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User-centered Assistive Robotics for Production - The AssistMe Project

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Abstract

In this paper we present the first results of the AssistMe project which aims at enabling close human-robot cooperation in production processes. AssistMe develops and evaluates different means of interaction for programming and using a robot-based assistive system through a multistage user-centered design process. Together with two industrial companies human-robot cooperation scenarios are evaluated in two entirely different application areas. One field of application is the assembly of automotive combustion engines while the other one treats the machining (polishing) of casting moulds. In this paper we will describe the overall project methodology, followed by a description of the use cases and a detailed outline of the first robotic prototype set up. The paper closes with an overview on the results of the first user trials that show very similar findings for both use cases and gives an outlook on the next expansion stage of the human-robot cooperation scenario.

1. Introduction

The idea that industrial robots need to leave their working cells and pre-programmed routine tasks in order to become more flexible in use and also more applicable for SMEs with smaller lot sizes and often changing production processes is nothing new. Robots, such as the collaborative robots from Universal Robots[1] and Baxter from Rethink Robotics[2] are entering the market with exactly that aim to offer robotic solutions for a closer human-robot collaboration, in which the strengths of the humans (e.g. problem solving, decision making) can get combined with the strengths of the robot (e.g. efficient fulfilment of reoccurring tasks) [1]. Companies such as KUKA start investing more and more in user-centered development (UCD) and usability standards such as ISO/TR16982:2002 were developed to support safe and close cooperation. Nevertheless, little user-oriented research has been performed so far outside the laboratory in the industrial context to understand what makes operators

[1] http://www.universal-robots.com/de/
[2] http://www.rethinkrobotics.com/

accept or reject robotic assistance (e.g. [2]). Similarly, little is known about best practices of user-centered development in the industrial context [3] [4].
Up to now, robot-based assistive systems are not widely spread in the manufacturing industry, as there is still research missing to uncover their full potential, and room for improvement in terms of usability, user experience, and subsequently user acceptance. Assigned purpose of the project AssistMe is the user-centered development and evaluation of innovative means of interaction for human-robot cooperation to improve usability and user experience of robot-based assistive systems in order to flexibly automatize selected production steps in an economically viable way.
The aim of the AssistMe project is to develop innovative haptic and optic concepts for human-robot cooperation in two different applications contexts, namely the assembly of automotive combustion engines while the other one treats the machining (polishing) of casting moulds. These concepts can be used during set up and interaction with a robot-based assistive system.
The project consists of three major development cycles. In a first iteration an assistive robot system, more or less out of the box is implemented for the use cases by application of process equipment. User studies regarding teaching and use of the systems are carried out. User-centred improvements in terms of usability and programmability are implemented as technical components in order to reduce programming complexity and programming duration as well as to improve system reliability and process quality.
Therefore different technology options are foreseen by the project frame. Force feedback technology will support programming and the usage of robot programs in order to make better use of robot articulated machining tools supporting the navigation through the real world by position-based haptic force feedback. Optic interaction technology, 2D and 3D sensors (and the corresponding machine vision algorithms) integrated with projection devices will render spatial augmented interaction e.g. textual feedback – instructions and explanations, during use. Apart from visualization, spatial augmented reality concepts with position and object-based projected information will be developed in order to be able to define virtual light barriers and projected buttons. Tools will be automatically positioned relatively to objects (due to object pose recognition technology). In combination with haptic interaction technology interaction concepts will be evaluated that prevent users from the violation of 3D collision contours that have been captured and automatically interpreted as such by optical reconstruction technology beforehand. These interaction paradigms will be developed in a multi-stage process, together with operators in the two different testbeds and subsequently they will be evaluated in different expansion stages of the interaction technologies.

2. User-centered Design Approach

The two-years project is based on the concept of iteratively evaluating the same robotic assistance in different stages of expansions for the two different use cases. Stage 1 is an off-the-shelf robotic arm from Universal Robotics. Stage 2 will be further enhanced with a 3D sensor and stage 3 with force feedback. Every stage of expansion will be evaluated together with representative target users from our industrial partners with respect to usability, user experience, and acceptance. After every evaluation implications for improvement for the next expansion stage will be derived to keep the operators' point of view in the development process. The AssistMe project thereby follows a very similar user-centered design approach as presented in [3] and the evaluation activities are methodologically grounded in the USUS evaluation framework [5]. The work presented in this paper are the general use cases for both application contexts, as well as the first expansion stage and its evaluation. Before we go on detail with our use case implementation, we will give a short overview on related state-of-the-art assistive robot systems.

