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DEVELOPMENT OF A ROBOT-HUMAN -INTERFACE USING AN RGBD CAMERA

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ABSTRACT

Against the backdrop of global economic development, industrial assembly in Germany is in a state of change, prompted by the country's high-wage business environment. This article describes the need for new technologies to the increase flexibility and security regarding human-robot cooperation. Furthermore, a possible model for managing this transition is described on detail, involving the use of an RGBD camera from Microsoft. With this camera, it should be possible to detect state and position changes of people in a human-robot workstation and consequently adapt the movements of the robot. Overall, the essential aim of this paper is to suggest ways to increase economic efficiency within assembly processes along with increasing security.

Index Terms – Human-robot cooperation, face tracking, RGBD camera, adaptive technology, robot manipulator

1 INTRODUCTION

The demands on the production line are constantly increasing, meaning that automation solutions must become more flexible in order to manufacture products in small batches to fulfill customer requests. Meanwhile, fully automated production lines are inflexible and cost-intensive, while manual production, which is also cost-intensive, is slow and error-prone. It is for these reasons that, in the future, the human and robots need to work together without the need for a safety fence, so that the benefits of robot-based automation and increasing flexibility can be exploited in an efficient way. The configuration of new workplaces along these lines will be dividing into according to coexistence, cooperation and collaboration (Fig. 1) [1].

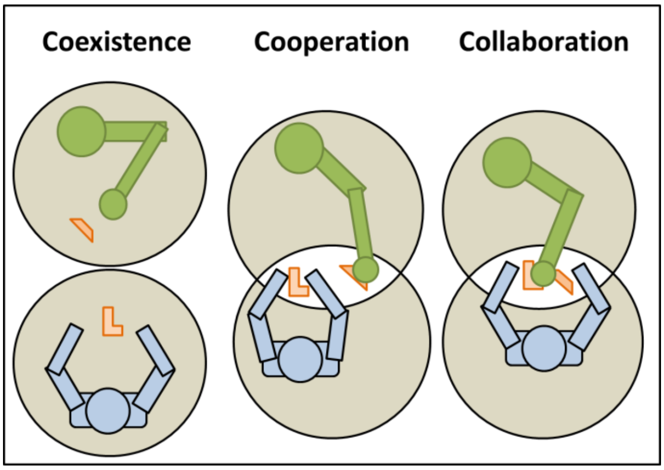

Figure 1. Realization possibilities of human-robot workstations (according to [2])

At the moment, human-robot coexistence represents the most frequently integrated solution in the context of industrial production. The risk of injury is very small due to the imposition of separate workplaces. In this scenario, humans and robots perform different duties in separate working areas. In the context of human-robot cooperation, working areas are aligned, but operations are kept temporally separate and executed in rotation. In a collaborative setting, however, direct interaction takes place, as spatial and temporal separation is broken down. In this context, safety requirements for human-robot cooperation and collaboration are increasing in importance [3].

To be able to provide the necessary security, for example, camera systems are used to monitor the workplace or sensor systems are directly integrated into the robot [3]. If humans and robots are kept separate in a workplace, the activities to be carried out are designed in such a way that the skills of both are productively used. Nevertheless, factors such as inattentiveness, distraction and tiredness among humans can influence the manufacturing process and negatively impact on the quality of the process and the volume of production. Therefore, the aim is to connect humans and robots via modern automation. This technology recognizes the fact that the humans, like robots, are empowered to make decisions regarding the operation sequence. Consequently, the security of the process should be guaranteed without endangering the health of the human [4].

This paper is organized as follows. First, the foundations are summarized with regard to human-robot cooperation. The application area, related challenges and system requirements are described closer. Next, the setup of a demonstrator for the purposes of implementing the project is discussed, after which the results are presented with regard to data capture and analysis by means of an RGBD camera, as well as a discussion on the necessary software for implementing this software in the demonstrator. The paper ends with a summary.

2 THEORETICAL FOUNDATIONS

2.1 Possible application

The number of robots is steadily rising, with recent studies suggesting that, in 2016, there were 301 robots per 10,000 manufacturing employees in Germany [5]. This makes Germany the European leader in this field. For this reason, the current paper deals with the application of robots in industrial production. This kind of application is varied, although up to three quarters of robots are used in the automotive industry, as well as the metal and electrical industries [5].

