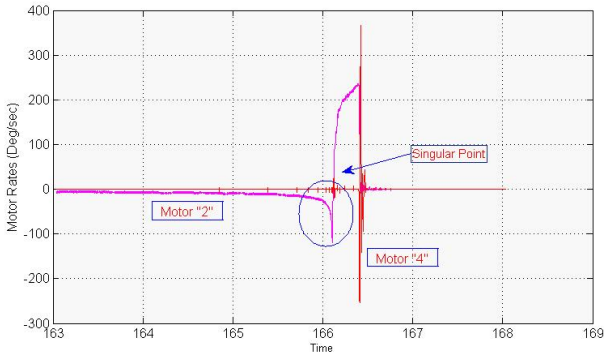

Figure 6: The rates of motors 2 and 4 during singularity of joint 3

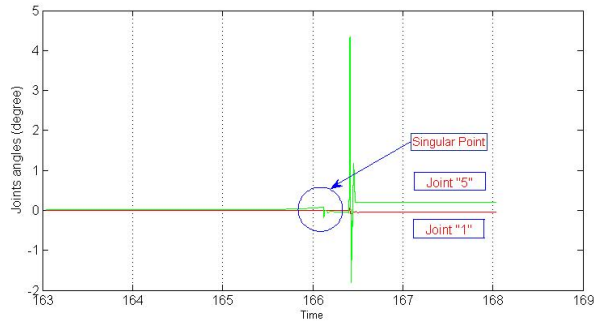

Figure 7: The joint movement of both joints 1 and 5

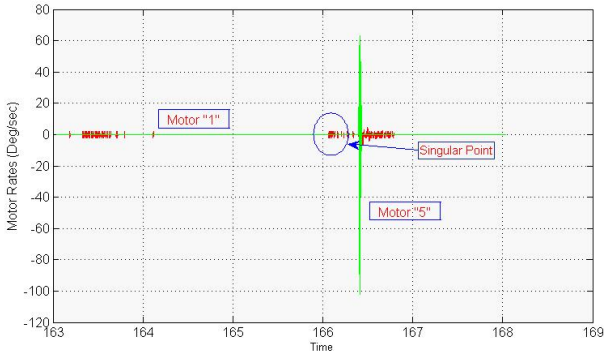

Figure 8: The rates of motors 1 and 5 during singularity of joint 3

Experiment 2: This experiment is performed to investigate the effect of applying the avoidance mechanism represented by Equation (10) on the system of CRS catalyst 5T arm robot. The behaviors of joints 2, 3 and 4 are illustrated in figure (9). It is clear that as soon as the value of θ_3 decreases and approaches 5^o, which is close to a singular configuration, the avoidance task is activated to forbid the robot from reaching its singular configuration at $\theta_3 = 0$. The behaviors shown by θ_2, θ_3 and θ_4 are different than the corresponding behaviors shown in the first experiment, where no avoidance is considered and undesirable velocity is presented. In figure (10), the main angular velocities $\dot{\theta}_2$, $\dot{\theta}_3$ and $\dot{\theta}_4$ are presented. The avoidance task does not affect the angular velocities of joint 3 before reaching the pre-defined threshold located at $\theta_3 = 5$. Just at iteration 534 the avoidance task is activated. It is clear that θ_3^* kept on decreasing which cause θ_3 to reach the second threshold value at $\theta_3 = 0.2$ in which the avoidance task forbids joint 3 from extra movement toward the singularity. As can be seen the motion of joint of joint 3 is smooth compared to the motion in experiment 1 thanks to activating the avoidance task. However the motion is stop as soon as it reach the second threshold.

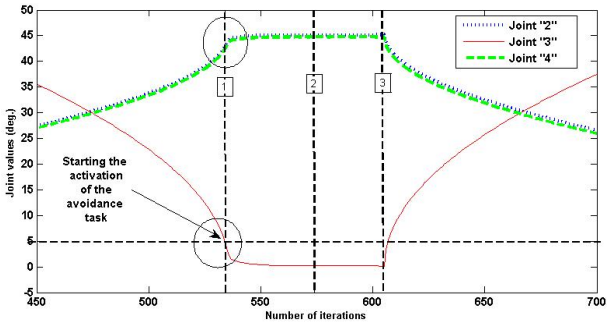

Figure 9: Values of $\boldsymbol{\theta_2}$, $\boldsymbol{\theta_3}$ and $\boldsymbol{\theta_4}$

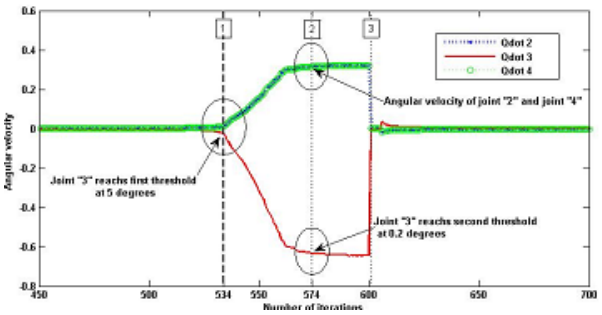

Figure 10: $\dot{\boldsymbol{\theta}}_3$, $\dot{\boldsymbol{\theta}}_2$ and $\dot{\boldsymbol{\theta}}_4$

Experiment 3: This experiment is performed validate the results obtained from the GA. The robot arm was moved between different positions. The configuration of robot position is set to simulate the values obtained from the GA. At the singular configuration [0, 50, 0, 80, 0], the pose between the camera and object is stored. Then, a list of different configuration was defined such that each configuration is the similar to the singular configuration, after adding a constant value to θ_3, and subtract the half of this value to θ_2 and θ_4. For example, the second configuration can be [0, 49, 2, 79, 0]. This procedure was repeated for θ_3 equal to 1, 2 , 10 and 20. The values can be seen in table (2).

Table 2: Validation of genetic algorithms results

Link	$\boldsymbol{\theta_3 = 0}$	$\boldsymbol{\theta_3 = 1}$	$\boldsymbol{\theta_3 = 2}$	$\boldsymbol{\theta_3 = 10}$	$\boldsymbol{\theta_3 = 20}$
X	428.1	428.1	428	426.6	422.22
Y	0	0	0	0	0
Z	547.9	547.9	547.6	456.61	542.9
$\propto$	2.269	2.269	2.269	2.22691	2.269
Ø	0	0	0	0	0
ψ	0	0	0	0	0

The six rows represent the Cartesian coordinates of the end effector. From the results in the table it we conclude that the results from the GA are correct and valid in the cases when small difference in θ_3 is considered. When a higher change in θ_3 is tested the error will increase in the end effector Cartesian coordinates.

Conclusion

In this paper the kinematic singularities of CRS catalyst 5T robot arm are studied analytically and numerically. The genetic algorithm is used to find alternative poses corresponding to the pose at singular configurations. A singularity avoidance mechanism is proposed to enhance the behavior of the system near singularities. Many experiments are performed on the real arm robot.

The results of the analytical study showed that the robot has three singular configurations, two of them are shoulder singularities at $\theta_2 = 135$ and at $\theta_4 = -45$ which are not in the configuration space of the robot while the third one is an elbow singularity at $\theta_3 = 0$ which is in the robot configuration space. The numerical results is coherent with the analytical results with respect to the singularity at $\theta_3 = 0$ which is the only discovered singularity in the work space.

