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Augmented Reality for Telemaintenance and -inspection in Force-Sensitive Industrial Robot Applications

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Abstract: Telematic solutions allow fast remote support in industrial robot work cells: Robotic experts can assist the local staff in work process modifications or in tracking down errors without having to actually travel to the remote site. In order to be able to perform such teleinspection and telemaintenance tasks the operator needs to establish a data connection to the robot and get an understanding of the remote work process, as well as of the transmitted data.

This contribution introduces a telematic control system developed for remote monitoring and control of an industrial robot performing force-sensitive work applications. An Augmented Reality interface is proposed for intuitive representation of complex robotic data, allowing quick analysis of the current working cycle and process data and altering the robot's program remotely while still having a clear spatial reference to the work environment.

Keywords: Industrial Robots, Augmented Reality, Telecontrol, Human-Robot-Interaction, Tele-robotics, Control Interfaces.

1. INTRODUCTION

Industrial robots nowadays are employed in a number of different application areas: from traditional fields like material handling over welding and spray painting up to industrial processing tasks like cutting, grinding, deburring or polishing. While they used to be employed in a "program-once, run-forever" manner, today, declining life-cycles for products and an increased variety of product ranges require a more flexible automation (IFR (2014)), thus also requiring more frequent modifications to the robots' work programs.

Since not all companies employ robotic experts these modifications prove problematic for some, especially in case of complex applications like grinding or deburring (Thomessen (2000)), when working in direct contact with the work piece and where workpiece geometry is often complex. This raises a demand for robotic experts that assist users with modifications of their programs or can provide support in case of errors or undesirable results.

While formerly, such an expert had to be summoned from the manufacturer or robotic service provider, nowadays several of these tasks can be approached using telematics: this means establishing a communication link to transmit the relevant data from the work cell and analyzing and solving the problem remotely. There are several advantages for using telematics in inspection and maintenance scenarios: being able to perform work program modifications or analyze and correct erroneous behavior of the industrial robot completely remotely allows for a fast intervention – the experts do not have to travel to each customer, allowing for a quicker response and alleviating travel time and costs. The customer can request short-hand support right when he needs it; the robotic service provider can bundle his expertise in one central telematics center, from where he can provide support to users from all over the world. Of course, some work modifications or maintenance tasks may require physical intervention in the work cell: in these cases, the telematic support should be conducted together with the personnel in place. In this case, the operator provides instructions and oversees the execution by the local staff. If this does not prove sufficient, a technician can still be dispatched.

However, in order to allow such telemaintenance and inspection tasks to succeed in the first place, the teleoperator needs to get a good understanding of the transferred data and of the situation in the remote work cell. This understanding of the remote circumstances or the feeling of even "being at the location occupied by the slave device" (Loomis (1992)) is often termed situational awareness (Endsley (1988)). Only after gaining this awareness, the teleoperator can analyze the task/problem properly, come up with a solution and provide the necessary work program modifications.

In order to help the teleoperator gain this awareness, we propose the use of Augmented Reality (AR) to intuitively visualize the transmitted robotic data at the teleoperation center. This technique allows showing the user an enhanced view of the work surroundings which displays data in an easily understandable way, at the position it corresponds to. This relieves the mental workload of the teleoperator (Wickens (2005)) and thus leads to higher efficiency in the teleoperation process.

This contribution introduces an AR-supported teleinspection and -maintenance interface developed in the context of the

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project *ForTeRob* (Force Controlled Teleoperated Machining with Standard Industrial Robots). As the name indicates, the interface is developed for teleoperation of standard industrial robots, with special emphasis placed on force-sensitive applications like grinding or polishing. This article first gives a brief introduction into the goals and architecture of the system and AR in general. Afterwards, the developed control interface is presented, with focus on the AR-based display of robotic and process data for analysis and modification of the work process. Finally, the conducted experiments and evaluation of the developed system are described, and a brief summary of the results is given.

2. OBJECTIVES, SYSTEM ARCHITECTURE AND COMPONENTS

2.1 Objectives of ForTeRob

The project ForTeRob was mainly concerned with industrial robots performing force-sensitive operations like grinding or polishing of work pieces. One project task was to develop a novel control system to improve force control capabilities of standard industrial robots (Lotz (2014)). The other task described here was to develop a telematic user interface for those application scenarios that would allow an expert to monitor, analyze and modify the robot's behavior remotely. Data analysis and program modification options should be suited to the needs of the support staff and allow quick intervention in case it is needed.