3. Assistive Robotic System

Robot-based production nowadays is essential for industrial manufacturing. Due to safety reasons industrial robots are placed in a cell behind spatially separating safety equipment such as fences. As precise playback machines for movements, industrial robots remain insensitive towards their environment and repeat predefined sequences of actions. Industrial robots cannot react to changes in their environment and require reprogramming. [6] differentiate automatic and manual robot programming systems. In industrial scenarios robot specialists do reprogramming and reconfiguration partly with text-based, controller-integrated, teach-pendant-based (online) tools as well as with CAD-based graphical robot simulation tools. Results are, apart from some sensor signal inputs, more or less inflexible robot programs. Recently, a new class of industrial robots hit the market namely [7] [8] [9] to mention a few, which can be potentially used in the same environment as human co-workers if relevant norms (A,B level norms that define Safety Integrity levels, performance levels, application specific C level standards) are fulfilled. [10] [11] define four modes of human-robot coexistence and collaboration as relevant for robotic applications. [12] specifies safety requirements for collaborative industrial robot systems and the work environment, and supplements the requirements and guidance on collaborative industrial robot operation. Programming of collaborative robot systems is equivalent to standard industrial robots since trained robot programmers are target on the one hand. On the other hand programming is simplified using macros to support unexperienced users. [9] provides the possibility of hand guidance during system teach in. This input modality is evaluated in the project, but gear friction renders exact hand guided teach-in difficult. Industrial installations of collaborative robots remain (until the integration of the project results) inflexible and unintelligent playback machines for movements and process technology such as intelligent cameras etc. It remains complicated and almost impossible with commercially available systems to integrate that renders in adaptive behavior. The AssistMe projects wants to enable naïve operators to manually teach a robotic arm for their purposes with little pre-knowledge requested. Afterwards a safe and user-friendly cooperation with the robot in the production process should be possible.

4. Use Cases

4.1 Assembly of automotive combustion engines (use case A)

The assembly of a combustion engine includes the installation of a cylinder head cover. The installation is carried out manually by stacking the cover with pre-inserted screws onto the motor block and tightening the screws with a manual power tool. The electronic screwdriver of the manual workplace is fitted with a push start mechanism, electronic control unit and a shut-off clutch and therefore starts rotating when pushed onto the screw and stops motion when retracted respectively when a predefined torque is reached. The working instruction of the workstation includes several additional process steps. An automatic screw tightening system is expected to provide assistance and to reduce the workload at the workstation for the human worker.
A state-of-the-art collaborative robot system [10] [11] is equipped with the power tool (Figure 1) and programmed to perform screw tightening operations in the required order and accuracy to meet a defined process quality (screw-in depth, torque,…). In the first expansion stage, the project evaluated the effectivity and simplicity of the user interface as implemented by the robot manufacturer and proposed modifications, which will inform the implementation of expansion stages 2 and 3.

