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Human-Robot-Interaction for mobile industrial robot teams

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Abstract

Due to high variants and small lot sizes, a conventional use of robots behind fences does not fulfill the requirements of today's production anymore. Therefore, the importance of mobile robot systems is increasing. In order to best use the capabilities of these robots, teams consisting of several robots or a robot and a human are built. For a cooperative work between robot and human, interaction systems are necessary. This paper describes an interaction concept, where the channel to the robot system is realized through gestures and eye tracking and the channel coming from the robot system is realized with projection.

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1. Introduction

The requirements for today's production base on the demand for individual products, which result in small lot sizes and a high amount of variants [1]. This leads to a need for a flexible production that can adapt to changing conditions. However, in high-wage countries, the degree of automation has to be increased in order to keep the producing company in this country [1].

In order to meet the requirements of both an adapting, bit also automated production system, the resources need to provide a certain amount of flexibility. A human worker is still the most flexible resource concerning the ability to adjust to changes, but raises the production costs. Next to the human, industrial robots are machines that allow flexibility due to their degrees of freedom [2]. The newer generation of industrial robots that are designed for the human-robot-collaboration have up to seven axes and include force-torque-control in their axes. This allows movements which are similar to a human arm and enables a sensitive handling of parts [3]. The enhancement of these robots by using them on an autonomous platform results in a further degree of freedom and a location-independent application.

However, implemented tools, such as a gripper or screwier, still limit the capabilities of one single mobile robot. Therefore, capabilities of different resources are joined to a team in order

to maximize the output by allocating tasks to the team member with the best skills to fulfill this task. This team can either consist of several mobile robots or mobile robots and humans. In the second case, a communication between the team partners is essential to achieve a common objective [4].

For a mutual communication between (mobile) robots and humans, this paper presents an approach for the integration of different interaction technologies to a mobile robot system. As input system, a gesture control and an eye-tracking system are implemented. A projector allows the presentation of information towards the human for a better understanding of the robot's actions. In this paper, a mobile robot is defined as a combination of an industrial robot arm on an autonomous guided vehicle.

2. State of the art

The following sections describes the state of the art regarding the individual topics, which are relevant for an improvement of human-robot-interaction. Firstly, current works in the field of human-robot-collaboration concerning the interaction are introduced, which are followed by researches focusing the human-robot-interaction not only in the industrial environment. The section finishes with a summary of current interaction technologies.

2.1. Human-robot-collaboration

In a human-robot-collaboration, both entities operate in the same workspace and work together on a task. Many researches in this area regard the planning of such an application or the programming of the robot [5]. For the operation mode, when robot and human actually perform their tasks, most approaches focus on the adaption of the robot to the human [6–9]. In these approaches, a decision system enhances the robot system in order to evaluate and perform the next task of the robot. Furthermore, these approaches address the application of a stationary robot within the human-robot-collaboration. For the interaction between human and robot during operation, some approaches use interfaces, such as presented by Tsarouchi, who presents the current task to the worker on a display [10].

Although many approaches exist that work on the collaboration of human and robot, they mostly do not focus on intuitive interaction technologies for an interaction between human and robot in industrial environments.

2.2. Human-robot-interaction

The interaction between human and robot is mostly realized by user interfaces, which are defined by DIN EN ISO 9241-110. Human-robot-interaction is part of the human-machine-interaction that can be described as the information exchange between human and machine [11].

The capability of robots for the interaction with a human depends on the type of robot. DIN EN ISO 8373 distinguishes industrial mobile robots from service robots. Thereafter, the target of an industrial robot is automation and of a service robot the performing of tasks for people or institutions [12]. Whereas industrial robots offer only a few interaction capabilities, other robots, such as service robots, are designed for the interaction with humans. According to Goodrich, the media for human-robot-interaction includes visual displays, gestures of hands and face, speech and natural language, non-speech audio for alerts and physical interaction and haptics [13].

The interaction technologies in the field of industrial robots were limited for the time when the robots worked behind fences [14]. With the decreasing distance between human and robot and the increase of human-robot-collaboration, the meaning of human-robot-interaction for industrial robots increases [5, 15]. In this context, gesture recognition is evolving [5]. Besides gesture control, the use of speech recognition is being researched. Bugmann and Pires (2005) developed and evaluated speech recognition in an industrial context [16].

