TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special II, April, 2024

NEEDS ANALYSIS FOR DESIGN AND DEVELOPMENT OF AN EDUCATIONAL HUMANOID ROBOT

Ileana DUGĂEȘESCU, Angela Miruna NEACȘU, Vlad Cristian ENACHE, Alexandru Ionuț NICOLESCU, Mihaela-Elena ULMEANU, Cristian-Vasile DOICIN

Abstract: *This study introduces the initial phase of Ulrich and Eppinger's' product design approach, specifically the requirements analysis, employed to architect a cost-effective, education-oriented humanoid robot. Existing robots in education are costly and inaccessible. Addressing the necessity for all educational institutions to possess such a robot, this research proposes the development of an experimental model attainable at an affordable price. However, such a process requires the identification of the particular needs of clients. It necessitates the discernment of specific client needs through a concise questionnaire. The responses are subsequently analyzed to convert needs into functional specifications. The next stage is the creation of a functional hierarchy, paving the way for future investigations on the optimal concept and the development of the proposed experimental model.*

Key words: *needs analysis, design engineering, educational, product design and development, humanoid robot*

1. INTRODUCTION

Recent scholarly investigations into anthropomorphic robotic systems in the preceding years have elucidated an array of prospective commercial utilizations for these automatons [1,2]. Humanoid robots represent a technical system that was built to resemble a human's behavior and its appearance [3].

Across the specialized scientific literature, there is an abundance of exemplifications where the successful execution of tasks by humanoid robotic systems is contingent upon the utilization of sensing proficiencies that are superior to those inherent in humans [4]. Another use of humanoid robots is for assisting people whether we are talking about human living situations or in case of disasters [5].

In order for the following conditions to be fulfilled the robot's design must follow three simple principles: 1. Robots need to have human body proportions in order to function in conditions matched for human anthropometric limitations; 2. Robots need energy sources like batteries with a long life; 3. Biped or quadruped robots need to continue working in harsh environmental conditions.

Another important aspect of humanoid robots is the way they process a path and how they avoid obstacles that appear on that specific path. Robots need to plan the path in smaller segments between the start and the end point of their task. They need to configure the space and to determine the optimal criteria for following the path. During this path planning the distance is also taken into consideration, so that the robot does not take a longer distance than it needs. Because of their precision and efficiency in work, humanoid robots are considered an optimal replacement for human work force. They are capable of achieving a task with talking minimal and discrete footsteps [6].

Humanoid robots also need to have a way of processing human instructions and applying them into the real world. They need to develop an ability to communicate with humans and to adapt to the constant changes of the environment and complete tasks. Such concept is referred to in the Xperience project [7] and is called *structural bootstrapping*. This concept refers to the semantic and syntactic similarities of certain tasks, and how these tasks can be completed with the replacement of certain entities inside these tasks. For example, if a robot is asked to bring a coffee from the kitchen, the robot can suggest to replace it with another beverage. Thus, the structural bootstrapping allows the robot to observe and learn from certain situations [8].

2. STATE OF THE ART

Humanlike robots nowadays have reached some impressive capabilities, but they still need development to attain the science fiction or books standards yet. One big challenge is for these robots to mimic identically the human behavior and movements [9]. One of the first approaches for humanlike robots was for them to be controlled for highly complex functions by a human in an avatar form. An example of such form is what NASA developed in 1990, Robonaut I, a robot that can mimic the upper body movements of a human. In recent years, the control for humanlike robots shifted from human control to fully autonomous operation [10].

Progress in the development of humanlike robots is advancing, but researchers still face a lot of challenges that limit the widespread use of these machines. These include limited battery life, limited control and a very high cost.

One of the most recent humanlike robots are NAO robot and Pepper Robot [11]. These are two types of robots that can perform certain tasks fully autonomous. The Pepper Robot can recognize human faces and understand some of their emotions through its sensors and built-in models. These robots can be used for educational and business purposes [11].

