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COMPUTERIZED DEVICE FOR MONITORING ECG AND PPG SIGNALS - DESIGN AND REDESIGN BASED ON VALUE ENGINEERING METHOD

BY

ADRIAN VÎLCU[1,*], EDUARD LUNCĂ[2], SILVIU VORNICU[2], IONUȚ-VIOREL HERGHILIGIU[1,3] and CLAUDIA TOPORĂSCU[1]

[1] “Gheorghe Asachi” Technical University of Iași,
Faculty of Industrial Design and Business Management, Iași, Romania
[2]“Gheorghe Asachi” Technical University of Iași,
Faculty of Electrical Engineering, Iași, Romania
[3]Academy of Romanian Scientist, Bucharest, Romania

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Abstract. In the current medical, social, and technological context, where cardiovascular diseases have a high incidence in mortality statistics, dynamic social life, and rapid technological advancements, computerized systems for monitoring personal health parameters, independent of the medical system, are in great demand. The current research aims to design a prototype of a computerized system for monitoring cardiac activity (ECG and PPG) and improve it through functional optimization using an incremental innovation method based on value engineering applied to the product. This paper presents the stages of physical prototyping, device design based on its primary functions, functional optimization through balancing the cost-effectiveness ratio for each function, selecting device redesign solutions, and implementing them in the final product. The novelty of this research lies in the physical realization of a cardiac activity

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*Corresponding author; *e-mail*: adrian.vilcu@academic.tuiasi.ro

monitoring prototype and the application of an incremental innovation methodology and device redesign. The research falls within the technical field - through the development of the ECG-PPG prototype - and the economic field - through the application of functional analysis to improve this device.

Keywords: computerized ECG-PPG prototype, functional analysis, cardiac activity monitoring, the process of conception and reconception.

1. Introduction

It is well known that cardiovascular diseases remain one of the leading causes of morbidity and mortality in Romania and Europe. Although the population of Romania decreased by 12% from 2001 to 2016, the total number of deaths from cardiovascular causes decreased by 7% (National Institute of Population Statistics) (Forbes, 2019). The number of deaths due to complications of hypertension has increased by 71% in recent years. Approximately 7.4 million people suffer from this condition, and what is even more serious is that more than 20% of those affected are unaware that they have any cardiovascular disease and do not seek treatment (Forbes, 2019). These include coronary heart disease - myocardial infarction and angina pectoris, stroke, heart failure, hypertension, cardiac rhythm disorders, and other heart conditions. Furthermore, a report published in 2018 by the Romanian Ministry of Health showed that in 2016, approximately 4.5 million Romanians had cardiovascular diseases, which represented the most common cause of hospitalization and death (Forbes, 2019).

In this context, the research aims to develop a prototype of a computerized system for monitoring ECG and PPG. Furthermore, a value engineering technique is applied to add value to the device after creating the prototype. The research results consist of producing a functionally optimized cardiac activity monitoring device through a value engineering methodology.

Value analysis and engineering method is an incremental innovation methodology applied to a product or service (Gartner *et al.*, 2022) belonging to the same category as the *Design Thinking method* (Souto, 2015) and focused on meeting the customer's needs in the most efficient way possible, technically and economically (Nor'Aini Yusof, 2023).

The stages of applying the innovation method are presented in the Fig. 1 (Thanh and Phong, 2023).

It should be noted that Fig. 1 illustrates only one step in increasing the value of the ECG-PPG prototype. This sequence of steps can be applied iteratively as many times as necessary to improve the ECG-PPG device.

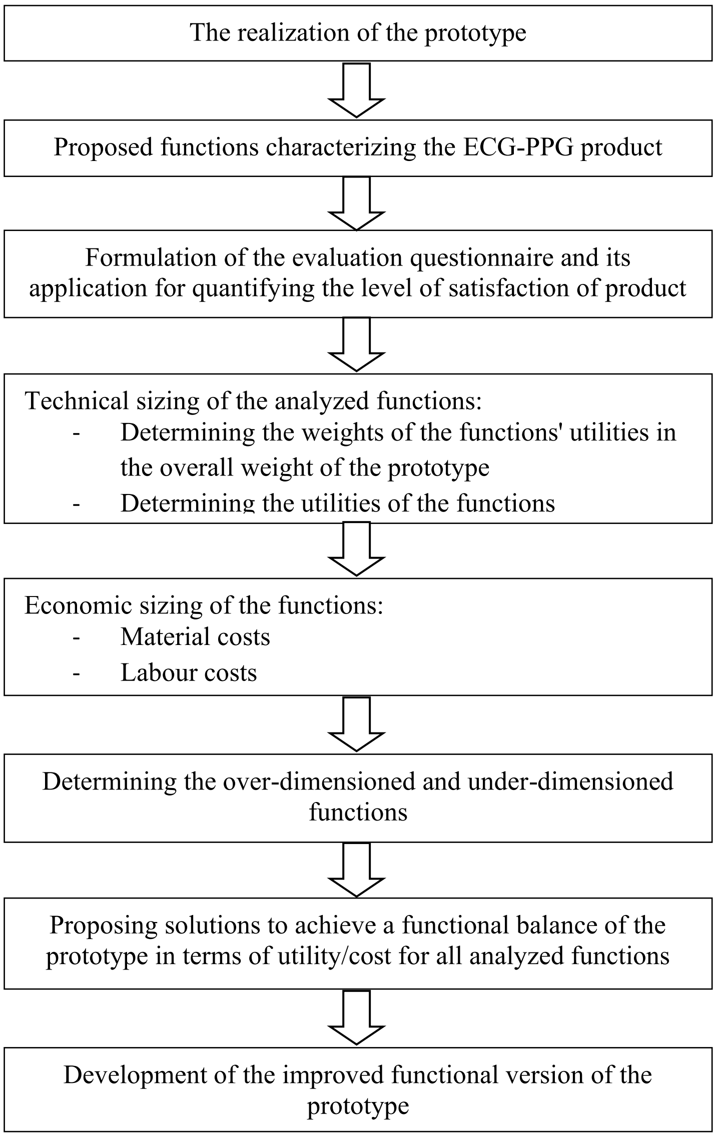


Fig. 1 – Steps for an incremental innovation method.

