Chapter 32
Time-of-Flight Cameras Enabling Collaborative Robots for Improved Safety in Medical Applications

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ABSTRACT

Human-robot collaboration is being used more and more in industry applications and is finding its way into medical applications. Industrial robots that are used for human-robot collaboration, cannot detect obstacles from a distance. This paper introduced the idea of using wireless technology to connect a Time-of-Flight camera to off-the-shelf industrial robots. This way, the robot can detect obstacles up to a distance of five meters. Connecting Time-of-Flight cameras to robots increases the safety in human-robot collaboration by detecting obstacles before a collision. After looking at the state of the art, the authors elaborated the different requirements for such a system. The Time-of-Flight camera from Heptagon is able to work in a range of up to five meters and can connect to the control unit of the robot via a wireless connection.

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INTRODUCTION

Industrial robots have seen an enormous growth in sales numbers in the past years and will most likely continue to grow strongly in the upcoming years (IFR, 2017). Where the standard industrial robot is fenced off from any human worker, a collaborative robot (Cobot) interacts with a human being (human-robot collaboration, HRC) or even with another robot (robot-robot collaboration). Due to their flexibility, these collaborative robots are growing out of their industrial environment into our everyday lives as smart assistants in our home, restaurants and shops or in healthcare situations. One can distinguish three different kinds of human-robot interactions:

- Coexistence
- Cooperation
- Collaboration

While in a coexistence scheme, the human is still fenced off the robot and only interacts via a transfer station like a rotating table, a cooperation scheme has no fence and the worker can hand over materials or workpieces directly into the working space of the robot. The most complex scheme of human-robot interaction is the human-robot collaboration. In this scheme, the human works hand in hand with the robot within the workspace of the robot (Sick, 2017).

The safety aspect is the highest priority in all three schemes. Different sensors and processes are available to protect the worker. Where safety in the coexistence and cooperation schemes has elaborated solutions, the safety for the collaboration scheme still has room for improvements. This is where this paper focuses on the state of the art and presents a method for using Time-of-Flight cameras to increase safety of human-robot collaboration.

The organization of this paper is as follows: The next section discusses state of the art collaborative robots. The section explains how these collaborative robots detect obstacles. It also shows state of the art Time-of-Flight cameras and their properties. The section *System* provides a list of requirements for the system and presents a possible solution. Section *Results* talks about the results of the proposed system. A short outlook on further work on this topic is given in Section *Outlook,* before the paper ends with a conclusion.

STATE OF THE ART

Collaborative robots have to work at a reduced speed of 250 mm/s when a human is close by (ISO10218-1-2011). State of the art robots for human-robot collaboration use motor-current sensors, torque sensors or a combination of both to detect obstacles in their way. Examples for such robots are the ones from KUKA, Rethink Robotics and Universal Robots. All solutions have one big disadvantage that these robots can only detect an obstacle by contact with the obstacle. Recent research on momentum-based collision detection can be found in (He et al., 2015).

These solutions detect the obstacle safely and reliably, but there are situations where a contact is not desired. One example is the human worker who has to work in close proximity of the robot. Even if it is a very smooth contact, the human worker will eventually get annoyed of the robot constantly touching him. Other examples can be found in medical applications, for example in surgeries where the robot