DB (Dynamic Brain) is a robot with eyes on its' face. One problem these types of robots face is touching and manipulating a visual target. The team behind Dynamic Brain robot used learning algorithms to study the model of the *Forward Kinematics*. This means that the robot, in order to touch a visual target, it needs to choose the appropriate set of joint angles that it will let it reach the target. To touch a visual target, the robot must choose the appropriate joints that will make its fingers to be at the target, also known in robotics as *Inverse Kinematics* problem. This type of robot was made to learn through algorithms what would be the optimal movement path and what joints it should use when it comes to complex actions [15].

Nao Robot was used in a study in 10 schools, with 29 teachers across early childhood to Year 10. These robots were used to study how they would fit in the curriculum and how they would help in student engagement in classes. Each school had access to the robot for a period of eight weeks to nine months, and the teachers received two days of training beforehand. The team collected the data through a questionnaire that was aiming to find out how the robot performed in the daily tasks in the classroom, what benefits did they provide and how the teachers interacted with them. The result of this study indicates that the robots had a positive impact on students' learning process [14].

CommU Robot was used in a study case involving people with autism spectrum disorder and anxiety disorder to help them communicate better. Previous studies showed that people with these disorders are more likely to prefer to interact with a robot. The results showed that for a patient that can't talk in front of other people, interacting with a robot avatar can be really helpful. Also, the interaction with a humanoid robot helped the patient to observe and understand several aspects of conversation [13].

To accomplish the objective of this article, namely, the analysis of the requirements for the development of the humanoid robot, the theoretical concepts developed by Ulrich and Eppinger was used [12].

3. CLIENTS NEEDS FOR THE PRODUCT

To discern customer needs, a questionnaire was designed comprised of 20 concise and open-ended questions. This questionnaire has been implemented using Google Forms, leveraging its advanced features to capture relevant information from respondents. The responses obtained were categorized into two distinct types: quantitative and qualitative. In the following analysis, the quantitative responses were examined, while the qualitative ones were integrated within the framework of obtained needs. Based on this questionnaire, the statements of 82 respondents were translated and the obtained information was processed. The questionnaire was addressed to the following distinct categories of individuals: Teaching Staff, Researchers, Executive Administrative Personnel, Administrative Leadership Personnel, Business Partners, and Students. Through the survey respondents have the opportunity to share their perspectives on the extent to which the current existing robots satisfy their needs and offer insights into the enhancements necessary for their optimal utilization in the educational environment.

Figure 1 shows that students represent a significant majority, constituting 74,4% of the respondents, while the remaining categories account for minor proportions, each with percentages below 12%. Taking into consideration this aspect, it can be concluded that students are the primary target audience for the product.

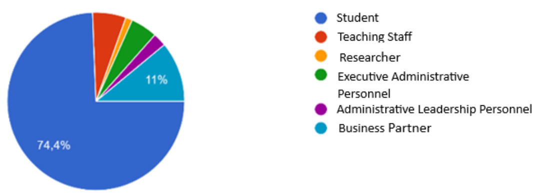

Fig.1. Responses to question 1

Figure 2 depicts that the majority, namely 69.5% of the individuals who received the questionnaire have not yet utilized an educational robot, as compared to the 30.5% who did not used.

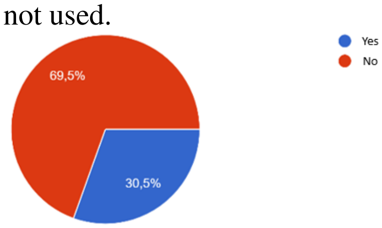

Figure 2.Responses to question 2

Fig.3. Responses to question 4

Taking into consideration the responses to questions 4 and 5, as depicted in Figures 3 and 4, it is evident that the majority perceives exploratory learning, based on student interest and curiosity, as being important. Furthermore, a high level of person-robot interaction is deemed necessary, employing personalized learning, continuous feedback, and encouragement.

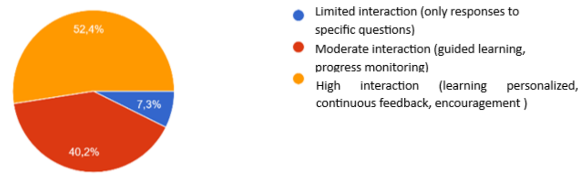

Fig.4. Responses to question 5

A significant proportion of respondents, accounting for 41.5%, attribute the primary role of robots in the educational environment as interactive learning tools. At the same time, 31.7% of respondents highlight the importance of robots using as sources of information (Figure 5).

