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FROM INTUITIVE PROGRAMMING OF ROBOTIC SYSTEMS TO BUSINESS SUSTAINABILITY OF MANUFACTURING SMEs

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Abstract

Economic growth and sustainable development are issues which are becoming more and more important for nowadays companies. Sustainable development strives for moderate and responsible use within the economic and production activity the limited resources of our planet. Eco-innovations, eco-efficiency and corporate social responsibility practices define much of the current industrial sustainability agenda. While important, they are insufficient in themselves to deliver the holistic changes necessary to achieve long-term social and environmental sustainability. This paper proposed a framework for designing multimodal human-robot interfaces and a demonstrator that facilitate a sustainable use of robotic systems with positive effects on SMEs business sustainability. The proposed approach is intended to bring important contributions to the development of human robot interaction in order to facilitate intuitive programming and to enable easily adapting to changes in robot tasks and applications without the need of using skilled personnel. Our research emphasize the idea that new technologies in product and process create and enable new business strategies; and we demonstrate that changing the paradigm in programming industrial robotic systems it is possible by a “business case for sustainability” to have a sustainable development of the business, in special in case of SMEs.

Keywords: intuitive programming of robotic systems, business case for sustainability, sustainable production.

JEL Classification: O14, O33

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Introduction

Sustainable development within robotic based automatic manufacturing systems requires radical and systemic innovations regarding methods of implementation, programming and ramping up the production (Pires, 2006). Such innovations can be more effectively created and studied when building on the concept of business models (Keskin, et al., 2013). This approach provides firms with a holistic framework to envision and implement sustainable innovations. Nowadays, sustainable manufacture and business have become a very important issue amongst companies around the world (Fritz, and Koch, 2014). Achieving sustainable manufacturing based on a sustainable business model has been recognized as a critical need due to diminishing non-renewable resources, stricter regulations related to environment and occupational health and safety, and increasing consumer preference for smart, customized and environmental-friendly products (Coenen and Díaz López, 2010).

Over the last decades the industrial robots and robot based automatic production systems have become more powerful and intelligent (Mocan et al., 2014). Thus, in many cases an investment in industrial robots is seen as a vital step that will strengthen a company's position in the market because it will increase the production rate and the process efficiency and it will reduce the operating costs (Akan et al., 2011). Industrial robots based automation represents the best solution for increase technological processes efficiency, productivity, and flexibility which will reduce the production costs that creates premises for a sustainable manufacturing system (Pires, 2006). However, in small and medium enterprises (SMEs), in special in Romania, industrial robotic systems are not commonly found. Even though the hardware cost of industrial robots has decreased, the implementation within the technological process and programming costs for robots make them unaffordable for SMEs (Kong, et al., 2011). It is, thus, quite difficult to motivate a SME, which is constantly under market pressure, to carry out a risky investment in industrial robots which probably will never achieve the designed efficiency and production (Akan et al., 2011; Mocan, 2012). Typically for those SMEs, that have frequently changing applications, it is quite expensive to afford professional programmers or technicians to adept the robot's task programs, and therefore a human robot interaction solution is demanded (Hsiao et al., 2008). Therefore, today's industrial robots do not offer rich human-robot interaction (multimodal interaction), and they are not simple to program for end-users, the programming procedures are time consuming and finally investment may be not profitable and the business unsustainable.

The idea of this paper was that if the industrial robots become intuitive to use, easily adapted to changes in task without the need to use skilled systems configuration personnel, and by adequate programming facilitate the energy savings the SMEs addressability and process energy efficiency will increase and the business could become sustainable on long term. Thus, this paper propose an approach that enable the development of a multimodal interface that facilitate an intuitive programming of the industrial robots and facilitates the adoption of different strategies to reduce robots energy consumption. Our goal is to give an industrial robot the ability to communicate with its human operators in a more intelligent way, thus making the programming of industrial robots more intuitive and easy. Developing such an interface which is easy to learn and use enables large numbers of users to benefit from that technology. Minimizing the need of expert knowledge is very beneficial for the industry, especially for SMEs, because it allows the technicians to focus on process technology rather than on how to program the robots. We expect that such an

approach will have an impact at all levels of the business and will generate a business case for sustainability to achieve corporate sustainability and sustainable development.

This paper is structured on five sections. Following this introduction, section one describes the background and related works regarding business cases for sustainability and sustainable business cases, and multimodal interfaces for programming the industrial robots and the impact upon the sustainability of the business. Section two highlights issues to be considered in the design process of multimodal interfaces that facilitates intuitive programming a robotic system to generate sustainable business development. Section three emphasises the methodology - design process of the multimodal interface that lead to an intuitive programming of a robotic system considering the implications on business sustainability. In section four are highlighted the results and discussions - evaluate the developed multimodal interface human interaction and the impact of such approach on business sustainability; research limitations and finally, the conclusions are discussed in fifth section.