Besides the direct interaction between human and robot, when they work next to each other, interaction occurs through teleoperation. In this case, the robot is manipulated by a user in a remote environment [17].

2.3. Interaction devices and technologies

A human has different senses to interact and communicate with his environment including seeing, hearing, smelling, tasting and fumbling. These can be described with the

modalities visual, auditory, olfactory, gustatory and tactile. Next to these five senses, pressure and force can be recognized by haptic and touch and vibration through a tactile modality [11].

The modalities can be divided in input and output channels to allow an interaction [18]. Whereas a human can use its senses, a robot system has to be enhanced by sensors.

To start an interaction, there is a request for information or a command as input. This is usually followed by an information or command sent back to the user. The exchange of these information is a simple form of a dialog to generate an interaction between two or more entities [19].

In order to enable this dialog between two entities, different interaction technologies exist. These can be divided into input and output technologies. Input technologies include keyboards, acoustic, optical and haptic components and input systems for virtual environments [20]. The output of information is mostly realized by monitors, but technologies for acoustic or tactile output are currently increasing [20]. In addition, the application of projector technologies is growing [21]. These allow a wider display area than monitors and use LCD, DLP, Laser or LED-technologies. Next to these output technologies, Augmented Reality gains importance. Augmented Reality combines virtual presentation with the real environment through the overlay of these pictures on the reality [22]. Interaction technologies that combine input and output are touchscreens, which are mostly applied for tablets and smartphones.

The above-mentioned devices allow an interaction with the user without or with few algorithms following the interaction signal. More advanced interaction technologies are gesture control or speech control where the signal has to be processed before a machine's reaction. For the gesture recognition, a camera device is applied in order to record the body parts or movements. There exist many approaches using a Kinect ® sensor [23–25].

There are many different interaction technologies and also many approaches for an industrial use. The use on a mobile industrial robot however, is currently rarely regarded.

2.4. Need for action

The specific requirement for mobile robots in an industrial environment is the application of a robot arm in order to handle objects. Although many service robots already use different interaction technologies, the robots in an industrial context are mostly not able to interact with a user. The interaction technologies used for service robots can partly be transferred to an industrial context, however, not all of the properties are suitable due to different targets of the interaction in industrial environments. Therefore, it is evaluated which technologies can be transferred and how the industrial robot's interaction technologies can be enhanced.

3. Interaction technologies for industrial mobile robots

As described, the aim of the approach presented in this paper is to enable mobile robots in an industrial context for an

interaction with the user in order to perform a common task as a team.

For the identification of capable interaction technologies, the work of Goodrich and current technologies in the field of service robots were regarded. As mentioned above Goodrich names the following technologies as interaction technologies in a robotic context: visual displays, gestures of hands and face, speech and natural language, non-speech audio for alerts and physical interaction and haptics. Interacting service robots offer a range on interaction technologies, such as touch displays, hands for gestures, microphones for audio input, speakers for audio output and sometimes have a face. Since the main target of service robots is the communication, not the physical support, the interaction technologies can only be transferred partly to the industrial system, because the different purpose requires different commands and information.

Interaction by speech, which is a common used technology for service robots, is firstly excluded in this concept due to a noisy environment in production. Displays will be integrated into the concept, however at this stage, the focus is the interaction with a mobile robot which should also be possible from a little distance between human and robot. Thus, a display on the robot is not regarded in this paper. Non-speech audio systems for alerts are already used on industrial mobile robots and stay on the robot system.

After this exclusion of some interaction media, gestures of hands and face stay as possibility. Furthermore, instead of a display on the robot platform for the presentation of information, a projector is addressed as described in section 3.2. Through this, information can be displayed in a bigger size and is therefore capable for mobile robots and the recognition from a distance. The information exchange between human and robot is divided into input of commands or information to the robot system, and the output of information coming from the robot system. The next sections describe the three evaluated interaction technologies, which were implemented for evaluation.

3.1. Command Inputs

In a human-robot-team, the user has to be able to give commands to the robotic partner in order to stop or pause its movements, especially in a dangerous situation, to show the next step or to start a task. Contrary to the programming of conventional robots, the input of commands should be easy for the user to perform, or even be intuitive. According to Köpsel, intuitive in the context of gestures, means easily to retrieve and remember, as well as easily to learn and execute [26]. In this context, the gesture control by hands and by eye tracking are regarded.