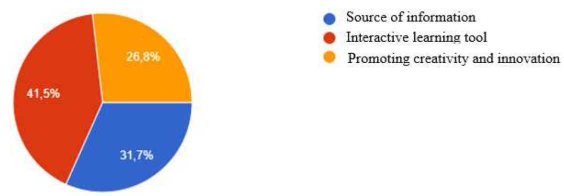

Fig.5. Responses to question 6

The most significant advantage of utilizing such a robot compared to other educational methods is noticed by 44 people as innovation and interactive approach, while 41 persons consider it to be availability and accessibility. Personalization and adaptability were chosen by 38 respondents, as depicted in Figure 6.

Fig.6. Responses to question 7

For each physical characteristic of the robot, potential users have assigned a certain level of importance based on the following criteria: size and shape, facial mimics and expressiveness, and manipulation capability. Figure 7 shows that respondents consider important the form and size of the robot, as well as its capacity to manipulate objects. At the same time, their opinion towards facial mimics and expressiveness is neutral, considering it primarily as an element of novelty.

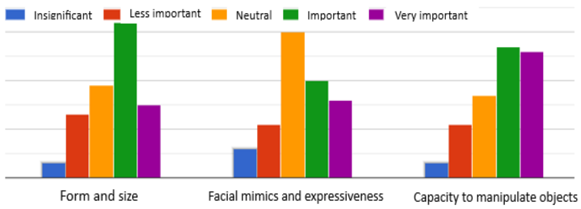

Fig.7. Responses to question 9

At the same time, when discussing about the ideal dimensions and weight of the robot, opinions are divided regarding dimensions, as shown in Figure 8. A majority of 56.1% consider the ideal weight for the robot to be between 1.5 - 3 kg, as indicated in Figure 9. Opinions regarding dimensions vary across multiple ranges: 50-80 cm, 80-100 cm, and more than 100 cm. The responses indicate a preference for a robot with medium dimensions, as evidenced by the respondents' opinions regarding ideal weight and size.

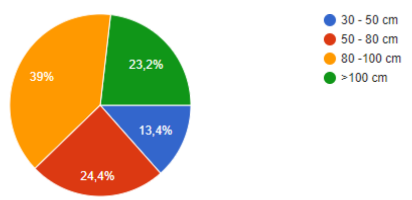

Fig.8. Responses to question 10

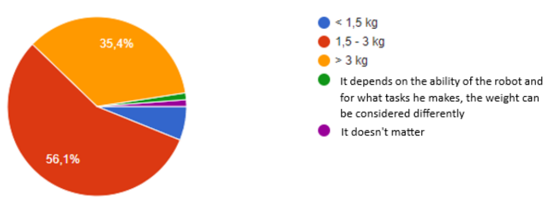

Fig. 9. Responses to question 11

Taking into account the opinions of potential clients, it can be observed in Figure 10 that a significant majority of 74.4% do not consider there to be any risk of injury during robot usage.

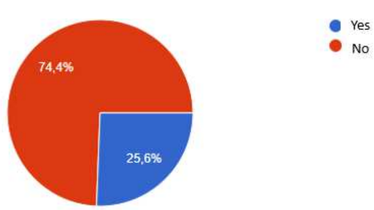

Fig.10. Responses to question 12

Furthermore, 87.8% of them regard the robot as a durable product, as depicted in Figure 11. Regarding the feedback that the robot should provide, respondents hold divided opinions as follows: 36.6% consider immediate feedback necessary (after each response or action), 34.1% prefer on-demand feedback (when requested by the student), while the remaining 29.3% express a preference for periodic feedback at the conclusion of a lesson or session (Figure 12).