1. Background and related work on the modalities of programming industrial robots and their impact on business sustainability

1.1 From business case for sustainability to sustainable business model

A business case is mostly described by a situation where economic success is increased while performing in environmental and social issues (Garriga and Melé, 2004; Tracey et al., 2005). A business case for sustainability should meet three criteria, as stated by Schaltegger (2012). Thus, firstly the company has to realize activities with the intention to contribute to the solution of societal or environmental problems. These are intended activities for the society or the natural environment which are not just a reaction to legal enforcement or dominated by legal requirements or which would be expected for economic reasons as part of conventional business behaviour anyhow. Secondly, the activities have to create a positive business effect or a positive economic contribution to corporate success which can be measured or argued for in a convincing way. Such effects can be the increase of sales or competitiveness, cost savings, improved profitability, customer retention or reputation, etc. The cause and effect relationship can be direct or indirect, however, must not be speculative but rather based on a sound business argumentation. Thirdly, a clear and convincing argumentation must exist that a certain management activity has led or will lead to both, the intended societal or environmental effects, and the economic effect. A business case for sustainability is characterised by creating economic success through (and not just along with) a certain environmental or social activity. To create a business case for sustainability requires strategic management to identify, create and strengthen the links between non-monetary social and environmental activities on the one hand and business or economic success on the other hand; and not seldom as a consequence of this approach even the business model of a firm, have to be oriented towards a sustainable approach.

In the context of this article hereinafter we will highlight how the academic literature define business model and a sustainable business model. A business model is a conceptual tool to help understand how a company does business and can be used for analysis, comparison and performance, management, communication, and innovation assessment (Osterwalder

and Pigneur, 2005). Business models are concerned with how the company defines its competitive strategy through the design of the product or service it offers to its market, how it charges for it, what it costs to produce, how it differentiates itself from other firms by the value proposition, and how the firm integrates its own value chain with those of other companies in a value network (Rasmussen, 2007).

The scientific literature presents various perspectives on the business model: Margretta's (2002), Zott and Amit (2010) and Beattie and Smith (2013) describe business models as a holistic description on 'how a firm does business' and Teece (2010) describes that a business model articulates how the company will convert resources and capabilities into economic value. It is nothing less than the organisational and financial 'architecture' of a business and includes implicit assumptions about customers, their needs, and the behaviour of revenues, costs and competitors (Teece, 2010). More specifically, Osterwalder and Pigneur (2005, 2010) describe a business model as a series of elements: the value proposition (product/service offering, customer segments, and customer relationships), activities, resources, partners, distribution channels (i.e. value creation and delivery) and cost structure, and revenue model (i.e. value capture). Richardson (2008) based on a wide range of literature, proposes a consolidated view of the components of a business models as: the value proposition (i.e. the offer and the target customer segment), the value creation and delivery system, and the value capture system. Zott and Amit (2010) take an activity based perspective, including the selection of activities ('what'), the activity system structure ('how'), and who performs the activities ('who').

Sustainable business models can serve as a vehicle to coordinate technological and social innovations with system-level sustainability. Lüdeke-Freund (2010) describes a sustainable business model as "a business model that creates competitive advantage through superior customer value and contributes to a sustainable development of the company and society". Building on Garetti and Taisch's (2012) views on sustainable manufacturing, business models preserve the environment, while continuing to improve the quality of human life. Stubbs and Cocklin (2008) assert that sustainable business models use both system and firm-level perspective, build on the triple bottom line approach to define the firm's purpose and measure performance, include a wide range of stakeholders, and consider the environment and society as stakeholders. Extending this, a sustainable business model aligns interests of all stakeholder groups, and explicitly considers the environment and society as key stakeholders.

Based on these key assumptions this paper promotes the idea that by developing within a company one or more business cases for sustainability create and enable new business strategies which facilitates sustainable development that finally have to be supported by a sustainable business model. One of the key challenges is designing business cases for sustainability in such a way that enables the firm to capture economic value for itself through delivering social and environmental benefits.

1.2 Programming modalities of industrial robots

Sustainable business is a framework where sustainability considerations (environmental, social, and financial) are integrated into company systems from idea generation through to research and development and commercialization. This applies to products, services and technologies, as well as to new business and organizational models (Boons et al., 2013).