2. Material and Method

2.1. Realization of the prototype of a computerized ECG-PPG device

Like other tissues, the myocardium generates an electric field (variations in electric potential) that propagates to the surface of the skin. From there, the electric field can be recorded by placing electrodes at specific points on the human body. The resulting graph from this recording is called an electrocardiogram (ECG).

Therefore, an electrocardiogram represents the graphic recording of the variations in electric potential that occur during cardiac activity.

The interpretation of the ECG essentially refers to understanding the heart's electrical conduction system. Normal conduction follows a predictable pattern, and deviations from this pattern can be either standard or pathological. An ECG does not equate to the mechanical pumping activity of the heart. For example, an ECG signal associated with pulseless electrical activity (PEA) indicates a certain cardiac rhythm, according to which the heart should pump blood. However, in this case, no palpable pulse is felt (it constitutes a medical emergency, and cardiopulmonary resuscitation should be performed). Finally, an echocardiogram helps assess the mechanical function of the heart.

As in all medical tests, what is considered “normal” is based on population studies. A heart rate between 60 and 100 beats per minute (bpm) is considered normal because data shows this is the usual resting heart rate.

Monitoring dynamic changes in physiological and biological parameters through integrated non-invasive systems can play an essential role in various applications. Among these can be heart rate and tissue perfusion obtained through photoplethysmography (PPG) measurements. However, non-invasive integrated systems that measure such parameters require very clean (noise-free) physiological signals to enable robust and efficient calculation of medical indicators.

Photoplethysmography is a medical technique used to measure volumetric changes in blood in peripheral blood vessels. This technique is based on detecting variations in light intensity reflected by human tissues during a cardiac cycle. Photoplethysmography is often used to assess heart rate and monitor peripheral blood flow.

Recent advancements in technology have revived interest in this technique, which is widely used in clinical physiological measurement and monitoring and, recently, in wearable technology, allowing consumers to monitor their health.

ECG and PPG signals provide precious information regarding the functioning of the cardiovascular system. Given that there are currently numerous electronic solutions on the market for measuring and monitoring these signals (specific sensors, development platforms, acquisition modules), many of them at low prices, the development of tools and systems for monitoring personal health based on such solutions has become a common approach, further reinforced by the widespread availability of open-source software. This chapter details the design, implementation, and operation of a low-cost computerized system for monitoring both ECG and PPG signals, which can be used in various non-clinical applications, such as routine assessment of personal heart rate. Essentially, the ECG signal measurement is performed using an AD8232 analogue module, which is very popular in such applications, while the PPG signal is obtained from an HW-827 optical sensor. The acquisition of the two signals is performed using an Arduino Uno development platform, and the measurement software itself was developed in the LabVIEW graphical programming environment (Community Edition), provided free of charge by National Instruments.

The block diagram of the proposed system is shown in Fig. 2. As can be seen, it includes:

• The ECG analogue channel, composed of the ECG electronic module - AD8232, an additional low-pass filter (LPF) with a cut-off frequency of 40 Hz and an additional amplification block (with relatively low gain, A = 4).

• The PPG analogue channel comprises the HW-827 optical sensor and an amplification block with A = 21.

• The open-source Arduino Uno development platform, with the ECG and PPG signals connected to its analogue inputs A0 and A1 (the measurement of the two signals is performed alternately).

• A PC system is running application software based on the LIFA (LabVIEW Interface for Arduino) toolkit.

The power supply voltages for all electronic blocks, +5V or +3.3V (as applicable), are obtained from the Arduino Uno board connected to the PC's USB port.

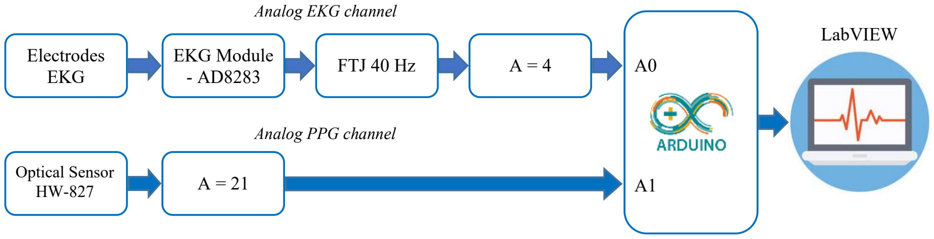


Fig. 2 – Block diagram of the proposed system.

The functional prototype of the computerized ECG/PPG monitoring system is presented in Fig. 3. Here, limb clamp-type electrodes are used for measuring the ECG signal, but adhesive disposable Ag/Ag-Cl electrodes can be used as well. In contrast, the PPG signal is measured by placing the finger on the upper surface of the PPG sensor. The analogue signal processing circuit for the two signals is implemented on a test board.