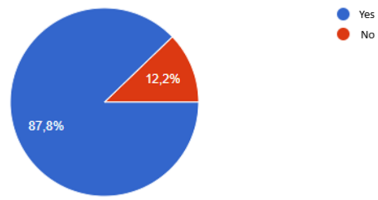

Fig.11. Responses to question 13

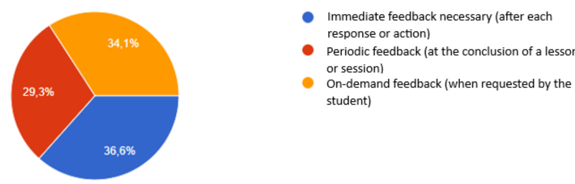

Fig.12. Responses to question 14

The robot is expected to have multiple applications, so it was necessary to inquire about additional domains where it could be used.

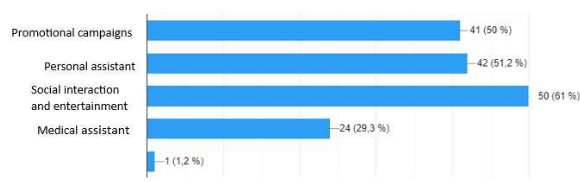

Fig13. Responses to question 15

The obtained results for question 15 are as follows: 50 individuals would utilize the robot for social interaction and entertainment, 42 as a personal assistant, 41 in promotional campaigns, and 24 as a medical assistant.

Due to the desired level of adaptability for the robot, the opinions of the respondents are necessary. The obtained results are as follows: 50 individuals find individual-level adaptation useful (based on the needs and performance of each student), 37 prefer group-level adaptation (based on the overall class performance), and 12 respondents indicate no need for any form of adaptation as the robot should function with predefined settings (Figure 14).

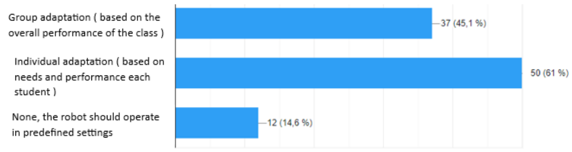

Fig.14. Responses to question 16

Similarly, when asked about the preferred administration of the robot, the responses were as follows: 48 individuals find the involvement of an IT specialist from the institution useful, 35 individuals consider necessary the involvement of a teacher, and 42 individuals tend towards administration by students under supervision.

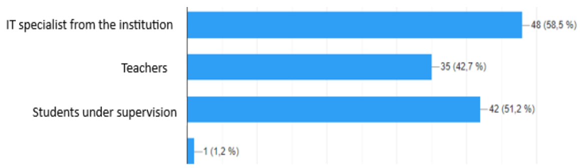

Fig.15. Responses to question 17

Considering the continuous development of technology, respondents were asked about the necessary updates and improvements of the robot.

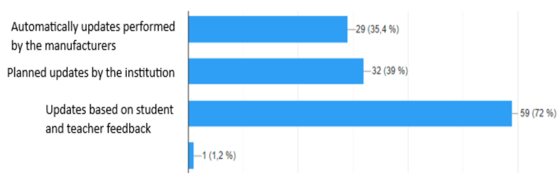

Fig.16. Responses to question 18

According to Figure 16, responses regarding updates were as follows: 59 persons find updates based on student and teacher feedback to be useful, 32 persons prefer planned updates by the institution, and 29 persons believe that updates should be automatically performed by the manufacturers.

Figure 17 shows that a majority of 91.5% find the integration of a humanoid robot useful for enhancing the learning process in the educational environment.

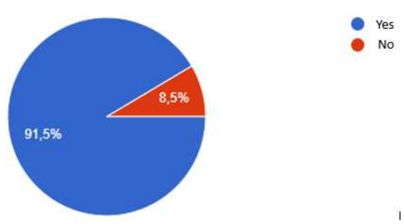

Fig.17. Responses to question 19

At the same time, in Figure 18, the majority of 91.5% would interact with such a robot on a long-term basis. After analyzing the data, the primary and secondary needs have been hierarchically ranked. To reduce the initial number of interpreted needs, they are grouped based on their level of similarity (identical meaning, similar meaning).

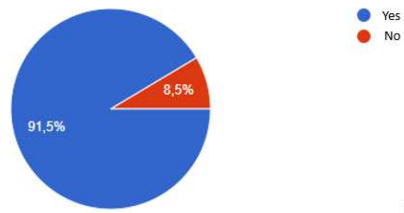

Fig.18. Responses to question 20

The higher-level hierarchy leads to the identification of a specific number of needs, with those of identical meaning being considered primary. These needs are presented in Table 1.