The experimental tests are performed to study the effects of the singularity on CRS catalyst 5T robot arm by considering the joint movements and motor rates. The results show that the joint singularity affects other joints behaviors. As expected, approaching a singular configuration leads to instability in robot motion and can damage robot internal mechanisms which may leads to a catastrophic situations.

A singularity avoidance mechanism is developed based on Genetic algorithm optimization technique. This technique is used to optimize the final position of the end effector. The objective function is defined to minimize the error between the singular configuration and the available alternative positions. Both of the Cartesian error and joints space error are monitored and controlled by the objective function. The results obtained from the genetic algorithm are validated on the real robot. The singularity avoidance mechanism using alternative pose is tested through a real time experiments on the CRS arm robot and the singularity is avoided successfully when performing positioning tasks.

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THE KNOWLEDGE ACQUISITION SYSTEM TRAINER1 AND FINSIM1 (SIMULATOR FOR TEACHING FINANCIAL ANALYSIS) AS INEVITABLE COMPONENT OF DISTANCE LEARNING

Tea Munjishvili

Abstract*: In article the existing systems of collection of knowledge are analyzed, need of computer simulars of creation for collection of knowledge in economy is checked, necessary conditions for their functional capabilities and use are defined, the initial computer simular for the collection of knowledge created by us is figured. In article the existing systems of training of the financial analysis are analyzed. One of ways in improving of quality of e-learning of objects of an economic profile - development and applications during training of simulator. In article the technology of preparation and training of the financial analysis with use of an assessment bankruptcy of the enterprise by means of the logician - probability and the Z-score of models, the developed author of software package TRAINER1and FinSim1 the exercise machine. The TRAINER1 and FinSim1 used for the multiscenario analysis and generalization of results to predict assumptions of possible errors and to create recommendations of their correction.*

Keywords*: Simulator, Fnancial analysis, Semantic analysis, Debriefing.*

Introduction

Achieved results in the field of informatization makes development of distance learning possible. Distance learning can be considered as form of teaching by correspondence approved in practice during decades, which is by correspondence in form but is relevant to form of attended teaching by its sense. Components of distance teaching of subject are as follows: textbook created by using hypertext technology, video lectures, special programmed environment, which provides:

1. Acquisition of knowledge in training regime;
2. Model typical situations and acquire decision making skills;
3. Demonstrate and assess acquired knowledge.

Problems of knowledge acquisition, demonstration and assessment have always been, is and always will be topical issue. Process of searching is infinite in time and space. Three approaches are singled out: traditional (informal), using computer systems (formal) and combination of these two.

Traditional method is effective one that has been experienced during centuries and is very unlikely to be changed ever. In the last three decades intense research has been taking place and computer programs of different kinds and functional possibilities have been created. These programs are oriented towards knowledge acquisition, demonstration and assessment.

In the field of knowledge acquisition transferring knowledge using video lectures, multimedia electronic books and printed publication are frequently used today. In addition, online consultations with the teachers is also widely accepted.

Many scientific publications are written regarding improving teaching process using electronic systems of knowledge acquisition. One of the directions is drawing out computer simulators.

In the exploitation of complex technical systems and training of management specialists different kinds of simulators have been used for a long time. In the article {Трухин 2008} teaching simulators of different aims existing in Russian Federation are analyzed. In the recent years simulators have been widely used in medical institutions in the process of teaching medical personnel and improving their qualification [Свистунов 2011]. Working out of simulators of different type and aim - started from physical ended by electric - is taking place in today's world. Mainly three kinds of simulators are prevalent: physical, electronic and combination of two.

Experience in drawing out and use of electronic simulators in the training of specialists in the area of management includes: Railway tickets cashier, managing and exploiting heating systems in train coach and etc. [3].

Training of specialist in any field including economist consists of two main components: theoretical knowledge and practical skills. Object of our research is acquisition of knowledge oriented towards searching for a method of elaboration mechanism of practical skills. Acquiring skills for operating aircraft, ships, boats and similar apparatus is impossible without physical simulators.

Object of the learning of economic processes are informational flows depicting movement and modification of material currents. Because of this only computer simulator can be used in training of economists. Their role is particularly important in the distance learning. Methodological foundations of realization of simulator are economic-mathematic models and computer systems. Teaching practical skills using simulator is achieved by solving situational problems.

Scientific research works done for elaboration of simulators for subjects of economic profile represented in scientific papers and dissertations are very interesting [Ельцин 2013, Рышкевич 2013].

Analysis of informational materials shows that there is no common understanding between the concepts of electronic simulator and simulator. Part of the researchers understand electronic simulator as a unity of textbook made using hypertext technology and informational-programed complex. Using electronic textbook introduction to and acquisition of the issue is done, while programed complex provides fixation

of acquired issues. In this process student solves the problems in an interactive regime and answers theoretical questions. In order to answer correctly to these questions student uses reminder represented by text, graph, and video. Process of the teaching and exam for certificate is made online.

Hence, for training high quality specialists of economic profiles and permanent qualification improvement of management specialist's two interlinked problems have to be solved: first – drawing out universal program package of electronic simulator, second – filling knowledge base of simulator by knowledge base of problematic section.

First problem consists of two interlinked problems: first – elaboration of electronic textbook using hypertext technology and second – elaboration of programmed environment for problem solving online in the interactive regime. In a special literature theoretical and practical issues of creating electronic textbooks using hypertext technologies are widely discussed. Simple programs – editors are available in the environment of which any teacher or professor working in the field of economics can create electronic textbook after some training. Today, many electronic textbooks are created. Any textbook is presented with text, graph, video. It serves as a basis for knowledge acquisition. After introducing materials in the textbook it is necessary to solve practical problems, analyse theoretical issues and etc. This goal can be achieved by program – simulator.

Different kinds of simulators have been used in exploitation of complex technical systems and training of specialists for a long time. In article /1/ simulators existing in the field of business and used on the levels of teaching and functioning are given: AdSim Advertising, Baton Simulations, Blue Ocean Strategy Simulation (BOSS), Capsim Foundation and etc.

In article /2/ simulators of teaching purpose existing in Russian Federation are analyzed. In the recent years simulators have been widely used in medical institutions in the process of teaching medical personnel and improving qualification /3/. This is not surprising, because any mistake made by technical system and medical personnel brings immediate results. Moreover, mistake of technical system – made by ship or aircraft crew brings their life under risk.

Because of the fact that result of the mistake caused by low qualification of an economist will show up after Δt period, it remains unnoticed for the decision makers. Result of the mistake can be fatal for the society.

Mistakes made by economists on a different level of management are the results of impunity syndrome. Economists' inability to predict the possible result of their decisions comes from the low level of their training. Processes of transferring, acquiring, revealing of knowledge must be changed as a matter of principle.

Our focus is made on searching for the methods, ways and means of reduction or in ideal case – liquidation of errors made by economists that are caused by low qualification.

At the moment simulators of different kinds and purpose are being drowned out in developed countries – started from the physical simulators ended by electronic ones. It won't be mistake if we say that there are mainly three kinds of simulators being constructed: physical, electronic and combination of two

For the training of economists we can create and use only electronic simulators.

Modern information tehnologies allow us to look differently to the teaching process and cunduct it in an unusual way.

Analysis of informational materials shows that there is no common understanding between the concepts of electronic simulator and simulator. Part of the researchers understand electronic simulator as unity of textbook made using hypertext technology and informational-programed complex. Using electronic textbook introduction to and acquisition of the issue is done, while programed complex provides fixation of acquired issues. In this process student solves the problems in an interactive regime and answers theoretical questions.

