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COMPARATIVE CASE STUDY ON SYSTEM-INTEGRATED MEASUREMENT TECHNOLOGIES

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Abstract: The aim of the research is to make a comparison between system integrated measurement technologies in the field of engineering education in order to the students getting more detailed knowledge about the high level problem solving. A comparative case study was conducted with 3 different types of systems, as follows: Beckhoff, National Instruments, and HBM. The criteria of the systems are determined based on experience and the importance level of them was calculated by preference matrix. The ranks of the alternatives are calculated by Kesselring method, which provides the effectiveness value of the systems compared to the benchmark. The result of the paper shows a suitable method for selecting engineering systems.

Keywords: Multi-criteria decision making, Industrial measurement technologies, Kesselring method, Industry automation

1. Introduction

Today, information is becoming increasingly important in the accelerated world. A great deal of information is available but unfortunately it is not a high standard. It makes a difference what information is available at what time. This kind of advanced intensive information might serve the development of technology. It does not matter what area of life is given as an example, that of a dentist's, a cinema show, a writer's year of birth, the current state of the ordered package.

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All the important information emerges from a lot of data collection and data processing [1], so it is very important to know from the beginning what tools and methods can be used to extract information. The intensive collection of information in industry is a major challenge, since the quantity and quality of information affects the product be manufactured. It is very important to know who, when and by what means, what tools, built the device in what way. These data are essential for future developments, or even a possible investigation of complaints. That is why it is fundamental part of the education that the students get up to date knowledge in field of measuring systems. Therefore, it is essential to be able to clearly compare desired industrial measuring systems for the production processes [2].

It is possible to compare different aspects/criteria systems with many types of decision making methods.

2. Selected industrial measuring systems

The article introduces classical industrial measurement technology solutions. The basis of the comparison (the smaller one) is provided by the systems applied at the Faculty of Engineering, the University of Debrecen. The article compares the different industrial measuring systems of three different manufacturers without completeness.

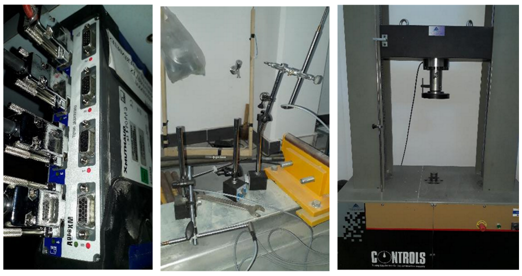
2.1. HBM

HBM is the market leader in the test and measurement technology and offers products and services for an extensive range of measurement applications in many industries.

The potential fields of application can be found in every branch of engineering and industry in both virtual and physical test and measurement.

HBM's product range covers strain gauges, load cells, force sensors, torque sensors, amplifiers and Data Acquisition Systems (DAQ) as well as software for structural durability investigations, tests and analysis.

In the HBM example the central pressure head and three displacement signals are measured (*Fig. 1a* is the signal amplifier, *Fig. 1b* is the displacement sensor *Fig. 1c* is the testing machine) how much the material rises at its two edges.



a) b) c)

Fig. 1. Physical devices of the HBM measuring system

The signals are provided by the force cell and the signal transducer sensors are evaluated using catmanEasy software (*Fig. 2*). It can parameterize the received signals in catmanEasy software. The resulting values can be monitored continuously. It is possible to export the signals, collected by DAQ in various formats. The catmanEasy software is not suitable for direct machine control.

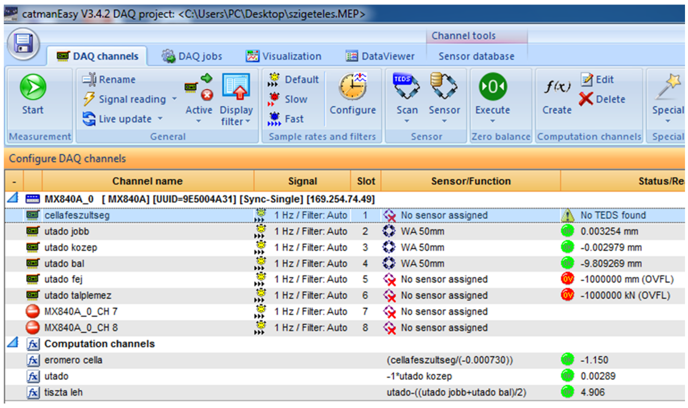


Fig. 2. CatmanEasy measuring software of the HBM

2.2. National Instruments

For more than 40 years, National Instruments (NI) has been developing high-performance automated test and automated measurement systems, which help to solve engineering challenges now and well into the future. It is directly present in more than 50 countries. NI prepares engineers and scientists with systems, which accelerate productivity, innovation and discovery.