As mentioned above, LabVIEW is used as an integrating platform for acquiring, processing, displaying and recording physiological data. The developed application software is mainly based on LIFA, an open-source toolkit designed for (and tested using) Arduino Uno, which allows users to quickly and easily create graphical user interfaces for virtually any component compatible with the Arduino microcontroller. In addition, LIFA allows complete control of the sampling time, which is one of the significant parameters of any embedded system for physiological data acquisition. Moreover, the firmware source code is included within the LIFA installer (only minor changes were made in this project).

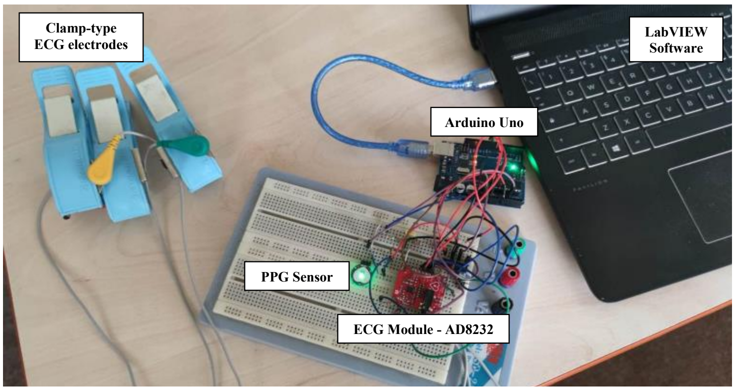
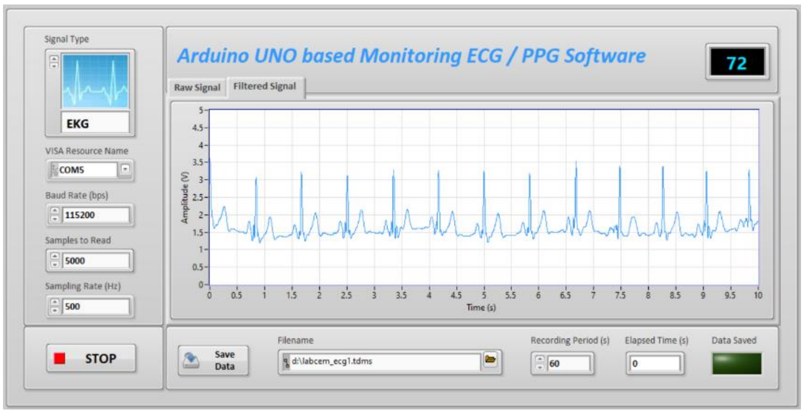
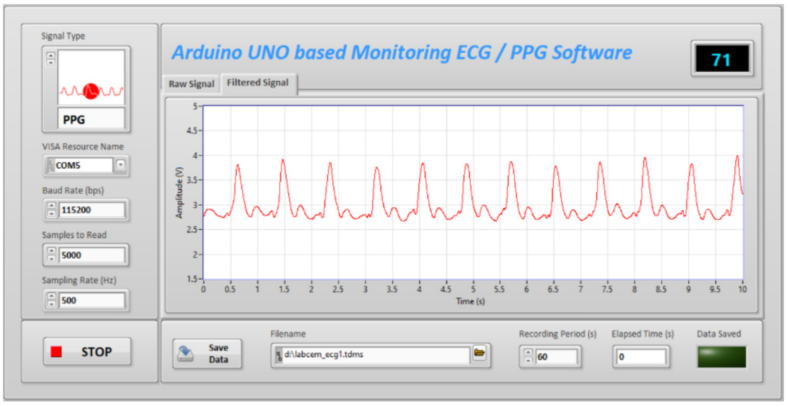


Fig. 3 – Computerized system for ECG-PPG monitoring.

Figure 4 shows the graphical user interface of the developed application software. Basically, this LabVIEW program allows user to select the communication port to which the Arduino Uno platform is connected, specify the data transfer rate via the USB connection (default, 115200 bps), specify the sampling rate and the number of samples to read, display the raw and digitally-processed ECG (a) and PPG (b) signals (a Wavelet-based denoising approach is further applied to the raw ECG and PPG signals), display the instantaneous heart rate (in beats per minute) and record the ECG and PPG signals in data files for further analysis, such as heart rate variability (HRV). Note that both signals were taken from the same person over a time window of 10 s.



a)



b)

Fig. 4 – Graphical user interface of the ECG-PPG monitoring software: a) ECG measurement; b) PPG measurement.

2.2. Proposed functions of the ECG/PPG device

During this stage, the goal is to understand the needs, desires, and requirements of users for devices with ECG and PPG monitoring functions, as well as to evaluate the correct understanding of the main characteristics of this device.

The following functions have been proposed for a computerized ECG-PPG monitoring system:

F1: Pulse measurement - the PPG device can monitor a person's heart rate (pulse) by measuring variations in blood volume in the superficial blood vessels.

F2: ECG measurement - this function refers to the device's ability to detect the frequency and shape of the cardiac activity curve.

F3: Easy sensor attachment - this function refers to the efficiency of the sensor attachment system on the skin.

F4: Accuracy of information measurement - this function refers to the sensitivity of the sensors and the device's ability to analyze the data they provide.

F5: Easily understandable information format - this function refers to the format of the ECG and PPG information provided by the device. This format should be easy to understand, process, and use by the device user.