Under the simulation modeling informational-programed environment is considered in which specific type of situation is being modeled.

Aim of the elaboration and use of simulators is:

First – Enabling for understanding management of the situations arising on a real object, decision making and analysis of expected results of decision in the teaching process.

Second – Enabling modeling existing situation with real data and looking at expected results before making decision in the practical activities.

It is worth to be mentioned that like electronic diagnostics it is impossible to achieve adequate modeling of actual situation regardless the perfection of the situational model. Because of this, final word is on decision maker and he/she makes decision under self-responsibility.

Topics discussed in the specific discipline include discussion and acquisition of typical finite situations for those simulation models should be drowned out.

Second problem consists of two interlinked problems: first – elaboration of electronic textbook using hypertext technology and second – formation of system knowledge base.

Simulators can be used invariably or with the little modification in the following areas with the common legal space:

1. In the higher education institutions in different countries, including Georgia:
   - For the training of specialists;
   - For the retraining of specialists in the field of management: economists, financiers, marketing specialists and others.
2. In the process of enterprise management.

Preconditions for drawing out simulators for economic processes exist – these are theoretical and practical experience of elaboration and use of intellectual systems of decision making in different problematic areas (medicine, technical systems and etc.). Like economic processes in medical diagnostic systems here we deal with the information processes. Because of this while drawing out simulators of economic processes modeling mechanisms for knowledge demonstration and decision making can be taken into account. Clearly, like medical diagnostic systems at first classification of economic simulators using certain criteria must be done. This criteria include: problematic areas (entrepreneurial, macroeconomic processes), kinds of problematic areas, situation types and etc.

Problems of elaboration and use of simulators depicting economic processes for training of economists stand in the center of our attention. Form of the realization of economic simulator is computer programmed complex. Its aim is to ensure that in the teaching process student acquires skills for situation analysis, economic decision making and assess results of the decision for the different values of real data.

Use of simulators in the teaching process changes methods and approach to the transfer of knowledge.

The role of the teacher is particularly increasing, which should be able to:

- Comprehend the working principles of the simulator;
- Understand the realization algorithm of the problematic situation that is simulated;
- Interpret the results of the simulation;
- Correct of the simulation results taking into account the factors considered by the simulator;
- Approve/reject simulation results

On the practical lessons student is required to explain simulation results. Simulation realization and analysis of the results depend on the knowledge about problematic area. Because of this, introduction to and acquisition of issues regarding the simulation are integral parts of the simulator.

Components of study using the simulators are as follows: computer turned in a global network, program simulator, electronic textbook realized by hypertext technology linked to simulation organized on a server. Integral part of the any kind of studying process including the studying process using simulators is video clip representing the process of studying. After classes the video is placed on the internet and student gets it.

Our modest experience in drawing out economic simulators enables us to form necessary requirements for simulators:

Simulator is used to:

- Model problem depicting actual economic process using certain algorithm;
- Solve linear and non-linear optimization problems;
- Form multi-optional plans;
- Comply and select options;
- Visualize of simulation results in a form of diagrams, tables, videos or their combination;
- Model N independent variable in the problem depicting model by $\forall n_i$ variable and represent the results in the form of diagram;
- Model by any of n_i and n_{i+1} variable from the set N simultaneously and represent the results in the form of table;
- Model using number of variables simultaneously for the different values of variables;
- Represent multi-optional results of modeling;
- Explain simulation results.

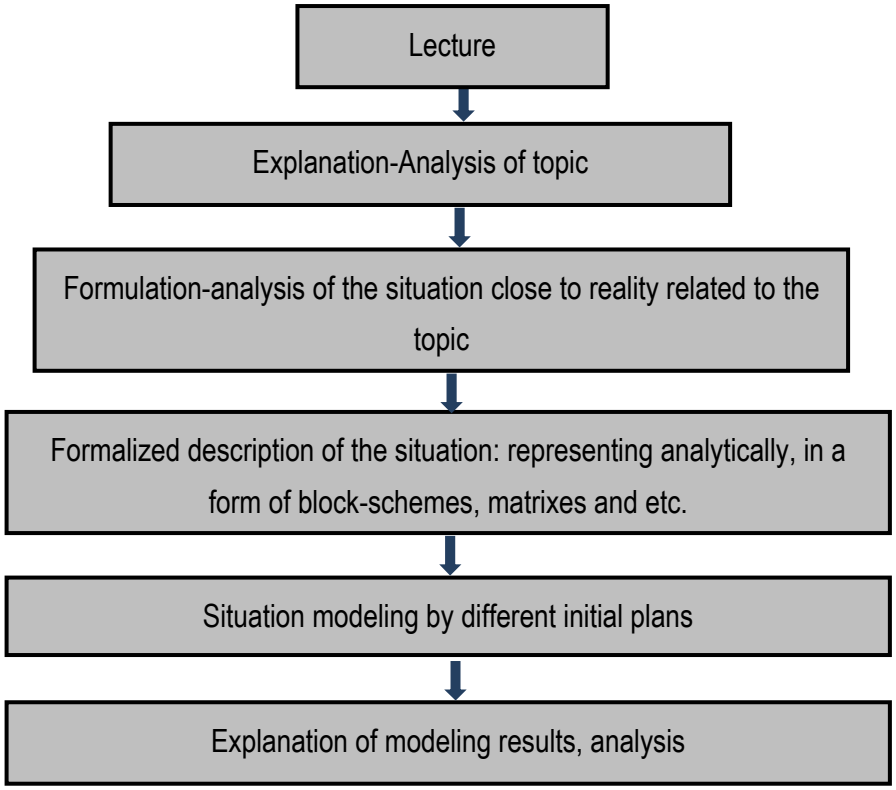
Using program package it can be possible to:

- Introduce to the essence of the problem, algorithm;
- Realize simulation in many natural language.

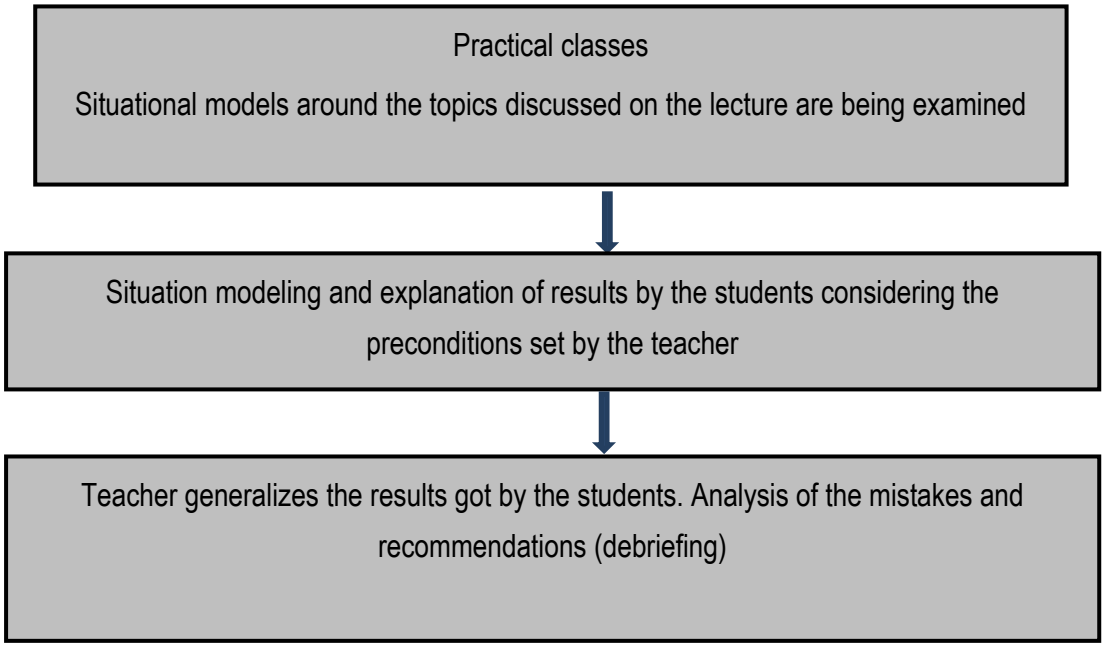
Work with the simulator must be allowed for every interested person without any kind of registration and passwords.

