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Augmented Reality meets Industry: Interactive Robot Programming

A. Ameri E.[1,2], B. Akan[1,3] and B. Çürüklü[1,4]

[1]Malardalen University, Sweden
[2]aai08001@student.mdh.se
[3]batu.akan@mdh.se
[4]baran.curuklu@student.mdh.se †

Abstract

Most of the interfaces which are designed to control or program industrial robots are complex and require special training for the user and the programmer. This complexity alongside the changing environment of small medium enterprises (SMEs) has lead to absence of robots from SMEs. The costs of (re)programming the robots and (re)training the robot users exceed initial costs of installation and are not suitable for such businesses. In order to solve this shortcoming and design more user-friendly industrial robots, we propose a new interface which uses augmented reality (AR) and multimodal human-robot interaction. We show that such an approach allows easier manipulation of robots at industrial environments.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Line and curve generation

1. Introduction

For several decades large companies producing mass-market products have used industrial robots in, e.g. machine tending, welding, and palletizing. Robots are cheaper nowadays and their technology has improved significantly, yet still, in small medium enterprises (SMEs) robots are not commonly found. Even though the hardware costs of industrial robots have decreased, the integration and programming costs make them unfavorable for many SMEs. In order to make industrial robots more common within the SME sector, industrial robots should easily be (re)programmable by engineers that work in the production line at a manufacturing plant. Our goal is to give an industrial robot the ability to communicate with its human colleagues in the way that humans communicate with each other, thus making the programming of industrial robots more intuitive and easy. Consequently, a human-like interaction interface for robots will lead to an easier and richer communication between humans and robots.

Traditional way of programming industrial robots is to use the teach pendant to sequentially move the robots tool center point (TCP) through the desired points. However the traditional programming method suffers 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 [PPS+06].

Developing new methods for operating or programming robots needs to address these problems. A visual feedback on what the robot is viewing and what it is (or will be) doing, can help the operator to get a better understanding of robot's actions and perform complex actions easier and faster. To implement the visual feedback channel, a view of the working environment is presented to user through a unified system. The system overlays visuals through augmented reality to the user and it also receives inputs and commands through a high level multi modal language. Such

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an approach would speed up the programming phase of the industrial robot and utilize the intuitive process knowledge of the operator. Furthermore, it can provide usability of previously learned/taught skills at higher levels.

Augmented reality (AR) is a term used for overlaying computer generated graphics, text and three dimensional (3D) models over real video stream. Virtual information is embedded into the real world, thereby augmenting the real scene with additional information. Augmented reality proved to be useful in several industrial cases, for visualizations. Regenbrecht et al. [HGW05] have applied AR in different automotive and aerospace industrial scenarios successfully. Their field of research included applying AR technology to service/maitenanace, design/development and training. They conclude that there are some more steps needed until the end-users accepts this technology in their field of expertise. Olwal et al. [OGL08] used 3D optical visualization techniques to visualize the process of a CNC machine to the operator. AR also provides great opportunities for Human Robot Interaction (HRI), and has been widely used in tele-robotics because AR allows the operator to work as if he is present at the remote working environment [FON09, MSS02, JCG+05]. However AR can be very beneficial for programming industrial robots as well whether it is remote or local. Through wearable computers and head mounted displays it is possible to visualize and generate paths through a pointing device [PPS+06]. In their work Chong et al. [COaNYY09] visually tracked marker to define collision-free paths for the industrial robot to follow. Once the path is generated a virtual robot simulates the behavior of the robot on the screen.

In this paper a context dependent multi modal language which is backed up by an augmented reality interface that enables the operator to interact with an industrial robot is proposed. The proposed language architecture makes it possible to manipulate, pick or place the objects in the scene. Such a language shifts the focus of industrial robot programming from coordinate based programming paradigm to object based programming scheme.

The rest of the paper is organized as follows: In Section 2 we give an overview explanation of proposed system architecture and the augmented reality module. In Section 3 we present test cases and Section 4 provides discussion and conclusion.