To further detail the requirements of the telematic interface, an initial survey was conducted with the technical support personnel of the robot manufacturer Reis Robotics. Three main tasks for it were identified:

- Easy and fast analysis of the current work program execution and work results
- Autonomous, permanent monitoring of work execution to detect anomalies, deficiencies or errors
- Intuitive modification, and afterwards testing of altered work programs in the remote work environment of the manipulator,

all with special emphasis on force-sensitive applications. The second point involved developing an autonomous monitoring system that could track system and process related events, and report or react to them, and will not be detailed further in this article. The other two objectives were solved using image and video data from the work cell together with logged or live machine data – visualized with Augmented Reality; this will be further detailed in the following sections.

2.2 Augmented Reality (AR)

In order to allow the desired intuitive representation and analysis of the data transmitted from the remote robotic work cell, an Augmented Reality interface for the teleoperation system was proposed. Augmented Reality – as a form of Mixed Reality (Azuma (2001)) – is a technique that enhances the view of the natural surroundings of a user with additional helpful virtual information to aid him in his tasks; these virtual additions need to be correctly registered (integrated, positioned and oriented) within his view of the surroundings and should be dynamic and interactive in real-time (Azuma (2001)). Several techniques exist to actually enhance the view of a user, ranging from head-mounted displays in helmet systems over portable displays like smartphones, enhanced camera images on stationary monitors as in (Sauer (2010)) up to visualizations being projected directly into the workspace (Leutert (2013)). Since the operator here can only enter the work environment remotely, AR visualizations with enhanced camera images on monitors were used.

The goal of the AR system here is to take complex robotic or process data and make it easily understandable by visualizing it in an intuitive manner and showing it at the correct place in the work environment. By enabling the user to simply *see* the necessary complex information at the corresponding position, he on the one hand does not need to locate the data in relation to the robot; on the other hand, interpretation is made easy by choosing an appropriate visual representation for the data (see Section 4). This approach has been shown to reduce the mental workload of the teleoperator (Wickens (2005)) and will allow him to analyze and solve remote tasks quicker.

2.3 System architecture

In order to make any teleoperation process possible, data first has to be transmitted between the remote location and the teleoperation center. The operator there needs to gain an understanding of what is happening at the controlled plant, and the controlled device needs to be able to receive commands to allow modifications to be made to the process.

The developed basic system architecture in ForTeRob to allow remote monitoring and modification of an industrial manipulator robot performing force-sensitive applications is depicted in Fig. 1.

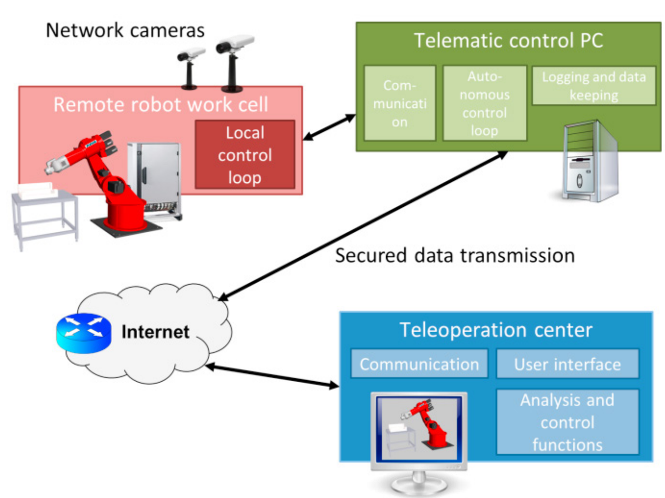

Fig. 1. Basic system architecture of the telematics interface in ForTeRob.

The data gathered at the remote location can be divided into three categories: first, data from the robot itself and from the performed work process. Second, visual data from deployed network cameras that are essential for an AR-visualization of said data, and third, (optional) additional data from external sensors (depending on the work application and the data needed to properly analyze and/or control it). All this data is