Simulator should enable us to make as situation modeling as well as simulation of solving problem using known algorithm and research the algorithm to solve this problem. Clear example of it is solving the problem in Excel with its financial functions. Observing the process of problem solving in Excel using its functions we can see how the result is being changed in response to the changes made in the values of arguments. Arguments themselves reflect occurrence of the certain fact such as taking credit, investing, amortization and etc.

We see conducting lectures and practical classes using simulators in such way: /picture 1, 2/



Pic. 1. Block-scheme for giving lecture using simulators

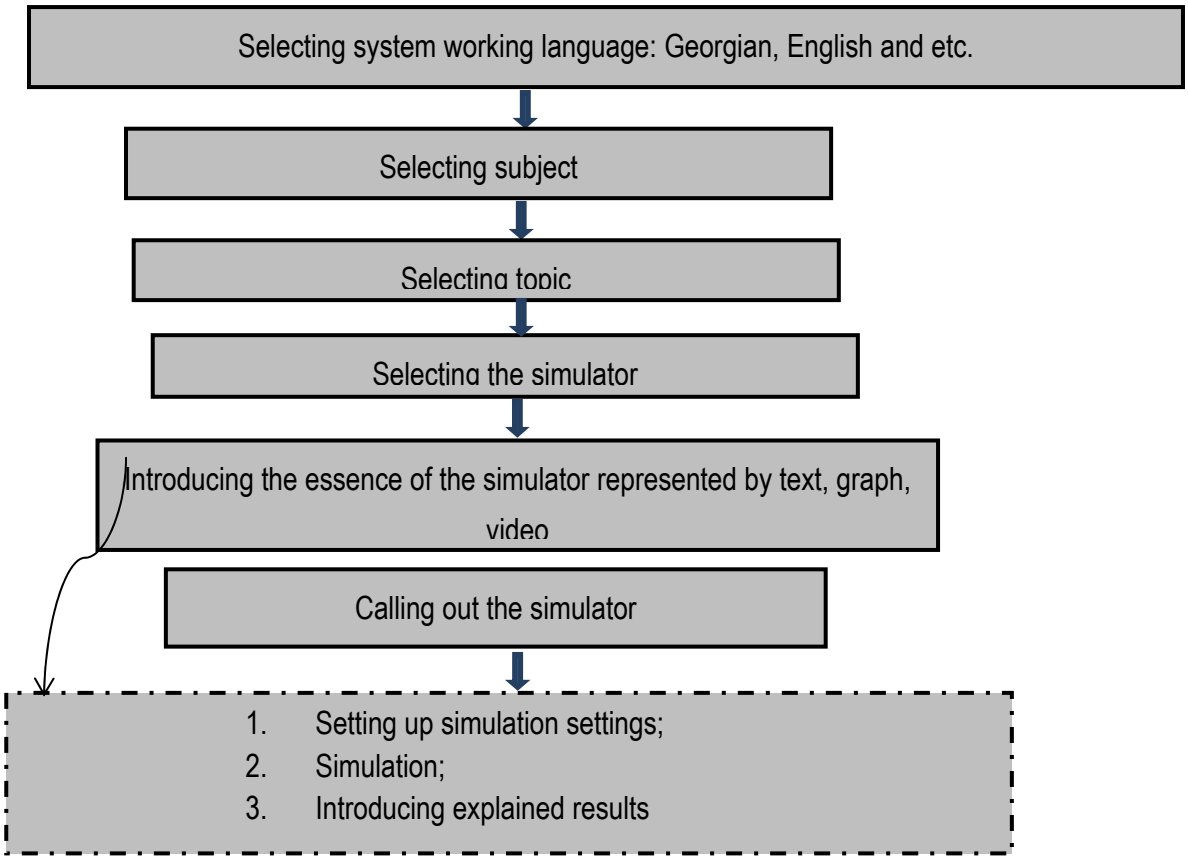


Pic. 2. Block-scheme of conducting practical classes using the simulators

Use of the simulator in the teaching process consists of the stages of planning and functioning.

On a **planning stage** from the set of the simulators teacher selects simulator(s) depicting the given topic;

Functioning stage /pic. 3/



Pic. 3. Stage of functioning in conducting teaching with the simulator

In the program package FINSIM1.1 created by us simulators are realized that are used in: first, modeling evaluation of financial stability of enterprise by Altman, Springate, Fulmer, Brzezinski, DuPont models. With these models financial stability of enterprise is evaluated using one, two and many (all the variables included in the model) variables; second – simulating 15 functions of Excel by one or two variables.

Algorithmic-programmed environment of the simulator is universal, but its informational inside part depends on the teacher of subject, its approach to the transfer of knowledge and etc. Because of this, drawing out typical simulators in the teaching process as a standard is unacceptable. Simulators by subjects can have recommendation-auxiliary role.

Currently, analysis of the simulators used in trainings of the specialists in different fields and our years-old experience in computer systems for demonstrating and assessing knowledge and practical exploitation allows us to form necessary requirements for the computer simulators oriented towards economic profile subjects:

1. Existence of theoretical and practical issues;
2. Formation of knowledge base according to the theoretical and practical issues of the subjects, subject topics and sub-topics;
3. Formation of standard tasks for training;
4. Explanation of any task in the exercise demonstrating specific method, algorithm and solution;
5. Formation of base of advices and recommendations for avoiding repetition of the errors made during the training;
6. Introducing specific results of the training, advices for correction of the errors and showing recommendations;
7. Making analysis of the errors made during the training in the certain period of time;
8. Changing trajectory of training by student based on the answers.

Formation of the knowledge base of the simulator.

Basis of the training is formation of knowledge base by the teacher according to the subjects, subject topics and sub-topics. Knowledge base general tests have two types – closed and open.

Closed tests are ones for which on every posed question maximum seven answers comes out of which three are correct. Answering to the posed question is brought down to selection of the right answers out of maximum seven options.

Open test is a test in which the answer of the student must be written in the form of numerical value, sentence or expression.

Based on our experience it is better to have 70% open tests in the test base and remaining to be closed tests, which can preferably be distributed according to the number of right answers in the following way:

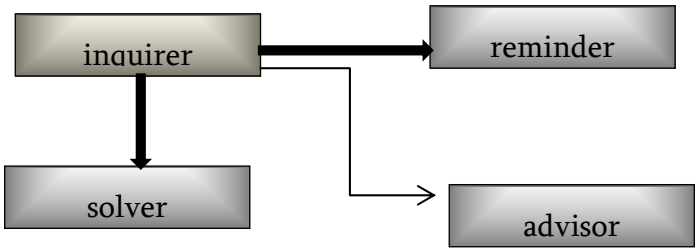
Table 1.