2. System Design

The Augmented Reality (AR) module is a part of our multimodal interface for controlling and programming the robot. It acts both as a visual interface which represents visual data about the scene and robot actions to the operator. It also acts as one of the input modalities and allows the operator to manipulate the AR scene by mouse and voice commands. The AR module is an extension of the virtual reality (VR) and simulation environment described in [ACSA09]. The augmented reality environment consists of the virtual models of the physical entities that are around the robots operating range, such as other robots, work-objects, tools, work-benches, etc. The objects and the robots are defined in local coordinate systems, therefore allowing the system to represent drop zones and gripping locations in object coordinates. Parent child relations are also kept for every object and their sub-objects. When an object is put into another object or over another object, it becomes its child object, and its coordinates and orientation are represented in its parent's coordinate system, which enables the system to track the objects location. If the parent object is moved then all the child objects follow the parent object.

The AR system consists of a camera which is mounted on the robot's gripper. In order to generate the virtual simulated scene for the same view, the OpenGL camera in the simulation engine will be following the robot's camera and the output from the virtual simulation system is overlayed on the video stream from the camera, thus generating the augmented reality scene for the user. Another benefit of having the camera on the robot's gripper is the fact that robot and operator share the same view and therefore the operator can supervise the working range of the robot through a single camera. It also helps the user to understand the scene better through the robot's view. In this work the camera is used by the user to monitor the workbench. Based on the view from the camera the user gives instructions to the robot. Note that, the main focus of this work is to evaluate the multimodal AR/Speech robot control system and we are not using the camera for object recognition (although it is possible). Figure 1 shows the ABB IRB140 robot with the mounted camera on our test setup.

As mentioned before, the AR frontend acts as a modality for controlling the robot through the multimodal interface. The user is able to select objects or drop places on the AR scene by a mouse. For example if the operator is planning to move an object from one place to another they can say 'move this' while clicking on the desired object and clicking on the target location after that. It is also possible to just move the object by selecting it and moving it to a drop zone through drag drop on the AR view. The operator will then be presented by the set of actions on the AR view which show robot's simulated plan for performing the command. Operator can then decide to execute or cancel the actions.

Augmented reality also acts as a mean for presenting visual feedback to the operator. All the recognized objects in the robot's field of view are presented with a green semi-transparent overlays and the selected object is presented with a red color including information about it. The information includes coordinates, orientation and any meta data associated with it (weight, material, etc.). AR view also represents robot actions to the operator. The actions and path to be taken by the robot arm are shown by red wireframe

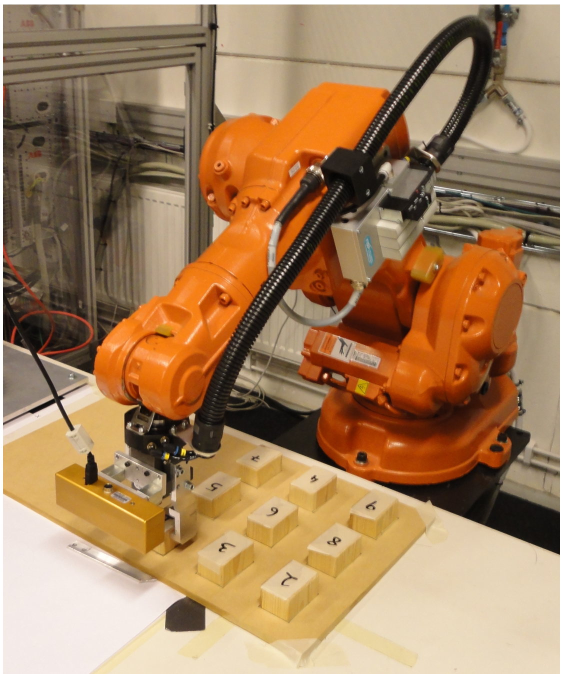

Figure 1: *Robot at work. Note that the camera is mounted on top of the gripper.*

cubes (gripper action) and yellow lines (movements). This allows the user to view the simulated actions and paths and revise or remove it before the actions are performed. Figure 2 shows a screenshot of the augmented reality interface.

Since the camera is mounted on the gripper of the robot, it is not always possible to visualize the paths to be taken by the robot, because the robot is not fully visible in the AR view. In such cases it is easier for the user to switch to virtual reality view, observe the path to be taken by the robot and switch back to AR view. Figure 2 shows two screenshots of the system, one in AR and the other in VR view.

3. Experiments and Results

In order to test efficiency of the augmented reality robot control interface, two tasks were defined and the participants were asked to perform the tasks by using the robot through the AR interface. The first task was simple and aimed at helping the users to get familiar with the interface. The second task was more complex and will be our main point of discussion.