Manufacturing sector is very important in modern society. The higher value added within the developed products the greater benefits to society. Improving energy efficiency of a production system can improve the competitiveness of a manufacturing company, since the production cost is decreased and dependency on non-renewable energy sources may also be reduced. Energy consumption is directly related to sustainable business and companies (Diaz and Dornfeld, 2012). Global manufacturing industry progressively adopts strategies to keep under control energy consumption, robots will be more and more judged by their energy efficiency and consumption (Herrmann and Thiede, 2009). The obstacles encountered by robots as they move around, the need to make sharp turns, and improper robots installation and utilization are just three factors that drive up their energy consumption (Verl et al., 2011).

Considering that a sustainable approach involves reducing a company's environmental impact (e.g. reducing energy consumption of the robotic production system), considering social issues (e.g. developing employees' skills and their accessibility on a new technology) and generating profit (e.g. increasing the efficiency of programming and the productivity of the robotic system) through an innovative approach that facilitate the development of multimodal interfaces that facilitate an intuitive programming of industrial robots can settle all three issues which contribute to a sustainable business.

Currently, there are two modalities of programming the industrial robots: online programming and offline programming. The traditional online robot's programming can be done in three ways: (i) jogging an industrial robot with 6 degrees of freedom with a joystick with two degrees of freedom is very time consuming and cumbersome; (ii) the operator doesn't get any visual feedback of the process result before the program has been generated and executed by the robot; (iii) many iterations are needed for even the simplest task (Akan, et al., 2011). Offline programming environments like RobotStudio from ABB Company solve some disadvantages described above in online programming. But also the offline programming software presents several issues that have to be more developed on-line in many industry applications, particularly, when the robot task or the robot trajectory needs frequent change (Mocan et al., 2014; Kellens et al., 2012).

The obstacles encountered by robots as they move around, the need to make sharp turns, and improper robot programming are just three factors that drive up their energy consumption. The industrial robot itself is designed and manufactured to be an energy efficient equipment, but programming it in an improper way could make it unsustainable. Current robots programming interfaces do not emphasize to the user the programming ways for industrial robots energy consumption reduction (Vergnano et al., 2012).

Current researches are on the development of multimodal interfaces that allow users to move effortless between different modes of interaction, from visual to speech and touch, according to changes in context or user preference (Turk, 2014). These interfaces have the advantage of increased usability and accessibility (Brad et al., 2014). In multimodal interfaces, the weaknesses of one modality can be offset by the strengths of another; accessibility determines how easy it is for people to interact with the robot. Thus, multimodal interfaces can increase robot task efficiency, increasing the operators' addressability, and reducing energy consumption as pointed out by reference (Turk, 2014).

A multimodal interaction scheme is very convenient for robot programming operator because combining two or more interaction modalities can even provide improved

robustness of the robot task (Dumas et al., 2009). Some recent researches highlights the possibility of combining the speech and static gestures in order to program a robot for grasping and manipulate an object, or combining augmented reality with the voice recognition and gesture commands (Pires, 2006). Kong (2011) within his researches, pointed out that coupling of speech recognition and dialog management (multimodal approach) can improve the performance of a robotic system.

With the development of more powerful CAD/CAM/PLM software, robotic vision systems, sensor technology, control systems, driving devices, etc., new programming methods, like multimodal interactions, suitable for SMEs are expected to be developed in years to come.

1.3 The impact of the various modalities of programming industrial robots on business sustainability

The scientific research in the field of sustainable business models identified emerging themes in the study of sustainable business models, including: the role of technology advancement and level of innovation, the application of a systems perspective, introducing innovative approaches to collaboration, and the need for education and raising awareness to facilitate successful adoption of sustainable business models. Technology innovation can drive new business model and vice versa and also one or more business cases for sustainability can cause a change of strategy in adopting a sustainable business model. Thus, the literature and practice of business models for sustainability is vast but fragmented, with various conceptual papers and many potential innovative approaches that may contribute to sustainable business model.

Regarding the research domain of intuitive programming of industrial robots: a multimodal interaction scheme may be very convenient for robot programming because combining two or more interaction modalities can provide an improved robustness. According to current researches and developments all multimodal robot programming systems are in a way similar in the sense that they receive inputs from different devices and combine the information to build a common semantic meaning from these inputs. Up to now there is no commercial multimodal robot programming software on the market.

Our article will exploit the opportunity to conduct researches in multimodal programming of industrial robots and implement features and functionalities that facilitate reducing energy consumption of the robotic systems and to increase addressability and access of SMEs to these technologies. All these efforts will be done with the hope of a sustainable development of the business.