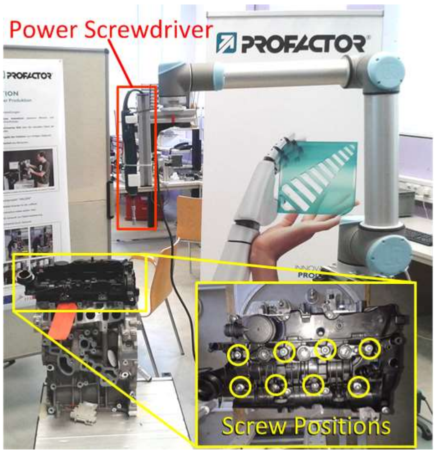

Figure 1- collaborative screwdriver robot system

Figure 2-manual polishing workplace

4.2 Machining (polishing) of continuous casting moulds (use case B)
Continuous casting of profile bars requires high precision moulds with excellent surface finish. Casting moulds are crafted from flat material by wire electro discharge machining that leaves eroded surfaces without the required surface finish quality. Manual polishing (Figure 2) by air pressure driven oscillating polishing machines is extraordinary labour intensive, unergonomic and harmful to health. Prolonged exposure to hand transmitted vibration from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurological and osteoarticular systems of the upper limbs [13]. Setup and programming time is crucial for the use case since continuous casting molds are usually one of a kind products, manufactured in lot size one, with polishing being by far the most labor intensive production step causing umpteen hours of labor per mold. Therefore an assistive system, easy to program and setup, is desirable that can reduce the amount of labor especially for ergonomic and health reasons.
A state-of-the-art collaborative robot system [10] [11] is equipped with a polishing tool and programmed to perform polishing operations. In the first expansion stage, the project evaluated the effectivity and simplicity of the user interface as implemented by the robot manufacturer and proposed modifications, which will inform the implementation of expansion stages 2 and 3.

5. Preliminary User Trials

The first expansion stage of the two use cases was evaluated in the first year of the project. In total three user trials were conducted in order to get feedback from the workers who actually used the new robotic system. Participants were recruited by our industrial partners and we explored the teaching of the robotic arm in Trial 1 and 2 and the actual collaboration with the robot in Trial 3 (see Table 1 for an overview).

All participants in Trial 1 and 2 successfully completed both teaching tasks (only one participant did not finish the second task due to time constraints). The gathered data showed that the touch panel in its off-the-shelf version was experienced as not feasible and too complex to control the robot during the teaching task for participants of both use cases. There was a strong tendency to omit the panel as an intermediate device and to try to directly control the robot using kinesthetic teaching. However, this type of control was also limited in feasibility as the robot arm was experienced as too bulky and unprecise for teaching positions that way. Overall, the teaching of expansion stage 1 was rated as low with respect to usability, user experience, and acceptance, which can be explained by the fact that the actual teaching was only a fraction of the whole process, which was experienced as too complicated due to the touch panel. Trial 3 revealed that in the actual collaboration with the robot its working pace was perceived as not flexible enough, which bears the risk to re-establish a rigid production line logic. More details on the studies can be found in [14].

Table 1. Overview of the three user trials.

	User Trial 1 **Use case A**	**User Trial 2** **Use case B**	**User Trial 3** **Use case A**
Environment	Factory	Laboratory	Factory (assembly line)
Task	Teaching of screw positions	Teaching of polishing positions	Cooperative screwing
Duration	1 day	2 days	3 weeks
No. of Participants	5	5	5
Research Methods	Oberservation, Questionnaires	Oberservation, Questionnaires	Interviews

6. Inferred Usability Improvements

6.1 Technical project outlook: Expansion stage 2

Usability studies yielded requirements regarding robot hand guidance. Gear friction yields stacking and imprecise movement. Locking of certain degrees of freedom (e.g. rotation or translation,…) is asked for by users as well as semiautomatic tool alignment and expected to improve both programming time and process quality. A state-of-the-art force torque sensor was integrated as well as buttons to call perpendicular realignment (Figure 4) or locking of rotational or translational degrees of freedom.

6.2 Technical project outlook: Expansion stage 3

Collaboration can be improved by adding visual feedback on the robot and the work piece during the teaching (to reduce the burden of switching attention between the robot and touch panel). [15] [16] introduce the notion Spatial Augmented Reality (SAR) and describe it as enhancement or aggregation of several Augmented Reality (AR) technologies. One formulation [17] might be a depth camera projector based system to project (correctly distorted) information on three dimensional objects instead of flat screens (Figure 3) and may be used for projection of buttons.

(Applied) robotics does not make use of SAR methods extensively. [18] introduces a projection-based safeguard system for robotic workspaces especially for collaboratively used workspace. [19] gives an overview on Tangible User Interfaces (TUI) which denote interfaces that can be manipulated physically, and which have an equivalent in the digital world and represent a mean for interactive control. The project proposes a combination of TUI and SAR methods. Hand guided positioning of the robot might be uncomfortable or time consuming due to inappropriate input modalities (friction afflicted robot drives, unintuitive touch screens,…).