Table 1

Hierarchy of identified needs

The interpreted need
The robot can be used
The robot cannot be used
The person carried out educational activities with the robot
The person carried out transport activities with the robot
The person carried out administrative activities with the robot
The person carried out sports activities with the robot
The person carried out promotional activities with the robot
The person did not carry out activities with the robot
The robot uses exploratory learning
The robot uses guided learning
The robot uses project learning
The robot has a high interaction
The robot has moderate interaction
The robot has limited interaction
The robot is an interactive learning tool
The robot's role is to provide information
The robot's role is to promote creativity and innovation
Robot has innovative and interactive approaches
The robot has as an advantage availability and accessibility
The robot has as an advantage personalization and adaptability
The robot must transmit information
The robot can be an assistant
The robot can be the interactive interface
The size and shape of the robot are important
The facial mimics and expressiveness of the robot are neutral
The ability to handle objects is important
The robot has an ideal size of 80-100 cm
The robot has an ideal size of 50-80 cm
The robot has an ideal size of 30-50 cm

The robot has an ideal size more than 100 cm
The robot weighs ideally between 1.5 - 3 kg
The robot has an ideal weight of less than 1.5 kg
The robot has an ideal weight of more than 3 kg
The robot is safe when it is used
The robot does not provide safety when it is used
The robot is made of durable materials
The robot is made of less resistant materials
The robot provides feedback immediately
The robot provides regular feedback
The robot provides feedback on demand
The robot could be used in social interaction and entertainment
The robot could be used for promotional activities
The robot could be used as a personal assistant
The robot could be used as a medical assistant
The robot adapts individually
The robot adapts to the group level
The robot should operate in predefined settings
The robot should be administered by an IT specialist
The robot should be administered by teachers
The robot should be administered by supervised students
The robot requires updates based on student & teacher feedback
The robot needs planned updates from the institution
The robot requires automatic updates from the manufacturer
Robot improves the learning process in the educational environment
The robot does not bring changes in the learning process in the educational environment
The robot can interact in the long term
The robot can interact in the short term

Table 2

The relative importance of the needs

No. crt.	Customers' need	Relative importance
1	*The robot can be used*	5
2	*The person carried out educational activities with the robot*	5
3	*The robot uses exploratory learning*	3
4	*The robot has a high interaction*	4
5	*The robot has the role of being an interactive learning tool*	3
6	*Robot has as an advantage innovation and interactive approaches*	2
7	*The robot must transmit information*	5
8	*The size and shape of the robot are important*	5
9	*The robot has an ideal size of 80-100 cm*	4
10	*The robot weighs ideally between 1.5 - 3 kg*	4
11	*The robot is safe when it is used*	5
12	*The robot is made of durable materials*	5
13	*The robot provides feedback immediately*	3
14	*The robot should be able to be used in social interaction and entertainment*	2
15	*The robot adapts individually*	3
16	*The robot should be administered by an IT specialist*	2
17	*The robot requires updates based on student and teacher feedback*	4
18	*Robot improves the learning process in the educational environment*	4
19	*The robot can interact in the long term*	5

The primary needs are written in italic font, while the others are secondary needs. To establish objective specifications, a hierarchy based on their relative importance must be determined. In determining the relative importance of the needs, a rating scale from 1 to 5 was utilized, with the following interpretation: •Rating 1: Undesirable property. Products with this property will not be considered; •Rating 2: The property is not important, but its presence does not cause any inconvenience; •Rating 3: It would be good to have, but it is not necessary; •Rating 4: The property is necessary; •Rating 5: The property is crucial. Products lacking this property will not be considered. The relative importance of the needs is presented in Table 2.