The main products of NI are the PC-based measurement and control systems, CompactRIO systems, PXI systems, software (for data collection, control, electronic tests, electronic instruments, wireless design and testing) LabVIEW, DIAdem.

An intelligent family house model has been implemented with a National Instruments device. Control and measurement tasks have been implemented (e.g. heating, cooling, access to garage door, irrigation, external as well as internal temperature). The model also provides remote access (*Fig. 3*) [3].

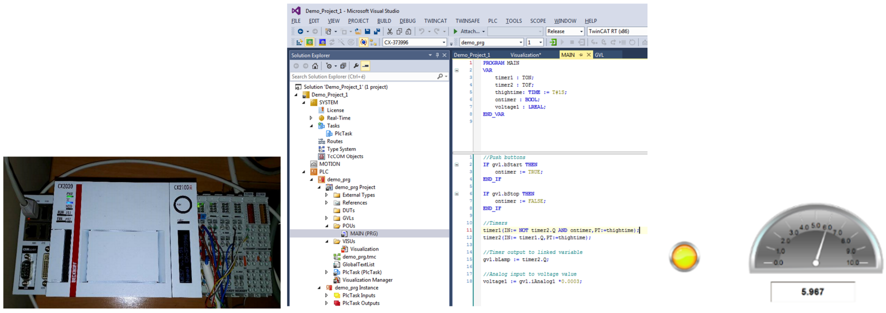
Fig. 3. Physical devices of the NI measuring system

2.3. Beckhoff

Since the foundation of the company in 1980, continuous development of innovative products and solutions using PC-based control technology has been the basis for the continued success of Beckhoff. EtherCAT, the real-time Ethernet solution, makes forward-looking, high-performance technology available for a new generation of cutting-edge control concepts.

The company's main products are Industrial PC, field I/O, servo drives, servo motors and system software.

Simple analogue measurement results were implemented with the Beckhoff device. The measured value is displayed from 0 to 10 V input signal. The flashing command part starts with the digital input (*Fig. 4c*). Industrial PC was used for the task solution (*Fig 4a*). These can be seen in the following *Fig. 4*.



a) b) c)

Fig. 4. Physical devices of the Beckhoff measuring system

3. Main goals

Based on the diversity of excellence between the three manufacturers it seems rather difficult to make comparisons between them. However, owing to the combination of Kesselring and multi-criteria decision making methods clear evidence arises as how to qualify different systems in a measurable way.

The primary goal of the presented method is to apply any technical systems for a standard approach to diverse systems. This might balance out the incongruence of difference systems.

4. Multi-criteria decision making

Multi-Criteria Decision Making (MCDM) analysis is a rapidly growing aspect of operations research and management science.

A decision matrix **A** is an ($M \times N$) matrix in which element a_{ij} indicates the performance of alternative A_i when it is evaluated in terms of decision criterion C_j, (for

i=1,2,3,...,M, and j=1,2,3,...,N). It is also assumed that the decision maker has determined the weights of relative performance of the decision criteria (denoted as W_j, for j=1,2,3,...,N).

For example:

Let **A** = {A_i, for i = 1,2,3,...,M} be a (finite) set of decision alternatives and **G** = {g_i, for j = 1,2,3,...,N} a (finite) set of goals according to which the desirability of an action is judged. Determine the optimal alternative **A*** with the highest degree of desirability with respect to all relevant goals g_i:

1) Determining the relevant criteria and alternatives;
2) Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria;
3) Processing the numerical values to determine a ranking of each alternative (*Table I*) [4], [5].

Table I

A decision matrix

	Criteria				
	C_1	C_2	C_3	...	C_N
Alt.	W_1	W_2	W_3	...	W_N
A_1	a_{11}	a_{12}	a_{13}	$\cdots$	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	$\cdots$	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	$\cdots$	a_{3N}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
A_M	a_{M1}	a_{M2}	a_{M3}	$\cdots$	a_{MN}

4.1. Kesselring method

The method of system comparison was developed by Fritz Kesselring. This method was used for technical factors assessment that can be calculated by means of a ratio or interval factors. Kesselring developed a simple but very effective decision support method for the design process. Kesselring compared the data of products under investigation with the data of best product of a set ideal value. These data were the highest and got a score of 4 [6], [7]. The value of the parameter is determined on the scale of 0-5 with the actual value of product with comparison to the ideal value. It is explained as:

- 5 point - Excellent;
- 4 point - Very Good;
- 3 point - Good;
- 2 point - Satisfying;
- 1 point - Acceptable;
- 0 point - Insufficient.