Name	Number (%)
Tests with one right answer	25%
Tests with two right answers	35%
Tests with three right answers	40%

In the closed tests assessment mustn't be partial, because selecting two or three right questions out of seven is quite hard and requires thorough knowledge of the issue. Open tests are tasks. Possible answers to the tasks aren't limited. Teacher assesses solution result according to his/her attitude and makes ranging of total points based on the answers. Formation of the test base according to the sub-topics occurs in a way that closed and open tests describe typical situations.

For the closed tests firstly, correct answers with detailed proofing are provided by the teacher and secondly, in case of wrong answers advices and recommendations are provided.

For the open test (task) the teacher indicates: firstly, solution for the specific task, secondly, method for solution such task, algorithm, mathematic model, area of use, solution technique and technology, programmed means such as Excel, MATLAB used in solution and etc.; thirdly, the reasons for the wrong answers and the ways and means to avoid them.



Pic. 1. Essence structure of the tests

Hence, basis of representing any test is information given in a following structure /pic. 1/

"Inquirer" consists of two sections: question (task) text and the possible answers.

"Solver" consists of question, task solution algorithm, model, solution description formulated in specific "inquirer".

In the "reminder" solution method, experience of solution of analogous task, expected results in case of wrong answer and etc. are given.

In the "advisor" negative results are discussed. Reasons causing them and the ways of avoiding negative results are shown here.

In order to study causes for negative results and factors affecting them there is tight connection between the "reminder" and the simulator of specific economic processes given in the "inquirer". Using it the process of the modeling by one, two and multiple variables, formation of multi-optional plans and etc. are made [Tea Munjishvili, 2017].

Any functional block given on the pic. 1 can be shown by the text, graph, video or their combination.

Planning the training.

Planning the training - selection of the topics, sub-topics, tests, time of the training – is made by the teacher within the simulators familiar to us and individual potential of the student isn't taken into account. In the ideal case student should have possibility to select topics for training from the test base and sub-topics, their number and training time. In practice a compromise option can be found, particularly:

- Teacher forms standard exercises according to the sub-topics showing all the tests regarding this sub-topic;
- Certain points are assigned to the answers for any closed and open test;
- Partiality of assessment for any test and necessity for semantic analysis are showed for any test.

Before a start of the training 1) student selects topics and sub-topics, 2) defines number of the tests for the training according to the sub-topic and 3) sets total time for the training.

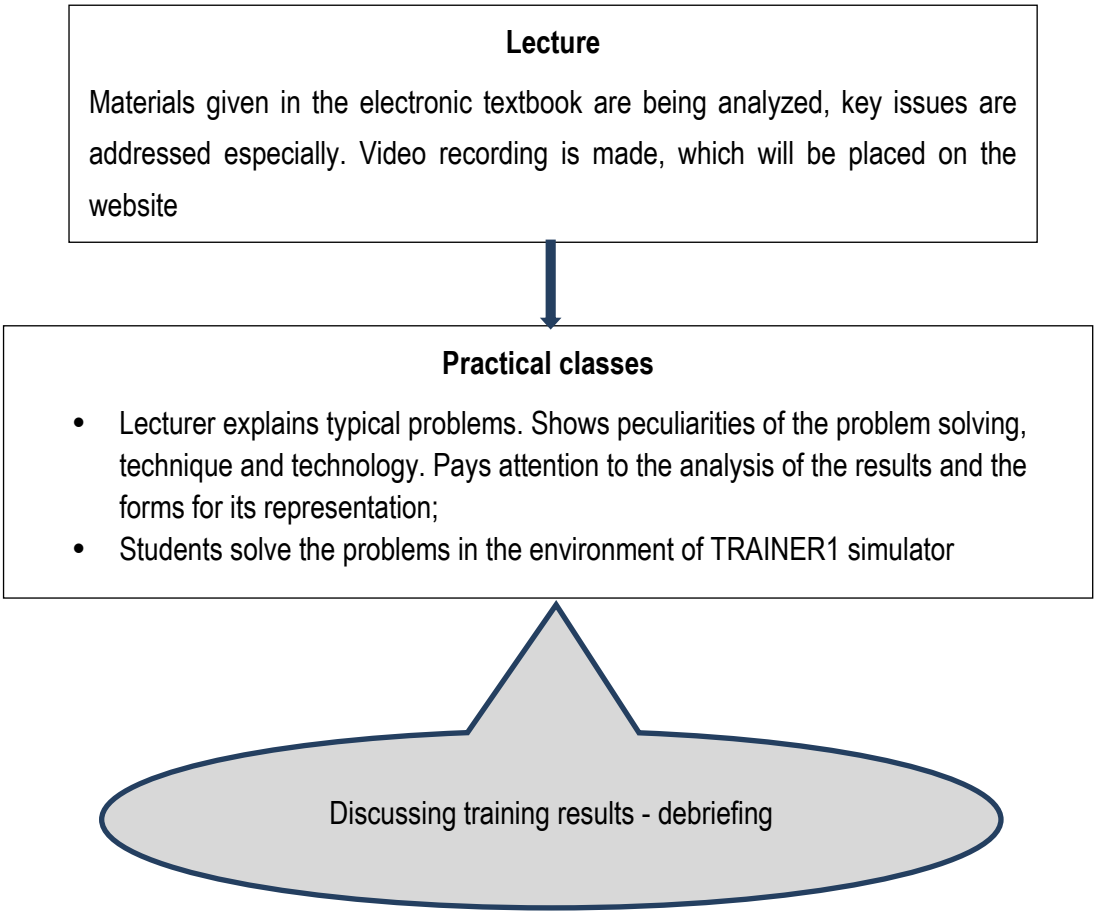
Teaching the subject using the simulator is done in the following sequence /pic. 2/:

In the given scheme of knowledge acquisition we pay attention to the discussion of the training results – debriefing stage (debriefing is an English word meaning discussion of the results of the work done). In some way this is actually done in many cases by the lecturers, but has no clearly shaped form. Errors made by the students while working with the simulator are shown on the computer display of the lecturer in the form of report. Lecturer analyses it and discusses the results with the students after the training – debriefing.

The process of debriefing is informal. In the article A. A. Svistunov [Свистунов 2013] describes the tasks and aim of debriefing in details. It pays particular attention to the role of the lecturer as a leader in the process of the debriefing. He notes that the leader is obliged to create emotionally compatible environment. It is unacceptable to concentrate attention on the mistake done by the student, on the contrary it should be represented as group mistake and allow the members of the groups to express their thoughts. In such discussion ideas, problem solving ways and methods are generated among the group members.

Requirements set for the leaders in [Свистунов 2011] aren't new. They are formed fully and in details in the work regarding the method of managing intellectual processes, psycho-heuristic programming method [В.В.Чавчанидзе 1974].

Thoughts and proposals expressed by the students in the process of group discussion are taken into account by the lecturer while working on preparing materials and making corrections for the simulator.



Pic. 2. Teaching the subject using the simulator

Exercise created by the student can be represented before the start of the training graphically in a form of looped finite oriented G graph, where $\forall v_i, \mathrm{v}_i \in V$. From the set of the tests indicated in the exercise P is the selected test by probability. $\forall v_i, \mathrm{v}_i \in V$ is linked to the neighboring knot with one rib $e_i \in E$. $\forall v_i, \mathrm{v}_i \in V$ of G graph has loop (cycle). Number of the cycle depends on a student. Realization of the loop emerges in the system when the test is wrongly answered. Student can call out the “advisor” N times.