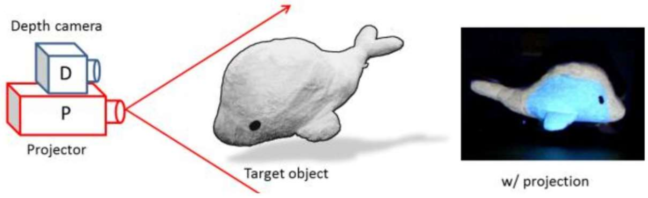

Figure 3- Depth Camera based tracking for Spatial Augmented Reality [17]

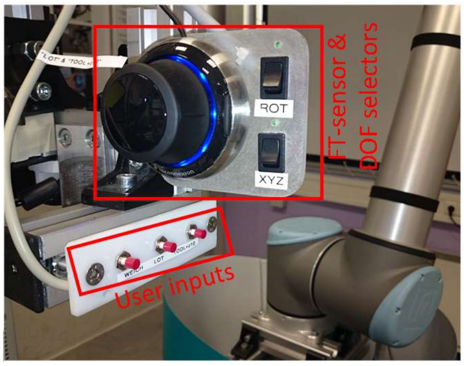

Figure 4 - projected buttons

Tightening order and poses of screws might be programmed by pointing to the screws with the finger [20]. Object and pose recognition introduces TUI to the world of AR. We propose a system that provides spatial detection functionality of teach-in devices (e.g. a spherical marble) that can be manipulated by the human. The system consists of one or more 3D sensors and a calibrated projector. Information on dynamic marble pose (resting marble may denote an underlying screw to be tightened) may be used for the programming of process points. A marble is placed on the cylinderhead cover. A projected interface element is pushed by the programmer who has to hold in order to avoid accidental acknowledgements. Once acknowledged, the 3D pose of the marble and thus the underlying screw is programmed to the system.

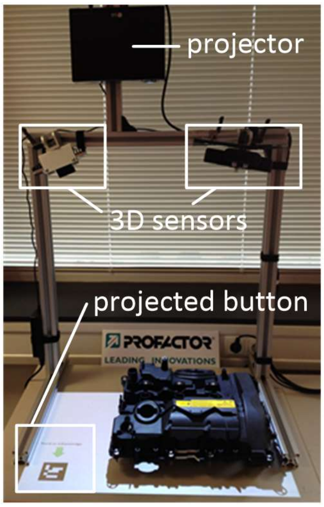

Figure 5 - system setup

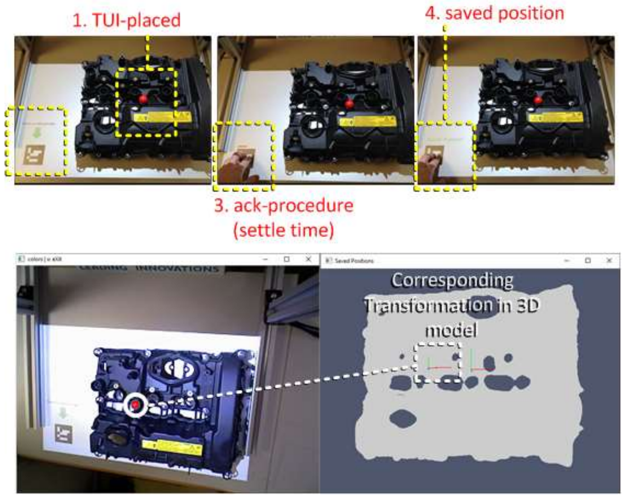

Figure 6 - SAR-TUI based process point programming

The system architecture (Figure 8) motivates advanced functionality in terms of robot hand guidance. Figure 7 shows first results of the environmental modelling system. An arbitrary placed object is recognized by the 3D camera and a virtual environmental model is updated (in realtime) with the model of the recognized object in its correct pose.