2. Sustainable design of the robotic intuitive multimodal programming interfaces

Since sustainable business can be seen as the business that have multiple facets to balance triple bottom lines (i.e., profit, planet, and people), it is natural to introduce environmental, social, and sometimes ethical aspects to a conventional business framework (Gecek and Legovic, 2012). In order to take them into account, it is crucial to broaden business scope to the process or product design. In this respect multimodal interface design will be made considering sustainability driving elements (Jackson, 2010).

Designing multimodal systems for industrial robots is challenging. The classic design approaches and insights from personal computer environments do not necessarily translate well to industrial robots multimodal environments. Designing a multimodal interface for industrial robots, have to focus on robot tasks and operator needs. The set of tasks that an industrial robot can perform are directly affected by the robot pose, namely by the robot configuration at one moment (Mocan, 2014). Specifically, the followings are the challenges of the industrial robot programming: 1) Obstacle avoidance: in case that a robot approaches to an obstacle, the operator needs to modify a teaching position; 2) Joint limit avoidance: for example, when it reaches an axis limit of a wrist or when occur a singularity pose of the robot, the operator has to take out the robot from that position; 3) Task specific robot trajectories: operator has to develop the logic of the task and to integrate adequately target points within the robot trajectory.

In order to reduce the power consumption of the robotic system within the multimodal interface we will consider a series of programming strategies and will implement a series of features that facilitate: robot usage strategy, and end-effector tool-center-point (TCP) trajectory profile planning.

Concerning *robot usage strategy*: an industrial robot integrated within a manufacturing process (e.g. pick-and-place, assembly, arc welding operations) is programmed on the basis of manufacturing effectiveness and/or technological constrain (e.g. strictly sequential assembly operations). In figure 1 is presented a possible operation schedule for an industrial robot integrated in a pick-and-place robotic cell. The possibilities of industrial robot to move along a trajectory are mainly three: point to point (e.g. MoveJ – ABB robots), linear (e.g. MoveL, MoveABSL – ABB robots), and circular (e.g. MoveC – ABB robots).

According to the recent researches (Fysikopoulos, et al., 2012) in the automotive industry the industrial robots idle time and homing time amounts 74% respectively 15÷20% of the total working time (figure no 1). On the other hand a robot task normally consists of a sequence of the robot TCP movements. The time duration during which the sequence of the TCP movements is completed is referred to as cycle time. Minimizing cycle time implies increasing the productivity, improving machine utilization, and thus making automation affordable in applications for which throughput and cost effectiveness is of major concern.

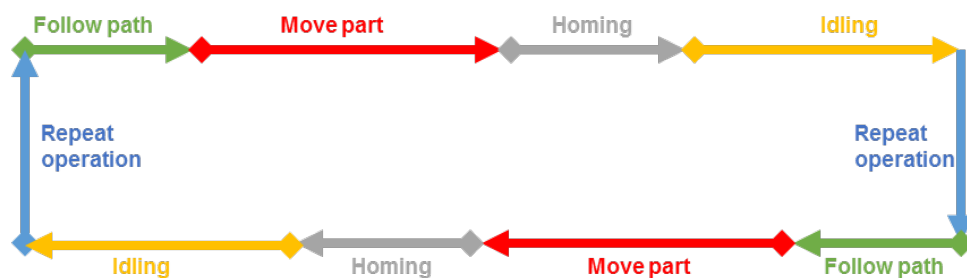
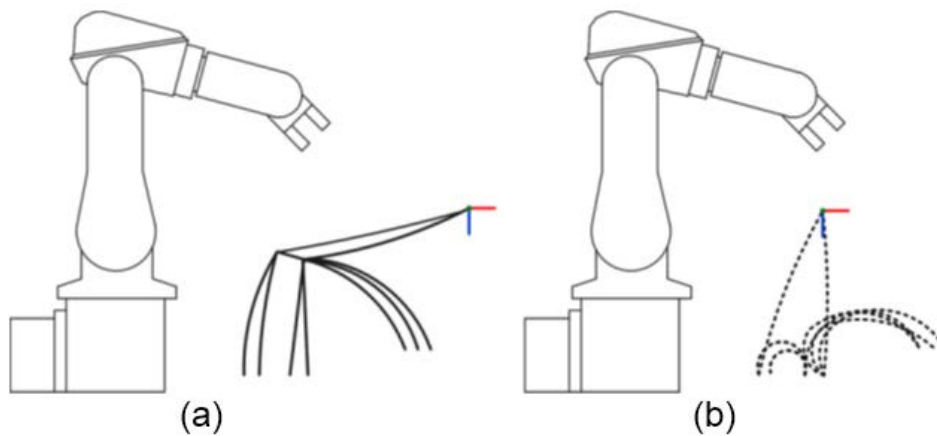


Figure no. 1: Industrial robot operation schedule

Regarding *end-effector tool-center-point (TCP) trajectory profile planning*: it is of general interest that a robot to perform the path motion as fast as possible. Minimizing motion time can significantly shorten cycle time, increase the productivity, improve robot utilization,

and thus make automation affordable in applications for which throughput and cost effectiveness is of major concern.