3.1.1. Gesture Control

Hand gestures represent an essential expression of humans. This form of expression is used for the easy input of commands and the communication between human and robot. Gestures are usually used in an intuitive manner according to the situation. For an application in the context of mobile robots, a study within the project was conducted to identify intuitive gestures

executed by a human in different situations. In order to detect gestures, a camera system must be chosen and installed to mobile robot. Other possibilities in order to track a gesture by using a worn sensor is not considered due to the context of mobile robots where every person within the production would have to wear such a device. The requirements towards the gesture control were defined as followed: the gesture should not be recognized when the user is moving and not intending a gesture, the gestures should not be confusable for the system and the gesture should be recognized by the system at the first execution.

3.1.2. Eye Control via eye tracking system

Eye Control is the ability to control technical systems using the eyes. Thereby, a camera system sends out infrared rays, which are reflected by the eyes of the users. Through the reflection, the viewing direction can be calculated [27].

The application of eye tracking systems are usually the recording of eye movements for evaluation purposes or the control of machines. A concept for the control of a robot by eyes has been presented by [28].

Eye tracking systems can basically be divided into two designs. The first variant is the wearing of the eye tracking system directly on the person. The other possibility is an external system that can be adjusted to monitors.

As stated, eye tracking systems can be used for the control of machines. A human worker that is working with both hands is similarly unable to give input on a tablet or with gestures and therefore gestures of face or eyes are evaluated.

Besides the usage of the eyes as control, the attention of the user towards the robot can be determined. Similar to two communicating humans, a long glare at someone can mean an intention to interact with the counterpart. Thus, the eye tracking installed on the mobile robot, can detect a glare of a human worker by detecting his eyes and count the seconds of the glare. This detection results in a stop of the robot and the change into an interaction mode. The control of the robot using the eyes is the second concept, which however is similar to the attention detection concerning the technical processing of the data.

3.2. Output of Information

In order to improve the understanding of the user towards the robot's behavior, information about its status can be presented. For the identification of usable technologies in the context of mobile robotics, firstly current technologies have been researched which were evaluated afterwards. In a first evaluation, some technologies that seemed not applicable for mobile robotics, were eliminated. Virtual Reality was eliminated, because the user would have to wear the glass constantly and could not further perform his actual tasks. After the elimination of some technologies, the following technologies were identified as applicable: control lights, display, projectors, Augmented Reality, speakers and headphones, vibration and smartphone and smartwatch as multimodal output technology.

For the identification of currently used output technologies in the field of industrial mobile robotics, a study was conducted

were the properties of robots have been recorded and evaluated. The result showed, that visual output technologies cover control lights for the representation of the status, the charge of battery or dangerous situation. Next to visual components, speakers are applied for simple signals and alerts and not for speech.

4. Implementation and Evaluation

In order to evaluate the effects of the interaction technologies in an industrial context, the interaction technologies were implemented on a mobile robot named SCOUT. For the gesture recognition, a Kinect® V2 is used. For the eye tracking, a system by Gazepoint is adapted and a pocket beamer realizes the projection. The system architecture is shown in Figure 1.

The mobile robot consists of two control units. The first one is responsible for the evaluation of the individual interaction systems and is called Interaction Unit. On the one hand it sends action commands towards the Robot Control Unit to start movements and on the other hand receives the actual state of the mobile robot system to display them via the pocket beamer.

The individual systems are directly connected to the interaction unit of the mobile robot. The Kinect® V2 and the Gazepoint system use an USB-interface to send their data and the pocket beamer is connected via HDMI. In the interaction unit there are different programs running, which collect the data of the Kinect and the eye tracker. After the analysis of the gestures, the appropriated command will be sent via an Ethernet connection to the robot control unit and the robot starts working.

To bundle the information flow an additional program is implemented within the interaction unit, which is called Multiplexer. The individual programs of the gesture recognition and output engine are connected via an internal TCP/IP connection to this Multiplexer. The data is collected and specifically sent to the robot control unit not to overload the system buffers.

The output engine running on the interaction unit is responsible for the presentation of the actual state and moving parameters. Thus, the actions of the mobile robot are more transparent for a user.