To be able to design more flexible and profitable production processes, the application of robots is also indispensable in manual workplaces. However, full automation is still not possible, particularly in areas such as assembly lines, given that some work patterns cannot be carried out in the absence of the motor abilities of the human. The human can work without sensors or other measuring instruments; for example, the human is able to easily assemble elastic parts. That said, the robot can perform its work patterns with higher levels of repeat accuracy and perseverance, as well as take over functions involving holding or moving heavy components or operating in danger areas. For this purpose, not only is further development of robots needed; it is also important to develop applications guaranteeing the security of the system involving human-robot cooperation in assembly processes.

2.2 The human

The human offers essential advantages over robots and machines due to intuition and flexibility. That’s why it is necessary to integrate the human into the assembly process. Nevertheless, the human also incurs risks because he/she is a partially unpredictable component. The movements by the human cannot be clearly defined, which is why it is very difficult to design appropriate safety regulations for the workplace. This difficulty is based on the fact that the human intuitively performs movements (e.g., gripping, running, sneezing or bending down), which cannot be defined by a fixed path, unlike robot motions. Alongside human movements, there are other legitimate factors, which have an important influence on the productivity; quality and security of the used system (see Fig. 2). Influencing factors on the behavior or physical construction of the human can be divided into two areas: external and internal factors of influence.

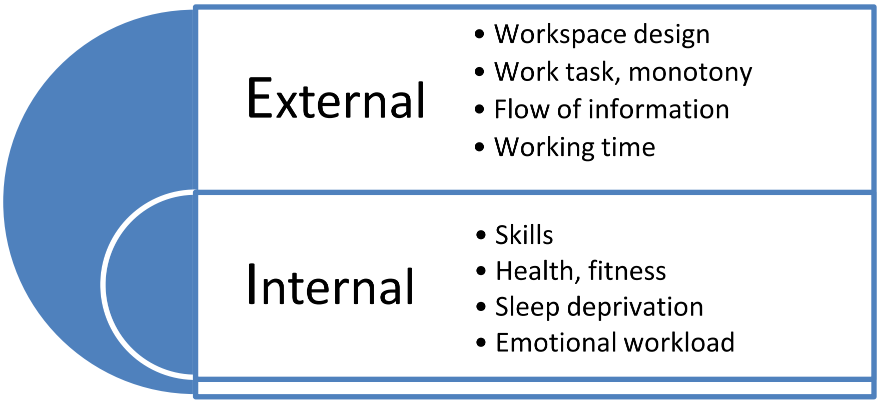

Figure 2. Factors of influence on the physical and emotional state of the human

From an entrepreneurial point of view, external factors can be controlled. For example, lighting, ergonomics, sound levels and room temperature play an important role in workspace design. Special working time models can also contribute to an increase in productivity by employees. In particular, a three-shift operational model can prevent tiredness and exhaustion. Meanwhile, as carelessness can be the result of monotony, it is important to design a varied work schedule or swap jobs between employees after a defined time [6].
Other than the previously mentioned factors, the company has no influence on internal factors. However, complaints due to illness, tiredness and physical strain also have a significant influence on the physical and emotional state of the human. Since internal factors are unpredictable, it is not possible to take them into account when designing a workspace. This is why the consideration of these factors only involves analyzing the state of the human and his capacity to react in an optimal way, with the aim being to ensure the safety of the system and the human [7].

2.3 The robot

Robots are complex machines, which are shown to have a high danger potential on account of their acting force and moments. From the point of view of work safety, then, it has been necessary to spatially separate the human from such a potential source of danger. Therefore, protective facilities have been established between humans and robots in such a way that collision can be reasonably prevented. For economic reasons, however, this spatial separation does not make sense, for example, on assembly lines, especially at the present time.
As already mentioned in 2.1, conventional industrial robots are suitable on account of their size and acting forces, rather than their capacity to be used in collaborative applications, due to the high risk of injury for the human. Lightweight robots have been developed for this reason. These robots are smaller and lighter than industrial robots. Furthermore, they are so designed that their structure involves the least possible number of sharp edges, which present a high risk of injury. An important advantage over their industrial counterparts is these lightweight robots' integrated capabilities, enabling, for example, the setting of different safety levels. This is very important for the realization of a 'fenceless' operation.