In industrial application, a robotic manipulator performs a repetitive sequence of movements. A robot task is usually defined by a robot program, that is, a robot path consisting of a set of robot positions (either joint positions or tool center point (TCP) positions) and corresponding set of motion definitions between each two adjacent robot positions. In this context, to reduce the energy consumption of a robotic system it is recommended to use the fly-by facility for programming particular points within a trajectory, and in special when using “joint movement” of the robot (e.g. MoveJ instruction on ABB robots). In those situations, referring to the specific industrial application, where we are not interested in precise TCP trajectory (e.g. homing, idling) it is recommended to use the fly-by facility in defining a robot target point. Target points approximation are visualised by the circular path segments in figure no. 2b, in contrast to sharp-edged path segments, where the manipulator stops, see figure no. 2a.



**Figure no. 2: Industrial Robot TCP trajectory
(a) before and (b) after the optimisation**

Source: Mori et al., 2011

3. Methodology for designing the intuitive multimodal interfaces of programming the industrial robots

Having the challenges regarding classical robot programming by using sustainable design principle and quality planning and innovation driving methods like TRIZ (Theory of Inventive Problem Solving), AHP (Analytical Hierarchy Process), PUGH (Pugh Method), and QFD (Quality Function Deployment) we developed a methodology (figure no. 3) for identifying the right operators requirements, process needs, objective functions, and the best combination of the multimodal interface inputs.

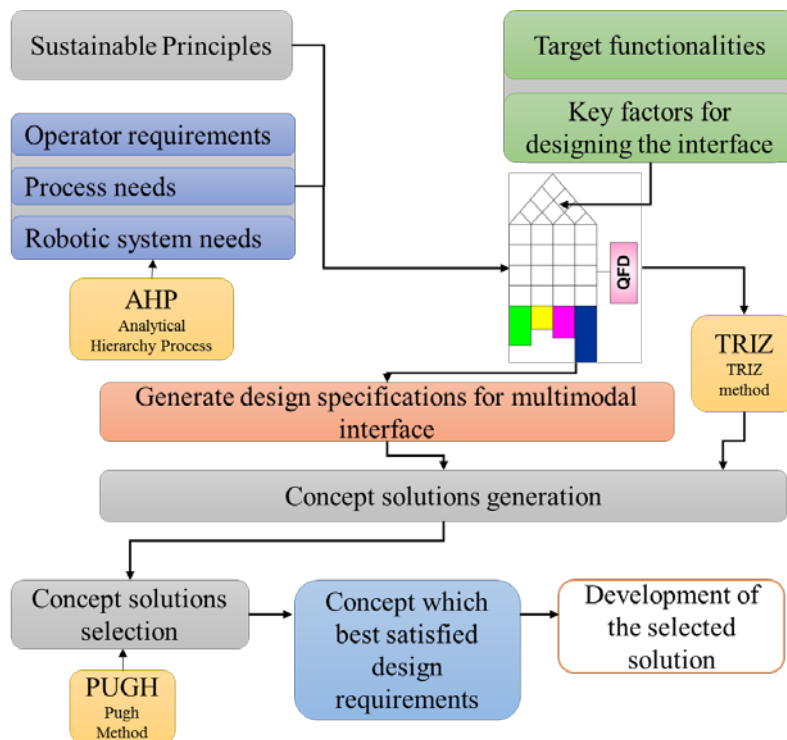


Figure no. 3: Roadmap for concept solution generation

The proposed methodology for concept solution generation (i.e. selecting the inputs of multimodal interface, for generating the design specification and for generation the concept solutions) consists the following steps (figure no 3):

Step 1: Establish the vision and the objectives of the multimodal interface which will be in accordance with the sustainable philosophy principles.

Step 2: Identification of the key principles of the sustainable philosophy.

Step 3: Define operator requirements, process needs and robotic system needs under the form of a set of requirements and rank these need-related requirements. For ranking, tool like AHP method might be used (Rozmahela et al., 2014).