After collection of data, the Kesselring method is used to calculate the technical value of complex systems as:

$$x = \frac{\frac{\sum_{i=1}^{n} p_i}{n}}{p_{\max}} = \frac{\bar{p}}{p_{\max}}, \qquad (1)$$

where x is the technical value of product; p_i is the point value of parameters; $\bar{p}$ is the arithmetic mean; $p_{\max}$ is the point value of ideal solution; n is the number of technical parameters.

Each parameter has different units. Kesselring formed a sequence of scale with measurements with a common denominator. The disadvantage of this method is that it does not take into account the different weights of parameters. It was solved by the Kesselring weighing method. v_i stands for weighing factor of parameter were coded on the factor 0-10. The technical values of products were calculated with the weight factor of parameter as the follow:

$$x' = \frac{\sum p_i \times v_i}{\sum p_{\max} \times v_i}. \qquad (2)$$

Here, x' can be up to 1 for complex system value. The Kesselring method is also used for the relative and absolute ranking of products. The system value is measured as:

- $1 \geq x' \geq 0.8$ = system is very good;
- $0.8 > x' \geq 0.6$ = system is good;
- $0.6 > x' \geq 0.5$ = system is appropriate;
- $x' < 0.5$ = system is unsatisfactory.

The Kesselring method was originally used to measure machine tools; however, it can also be used for a complex system. In order to be effective, this method was designed to operate on evaluation factors that can be measured on the scale of ratio and intervals.

For the matching of procedures, the steps are as follows:

1. Choose an alternative;
2. Select evaluation factors;
3. Define the target function. (e.g. minimum for better smaller values, maximum for higher value function);
4. Specify the value of rating factor based on scale;
5. Specify the weight of rating factor. (for example: pair-based comparison or preference based comparison) [8], [9], [10].

5. Application of the methods

The three manufacturer's measuring systems have been compared with measurement methodology of complex systems. The main goal is to quantify the efficiency of each measuring system based on the determined parameters shown in *Table II*.

Table II

Defined minimum and maximum target functions

No.	Name of the criteria	Target function
E1	Price of the measurement system	Min.
E2	Applicability for industrial processes	Max.
E3	Simplicity of programming	Max.
E4	User friendliness	Max.
E5	Data collection for reports	Min.
E6	Easy evaluation of data	Min.
E7	Size	Min.
E8	Sensor compatibility	Max.
E9	Documentedness	Max.
E10	Support	Max.
E11	Delivery time	Min.
E12	Professional pre-qualification	Min.
E13	IT requirements	Min.
E14	Compatibility with softwares	Max.
E15	Modularity	Max.
E16	Robustness	Max.
E17	Price of the softwares	Min.

The methods applied as the follows as it can be seen in *Fig 5*:

- Selection of alternatives;
- Definition of criteria;
- Preferential matrix for determining the priority of criteria;
- Specification of target functions for criteria;
- Scoring of values-criterion for all alternatives;
- Kesselring method for examining system efficiency.

Fig. 5. Steps of the methods used

The order priority of the preference matrix was determined on the basis of the chosen criteria (relationship of criteria).

1. The comparison is based on the 17 criteria (aspects) as it can be seen in *Table III*. These criteria are the most important for selecting a measurement system. The effectiveness of measurements system is determined the value of the criteria.
2. Best value criteria have been considered;
3. The low level of inconsistency of a pair wise comparison is a necessary condition to generate the acceptable result. The Consistency Ratio (*CR*) is based on the fact that the dominant eigenvalue of a consistent pair wise comparison

matrix is N [11]. Basically consistency ration is a positive linear transformation of the Perron eigenvalue λ_{max} as follows: $CR = CI/CR$, where CI stand for consistency index, $CI = (\lambda_{max} - n)/(n - 1)$. RI stands for random index. Consistency ration is zero if and only if the pair wise comparison is consistent otherwise CR is a positive value. The threshold values of 0.1 (10%) has been accepted in the practice [12]. The following table contains the value of consistency analysis.