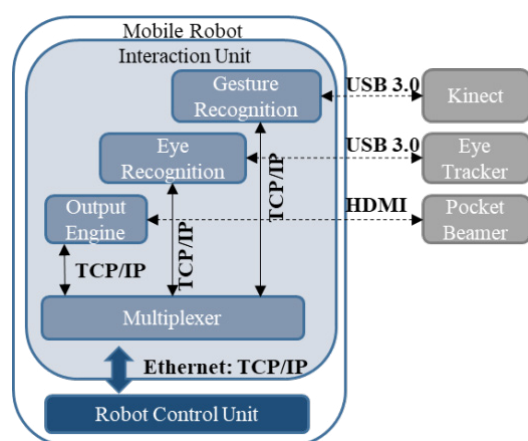


Fig. 1: System architecture

The exact function of the individual interaction systems are described in the following sections.

4.1. Implementation and Evaluation of Gesture control

An implementation of the gesture control on a mobile robot allowed the evaluation. As seen in figure 1, the gesture recognition communicates with the mobile robot by USB.

For the observation of the gestures, a Kinect® camera is used. The target was to identify gestures that can be recognized robustly by the system.

The different gestures are recorded and stored in a database. For the recording of the gestures, the Visual Gesture Builder provided by Microsoft was used. According to researches, Microsoft suggests to store as few gestures as possible, because a user can normally remember only six gestures and more gestures in the database can result in interferences. The Gestures can be divided into discrete and continuous gestures. Gestures, that describe one certain state, are defined as discrete gestures. Examples are an open hand or the victory sign. The detected state is represented by a binary value: detected or not detected. Continuous gestures follow a defined sequence of movements and can be detected progressively. Waving or clapping are examples for continuous gestures.

After the first evaluations using discrete gestures, it could be ascertained, that the solemn use of discrete gestures is not capable for a robust gesture recognition, because the detection is not sufficient. For an improvement of the detection, a discrete gesture was combined with a continuous gesture.

In total, seven different gestures were implemented and evaluated, whereas three of them are basically the same, but designed for left and right side. The following table 1 summarizes the gestures:

Table 1: Description of gestures

Gesture	Sequence
Gesture 1	Right fist to chest --> extension of right arm --> full extension of right arm with fist and shortly remain in position
Gesture 2	Same as above with left hand and arm
Gesture 3	Right arm points towards floor; hand in lasso position --> lift right arm; hand is still in lasso position --> lift right arm to right angle, keep hand in lasso position and shortly remain in position
Gesture 4	Same as gesture 3 with left arm and hand
Gesture 5	Both arms show towards floor, hands are open --> both arms lift up to right angle, hands are open --> left hand closes to fist, right hands stays open
Gesture 6	Left arm in salute position, hand is open --> extension of left arm, hand is still open --> full extension of left arm and shortly remain in position
Gesture 7	Same as gesture 6 with right arm

In order to evaluate the gesture recognition for the application with the mobile robot, several testers executed the gestures while the system tried to recognize them. The evaluator recorded if a gesture was correctly recognized, if several attempts were necessary for the recognition or if the wrong

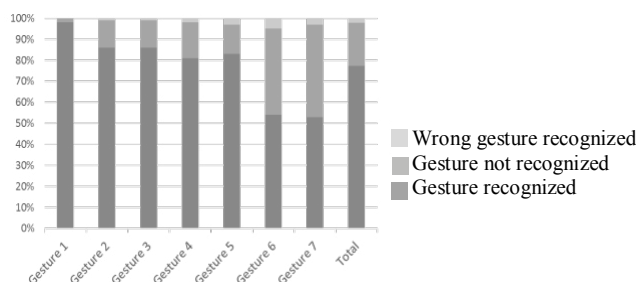


Fig. 2: Results of evaluation

gesture was identified. Every person executed each gesture ten times. The sequence of the different gestures was randomly chosen. The following diagram shows the rate of recognition for the different gestures:

With regard to mobile robots the important gestures are a stop command and gestures to show the direction for movements. Gesture 1 (Tab. 1) is implemented as the stop command to terminate the actual movement of the robot. With gestures 3 and 4 (Tab. 1) the user can give direction commands towards the robot to show the position where the robot can bypass the user for example.