4. COMPETITORS

In order for this paper to reach a final conclusion on the design and functionality of these robots, a market study was made. Two of the humanlike robot competitors are presented below. Based on this research some concept designs were created [11]. A study on what sensors might work best for the purpose of the robot was also undertaken. **Specifications for the NAO robot** [11]**:** Dimensions: 574x 311x 275 mm (22.6 x 10.8 x 12.2 inches); Weight: 5.48 Kg (12,08 lb); Autonomy: 60 minutes in active use et 90 minutes in normal use; Degrees of freedom: 25; Processor: Intel Atom E3845; Built-in OS: Linux (Gentoo); Compatible OS: Windows, Mac OS, Linux; Programming languages: Embedded: C++, Python, Remote: Java; Vision: 2 OV5640 2592x1944 cameras; Connectivity: Eth., Wi-Fi; Price: 10,800 €. **Specifications for the Pepper Robot** [11]**:** Dimensions: 120cm X 42.5cm X 48.5cm; Weight: 28 kg; Speed: 3 km/h; Actuators: 20 DC motors; Power: 30-Ah lithium-ion battery, 12 hours of operation; Computing: Intel Atom E3845 computer;

Speakers: Two speakers; Connection: Bluetooth, Ethernet, Wi-Fi; Software: NAOqi operating system, Choregraphe software development kit (SDK) and Pepper SDK for Android Studio, Support for Python, C++, Java, and JavaScript; Degrees of freedom (DOF): 19.

5. SPECIFICATIONS SETUP

Based on the hierarchical table of needs that was created above, a relative importance of the characteristics of the robot was made.

Table 3

Relative importance of characteristics

No. of the charac-terstic	No. of need	Characteristic	Relative importance	Units
1	1,8,9	Dimensions	5	mm
2	6,14	Color	2	-
3	1,8,10	Weight	5	kg
4	11,12	Material	5	-
5	13	Autonomous	3	hr
6	15	Area of effect	3	m
7	4,19	Battery Life	5	Ah
8	12,16	Price	4	€
9	16,17	System Updates	3	-
10	2,3,5	Ease of use	4	-
11	11	Eco-friendly	5	-
12	7,18	Compatibility	5	-
13	7,13	Speakers	4	db
14	11	Speed	5	m/s

After the relative importance of the characteristics was identified, the ideal values and limit values for these needs were established. In order for this to be done, an ideal characteristic value and a limit characteristic value are to be chosen (Table 4).

Table 4

Limit and optimal characteristics value

No. of need	Characteristic	Units	Limit	Optimal
1,8,9	Dimensions	mm	500-1000	800-1000
6,14	Color	-	Grey	White
1,8,10	Weight	kg	3	1.5
11,12	Material	-	HIPS	HIPS
13	Autonomous	hr	12	24
15	Area of effect	m	6	10
4,19	Battery Life	Ah	200	200
12,16	Price	RON	3000	2500
16,17	System Updates	-	Yes	Yes
2,3,5	Ease of use	-	Yes	Yes
11	Eco-friendly	-	Yes	Yes
7,18	Compatibility	-	Yes	Yes
7,13	Speakers	dB	80	80
11	Speed	m/s	1	1

6. CONCLUSION

Based on analyzed questionnaire data, and also the recent studies from the specialty literature, we concluded that an important aspect for the robot is to mimic the human behavior and their reactions. Therefore, through the use of its sensors, the robot must be capable of offering feedback according to the user's input.

Another aspect would be the dimensions and the weight of the robot. Based on the majority of the answers, the robot must have a weight of 1.5 kg up to 3 kg, and the dimensions must be between 80 cm-100 cm. Also, the robot will be developed for an educational environment to be useful in providing information for students.

Future research includes the development of possible concepts for the robot and a functional prototype. A final product will be designed and tested in a real-life scenario from a tertiary educational environment.

Based on the analysis conducted and in accordance with the market study, it is anticipated to develop a humanoid robot with innovative features, intended for use in the educational area.

7. REFERENCES

[1] B. Burton, The smithsonian's new tour guide isn't human, 2018

[2] J. Brown, Navigating the crowd with SPENCER, 2016

[3] J. Englsberger, A. Werner, C. Ott, B. Henze, M.A. Roa, G. Garofalo, R.Burger, A. Beyer, O. Eiberger, K. Schmid, A. Albu-Schaffer, Overview of the torque-controlled humanoid robot TORO, in: 2014 IEEE-RAS International

Conference on Humanoid Robots, IEEE, 2014

[4] K. Kojima, T. et all. Development of life-sized high-power humanoid robot JAXON for real-world use, in: 2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids), 2015, pp. 838–843

[5] K. Kaneko, K. Harada, F. Kanehiro, G. Miyamori, and K. Akachi, "Humanoid robot HRP-3," in Proc. IEEE/RSJ Int. Conference on Intelligent Robots and Systems, 2008, pp. 2471–2478.

