PARADIGM SHIFT IN ROBOTIC SYSTEMS PROGRAMMING FOR INCREASING BUSINESS SUSTAINABILITY

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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. This paper proposed a framework for designing a multimodal human-robot interface that will facilitate a sustainable use of robotic systems with positive effects on business sustainability. The proposed framework 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 task without the need of using skilled personnel. Results of this research showed that changing the paradigm in programming robotic systems it is possible to have economic growth without negative effects on sustainability.

Keywords
Economic growth, technological development, sustainable development, robotic systems programming, business sustainability.

JEL Classification
O14, O33

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 concept 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) 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 and easily adapted to changes in task without the need to use skilled systems configuration personnel, the SMEs addressability and process efficiency will increase and the business become sustainable. Thus, this paper propose an approach that enable the development of a multimodal interface that facilitate an intuitive programming of an industrial robot. 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 small and medium-sized enterprises (SMEs), because it allows the technicians to focus on process technology rather than on programming the robots. We expect that such an approach will have an impact at all levels of the business and will increase the business sustainability.

This paper is structured on five sections. Following this introduction, section two describes the background and related works regarding multimodal interfaces for programming the industrial robots and the impact upon the sustainability of the business. Section three emphasis the 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 is analyses and evaluate the developed software demonstrator for multimodal interaction and the impact of such approach upon business sustainability; finally, the conclusions are discussed in fifth section.

Background and related work

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 installation 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 in many industry applications, particularly, when the robot task or the robot trajectory needs frequent change (Mocan, et al., 2014).

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 though perhaps not significantly, 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, within his researches, pointed out that coupling of speech recognition and dialog management (multimodal approach) can improve the performance of a robotic system (Kong, 2011).

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.

Sustainable design of a robotic multimodal programming interface

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).

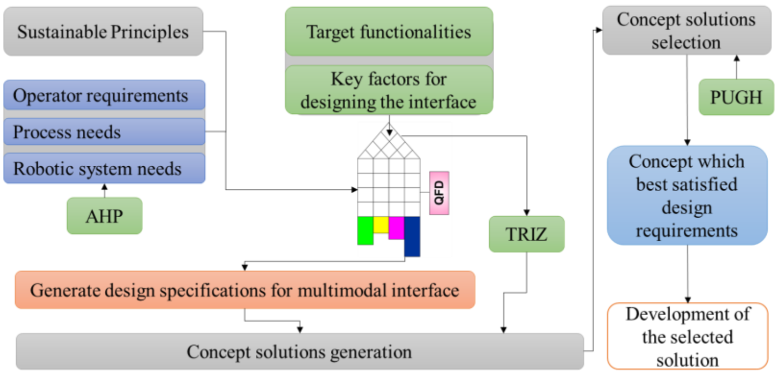

Fig. no. 1 Roadmap for concept solution generation

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 ex-ample, 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) Model task specific robot trajectories: operator has to develop the logic of the task and to integrate adequately target points within the robot trajectory.

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 1) for identifying the right operators requirements, process needs, objective functions, and the best combination of the multimodal interface inputs.

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 1):

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 5 and select the solution that best satisfies the planed performance for the multimodal interaction interface (see step 2). Pugh method could be used to fulfil this step.
Step 9: Result from step 6 is 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.

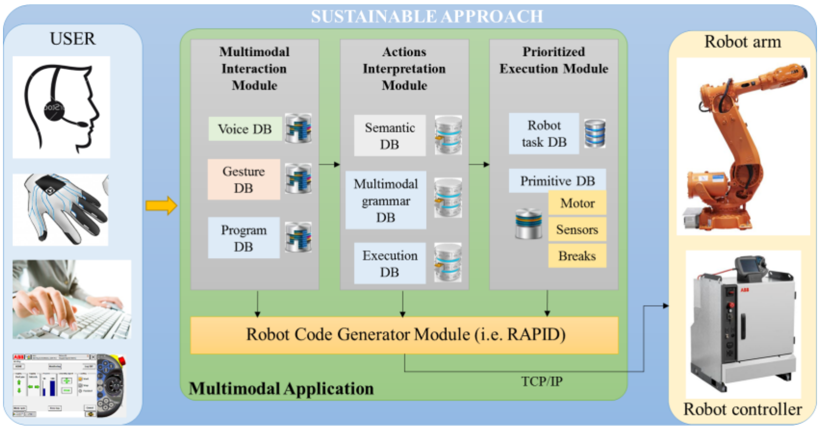

Fig. no. 2 The multimodal interface framework

The operator requirements, process needs and robotic system requirements were, as followed: a) automatic presentation of contextually-appropriate information (18%); b) easy to use by an operator with basic technical background (25%); c) easy to set up (16%); d) graphical intuitive interface (24%); e) clear indication on the robot's display the logical next step (17%). The percentage written within the brackets represent the rank for each requirement, identified with the help of AHP method. The selected inputs for the multimodal interface were speech and hand gesture recognition, backed up by text programming. Based on design guidelines and results highlighted above the proposed architecture of multimodal interface is composed of four functional modules, as illustrated in Figure 2. The first module (multimodal interaction) translates hand 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 have to be supported by an intuitive graphical interface.

Assessing the effects of implementing multimodal programming interfaces on business sustainability

We have developed a software demonstrator to exemplify the effectiveness of the multimodal interaction for intuitive programming the robotic systems. 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 products 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), developing employees' skills and their accessibility to a new technology (social issues).

In terms of efficiency of programming the 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 10-15%. 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 did not have any stage fright on using the robots and understanding the programming logic; in fact they have achieved results highlighted above.

Conclusions

In this paper, we proposed a framework to develop software architecture for interactive multimodal industrial robot programming interface and have illustrated the framework using a demonstrator. The programming approach offers, through an 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 pilot phase we are able to say that the robotic productions systems are sustainable, and integrating them within production systems will enhance the business sustainability!

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