Step 4: Define a set of target functionalities in accordance to the intuitive programming needs and deploy them against the set of need related requirements. Thus, value weights of target functionalities in relation to the multimodal programming needs are determined. Correlations between target functionalities have to be also established. QFD-type relationship and correlation matrices could be used to fulfil this step (Buchert et al., 2015).

Step 5: Formulate vectors of innovation for each negative correlation between target functionalities and for each challenging target. TRIZ method is a powerful tool to fulfil this process. The resulted vectors of innovation represent paths towards which creativity and skills must be directed when concept solutions (min. three solutions) are elaborated.

Step 6: Formulate design specifications for multimodal interface having in mind the needed target functionalities.

Step 7: Generate minimum three concept solutions for the multimodal interaction. Inputs from TRIZ method are expected to be integrated within the generated solutions.

Step 8: Evaluate the solutions that were generated at step 7 and select the solution that best satisfies the planned performance for the multimodal interaction interface (see step 1). Pugh method could be used to fulfil this step.

Step 9: Results from steps 1-7 are used for further development (detailed design and planning at component level). Use-cases, modelling languages (e.g. UML) and other specific tools for software analysis and design could be used to support this step.

Every step of the methodology comprises a tool or a method that lead the user to an optimum result regarding sustainable programming of the robots. The methodology cannot be entirely exemplified in the paper, but the main results of all nine steps are detailed bellow. The identified operator requirements, process needs and robotic system requirements were, as followed: a) automatic presentation of contextually-appropriate information (5.7%); b) easy to use by an operator with basic technical background (22.8%); c) easy to set up (6.6%); d) graphical intuitive interface (21.6%); e) clear indication on the robot's display the logical next step (28.6%); f) contextually-appropriate information for reducing energy consumption (14.6%). The percentage written within the brackets represent the rank for each requirement, identified with the help of AHP method (figure no 4).

ITEMS	Importances	Calculated Importance %	Final Importance %
1 automatic presentation of contextually-appropriate information		12,1%	5,7%
2 easy to use by an operator with basic technical background		19,0%	22,8%
3 easy to set up		10,5%	6,6%
4 graphical intuitive interface		19,3%	21,6%
5 clear indication on the robot's display the logical next step		22,2%	28,6%
6 contextually-appropriate information for reducing energy consumption		16,8%	14,6%
Most important item:		21,7%	
Least important item:		12,1%	

Figure no. 4: Rank for each requirement identified with AHP method (Qualica QFD)

Planning the performance of multimodal interface (step four within proposed methodology): QFD method is applied for deploying requirements into multimodal interface functionalities and features. This step will allow us to see the multimodal interface from a different perspective. We will visualize the key functionalities and features (and their impact in design), the measuring procedures and means, the correlations between these features and the optimization trends for each functionalities.

TRIZ method has been considered to support the innovation process both in defining the target functionalities and key factors in designing the interface and in finding innovative solutions for solving the conflicting situations in planning the interface performance with QFD method.

For intuitive programming, TRIZ (figure no. 3) recommends the following generic vectors of intervention to approach the first challenge (simplification of the programming interface without creating ambiguity or barriers in robot tasks): a₁) translate the problem from one dimension of an interface to several dimensions of an interface and use a multi-level assembly; b₁) make immobile elements movable; c₁) use mediator-interfaces to carry out some actions (see in reference (Brad, 2004) the pair “36-18” of TRIZ engineering parameters). For the second challenge related to the multimodal interaction (ensure the quality of results using different input modalities/devices/equipment), TRIZ recommends the following generic vectors of intervention: a₂) extract un-necessary parts from interfaces; b₂) use software applications able to reveal the “resonance” characteristics of the system; c₂) replace a complex interface with several simpler “copies” (see in reference (Brad, 2004) the pair “29-36” of TRIZ engineering parameters).

Further three concept solutions (mock-ups) for multimodal interface are generated based on results obtained up to step 6 from the proposed methodology. The mock-ups of the multimodal interfaces have to be elaborated to the level of detailed functionalities. For that it was used various sources of inspiration (e.g. books, patents, product catalogues, etc.).

Best solution selection based on a systematic algorithm: Pugh method was applied on the three variants proposed at step 7. Applying Pugh method we was able to see how well we have selected the most appropriate solution from the three possibilities (step 7). Based on this approach the selected inputs for the multimodal interface were: speech and hand gesture recognition, backed up by text programming. Considering design guidelines and results highlighted above the proposed architecture of multimodal interface is composed of four functional modules, as illustrated in figure no. 5.