4.2. Implementation and evaluation of eye tracking control

For the eye-tracking control of the mobile robot, an eye-tracking camera was installed. The camera is applied to detect the attention of people looking at a screen. For this purpose, the position of the pupils is tracked.

For the evaluation of the eye control, two use cases were implemented: The first case is the detection of the attention of a user. The person who wants to interact with the mobile robot gazes at the system. This gaze can be detected by a long eye contact with the eye tracking system, which the seconds with open eyes without blinking are counted for. This will set the robot into an interaction mode and helps to prevent unintentional commands to the robot.

The second case is a control of the mobile robot by commands via eyes. After setting the robot into the interaction mode as described, a command to the robot can be given by blinking twice. Tests have shown that the blinking has to be executed in a certain manner: a little time difference between both blinks must be ensured in order to give the command.

Besides, also more complex commands can be transposed by the eye tracking system, such as an active control of the mobile robot. Here, the look of the controlling person on a certain position leads the robot to move to this point. The coordinate system of the eye tracking camera and the internal navigation system of the mobile robot have to be combined to give movement controls to the robotic system.

The implementation of the eye tracking system on the mobile robot system shows that it is as possibility to set the robot into an interaction mode or give an input command. This is useful to prevent the input of unintentional commands and makes it feasible to communicate hands-free. However, the range of the tested eye tracking system with only 1 ms is not enough in order to detect people's eyes robustly.

4.3. Implementation of projector

The presentation of information towards the user by a projector was implemented on the mobile robot. During the development, the projector was a pocket beamer with a maximum of 50 Lumen and a resolution of 640 x 360 Pixel. The pocket beamer is installed on the robot so that it shows towards the floor where the pictures are displayed. The displayed information contains the moving direction, the robot's target and the charge of battery. The development of the displayed picture took place in accordance with DIN EN ISO 9241-12. This results in the limitation to five colors, red, green, orange, white and black and the bolding of the font. The display can take two different shapes. While the robot is moving forward, an arrow with the moving direction and the target is depicted. When the robot is turning around, moving backwards or stopped, the display changes and the information is shown in textual form.

In order to show information about the robot, this information must be transferred to the program where it is processed. For the used robot, the moving direction within the robot's trajectory cannot be extracted from the transferred data. The information that can be gained is the current position of the robot in a time frame of 100 ms. Thus, the moving direction is calculated and the arrow is designed dynamically based on the past positions of the robot.

The implementation of the pocket beamer showed the functionality of the application. However, it can be detected, that the light intensity is not sufficient to depict the information clearly in an industrial environment with lights turned on. Therefore, a different beamer with a luminosity of 800 Lumen substituted the first installed pocket beamer.

The presentation of the information on the floor helps the user to understand the robot's movements and intentions. Therefore, the user can react faster when detecting the robot and the movements are more transparent towards the users.

5. Summary and outlook

The paper presents an approach for the extension of a mobile robot system towards the capability of the interaction with a human. The target of the interaction technologies are intuitive input of commands on the one hand and the presentation of information towards the user on the other hand. For the intuitive input, a gesture control via Kinect® and an eye control through an eye tracking system are implemented. The presentation of information is realized through a projector

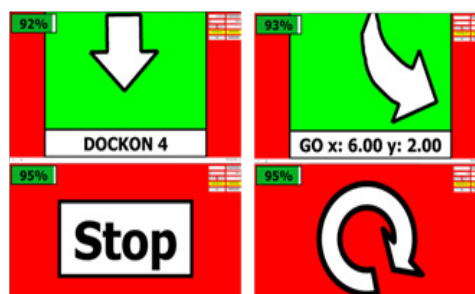


Fig. 3: Projected information

depicting information about its status, such as the moving direction and its target.

The implementation and evaluation shows that the technologies by themselves are applicable for the application in the context of mobile robots. In the further steps, these separated technologies will be linked to each other in order to realize a dialogue between user and robot. Then, a command by the user will be answered by an output through the robot system.

Furthermore, the mobile robot will be extended by the functionality to learn from the interaction with the users. So, it is possible that a mobile robot can communicate with no pre-defined answers to special input commands. This causes a higher degree of information output possibilities. Besides, the system will be more flexible because not every input command has to be programmed.

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