Force feedback algorithms are intended to render intuitive feedback for the user according to elements of the environmental model. E.g. boundary surface of volumes containing obstacles should make it impossible for the user to move the robots to or through such areas. Therefore negative force (as far as movement direction is concerned) has to be exerted to the hand guiding user. Positive forces may attract the user to process points contained by the model.

Virtual obstacles (attached to realworld 2D – markers can therefore easily be integrated into the environmental model).

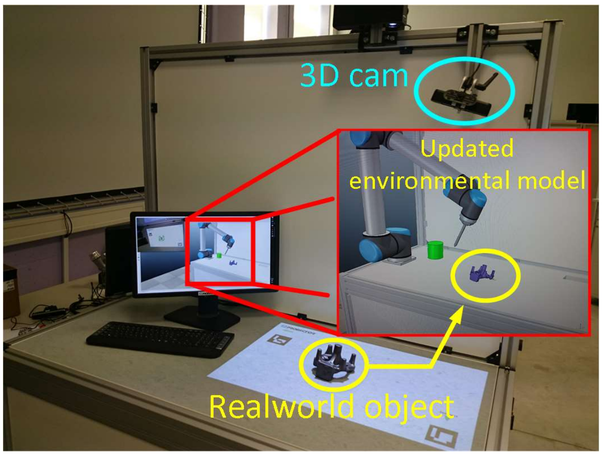

Figure 7- Augmentation of Virtual Model by Real World Objects

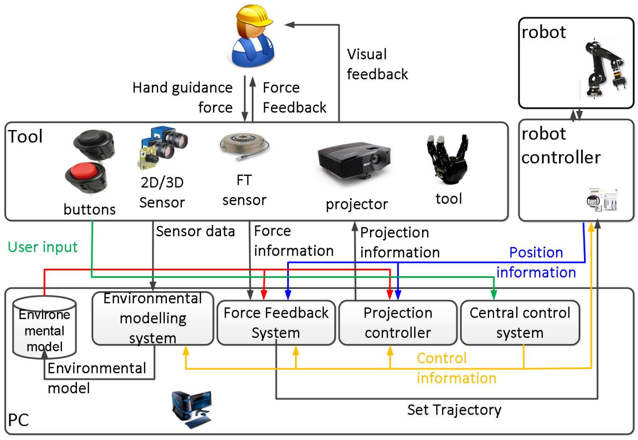

Figure 8 -system architecture

The force feedback system may not only render force feedback for the user during teach-in. It also can control process forces as e.g. required by the polishing process. Force-Torque information is acquired from the FT-sensor. An external sensor (Figure 9) is used instead of built in robot [9] functionality since force values estimated from required motor currents are too inaccurate due to e.g. gear friction. Process forces can be controlled e.g. for a touch-up operation to exact 5N which is well below the detection threshold of the robot (Figure 10).