3.1. Test Setup

A wooden palette is placed on the robot's workbench. The palette contains 9 drop locations which are organized in a 3x3 grid. There is also another drop location outside of the grid. There are also 9 wooden blocks which are numbered from 1 to 9. The grip locations on the blocks are predefined. The upper side of the blocks are also defined as drop locations, so stacking the blocks on top of each other will be possible. The whole workbench is accessible to the robot, so it can perform tasks on the blocks and palette.

Four subjects are asked to participate in the experiments. Two of them have no prior experience in operating industrial robots and two of them are professional robot programmers. A brief description of the system is given to all the subjects orally and they all receive the same instructions.

3.2. First Experiment: Stack-up

The goal of this task is to get the subjects familiar with the system, its commands and operation logic. Thus, it consists of the simple task of stacking all the blocks on top of each other. The order of the blocks is not important in this experiment. All the subjects could perform the task in almost 5 minutes and there was no visible difference between the performance of the subjects (professional vs unprofessional); therefore all the subjects find the instructions enough to operate the robot.

3.3. Second Experiment: Sort

This is a more complex task which challenges the subjects' ability to operate the robot: the blocks are put in a random order on different drop locations in the grid. The only empty location at start of the task is the one outside of the grid. The subjects are then asked to sort the wooden blocks inside the grid with block number one on top-left corner and number 9 on the bottom-right corner. There are of course many different ways to solve the problem, but the goal is to see if the users can use the robot to perform their plans easily. The test subjects used different approaches to solve the problem, but they all succeeded in sorting the wooden blocks in desired locations as they had planned.

During the experiment we noticed that some of the users decided to cancel some of the commands that they had given to the robot before executing them. This is due to the fact that the AR system gives immediate graphical feedback on the user's command; which in turn helps the user to visualize and review the results of that action. If the results are not similar to what the user had in his/her mind, they can simply cancel the command before performing it.

4. Conclusion and Future Work

Humans have the ability to absorb visual information with high levels of complexity in virtual environments and learn from visual medias faster than other ones [IMK09]. In this work we showed that integration of working area information and streamed video from robot's camera helps humans to operate and program a robot easier and faster. We

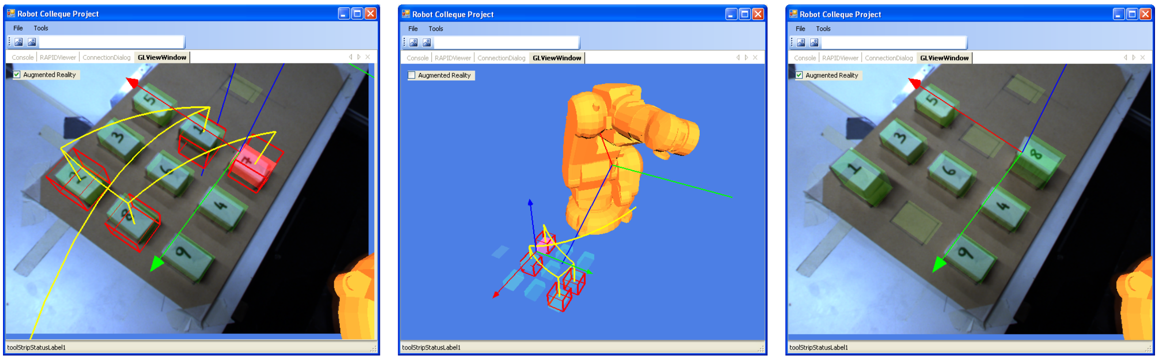

Figure 2: *Left: Screenshot from AR window. Yellow lines indicate paths and red cubes show gripper actions. Middle: The same scene at VR view. Right: AR view after performing the actions.*

have also showed that augmented reality interfaces can act as a 2way medium for interaction between the operator and the robot. In such a setup the AR interface presents graphical information to the operator in the form of live video and informative overlays. On the on the other hand, the operator can use the same screen to interact with the robot and its working area.

Designing and implementing richer AR interfaces which are capable of presenting and gathering more information through the same channel will be our next step towards a new generation of robot interfaces. Our final goal is to replace touch pendant controls with a more flexible device allows communication with the robot through the interface described in this paper. We believe that these interfaces alongside multimodal communication systems can change the way we program robots todays.

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