We have created electronic textbooks in economic subjects that have been functioning since 2013. These are: operational management, strategic management (author: Prof. Badri Ramishvili), financial functions in Excel (author: Prof. T. Minjishvili) and zero version of simulator [Tea Munjishvili 2013,....., Badri Ramishvili 2013]. Training is done using program package “Cyber1” [Tea Munjishvili 2014]. Considering negative and positive sides in the process of “Cyber1” exploitation, program-simulator TRAINER1 is elaborated in which abovementioned requirements are realized [Tea Munjishvili 2017].

Following are ensured using our computer simulator TRAINER1:

1. Formation of standard exercise by the teacher taking into account leading teachers in subjects, topics, sub-topics;
2. Formation of individual exercise by the student before the start of the exercise;
3. Possibility of elaboration of closed and open tests;
4. Existence of maximum three right answers out of seven options in the closed tests;
5. Existence of any number of the answers in open tests;
6. In the closed tests fixing the answers only after marking needed number of right answers and giving answer fixing command;
7. Using words, numbers, sentences or their combination, also abbreviations in the open tests;
8. Understanding indicative sentence used in the answers in case of breaking synchronization and inserting words;
9. Writing words used in the indicative sentences and general answers in any case, using wrong versions of these words;
10. Identification of actually written answer to the problems depicting certain subjects, topics, sub-topics, sub-chapters to the standard value of this answer. Breaking synchronization, writing words in any case, omitting or inserting words aren't allowed here;
11. Posing the problem using text, graph, video or their combination;
12. Existence of support on subject, test using text, graph video or their combination;
13. Existence of advices and recommendations for the mistakes in closed tests;
14. Existence of advices and recommendations for the mistakes in any answer in open tests;
15. Fixing respective points $q_i \in Q$ to the $\forall n_i, n_i \in N$ answer of the $\mathrm{problem}$. Point can be whole or decimal positive number;
16. Receiving different kinds of diagnostic messages during the training process. For example, omitting words, numbers and etc., while using unknown words;
17. Ordering tests in a probability sense at the beginning of the testing process and selection of tests in a probability sense in the process of training;
18. Getting different analytical information after the training, particularly: report on the training process, advices and recommendations for avoiding errors made at specific training (debriefing), statistics of mistakes made in certain period of time and their representation by the form of diagram;
19. Generalization of the errors made by the students, group discussion, formulation and realization of proposals and recommendations.

Necessary conditions for using computer systems:

1. Proper work of technical system: computers, computative network, server, program means. This condition is an axiom. It doesn't require noting;
2. Original discussion of topics, sub-topics according to the syllabus and formation of relevant tests by the lecturers;
3. Creation of comprehensive support according to the typical test, represented in the form of text, graph, video information;
4. Periodically renewing information in the support base, tests, adding new tests, modifying existing ones.

Metods: In TRAINER1 engineering approach to the semantic analysis of sentence is realized, i.e. method of "productive grammar", that bears certain universalism and is insured from the lack of table compatibility principle. Essence of this method, algorithms and programmed realization are discussed (T.Munjishvili, 2017). We describe algorithm of semantic analysis used in TRAINER1 briefly.

Indicative sentences are used in the possible answers of the open tests.

$$G = \bigcup g_j,\ \mathrm{j} = 1....\mathrm{n}.$$

Elements of the G set $g_i, \mathrm{i} = 1.....\mathrm{m},$ are answers to open tests.

Formulating following conditions for G set:

1. G is preliminary known finite set. Elements of the set are natural language sentences or word orders;
2. Indicate sentence with conditional number i by g_i and the word in this sentence with conditional number λ by $g_{i,\lambda}$. Then used $g_{i,\lambda}$ words constitute L dictionary. Contents of G depend on demonstration of knowledge by simulator and assessment subjects and sentences used in open answers of these subject tests;
3. Any two elements of G differs by one word at least;

$$\forall(g_i, g_{i_0} \in G) \Rightarrow (g_{i_0} \setminus (g_{i_0} \cap g_i) \neq \{\} \wedge g_i \setminus (g_{i_0} \cap g_i) \neq \{\})$$

4. Any pair can comprise words with similar essence.
5. In TRAINER1 any answer of specific test, phrase $g_i \in G$ is unequivocally matched by certain command ψ_i, or $g_i \rightarrow \psi_i$.

ψ_i can be phrase, word, unity of symbols and etc. Hence, elements of G set $g_i \in G$ are represented on G^* set.

$$\psi_i \in G^*, f : G \rightarrow G^* \quad \text{i.e.} \quad f(g_i) = \psi_i.$$

Desired results will be achieved if $\forall g_i \in G$, then g_i can be considered as production. g_i words $a_k \in L$ are considered as conditions, while ψ_i respective to g_i - as actions. In this sense "semantic analysis" of any indicative sentence is brought down to finding production system, organization of dictionary and relevant productions of incoming facts.

In the systems of knowledge demonstration and assessment, including TRAINER1, specific production (in our case – sentence) is selected, because we discuss specific answer with known value. It is necessary to define its relevance with existing one according to the incoming facts (words). Hence:

We have: not empty set of predicates (natural language words or word orders used in the open tests of the given subject) $L = \{a_k\} \neq \otimes,\ k = 1...n$, not empty set of activities $G^* = \{\psi_i\}, \mathrm{i} = 1..\mathrm{m},$ not empty set of productions (indicative sentences) $G = \{g_i\}, \mathrm{i} = 1..\mathrm{m},$ not empty set of informativeness. Elements of this set are scalar functions defined on G and they measure certain parameters of predicate by certain scale. Any criterion of informativeness has certain weight h_α so that

$$h_\alpha \in Q_+, \quad \sum \mathrm{h}_\alpha = 1.$$

Our tasks:

1. Reveal set of criteria of informativeness and ranging them according to their values;
2. Evaluation of each predicate from $a_k \in L$ dictionary by the given informativeness coefficient while organizing dictionary;
3. Understanding of the sentence given in the answer while entering n number of predicats in the system:
    - While changing word order in g_i ;
    - While omitting and inserting words in any part of the sentence g_i .

Basis of the organization of knowledge base are answers to the open tests – G set of the sentences (productions). We can consider G as a text consisting with semantically unrelated indicative sentences, while in the production system – choosing production as searched form.

We have answers of two types – R and RT. In the first type of problems in R or RT type answers where the words and their synonyms can't be used in different case, only the words used in the answers of the tests or their incorrect versions will be selected and directed to the entrance of the system. Morphological basis, wrong versions and synonyms aren't indicated in the dictionary. In this case described algorithm for sentence identification is used only with the difference that at the entrance of the system in $\mathrm{L_w}\{a_1, a_2, ...a_s\}$ phrase the order of the words must be strictly protected and $\mathrm{L_w^{'}} \equiv L_w$.

In the second type of problems while searching for relevant information for R or RT type answers written by the student synchronization can be broken. Words can be used in any case and conjugation, wrong versions, excess-any number words that exist or not in the dictionary can exist.

Despite its simple character proposed way of understanding indicative sentence can be considered unnecessary because, in many cases students try to write a sentence with the sequence familiar to them. Words are used in many cases and the words are omitted and inserted frequently. Writing erroneous versions of the words is rare (T.Munjishvili & Z.Munjishvili, The semantic analysis method and algorithms of open tests answers on "Cyber-2" patternin the Knowledge revival and evaluation systems, 2015).

