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Safeguarding and supporting future human-robot cooperative manufacturing processes by a projection- and camera-based technology

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Abstract

This contribution aims in presenting a projection- and camera-based technology that provides not only the safeguarding of humans but also capabilities for supporting and assisting the human in human-robot cooperative manufacturing processes. The proposed technology establishes dynamically generated safety spaces by directly projecting them into the shared workspace thus separating human and robot. Besides the safety aspect the proposed "speed and separation monitoring"- technology also allows the visualization of arbitrary information as well as interaction functionalities with the robot, process or system. This technology and its beneficial functionalities will be presented on basis of an industrial demonstrator featuring a screwing application.

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1. Introduction

The International Federation of Robotics (IFR) [1] forecasts that the number of newly installed industrial robots will reach 1.4 million by 2019. With this increase of robots in industrial automation, the demands for human-robot cooperative workplaces are also set to rise. Manufacturing processes that allow concurrent work of humans and

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robots in a shared environment require that the human is safeguarded at all times. But in future industrial manufacturing the hard-safety aspect won't be the only requirement to such cooperative workplaces. Soft-safety, interaction functionalities and worker assistance will contribute to an overall flexible and innovative human-robot workplace.

For monitoring human's safety we can differentiate between two approaches. The first one generally permits contacts between human and robot but it ensures that the arising forces are below the accepted thresholds. This "power and force limiting" – approach is used to design collaborative robots like KUKA Iiwa [2][3], the Universal robot [4] or Fanuc CR-35iA [5]. Besides these cobots there are sensory developments existing that enable industrial robots for safe human-robot collaboration. Pressure sensitive sensors are used to enclose the robot like an artificial skin to detect and to cushion collisions between human and robot [6][7]. Further developments are used to observe the nearby environment to detect objects in close proximity of the robot. Such sensors like ultra-sonic sensors or capacitive sensors are directly attached to the robots surface and may lead to a reduced robot speed or entire motion stop at object detection [8][9][10]. But, all of these solutions are only practical for small or mid-sized shaped robots and they require additional safety systems for monitoring additional tools and workpieces at the robot.

Safety systems that consider the entire robot system with tools and workpieces are following the concept of "speed and separation monitoring". Potential collisions between human and robot are detected in advance and can be avoided by particular reaction strategies of the robot. An innovative approach is based on pressure- sensitive mats that build up a tactile floor for monitoring the human's behavior [11]. Other systems are based on camera techniques. The optical sensor systems are mounted stationary in the environment for monitoring the robot's workspace and can consist of several camera combinations and configurations [12][13][14]. On basis of the camera's data the current distance between human and robot is determined which is further used to initiate a motion stop, speed reduction or trajectory adaption of the robot. A safety-certified monitoring system based on stereo-camera techniques is already commercially available by Pilz [15]. However, a main drawback of these optical sensor systems is whose dependency on environmental light conditions. Furthermore, the human is not aware about the separation distances that are actually monitored by the safety system. Unintended violations of the safety spaces by the human lead to a decreased availability of the robot and the entire system.

The main benefits of the proposed projection- and camera-based approach for workspace surveillance are the reduced dependency on environmental light conditions, intrinsic safety, high potential for safety certification and overall valuable functionalities [16]. Here, the capability of providing virtual interactive buttons that allow the control of robot (start/ pause motion), system (choose/ manage task) and process (confirm production step) offers an intuitive communication. Besides interaction, the system also offers the visualization of safety-, robot- or process-specific information by projecting them directly into the shared workspace to support the human at work, configuration-time, and even for failure diagnosis.

2. Projection- and camera-based technology

The projection- and camera-based technology is capable of establishing safety spaces of arbitrary shape, size and position directly into the shared workspace of human and robot. By connecting this safety system to the robot's controller, the safety spaces can be dynamically generated on basis of the robot's joint angles and velocities. Here, the approach formula described in ISO/TS 15066 is used to calculate the safety distances that will form a minimal safety hull enclosing the robot at any time. The safety system incorporates the calculated safety hull to generate and emit a border in the form of a line (i.e. the border of the safety zone) that separates the human and robot. If this projected line is disrupted by an object such as a human's hand or fingers, the surrounding cameras recognize this safety space violation robustly. A safety space violation results in the reduction of the robot's speed or even an immediate robot stop. From the perspective of the human co-worker, it is generally advantageous to be aware of the current safety space, giving them the possibility of actively avoid safety violations. This will lead to an improved availability of the robot and the overall system as well. Visualizing additional symbols, for instance, to represent intended robot movements will further enhance the user acceptance.

In the following we will describe in detail the operational principle of the projection- and camera-based technology. Afterwards we present the possibilities of using this technology as an interaction and visualization system to allow an easy and intuitive communication between human and robot.