Table III

Priority matrix determination

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17
E1	1	1/6	1/3	2	1/3	1/3	1/2	1/9	1/9	4	2	6	5	1/7	1/5	3	1/9
E2	6	1	8	6	4	1	3	2	2	2	2	2	2	6	3	8	5
E3	3	1/8	1	1	1/5	1/5	5	3	2	2	8	3	2	1	6	3	8
E4	1/2	1/6	1	1	2	2	5	2	3	2	9	7	6	2	2	5	6
E5	3	1/4	5	1/2	1	6	6	5	3	4	9	6	9	6	2	9	7
E6	3	1	5	1/2	1/6	1	9	7	6	5	9	9	6	6	6	9	9
E7	2	1/3	1/5	1/5	1/6	1/9	1	1/9	1/6	1/3	3	1/5	1/3	1/3	1/3	4	1/4
E8	9	1/2	1/3	1/2	1/5	1/7	9	1	9	6	9	7	5	1	4	4	8
E9	9	1/2	1/2	1/3	1/3	1/6	6	1/9	1	5	3	3	8	1/6	1/6	5	9
E10	1/4	1/2	1/2	1/2	1/4	1/5	3	1/6	1/5	1	9	9	7	1/6	1/3	3	5
E11	1/2	1/2	1/8	1/9	1/9	1/9	1/3	1/9	1/3	1/9	1	1/9	1/9	1/9	1/9	1/9	1/9
E12	1/6	1/2	1/3	1/7	1/6	1/9	5	1/7	1/3	1/9	9	1	9	1/9	1/3	5	9
E13	1/5	1/2	1/2	1/6	1/9	1/6	3	1/5	1/8	1/7	9	1/9	1	1/9	1/5	1/6	2
E14	7	1/6	1	1/2	1/6	1/6	3	1	6	6	9	9	9	1	9	9	6
E15	5	1/3	1/6	1/2	1/2	1/6	3	1/4	6	3	9	3	5	1/9	1	9	1/9
E16	1/3	1/8	1/3	1/5	1/9	1/9	1/4	1/4	1/5	1/3	9	1/5	6	1/9	1/9	1	6
E17	9	1/5	1/8	1/6	1/7	1/9	4	1/8	1/9	1/5	9	1/9	1/2	1/6	9	1/6	1

The calculated CR value is 0.073, that value can be accepted and the consistency is assumed in respect that there are 17 parameters in the calculation.

4. The manufacturers rating has been calculated based on the weighted scores (1-5) (subjective comparison). The results can be seen in *Table IV*;
5. Weighted scores of measuring systems (summary); all three measurement system were well done based on the criteria set up (*Fig. 6*). The rating scores for mean scores are significantly affected by the following weighted points: E5-Data collection for reports; E6 - Data evaluation; E3 - Difficulty of programming; E8 - Sensor compatibility; E4 - User friendliness [11], [12], [13], [14], [15], [16].

6. Results

As it is shown in Fig. 6, all three measuring systems achieved similar scores. Based on weighted scores (x'), the manufacturers achieved the following scores, HBM: 0.677, NI: 0.702 and Beckhoff: 0.812.

This means that all manufacturer's systems have received a good rating as described in paragraph 3.1 (0.8 > *x*' ≥ 0.6 = system is good, *x*'>0.8= system excellent).

Table IV

Rating of measure systems

		HBM	Value	NI	Value	Beckhoff	Value
Min.	E1	moderate	3	expensive	1	moderate	5
Max.	E2	moderate	2	moderate	3	simple	5
Max.	E3	moderate	3	easy	5	moderate	4
Max.	E4	moderate	3	high	4	moderate	3
Min.	E5	easy	5	easy	5	moderate	4
Min.	E6	easy	5	easy	5	moderate	3
Min.	E7	moderate	2	moderate	3	moderate	2
Max.	E8	high	4	high	5	moderate	3
Max.	E9	low	2	moderate	3	high	5
Max.	E10	moderate	2	moderate	3	high	5
Min.	E11	moderate	3	slow	1	fast	5
Min.	E12	moderate	3	moderate	2	low	4
Min.	E13	low	5	high	1	moderate	3
Max.	E14	moderate	3	low	1	high	5
Max.	E15	moderate	3	moderate	3	high	5
Max.	E16	moderate	3	moderate	5	low	2
Min.	E17	required	3	essential	1	not required	5
Average		3.18		3.00		4.00	

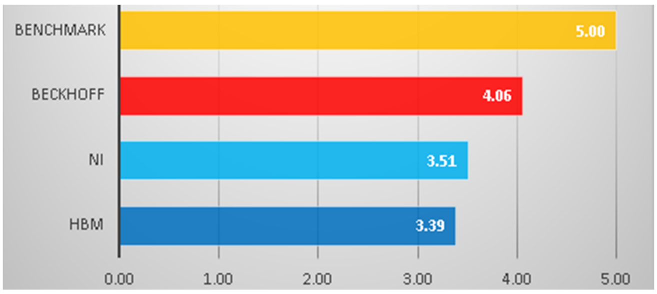


Fig. 6. Rating of measure systems

7. Conclusion

Based on subjective and objective factors, the Beckhoff's industrial measuring systems are ahead of the above-mentioned competitors. The rating obtained is further corroborated by the Beckhoff company fact that the price of the measuring instruments and the programming software is absolutely free.

The method can be used as a basis for a customer satisfaction measurement, which can be the basis for future product development.

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