Identification of open test answer – sentence is made in a following way: /pic. 3/

1. Suppose natural language words $a_0 \in L$, $\mathrm{L_w}\{a_1, a_2, ...a_s\}$ have come into the system. a_0 word can be wrong version of the word written in the answer, word written in any case, synonym or abbreviation.

↓

2. a_0 Word is being searched in L_1 dictionary. If one of the words from $g_i \subset G$ phrase regardless of its position coincides with a_0, or its base regardless of its position coincides with a_0, word is identified, otherwise next step is made.

↓

3. Finding synonyms. a_0 Word is being found in L_1 dictionary. If morphological basis of a_0 is found, then identification of the respective $g_i \subset G$ word is made by using L_1 dictionary.

↓

4. a_0 Word is being searched in L_3 dictionary. If the words respective to abbreviation in the dictionary coincide with the words $a_k \in g_i$ used in the answers in sequence then abbreviation is identified.

↓

5. If all words in open test answer $g_{i,\lambda} \subset G$ regardless their position coincides to $\mathrm{L_w}\{a_1, a_2, ...a_s\}$ set or $\mathrm{L_w^{'}} \in L_w$ sub-set, then the searched phrase is identified, otherwise the message regarding specification of the answer shows up.

Down we discuss the process of starting and running of training with TRAINER1:

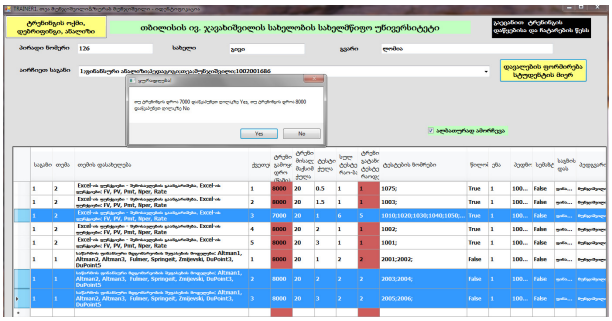
Any person interested in can conduct training. Person is identified by ID number or any number consisted of 16 digits. After identification and subject selection window will appear with the list of standard exercises from selected topic written by the teacher according to the sub-topics. Student can change number of the tests for the training and training time in any standard exercise. Before selection of sub-topic student can view at the tests in the exercise. /pic 4/

Following situation is depicted on the picture:

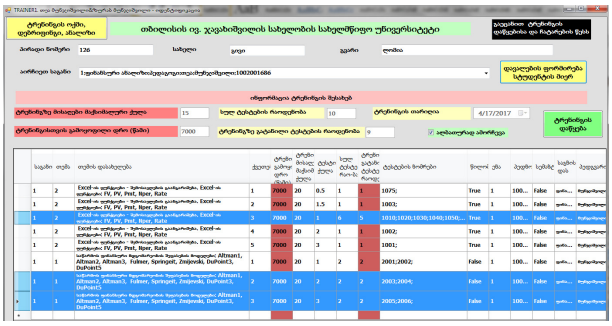
- Table pillars: number of the tests for training, training time. Values that can be changed are colored;
- Number of tests for the training on third sub-topic of second topic is changed (5 is written instead of 4);

- Total time for the training is changed (7000 seconds is written instead of 8000 seconds);
- Third, seventh and eighth lines in the table are marked to bring on training, i.e. second and third sub-topics from topic 1 and third sub-topic from topic 2;
- After pressing on a button “formation of exercise by student” message of choosing training time will appear.

Window appearing after pressing on a button “formation of exercise by student” is following: /pic.5/



Pic. 4. Formation of individual task of training by the student on the basis of standard exercise

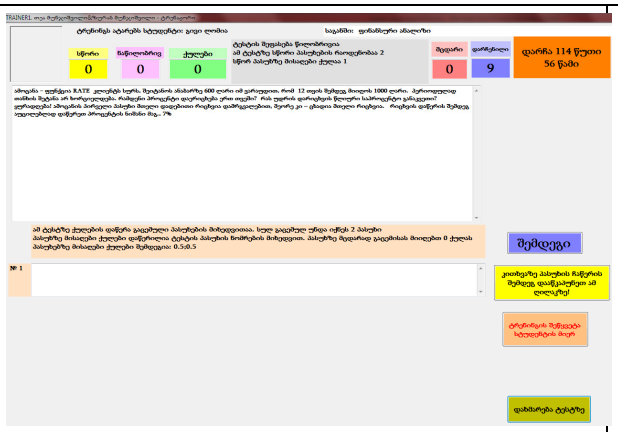


Pic. 5. Individual task for training formed by the student

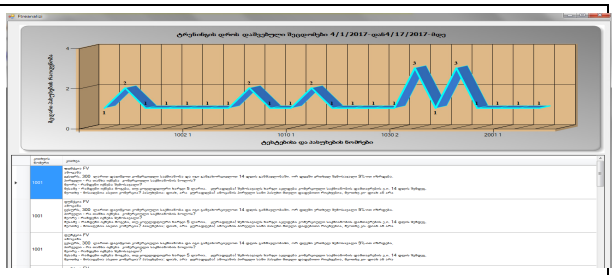
It is showed on the picture that time for the training is 7000 seconds, from the 6 tests of third sub-topic of second topic 5 tests are brought on the training. In total 9 tests are brought on the training, possible points to get is 15. 5 tests are open and 4 tests are closed (assessment of the open tests are partial, while that of closed tests isn’t).

After pressing the button “start training” the training starts. On the pic. 6 open type test is shown with two answers for it. Respective points for answers are also shown. “help on test” button is active in the same window. Pressing on it window will appear providing solution (solution method, algorithm, model and etc.) for the problem.

Student can conduct training everyday N times, get advices and recommendations for error correction made in the test. After finishing any training student can see training report, advices, recommendations and statistics of the errors made by him/her. /pic. 7/



Pic. 6. Window for listing problem solution results for open tests



Pic. 7. Statistics of errors made at training

Errors made in the certain time of trainings conducted by the students with the test number and correct answer are given on the picture. In the table in same window contents of the tests given on the diagram are shown.

Below we will discuss modeling of financial stability of enterprise by FINSIM1.1 simulator Altman model. In FINSIM1.1 three models of Altman are given. One of them named Altman1 is following /7/:

$$Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + 1.0X_5$$

where:

X_1- working capital/ total assets

X_2- undistributed profits/total assets

X_3- profit before interest and taxes/total assets

X_4- market value of capital/liabilities

X_5- sales/total assets

As it can be seen from the model, coefficient X_1 represents the measure of liquidity. According to the author Altman losses in the company reduces this coefficient first of all.

Coefficient X_2 is a kind of financial leverage, because in the firms with high level of this coefficient assets are financed more by own sources than by borrowed financial resources.

Coefficient X_3 shows actual profitability without taxes and interest rates paid.

X_4 market value of capital includes common and preferred stocks, short-run and long-run liabilities. Actually, using this coefficient lower threshold of the value of company's assets is defined, when it is below the liabilities.

X_5 shows number of sales company's assets can ensure.

Actually 7 variables are included in the model. After systematization of names of variables formula (1) gets following form:

$$Z = (1.2 * X_2 + 1.4 * X_3 + 3.3 * X_4 + X_7) / X^1 + 0.6 * X^5 / X_6 \quad (2)$$

Where:

X_1 – total assets;

X_2 – working capital;

X_3 – undistributed profit;

X_4 – profit before interest and taxes;

X_5 – market value of capital;

X_6 – liabilities;

X_7 – sales.