[6] Altan, A. (2020). Performance of Metaheuristic Optimization Algorithms based on Swarm Intelligence in Attitude and Altitude Control of Unmanned Aerial Vehicle for Path following. In 4th International Symposium on Multidisciplinary Studies and Innovative Technologies.
[7] Xperience project, website, available online at http://www.xperience.org
[8] M. Do, J. Schill, J. Ernesti, T. Asfour, Learn to wipe: A case study of structural bootstrapping from sensorimotor experience, in: Proc. of ICRA, 2014.
[9] Kerman J. B. Retrofitting Blade Runner: Issues in Ridley Scott's Blade Runner and Philip K. Dick's Do Androids Dream of Electric Sheep?, Bowling Green, OH: Bowling Green State University Popular Press, ISBN 0-87972-509-5 (1991).
[10] Yoseph Bar Cohen, Humanlike robots - state of the art and challenges, SPIE Smart Structures and NDE Symposia, Denver, CO, March 3 – 7, 2019 (Keynote Paper 10968-1)
[11] https://www.aldebaran.com/en/pepper
[12] Ulrich K., Eppinger S., (2012), Product Design and Development, 5th Edition McGraw Hill Publishing Company Ltd..
[13] Yoshida A., Kumazaki H., Muramatsu T., Yoshikawa Y., Ishiguro H., Mimura M., Intervention with a humanoid robot avatar for individuals with social anxiety disorders comorbid with autism spectrum disorders, Asian Journal of Psychiatry 78 (2022) 103315.
[14] Chalmers C., Keane T., Boden M., Williams M., Humanoid robots go to school, Education and Information Technologies (2022) 27:7563–7581.
[15] Atkeson C. G. and all, Kotosaka S. and all, Kawato M. and all, Using Humanoid Robots to Study Human Behavior, IEEE intelligent systems 1094-7167.

Analiza nevoilor pentru proiectarea și dezvoltarea unui robot umanoid educațional

În acest articol se prezintă faza inițială a abordării Ulrich and Eppingers' de proiectare a produselor, în special analiza cerințelor, utilizate pentru a proiecta un robot umanoid rentabil, orientat spre educație. Roboții existenți în educație sunt scumpi și inaccesibili. Având în vedere necesitatea ca toate instituțiile de învățământ să aibă un astfel de robot, această cercetare propune dezvoltarea unui model experimental la un preț accesibil. Cu toate acestea, un astfel de proces necesită identificarea nevoilor specifice ale clienților. Este nevoie de discernerea nevoilor specifice ale clienților printr-un chestionar concis. Ulterior răspunsurile sunt analizate pentru a transforma nevoile în specificații funcționale.

Ileana DUGĂEȘESCU, PhD Eng., Lecturer, NUST POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, Splaiul Independenței 313, București, ileana.dugaesescu@upb.ro
Angela Miruna NEACȘU, Eng., NUST POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, Splaiul Independenței 313, București, angela.miruna13@gmail.com
Vlad-Cristian ENACHE, PhD Student, Assistant, University POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, Splaiul Independenței 313, București 060042, enachevlad31@yahoo.com
Alexandru Ionuț NICOLESCU, PhD Student, NUST POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, nicolescu1alexandru@gmail.com, Splaiul Independenței 313, București, nicolescu1alexandru@gmail.com
Mihaela-Elena ULMEANU, PhD Associate Professor, Eng., NUST POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, Splaiul Independenței 313, București, mihaela.ulmeanu@upb.ro
Cristian-Vasile DOICIN, PhD. Professor, Eng., University POLITEHNICA of Bucharest, Department of Machine Tools and Manufacturing Systems, Splaiul Independenței 313, București, cristian.doicin@upb.ro