F6: Safety of use - this function refers to the primary characteristic of any device to be safe for use.

F7: Ease of portability - this function refers to the portability of the device, allowing it to be used by individuals who require cardiac monitoring at any time.

F8: Storage, access, and easy analysis of device-provided data - the ECG device is connected to computer systems and allows for data storage, management, and analysis. This facilitates access to patient information and enables comparison of ECG data with previous examinations or data collected from other sources.

F9: Ergonomics of the software application used - this function refers to how “user-friendly” the interface of the connected application is for the device.

F10: Portability of the application on different Operating Systems - portability is one of the sought-after functions by end-users for software applications built for various platforms (Windows *et al.*).

2.3. Questionnaire for measuring the level of satisfaction

To establish the relative importance of functional utilities within the product, we administered a questionnaire to a sample of 117 individuals who had used the designed ECG-PPG system. Participants were asked to evaluate the performance of the designed ECG-PPG device by assigning a score from 1 to 100 (1 = not fulfilled at all, 100 = fully fulfilled).

The questionnaire aims to numerically quantify the level of importance of the proposed functions of the ECG-PPG device as perceived by users.

The requirements of the proposed questionnaire are the rate satisfaction level from 1 to 100 for the following functions of the ECG-PPG device: pulse monitoring (F1), ECG monitoring (F2), sensor attachment (F3), accuracy of provided data (F4), information display format (F5), device safety (F6), device portability (F7), data storage (F8), application interface (F9), compatibility with different operating systems (F10).

It is necessary to evaluate the representativeness of this parameter (mean) in the response series. Therefore, the Kolmogorov-Smirnov (KS) normality test is applied (using SPSS v.22) (Aslam, 2020). The results of the KS test are presented in Table 1.

Table 1
K-S Test Values for Normality of Value Series

Function (short presentation)	Kolmogorov-Smirnov		
	Statistic	df	Sig.
F1: Pulse monitoring	*0.051*	*117*	*0.200*
F2: ECG monitoring	*0.068*	*117*	*0.200*
F3: Sensor attachment	*0.082*	*117*	*0.050*
F4: Accuracy of provided data	*0.050*	*117*	*0.200*
F5: Information display format	*0.065*	*117*	*0.200*
F6: Device safety	*0.070*	*117*	*0.200*
F7: Device portability	*0.071*	*117*	*0.200*
F8: Data storage	*0.097*	*117*	*0.009*
F9: Application interface	*0.074*	*117*	*0.161*
F10: Compatibility with different operating systems	*0.095*	*117*	*0.011*

From Table 1, it can be observed that the responses of those who tested the device for each individual function are normally distributed (p-value >= 0.05), except for functions F8 (data recording of the prototype, p-value = 0.009 < 0.05) and F10 (prototype portability, p-value = 0.011 < 0.05) (Hong *et al*., 2021).

The mean values of the responses for functions F1-F10, in terms of customer satisfaction level, are representative of the users who have used the ECG-PPG prototype.

The data provided by users are centralized in Table 2.

2.4. Technical sizing of the functions

The product characteristics contribute differently, independently or dependently, to satisfying customer needs. The principle of proportionality used by this value analysis method indicates a proportionality between the cost of each function of the product and its utility.

To technically size the functions of the prototype, their utility is calculated by determining the weight of each function's utility in the total utility of the analyzed product. This analysis determines how important the features represented by functions are in satisfying the needs of users of the ECG-PPG device (Table 2).

Table 2

Technical sizing of the functions

Function Parameter	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Sum	*8480*	*7594*	*9146*	*7926*	*7401*	*9726*	*8366*	*7846*	*8696*	*9355*
Total sum	*84536*									
Mean	*72.48*	*64.91*	*78.17*	*67.74*	*63.26*	*83.13*	*71.50*	*67.06*	*74.32*	*79.96*
Utility weight u_w [%]	*10*	*9.0*	*10.8*	*9.4*	*8.8*	*11.5*	*9.9*	*9.3*	*10.3*	*11.1*
Order	*5*	*6*	*3*	*7*	*9*	*1*	*6*	*8*	*4*	*2*
Utility	*0.500*	*0.58*	*0.599*	*0.50*	*0.40*	*0.505*	*0.50*	*0.45*	*0.398*	*0.609*

The following relationships are used in Table 2:

$$sum_j = \sum_{i=1}^{117} n_{ij}\,, with\ j = \overline{1,10}$$

$$n_{ij}\ with\ i = \overline{1,117}\,, j = \overline{1,10}$$

$$Mean_j = \frac{\sum_{i=1}^{117} n_{ij}}{117}\ with\ j = \overline{1,10}$$

$$u\_w_j = \frac{\sum_{i=1}^{117} n_{ij}}{\sum_{j=1}^{10} \sum_{i=1}^{117} n_{ij}} \ with\ j = \overline{1,10}$$

$$Utility_j = \frac{(mean_j - \min_i(n_{ji}))}{(\max_i(n_{ji}) - \min_i(n_{ji}))}$$

2.5. Economic sizing of functions

This phase of the functional analysis method is characterized by a matrix (Table 4) that corresponds material and labor costs with the weights of these costs in the functions of the device (Table 3) (Santoso *et al.*, 2022).