Nevertheless, based on observations of live applications, additional safety measures are essential, such as the adaptation of the robot speed. Even if a robot is supposedly secure, it is important to monitor how tools are used, as well as its geometry and mass [3] [8].

2.4 Safety of human-robot interaction

To guarantee the safety of a robot system, different regulations have been published. In this paper, cooperating and collaborating with robot systems are preferred. Therefore, the framework conditions presented in EN ISO 10218-1 [9] and EN ISO 10218-2 [10] are closely considered. EN ISO 10218-1 describes the safety requirements for industrial robots in the context of collaborative interaction. However, this regulation only refers to the robot itself, without any consideration of the periphery. For that reason, this regulation on its own is not enough to certify a safety system. EN ISO 10218-2 also considers safety regulations with regard to collaborative applications. ISO/TS 15066 [11] is another technical regulation that refers to robots and robotic devices, describing the safety requirements of a collaborating robot system, as well as the working environment. In this paper, only robot systems that have been developed after the publication of EN ISO 10218-1 and EN ISO 10218-2 are considered, along with other relevant norms for safety, such as ISO 13854 and ISO 13855.
A comprehensive risk analysis should consider not only the robot system, but also the entire working area in order to guarantee the safety of the system. In turn, it is mandatory to identify all hazards. These are divided into robot-related hazards and user-related hazards, which are linked with the robot system. On account of the acting forces and moments, there should be monitoring of collaborating robots in terms of their speed, force, moments and position. This monitoring should help to avoid injuries. Biometric limit values for the maximum permissible force and pressure during quasi-static and transient contact are summarized in ISO/TS 15066 [11].

3 SYSTEMS ENGINEERING

The aim of this research project is to develop an interface between a robot and a human for an industrial assembly process. In the used experimental setup, an assembly process is presented involving a simple design (Fig. 3). An essential part of developing adaptive technologies is data capture and data processing. The main component in the experimental setup is Universal Robots' lightweight robot (UR3). With a working radius of 500 mm, the UR3 is especially appropriate for working with impaired spatial capacities [12]. According to the manufacturer's data, the UR3 safely collaborates and conforms to the requirements of EN ISO 10218-1:2011 [13]. The robot disposes of power- and force-limited functions, while collaborating with safety-specific functions, which allow for operations to be performed without a safety fence.
Furthermore, the Microsoft Kinect 2.0 sensor is used. Unlike the robot, the camera does not meet safety regulations, which is why the camera is only used under laboratory conditions for the purpose of this research. As the Kinect sensor serves as an interface between human and robot, it is used to capture the facial expressions and the body motion of the human. The experimental setup consists of a PC with image processing software, as well as an external PC for robot control.
The working area is divided into two parts. Firstly, there is a fully automated robot process involving a workstation, which serves as a buffer, allowing the robot to work automatedly when the human is not present. From an economic point of view, it is important to avoid robot downtime. Secondly, there is a cooperative human-robot process involving a workstation where the motor skills of the human need to be aligned with the repeatability and perseverance of the robot.