Based on the values of Z we can talk over financial conditions of the firm, particularly:

Firm is in a safe zone	=	$Z > 2.99$
Firm is in a grey zone		$1.81 < Z < 2.99$
Firm is under the risk of buncrupcy in two years		$Z < 1.81$

We make simulation using actual data of actual enterprise. In the Table 1 values of $X_i \; i = \overline{1,7}$ variables for "X" JSC 2010-2016 are given:

Name	Years						
	2010	2011	2012	2013	2014	2015	2016
Total assets (000GEL)	1000	1300	900	950	800	1000	1000
Working capital	500	600	300	544	485	465	347
Undistributed profits	100	100	60	60	60	60	55
Profit before interest and taxes	60	60	40	40	40	40	30
Market value of capital	600	400	400	400	400	400	300
Liabilities	700	800	850	890	900	900	900
Sales	1200	1250	1200	1200	1200	1200	1200

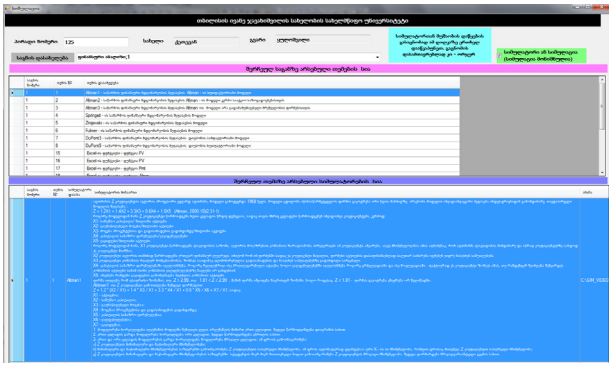
After calculating minimum, maximum and mean values of variables in program based on the table 1 we get new table with these results.

Using Altman model FINSIM1.1 simulation of financial stability of the enterprise is done in a following way:

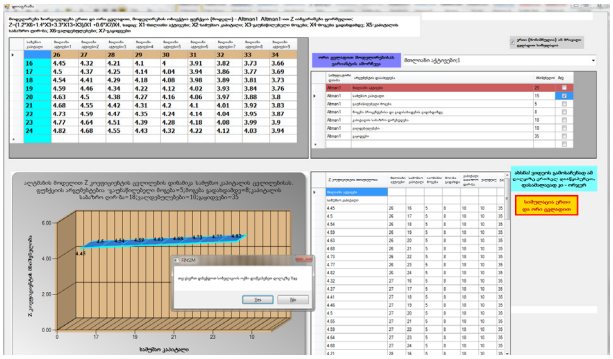
1. After calling out the program window will be showed up in which working language with the system can be selected – Georgian. After selecting the language window will appear in which after student identification and selection of subject and topic the list of simulators regarding selected subject and topic will be scrolled down /pic. 8/.

2. After clicking on the name of the simulator respective window will appear.

Basis of the simulation is Altman model. Values of arguments (variables) can be changed by the student. Modeling the process is made by one or two variables, because of this, indication of V x_i variable and modeling with this variable are taken into account. Result of the modeling will be received in a form of diagram and table. /pic. 9./



Pic.8 . Window after student identification and selection of subject and topic.



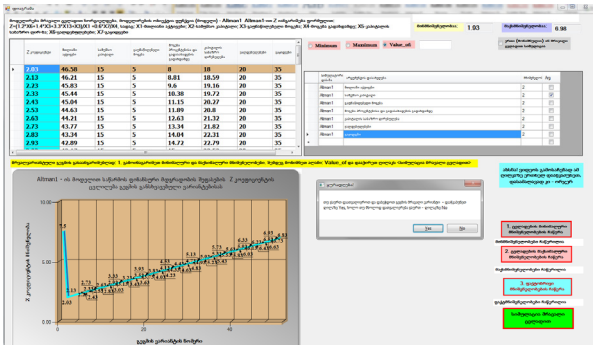
Pic. 9. Result of the simulation by one and two variables

On the diagram dependence of Z coefficient (function) on the changing of value of variable X_i is shown, while in the table dependence of change in values of Z coefficient on the changes in X_i and X_{i+1} variables is shown. After clicking on an "explain" button window will appear showing explanation of simulation result.

Modeling by multiple variables

Minimum, maximum and actual data of X_i $\mathrm{i} = \overline{1,7}$ variables calculated based on table 1 are given as a basis plan for modeling. In case of absence of the data minimum, maximum and initial data of variables are brought in by the student. Value of Z coefficient is calculated for the minimum and maximum values

of variables and multi-variant modeling is being made by certain step in $Z_{min} < Z < Z_{max}$ range. As a result of modeling $\forall Z_J \rightarrow X_i, i = 1 \ldots 7$ can be seen, i.e. value of any Z coefficient from selected values is defined by certain values of the variables. This allows us to define optimal values of the parameters of financial stability of enterprise using Altman model and after that control and manage their values in the process of functioning of enterprise. On a picture 10. Values of the variables respective to the different values of Z coefficient taken by modeling are shown. Multiple variants of plan is given on the picture 11.



Pic. 10. Results got by multiple variable modeling using Altman's 5 factors model

	Current Values:	2.03	2.13	2.23	2.33	2.43	2.53	2.63	2.73	2.83	2.93
Changing Cells:											
მთლიანი აქტივები	25.00	46.58	46.21	45.83	45.44	45.04	44.63	44.21	43.77	43.34	42.89
სამუშაო კაპიტალი	28.96	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
გაუნაწილებელი მოგება	10.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
მოგება პროცენტებისა და გადასახადების გადახდამდე	15.00	8.00	8.81	9.60	10.38	11.15	11.89	12.63	13.34	14.04	14.72
კაპიტალის საბაზრო ღირებულება	30.00	18.00	18.59	19.16	19.72	20.27	20.80	21.32	21.82	22.31	22.79
ვალდებულებები	10.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
გაყიდვები	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
Result Cells:											
O1											

Pic. 11. Multiple variances of plan got by multiple variable modeling using Altman's 5 factors model

Conclusions and recommendations

1. It is not a panacea to use simulator in the teaching process including our simulator. It is one of the means for deep understanding of the issue in a short time. Effect of the simulator is achieved with the use of using simulator with respectively designed electronic textbook. Under electronic textbook we consider a textbook designed using hypertext technology, subtle search system, represented by the graph and video;
2. Integral part of training, simulation is discussion and analysis of the results – debriefing. For conducting group debriefing by the teacher using FINSIM1.1 the report describing training, simulation is made;
3. Knowledge acquisition system TRAINER1 is attributed to the class of intellectual systems for knowledge acquisition. It is an integral part of distanc learning;

4. Defining individual exercises by the students within the training allows taking into account abilities of student as much as possible and paying attention by the student to the key issues for him/her;
5. Giving advices and recommendations timely in case of mistakes allows repeating solution of the problem several times that makes the process of knowledge acquisition easy and fast;
6. Semantic analyzer of indicative sentence in TRAINER1 allows for taking into account peculiarities of problem solution;
7. Adaptation of TRAINER1 to specific subject is made by inclusion of information describing this subject in the database of TRAINER1;
8. Necessary condition for using TRAINER1 is preparation of information describing the subject, particularly: single out topics, sub-topics; form typical problems in any sub-topic; explain problem solution method, algorithm; experience for solving such problems; characterize typical errors made in problem solving and show the ways of their improvement;
9. TRAINER1 allows the information describing the same subject to be represented by different teachers (indicating their authorship): problems, solution methods and etc.

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