I concentrated the technical information in the following notations: *M1*= ECG Module - AD8232, with electrode cable + 3 disposable electrodes included; *M2*= Optical Sensor HW-827, *M3*= Arduino Uno Development Board, with USB cable, *M4*= Connection wires, *M5*= Plastic casing, *M6*= Electronic module fastening accessories at the casing level, *M7*= Software application for monitoring ECG and PPG signals.

Table 3
Cost weights (materials and labour) of the prototype functions

No	Module	Allocation of components and labour per function as a percentage of the total cost									
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
1	*[M1]*	*0*	*30*	*10*	*10*	*10*	*10*	*10*	*10*	*0*	*10*
2	*[M2]*	*30*	*0*	*10*	*10*	*10*	*10*	*10*	*10*	*0*	*10*
3	*[M3]*	*10*	*10*	*0*	*10*	*10*	*15*	*15*	*10*	*10*	*10*
4	*[M4]*	*15*	*15*	*20*	*15*	*0*	*15*	*10*	*10*	*0*	*0*
5	*[M5]*	*0*	*0*	*0*	*0*	*0*	*50*	*50*	*0*	*0*	*0*
6	*[M6]*	*10*	*10*	*0*	*20*	*30*	*0*	*30*	*0*	*0*	*0*
7	*[M7]*	*10*	*10*	*0*	*10*	*20*	*0*	*0*	*20*	*20*	*10*

The value “0” indicates that there is no correspondence between the device module/software application and the analyzed function, or in other words, the function does not have a projection on the included device module or software application in the ECG-PPG device.

This matrix is created by the design engineer and the specialist in the economic aspect (Gonzalez-Sanchez *et al.*, 2020).

Table 4
Economic sizing of the functions of the ECG-PPG device

No	Comp	Mat cost	Labour cost	Total Cost	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
1	*[M1]*	*15*	*0*	*15*	*0.0*	*4.5*	*1.5*	*1.5*	*1.0*	*1.5*	*1.5*	*1.5*	*0*	*1.5*
2	*[M2]*	*11*	*0*	*11*	*3.3*	*0.0*	*1.1*	*1.1*	*1.1*	*1.1*	*1.1*	*1.1*	*0*	*1.1*
3	*[M3]*	*15*	*0*	*15*	*1.5*	*1.5*	*0.0*	*1.5*	*1.5*	*2.2*	*2.2*	*1.5*	*1*	*1.5*
4	*[M4]*	*1*	*0*	*1*	*0.1*	*0.1*	*0.2*	*0.1*	*0.0*	*0.1*	*0.1*	*0.1*	*0*	*0.0*
5	*[M5]*	*5*	*2*	*7*	*0.0*	*0.0*	*0.0*	*0.00*	*0.0*	*3.50*	*3.5*	*0.0*	*0*	*0.0*
6	*[M6]*	*5*	*6*	*11*	*1.1*	*1.1*	*0.0*	*2.20*	*3.3*	*0.00*	*3.3*	*0.0*	*0*	*0.0*
7	*[M7]*	*0*	*10*	*10*	*1.0*	*1.0*	*0.0*	*1.00*	*2.0*	*0.00*	*0.0*	*2.0*	*2*	*1.0*
Total Cost		*67*	*52*	*18*	*70*	*7.0*	*8.2*	*2.8*	*7.4*	*9.4*	*8.5*	*11.7*	*6*	*3.5*
Cost weight c_w [%]		*95.7*	*74.29*	*25.7*	*10*	*10*	*11*	*4.0*	*10*	*13.4*	*12.1*	*16*	*8*	*5.0*

2.6. Determination of over and under-dimensioned functions

For this analysis, the utility weight of the functions is compared with the total utility weight and the cost weight of the functions is compared with the total cost of the product. An ideal product has a unity ratio for each individual function (Rwelamila and Savile, 1994). An over-dimensioned function is characterized by a relationship of the form c_w > a * u_w, where c_w is the utility weight, u_w is the cost weight, and a is the slope angle of the regression line in the [u_w, c_w] reference system.

Similarly, an under-dimensioned function has the relationship c_w < a * u_w, while a well-dimensioned function exhibits an equality relationship between these values (Pislaru, 2015).

The graph of the function dimensions in the orthogonal reference system of utility-cost weights is shown in Fig. 5, and the data used to create the graph are presented in Table 5.

Table 5 contains the parameters of the utility weights (Table 2) and the cost weights (Table 4) of the functions, as well as the mathematical calculation for determining the total deviation value (Pislaru, 2015).

Table 5

Systemic analysis of functions

No	Funct	u_w	c_w	$(u\_w)^2$	u_w*c_w	a*u_w	c_w-a*u_w	$(c\_w-a*u\_w)^2$
1	*F1*	*0.10*	*0.10*	*0.0101*	*0.0101*	*0.0983*	*0.0024*	*0.0000*
2	*F2*	*0.08*	*0.11*	*0.0081*	*0.0106*	*0.0880*	*0.0298*	*0.0009*
3	*F3*	*0.10*	*0.04*	*0.0117*	*0.0043*	*0.1060*	*-0.0660*	*0.0044*
4	*F4*	*0.09*	*0.10*	*0.0088*	*0.0100*	*0.0919*	*0.0145*	*0.0002*
5	*F5*	*0.08*	*0.13*	*0.0077*	*0.0118*	*0.0858*	*0.0485*	*0.0024*
6	*F6*	*0.11*	*0.12*	*0.0132*	*0.0140*	*0.1128*	*0.0087*	*0.0001*
7	*F7*	*0.09*	*0.16*	*0.0098*	*0.0166*	*0.0970*	*0.0709*	*0.0050*
8	*F8*	*0.09*	*0.08*	*0.0086*	*0.0082*	*0.0910*	*-0.0024*	*0.0000*
9	*F9*	*0.10*	*0.05*	*0.0106*	*0.0051*	*0.1008*	*-0.0508*	*0.0026*
10	*F10*	*0.11*	*0.07*	*0.0122*	*0.0081*	*0.1085*	*-0.0356*	*0.0013*
	TOTAL	*1.00*	*1.00*	*0.1008*	*0.0988*	*0.9801*	*0.0199*	*0.0168*

