A Spatial Augmented Reality System for Intuitive Display of Robotic Data

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***Abstract*— In the emerging field of close human-robot-collaboration the human worker needs to be able to quickly and easily understand data of the robotic system. To achieve this even for untrained personnel, we propose the use of a Spatial Augmented Reality system to project the necessary information directly into the users' workspace. The projection system consists of a fixed as well as a mobile projector mounted directly on the manipulator, allowing for visualizing data anywhere in the surroundings of the robot. By enabling the user to simply see the necessary complex information he can better understand the data and behavior of the robotic assistant and has the opportunity to analyze and potentially optimize the working process. Together with an input device, arbitrary interfaces can be realized with the projection system.**

***Index Terms* — Augmented Reality; manipulators; robotic interfaces; human-robot-interaction**

I. Introduction

In Robotics, there currently is a trend away from using manipulators only as shielded handling devices with fixed working cycles towards using them as assistants for direct collaboration with a human coworker. To efficiently and safely work closely together with a robot, the operator should have some understanding about the robotic system, its programming language and the data from its control system. However, when using the robot as an assembly or handling assistant, the working personnel cannot be expected to have a background in robotics, which makes understanding the behavior and the data of the manipulator possibly difficult for them.

This is also the case in our project AsProMed (assistance systems for production and medical-related fields) with the goal to develop a manipulator-based assistance system for disabled persons, enabling them to do work they could not perform without robotic assistance. One example is the manufacturing and handling of wooden pallets.

For this assistance system an easier and intuitively understandable way of displaying complex robot data is needed. We propose the use of a Spatial Augmented Reality system (besides a realistic monitor-based visualization system as in [5]) to enable the working personnel to easily understand robotic data and the intentions of the partly autonomous assistance system, as well as using this system as an intuitive input interface for teaching the robot. This is the focus of this contribution; other components of the assistance system will not be presented here.

II. Spatial Augmented Reality

Augmented Reality (AR) – as a form of Mixed Reality [1] – is a technique that enhances the natural surroundings of the user with additional helpful virtual information to aid him in his task; the virtual additions need to be correctly registered (integrated and oriented) within the surroundings and should be dynamic and interactive in real-time [1]. Several techniques exist to actually enhance the view of a user, ranging from head-mounted displays in helmets over portable displays like smartphones, enhanced camera images on stationary monitors as in [2] up to visualizations directly made visible in the workspace of the user, the aforementioned so called Spatial Augmented Reality (SAR). This technique can make use of projectors to directly project additional information on objects in the work surroundings, liberating the user from carrying any display equipment and allowing him to retain his focus solely on his work. An overview over SAR and the challenges of its employment can for example be found in [3].

III. SAR-Projection System

To realize SAR-visualizations in the work area of our assistant robot we deploy two projectors: a stationary one mounted on the ceiling above the manipulator, covering the working area and a small LED-projector mounted directly on the robot flange. The mobile device gives our system a distinct advantage over ones just employing stationary devices, since this allows for realizing projections virtually anywhere in the surroundings, even in difficult to reach areas not covered by the stationary projector, just by (potentially autonomously) repositioning the robot. It can also be used for occlusion compensation, if an object (or the user) is blocking the projection path of a device. Both projectors first have to be calibrated; afterwards, SAR-visualizations can be drawn at those computed locations on the projectors' input image that result in them being projected onto precisely the desired position in workspace.

IV. SAR-Visualizations

The SAR-system allows for intuitively visualizing almost all of the data in the robot control system, as well as process specific data of the work process that has a spatial reference.

Examples range from simple annotations like coordinate reference frames up to completely pre-visualizing a robot handling program, making its work result visible beforehand without having to actually move the robot (Fig. 1). This can be used to easily analyze and optimize the robot's path. Other examples are graphical placement instructions (where and how to place parts) for the wooden pallets shown to the worker as well as specific operation points in the robot handling program, like the precise position the manipulator is going to nail the wooden planks together (e.g. shown as dots). This spatial information needs to appear at precisely the indicated position in the work surroundings so the user can place trust in the displayed data – this however, if achieved, allows for very fast and easy verification and understanding of information that is inherently difficult to grasp from the raw data (e.g. in form of numerical coordinates) of the robot control.