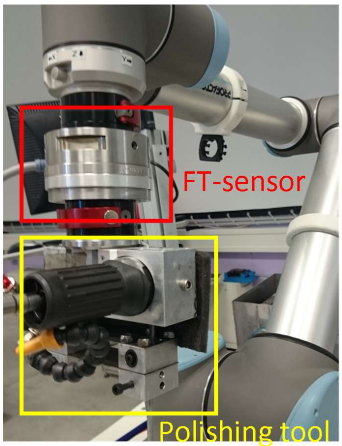

Figure 9- FT-sensor and polishing tool

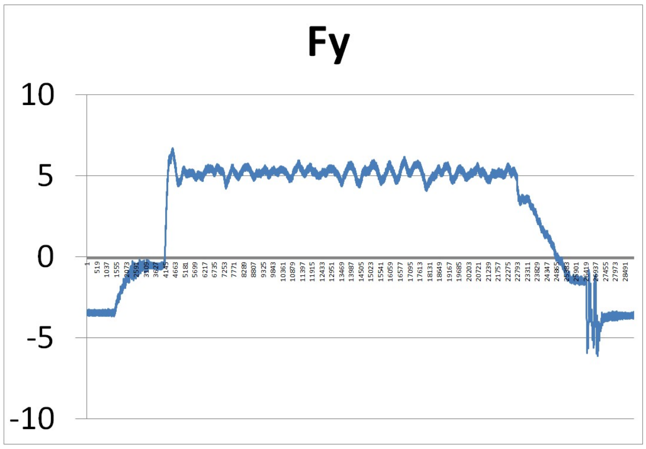

Figure 10- measured process forces

7. Conclusion

In this paper we presented the AssistMe project, which aims at enabling more flexible human-robot collaboration in the industrial context through a user-centred design approach. We outlined the overall approach of the project as well as its two use cases: (1) Assembly of automotive combustion engines and (2) Machining (polishing) of continuous casting moulds. We roughly described the main findings from the first end user evaluations which used a state-of-the-art robotic system. An outlook on expansion stages 2 and 3 were motivated and described.

8. Acknowledgements

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9. References

[1] A. Weiss, R. Buchner, M. Tscheligi und H. Fischer, „Exploring human-robot cooperation possibilities for semiconductor manufacturing," in *Collaboration Technologies and Systems (CTS), 2011 International Conference on*, 2011.

[2] D. Wurhofer, T. Meneweger, V. Fuchsberger und M. Tscheligi, „Deploying Robots in a Production Environment: A Study on Temporal Transitions of Workers' Experiences," in *Human-Computer Interaction--INTERACT 2015*, Springer, 2015, pp. 203-220.

[3] R. Buchner, N. Mirnig, A. Weiss und M. Tscheligi, „Evaluating in real life robotic environment: Bringing together research and practice," in *RO-MAN, 2012 IEEE*, 2012.

[4] S. Griffiths, L. Voss und F. Rohrbein, „Industry-Academia Collaborations in Robotics: Comparing Asia, Europe and North-America," in *Robotics and Automation (ICRA), 2014 IEEE International Conference on*, 2014.

[5] A. Weiss, R. Bernhaupt und M. Tscheligi, „The USUS evaluation framework for user-centered HRI," *New Frontiers in Human--Robot Interaction,* Bd. 2, pp. 89-110, 2011.

[6] G. Biggs und B. MacDonald, „A survey of robot programming systems," in *Proceedings of the Australasian conference on robotics and automation*, 2003.

[7] *http://www.kuka-robotics.com/en/products/industrial_robots/sensitiv/lbr_iiwa_7_r800/start.htm.*

[8] *http://www.mrk-systeme.de/index.html.*

[9] *https://en.wikipedia.org/wiki/Universal_Robots.*

[10] *ISO 10218-1:2011 Robots and robotic devices -- Safety requirements for industrial robots -- Part 1: Robots.*

[11] *ISO 10218-2:2011 Robots and robotic devices -- Safety requirements for industrial robots -- Part 2: Robot systems and integration.*

[12] *ISO/TS 15066:2016 Robots and robotic devices -- Collaborative robots.*

[13] M. Bovenzi, „Health effects of mechanical vibration," *G Ital Med Lav Ergon,* Bd. 27, Nr. 1, pp. 58-64, 2005.

[14] A. Huber, A. Weiss, J. Minichberger und M. Ikeda, *First Application of Robot Teaching in an Existing Industry 4.0-Environment. Does it Really Work? Societies,* 2016.

[15] O. Bimber und R. Raskar, Spatial augmented reality: merging real and virtual worlds, CRC Press, 2005.

[16] R. Raskar, G. Welch und H. Fuchs, „Spatially augmented reality," in *First IEEE Workshop on Augmented Reality (IWAR'98)*, 1998.

[17] K. Tsuboi, Y. Oyamada, M. Sugimoto und H. Saito, „3D object surface tracking using partial shape templates trained from a depth camera for spatial augmented reality environments," in *Proceedings of the Fourteenth Australasian User Interface Conference-Volume 139*, 2013.

[18] C. Vogel, M. Poggendorf, C. Walter und N. Elkmann, „Towards safe physical human-robot collaboration: A projection-based safety system," in *Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on*, 2011.

[19] H. Ishii, Tangible user interfaces, CRC Press, 2007.

[20] C. Harrison, H. Benko und A. D. Wilson, „OmniTouch: wearable multitouch interaction everywhere," in *Proceedings of the 24th annual ACM symposium on User interface software and technology*, 2011.