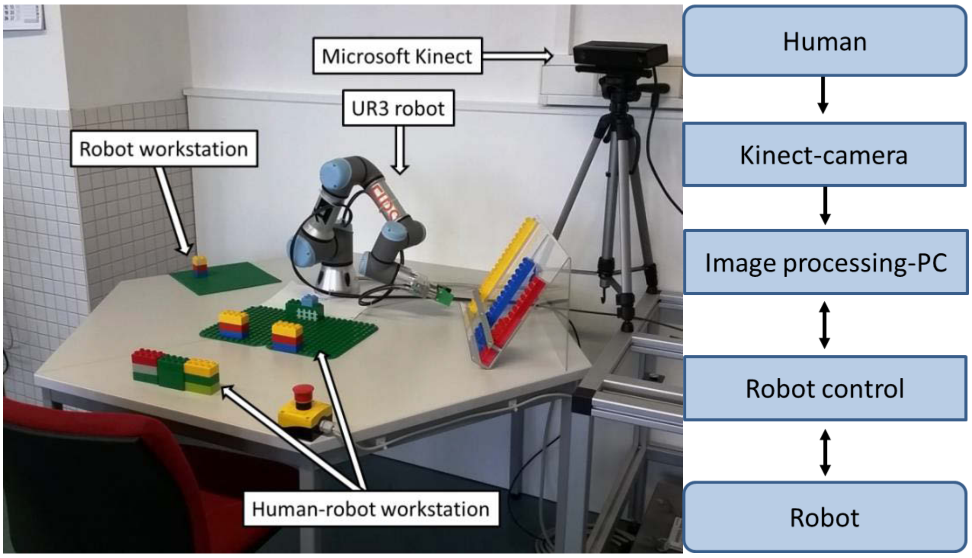

Figure 3. Human and robot workstation (left) and block diagram of the system design (right)

For system control, software is developed in order to receive and process data from the image processing PC. Furthermore, these data are sent to the robot. The software should be configured in such a way that the robot stops if the vision direction of human is outside the work cell or the human leaves this area. Another feature is a visual signal that appears as soon as a critical change in the condition and/or position of the human is detected. When the human is informed about his/her current condition and/or position, he/she to decide whether to continue working or take a break. If the human decides to take a break, the robot can continue the automated process.

Within the demonstrator, different approaches involving possible influencing factors can be explored. First, the facial expressions are analyzed from the point of view of increasing process reliability. For that, the eyes and mouth need to be closely considered. If the eyes are closed and the mouth is open for a longer time, for example, this may be an indicator of tiredness. In such a case, the software can help to avoid failures made by the human or injuries to the human.

A second approach is to observe the viewing direction of the employee. If the employee is in his/her place viewing the workplace, the process may be performed as intended. But, if the direction of vision is outside the work cell, this could reduce robot speed or stop the robot from working altogether.

Finally, the position of the human can be detected. When the human sits in front of the workstation (e.g., as in Fig. 3), the process may also be performed as intended. But, if the employee stands up he/she cannot continue working in such a position, so the process comes to a halt.

4 RESULTS

The experiments were divided into two sections: 1) data capture and evaluation by the Microsoft Kinect sensor, and 2) development and implementation of the software for the experimental setup with the robot. First, the possibility of data capture will be described in more detail. In this research, the camera's internal software for face recognition was used to examine the movements of the eyes and mouth close up. The local coordinate system of the camera is in the center of the infrared sensor (Fig. 4), thus forming the basis of this exploration. The orientation of the head in the space involved three variables: pitch, yaw and roll by the camera. These variables described the rotation of the head around the x-, y- and/or z-axis in relation to the local coordinate system.

Figure 4. Position and orientation of the camera coordinate system

Our examinations proved that the face can certainly be detected in an area from ±25° in relation to the rotation's pitch and yaw, as well as ± 45° for the roll (Fig. 5). This means that the camera must be in front of the human to detect his/her face. However, this is not possible given the position of the human-robot workstation. Since the robot covers the camera image, this can prevent data capture or even damage the camera. The analysis of facial features during human-robot cooperation is not possible at the present time, which explains why it is necessary to adapt the experimental setup in such a way that the camera can be integrated into the workstation. Another possibility is to use two cameras, which are installed alongside the workstation. Thus, an unobstructed view of the area and a bigger detection range can be realized.