The first module (multimodal interaction) translates hand/arm gestures and voice command into a structured symbolic data stream. The second module (actions interpretation) selects the appropriate set of primitives based on the user input, current state, and robot sensor data. The third module (prioritized execution) selects and executes primitives based on the current state, sensor inputs, and the task given by the previous step. Finally, the fourth module facilitate the translation of the actions, voice command and gesture into robot instructions native programming language to be integrated within a robot programming task. The multimodal interaction between human operator and robot will be supported by an intuitive graphical interface.

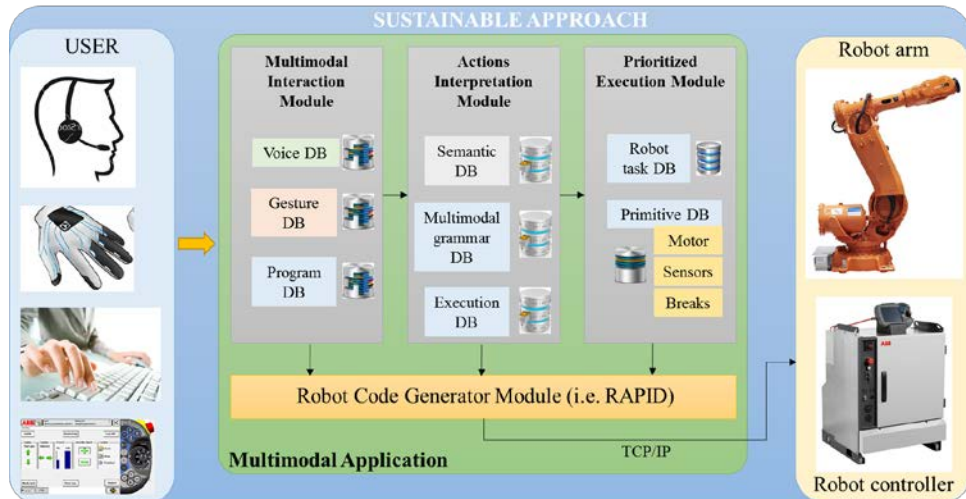


Figure no. 5: Multimodal interface framework

4. Results and discussions

As a first result of this research we have developed a software demonstrator to exemplify the effectiveness of the multimodal interaction for intuitive programming the robotic systems (figure no. 6).

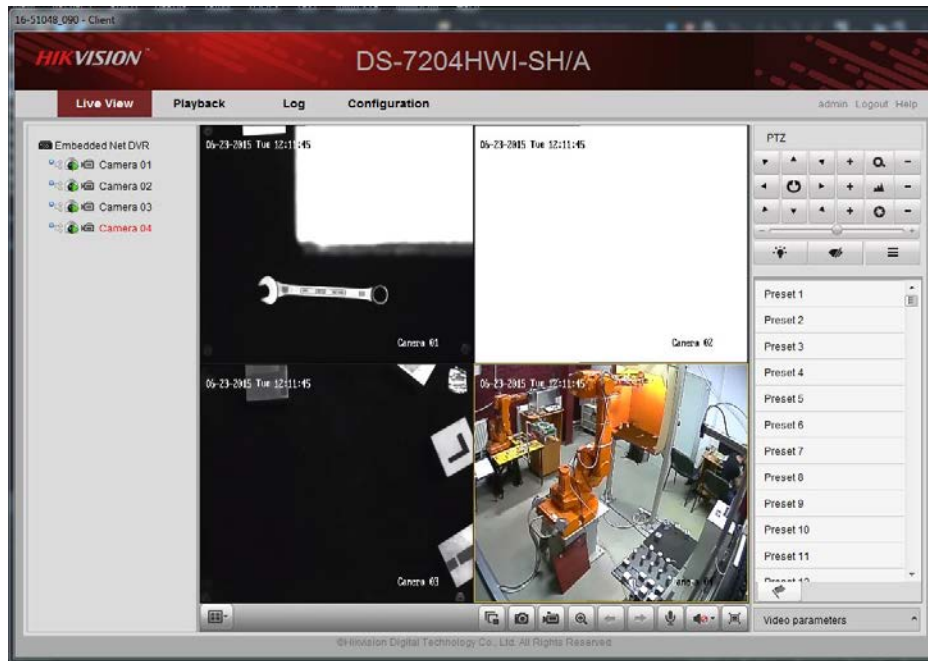


Figure no. 6: Multimodal interface demonstrator

Using the multimodal interface (software demonstrator – figure no. 6) the operator instantly can program the robot, using graphical interface for text programming and sensor glove for gesture commands. This approach will enable production engineer to focus on the manufacturing requirements, rather than to the robot programming issues.