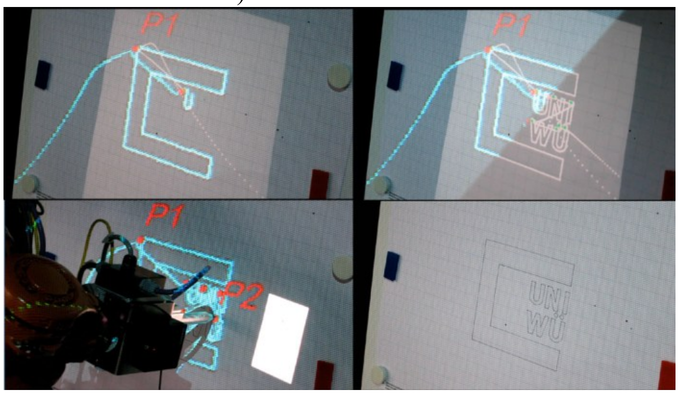

Fig. 1. Pre-visualization of a robot drawing program; individual projector drawings shown; robot executing program; result (top left - bottom right)

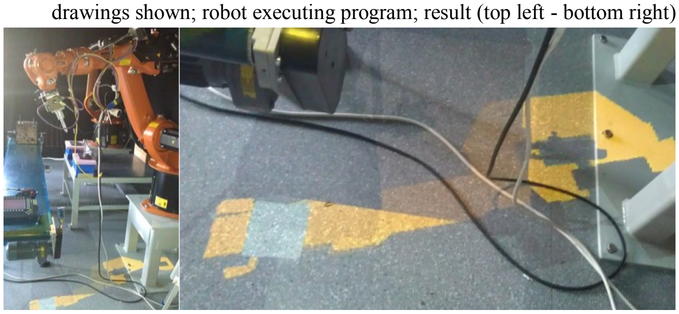
Fig. 2. Orthographic projection of robot pose (left); occlusion compensation by the mobile projector in the shadow of the conveyor belt (right)

Besides these rather static visualizations also dynamic data can be shown to the user. When the robot assistant is moving autonomously a close-by worker needs to be informed *that* and *where* the robot is going to move, to avoid feelings of uncertainty. For this, the user is first alerted (by highlighting the projection area), before the new position is indicated by projecting the manipulators pose as an orthographic projection on the floor (Fig. 2) and moving it towards the new pose, effectively showing the user the final position and the precise path the robot is going to take. He can then step back in case he is obstructing the movement. Another possibility is visualizing various sensor data (e.g. from an obstacle avoidance system) to inform the user of detected obstructing objects (by highlighting those) as well as the alternate path the robot is going to take. Adding a tracked input device to the system opens up particularly interesting possibilities for the SAR-system. First of all, the measured position of the device can be visualized (e.g. as a dot), giving the user direct feedback on his input and informing him which position effectively has been determined by the system; this might be important in case of less precise tracking systems. Furthermore, the input device can be used to draw trajectories for the robot for specific operations (like welding, cutting, painting (Fig. 3)) on a surface. The path can be drawn as if using a virtual pencil, and later be modified to the user's demands, similar to the system in [4]. Finally, arbitrary interfaces can be projected directly in the surroundings of the user. For example, different input fields or sliders can be shown, that trigger certain predefined actions (move the robot to a certain position, open/close gripper, activate external device etc.). This allows for defining virtually unlimited interfaces the operator can take advantage of without having to leave his workplace and switching his attention to another display.

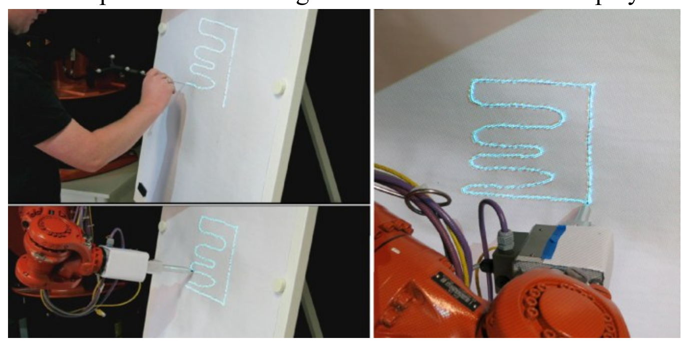
Fig. 3. Manual drawing of a robot path (top); robot following the specified trajectory (bottom); drawing results are as specified (right).

V. SUMMARY/FUTURE WORK

The proposed SAR-system allows very flexibly projecting arbitrary virtual information in the surroundings of a robotic system. Several SAR-visualizations have been developed and will be evaluated in an authentic working scenario of producing wooden pallets with disabled persons. Another future addition will be incorporating head-tracking into the system, enabling annotations that can span over multiple objects and create the illusion of being three-dimensional in space to the tracked user.

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