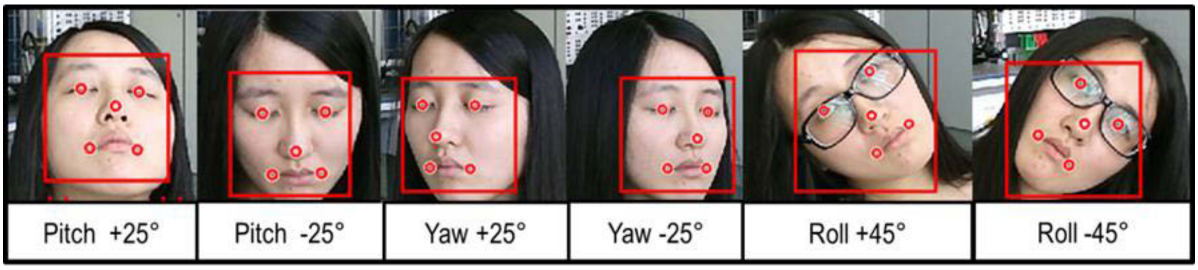

Figure 5. Workspace for face detection using an RGBD camera

The situation is different in the case of motion monitoring of the human. For this, it is sufficient to place the camera in such a way that the human can be clearly identified. The joints that are considered for positioning the employee are indicated in Fig. 6. The left picture shows the reference position while work is being performed, while both pictures on the right describe the position of a human who can no longer perform the demanded work. It is possible to clearly define the joint position in space by using a depth sensor, which means that the respective change can be determined in the XYZ-direction. These data should be sent to the robot in future.

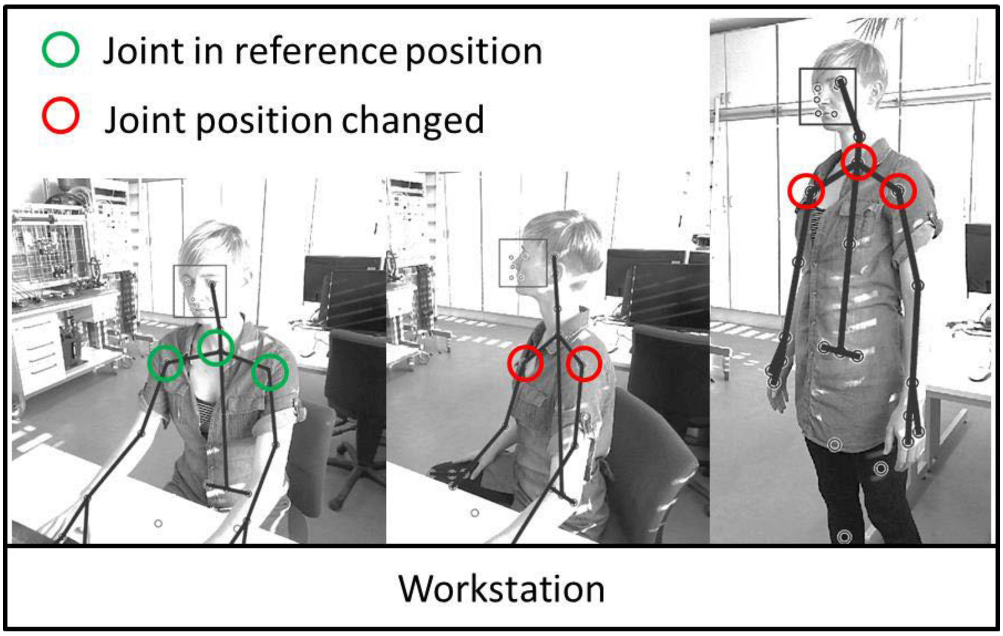

Figure 6. Determination of the joint position of the human

So that the camera data can be used, it is necessary to control the robot using an external computer, which means that an interface needs to be newly created. Compliance with the safety regulations for collaboration is given. Furthermore, image processing software should be integrated in order to control the robot via the external computer. For increasing safety, other measures are necessary. First, a safety stop should be initiated if the human leaves the workstation or overshoots the robot's workstation in bodily terms. Furthermore, the robot speed should be adapted as soon as the employee turns the upper part of his/her body away from workstation. In addition, a visual signal can be added in the form of an orange or red light as a warning signal. Finally, it is proposed that the robot performs a fully automated process when the human leaves the workstation. This should be carried out with the agreement of the human or independently by the robot.

5 CONCLUSION

This article has presented a concept for implementing the necessary conditions for human-robot cooperation via a Microsoft Kinect sensor. The aim was to develop and operationalize a demonstrator for human-robot cooperation. Using an RGBD camera to record facial features, it was not possible to achieve this aim. As such, the experimental setup must be adapted. That said, it is possible to monitor changes in the position data of the employee during work. On account of these data, movements caused, for example, by diversion or inattention can be identified, such that the system is able to react. In future, software for motion monitoring of the employee should be transferred to the robot controlling computer. This should serve to increase the safety of the system by reducing robot speed or operating a safety stop, as soon as position changes in the human are detected.

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