By implementing the developed multimodal interface creates prerequisites for increasing the availability of technicians to program industrial robots and the integrating features that facilitate reducing energy consumption generates a business case for sustainability within the SMEs which implemented it. In a favorable SMEs' context these business cases for sustainability can cause changes in business strategy and even in business model!

To evaluate the impact of the multimodal interface and the created business case for sustainability: the developed multimodal interface software was installed on three different robotic systems within three different SMEs (one for manipulating products, other for arc welding and the third for assembly). In Romania SME is defined as a company with less than 250 employees or a rate of turnover per year less than 50 million EUR. The sustainability criteria according to which the assessment was made were: 1) increasing the efficiency of programming and the productivity of the robotic system (generating profit); 2) reducing energy consumption of the robotic production system (environmental impact); 3) developing employees' skills and their accessibility to a new technology (social issues).

To assess the first criterion will be measured the usability of the developed multimodal interface in terms of efficiency, effectiveness and user satisfaction. Multimodal interface assessment was made compared to traditional interfaces. The analysis begins with a brief description of the new multimodal programming interfaces, highlighting the windows, the menus, and the buttons functions. Process applications were developed specific to each industry in which the SME operates.

In terms of efficiency of programming the industrial robots it can be seen that there was an increase in the performance of robot use with 243.62%. Also, navigation through the multimodal interface was much intuitive, with an average impact on users of 198.30%. The most important progress toward the user perspective was done in defining the robot target points (300%), instructions for closing and opening the end-effector (345%) and the instructions for completion and save the program (223%). In terms of robotic systems energy efficiency by using multimodal interface which facilitate the implementation of fly-by strategy as well as by reducing the overall path length the average energy consumption decreased by approx. 10%, within the evaluated robot applications (ABB IRB 1600). Regarding the addressability and accessibility to program the robotic systems for operators with basic technical background and no robotic programming background it is the case in which we made the evaluation; the evaluation was made on five technicians, that have been worked with the robotic systems, that had no robotic programming background and they didn't have any stage on using the robots and understanding the programming logic; in fact they have achieved results highlighted above.

The obtained results within this business case for sustainability were very good and enables further research and further development of multimodal interface for intuitive programming of industrial robots, and creates prerequisites for changing the organizational culture within those SMEs which ultimately will cause a change of strategy and business model.

4.1 Research limitations and implications

The authors propose a framework and develop a demonstrator that facilitates the intuitive programming of the industrial robots to enhance the utilization rates of the robots, the SMEs accessibility to new technology, and reduce energy consumption. The competitive design tools used in multimodal interface design ensured a high level of multimodal interface maturity and allowed taking into account sustainability issue.

By technical point of view to attain a comprehensive multimodal interface robot programming system, several elements still need to be further developed and others to be added in the future. We have to develop more the multimodal recognition module, to integrate speech interpretation module and to test more the actions interpretation module and the prioritized execution module. Although the programs generated by the current version can be re-executed, they are limited to simple robot task sequences. To expand the generality of the approach, we need to add the ability to define complex structures such as conditional logics and looping.

On the other hand to operate a sustainable robotic manufacturing system, a continuous development effort is required to further optimise the multimodal interface using existing knowledge and enhance its capabilities to fulfil low power consumption tasks in the manufacturing environment.

The presented work has thrown some light in the research area of intuitive programming of industrial robots and its implications on SMEs business sustainability. The intuitive programming concept has been introduced in a multimodal robot programming interface to maximize the utilizations of robotic based automatic manufacturing systems. Based on obtained results it is particularly sustainable for SMEs to adopt such sophisticated robotic systems for their manufacturing facilities.

Conclusions

In this paper, we proposed a framework for multimodal industrial robot programming interface and have illustrated the framework using a demonstrator. The programming approach offers, through the multimodal intuitive interface using intuitive text programming, hand gestures and speech recognition, the ability to provide interactive feedback to the industrial robot to “coach it” throughout the programming and execution phases. The user’s intent is caught in the form of a sequential robot program, and the flexibility given to the user by the framework through real-time interaction and the interface allows the captured intent to be closer to the user’s real intent.

In terms of obtained results these creates conditions for greater addressability among SMEs and reduce barriers in terms of needed knowledge for robots basic programming. Regarding the sustainability of a business that integrates such production facility (robotic systems with multimodal programming interface), based on obtained results within the business case for sustainability we are able to say that such robotic systems are sustainable, and integrating them within production systems will enhance the business sustainability!

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