$$S = \sum_{i=1}^{8}(c\_w_i - u\_w_i)^2 = 0.0168 > 0.01 \quad (1)$$

For S > 0.01, it is considered that the device is not correctly functionally dimensioned. The slope angle of the regression line is 44.42 degrees,

$$\alpha = arctg\left(\frac{\sum_{i=1}^{8} u\_w_i * c\_w_i}{\sum_{i=1}^{8}(u\_w_i)^2}\right) = arctg\left(\frac{0.098}{0.1}\right) = 0.98$$

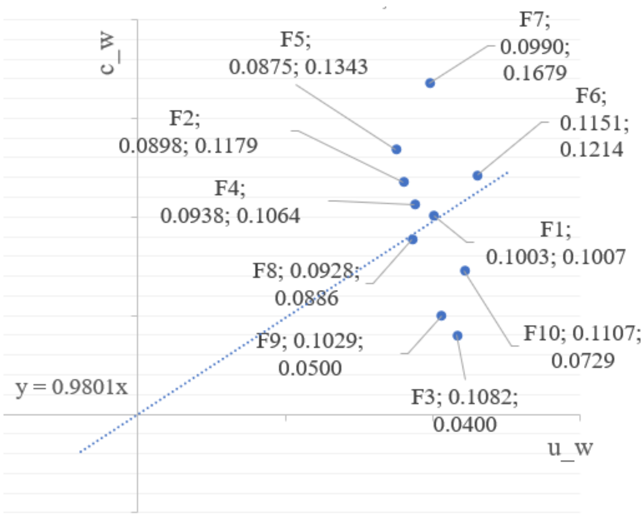


Fig. 5 – Systemic analysis of functions for the ECG-PPG device prototype.

The data resulting from the functional analysis can be centralized in a different way to better highlight the overall utility of the prototype according to the users' opinions (Toporăscu, 2023), and in the same coordinate system, the cost weights relative to the utility of the functions (Table 6 and Fig. 6).

Table 6
Data from the systemic analysis of the ECG-PPG device prototype

Indicator	Total	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Cost weight c_w [%]	*100*	*10*	*11.7*	*4*	*10*	*13*	*12*	*16.7*	*8.8*	*5.0*	*7.29*
Utility [%] weigh u_w	*100*	*10*	*8.9*	*10*	*9.3*	*8.7*	*11*	*9.9*	*9.2*	*10.2*	*11.0*
Utility Uj	*36*	*5.0*	*5.2*	*6.4*	*4.7*	*3.5*	*5.8*	*4.9*	*4.1*	*4.0*	*6.74*
c_w-u_w		*0.04*	*2.8*	*-6.8*	*1.2*	*4.6*	*0.6*	*6.8*	*-0.4*	*-5.2*	*-3.78*

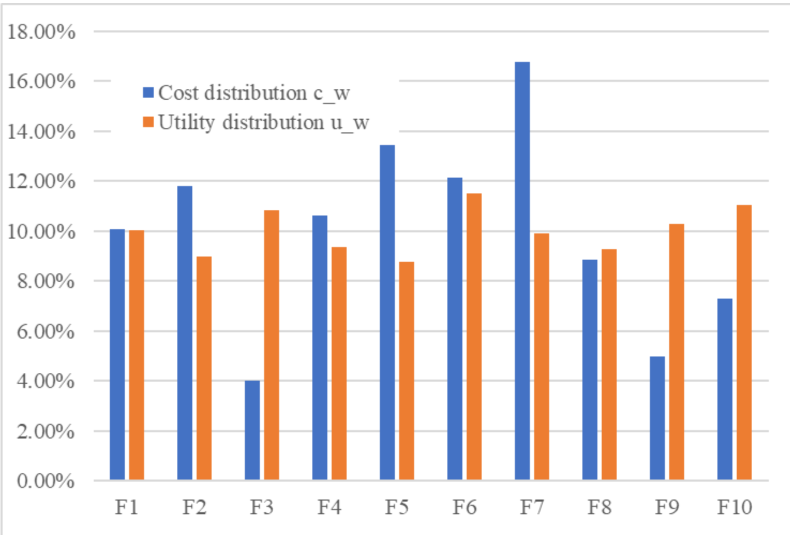


Fig. 6 – Utility and cost distribution of product functions.

2.7. Proposal of solutions for functional balancing of the prototype utility/cost for all analyzed functions

The solutions for the functional balancing of the prototype are as follows:

– Increase the level of utility (which can be validated by re-administering the satisfaction questionnaire for the ECG-PPG device by the clients) by further filtering the output signal using an additional low-pass filter with a cut-off frequency of 40 Hz and increasing the output signal level through post-amplification with a factor A=21 (Integrated Circuit TLC074/Resistors (10 pieces) - 6 x 1 kΩ, 4.7 kΩ, 30.1 kΩ, 45.3 kΩ, 75 kΩ/Capacitors (3 pieces) - 47 nF, 2 x 100 nF [M8]). These modifications of the prototype result in an increase in all analyzed functions except for function F3 (sensor fixation). A significant increase in the level of satisfaction is expected for all functions (except for function F3).

– For function F2 (ECG signal), which has a representative satisfaction level of only 65%, it is expected to be clearly improved to over 80%.

– For function F5 (readable and easy-to-follow format of the provided results), the aim is to increase the satisfaction level of users from 63% to approximately 80%. This can also be achieved through training and informing users about the format of the data provided by the prototype.

– Function F7 (portability of the device) can be resized for an optimized functional device by reducing the cost of the portable casing, but attention should be paid to the device's security function.

2.8. Implementation of the improved functional version of the prototype

Another applicable solution is to modify the cost weighting matrix for the prototype modules (Table 7).

Table 7

Redesigned functional prototype

No	Module	Allocation of components and labour per function as a % of the total cost									
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
1	*[M1]*	*0*	*20*	*25*	*10*	*10*	*10*	*5*	*10*	*0*	*10*
2	*[M2]*	*30*	*0*	*25*	*10*	*0*	*10*	*5*	*10*	*0*	*10*
3	*[M3]*	*10*	*10*	*15*	*5*	*15*	*15*	*5*	*10*	*10*	*10*
4	*[M4]*	*15*	*15*	*20*	*15*	*0*	*15*	*10*	*10*	*0*	*0*
5	*[M5]*	*0*	*0*	*20*	*0*	*0*	*50*	*20*	*0*	*0*	*0*
6	*[M6]*	*10*	*10*	*0*	*20*	*30*	*0*	*30*	*0*	*0*	*0*
7	*[M7]*	*10*	*10*	*0*	*10*	*5*	*0*	*0*	*20*	*25*	*20*
8	*[M8]*	*0*	*0*	*0*	*20*	*20*	*0*	*20*	*20*	*20*	*0*

The differences between the cost distributions on modules and on-device functions (the redesigned and the designed) are summarized in Table 8. The negative values represent a decrease in the weights in costs allocated for the realization of oversized functions (F7, F5, F2) by optimizing the realization process of the device. The differences are redistributed to the undersized functions (F2, F4, F8, F9, F10) (positive values). Null values mean that the parameters of the device creation process have not changed.

Table 8
Different cost weights between the redesigned and designed products

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
[M1]	*0*	*-10*	*15*	*0*	*0*	*0*	*-5*	*0*	*0*	*0*
[M2]	*0*	*0*	*15*	*0*	*-10*	*0*	*-5*	*0*	*0*	*0*
[M3]	*0*	*0*	*15*	*-5*	*5*	*0*	*-10*	*0*	*0*	*0*
[M4]	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
[M5]	*0*	*0*	*20*	*0*	*0*	*0*	*-30*	*0*	*0*	*0*
[M6]	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
[M7]	*0*	*0*	*0*	*0*	*-15*	*0*	*0*	*0*	*5*	*10*
[M8]	*0*	*0*	*0*	*20*	*20*	*0*	*20*	*20*	*20*	*0*

The results of the ECG-PPG device redesign phase are organized in Table 9.

Table 9
Economic sizing of the functions for the redesigned ECG-PPG device

No	Comp	Mat. cost	Lab. cost	Total cost	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
1	*[M1]*	*15*	*0*	*15*	*0.00*	*3.00*	*3.75*	*1.50*	*1.50*	*1.50*	*0.75*	*1.50*	*0.00*	*1.50*
2	*[M2]*	*11*	*0*	*11*	*3.30*	*0.00*	*2.75*	*1.10*	*0.00*	*1.10*	*0.55*	*1.10*	*0.00*	*1.10*
3	*[M3]*	*15*	*0*	*15*	*1.50*	*1.50*	*2.25*	*0.75*	*2.25*	*2.25*	*0.75*	*1.50*	*1.50*	*1.50*
4	*[M4]*	*1*	*0*	*1*	*0.15*	*0.15*	*0.20*	*0.15*	*0.00*	*0.15*	*0.10*	*0.10*	*0.00*	*0.00*
5	*[M5]*	*5*	*2*	*7*	*0.00*	*0.00*	*1.40*	*0.00*	*0.00*	*3.50*	*1.40*	*0.00*	*0.00*	*0.00*
6	*[M6]*	*5*	*6*	*11*	*1.10*	*1.10*	*0.00*	*2.20*	*3.30*	*0.00*	*3.30*	*0.00*	*0.00*	*0.00*
7	*[M7]*	*0*	*10*	*10*	*1.00*	*1.00*	*0.00*	*1.00*	*0.50*	*0.00*	*0.00*	*2.00*	*2.50*	*2.00*
8	*[M8]*	*10*	*0*	*10*	*0.00*	*0.00*	*0.00*	*2.00*	*2.00*	*0.00*	*2.00*	*2.00*	*2.00*	*0.00*
Total Cost		*62*	*18*	*80*	*7.05*	*6.75*	*10.35*	*8.70*	*9.55*	*8.50*	*8.85*	*8.20*	*6.00*	*6.10*
Cost weight c_w [%]		*77.5*	*22.50*	*100*	*8.8*	*8.44*	*12.9*	*10.8*	*11.9*	*10.6*	*11.0*	*10.2*	*7.5*	*7.63*

The graph of the functional analysis of the redesigned device (Fig. 7) is based on the data from Table 10.

Table 10
Data for the redesigned device

No	Funct	u_w	c_w	(u_w)^2	u_w*c_w	a*u_w	c_w-a*u_w	(c_w-a*u_w)^2
1	*F1*	*0.10*	*0.08*	*0.01*	*0.0088*	*0.0995*	*-0.0113*	*0.0001*
2	*F2*	*0.08*	*0.08*	*0.00*	*0.0076*	*0.0891*	*-0.0047*	*0.0000*
3	*F3*	*0.10*	*0.12*	*0.01*	*0.0140*	*0.1073*	*0.0221*	*0.0005*
4	*F4*	*0.09*	*0.10*	*0.00*	*0.0102*	*0.0930*	*0.0158*	*0.0002*
5	*F5*	*0.08*	*0.11*	*0.00*	*0.0105*	*0.0868*	*0.0326*	*0.0011*
6	*F6*	*0.11*	*0.10*	*0.01*	*0.0122*	*0.1141*	*-0.0078*	*0.0001*
7	*F7*	*0.09*	*0.11*	*0.01*	*0.0109*	*0.0981*	*0.0125*	*0.0002*
8	*F8*	*0.09*	*0.10*	*0.01*	*0.0095*	*0.0920*	*0.0105*	*0.0001*
9	*F9*	*0.10*	*0.07*	*0.01*	*0.0077*	*0.1020*	*-0.0270*	*0.0007*
10	*F10*	*0.11*	*0.07*	*0.01*	*0.0084*	*0.1097*	*-0.0335*	*0.0011*
TOTAL		*1.00*	*1.00*	*0.10*	*0.0999*	*0.9914*	*0.0092*	*0.0041*

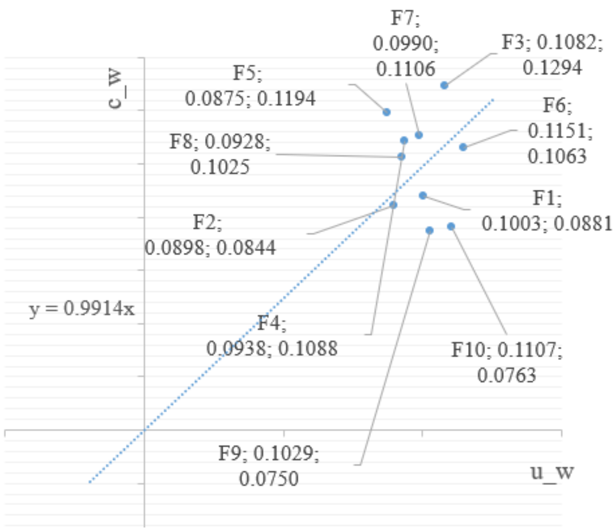


Fig. 7 – Systemic analysis of the redesigned device functions.

According to the relation S = 0.004 < 0.01, it can be concluded that the redesigned prototype has optimized characteristics for the analyzed functions in terms of user satisfaction, thus adding value to the initial device.

3. Conclusions

The paper is structured into three sections: the development of the cardiac activity measurement prototype (ECG-PPG), the application of a value increment technique to the prototype using the “customer-centred” method, and the redesign of the optimized functional prototype after implementing technical and economical solutions.

The elements of novelty are present in all three stages of developing the prototype for measuring cardiac activity and pulse:

- In the stage of designing the computerized prototype - the use of existing devices on the market, inexpensive (Arduino UNO) - development board, sensors, electronic components, connecting the device to the computing system, and data acquisition using LabVIEW software.
- It is enhancing the product's value using a method based on functional analysis "human-centred", finding technical solutions for redesigning the device in line with its market typology and orientation - introducing electronic elements for signal amplification and filtering, physical realization of the device, and testing it.
- The time required for redesigning the product with an improved utility-cost ratio was relatively short, as the application of signal filtering and amplification led to an optimized utility-cost ratio (regarding the weights assigned to these parameters).

The research limitation lies in the need for more iterative repetition of the value analysis and engineering method to further enhance the ECG-PPG device's performance and reduce its costs.

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DISPOZITIV COMPUTERIZAT PENTRU MONITORIZAREA SEMNALELOR EKG ȘI PPG – CONCEPERE ȘI RECONCEPERE BAZATE PE METODA INGINERIEI VALORII

(Rezumat)

În sistemul actual *medical* – incidența bolilor cardiovasculare în statistica mortalității, *social* – viață socială dinamică și *tehnologic* – explozie în evoluție, sistemele computerizate de urmărire a parametrilor de sănătate personală, independent de sistemul medical, au o foarte mare căutare. Cercetarea curentă urmarește conceperea unui prototip de sistem computerizat de urmărire a activității cardiace (EKG și PPG) și îmbunătățirea acestuia prin optimizarea funcțională folosind o metodă de inovare incrementală bazată pe analiza și ingineria valorii aplicată pe produs. Lucrarea prezintă etapele de concepere fizică a prototipului, proiectarea dispozitivului pe principalele sale funcții, optimizarea funcțională a acestuia prin echilibrarea raportului ponderii cost-utilitate pentru fiecare funcție în parte, alegerea soluțiilor de reproiectare a prototipului și aplicarea acestora pe produsul final. Noutătile acestei cercetări se regasesc în realizarea fizică a unui prototip de montorizare a activității cardiace și aplicarea unei metodologii de inovare incrementală și reproiectarea dispozitivului.