Responsible Robots – A Novel Approach to safe and productive Human-Robot Collaboration

Precision Mechanics
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Introduction

With the more open innovation model seen in the later years, small and medium enterprises have a growing importance in the industry. These types of companies require robotic equipment that is highly flexible, but also easy to use. An important approach to simple and flexible use of robots is through human-robot collaboration (HRC). In a HRC, one can combine the qualities of the different co-workers: the strength and repeatability of the robot, and the flexibility and adaptability of the human. However, there are still many challenges in the way before a high level of safe and productive HRC can be fully realized. One of the most critical challenges that comes as a bi-product of the robot's strength is the safety issue. If the human is to work alongside a robot, a system must be able to ensure the human operator's safety.

However, is it enough to be merely safe? As the human and the robot co-worker's collaboration grow closer, the importance of the human's aspect of the collaboration grows and a more advanced robot co-worker is required. Is it a selling point for a human employee that he is safe to work with? The safety strategy for robots have not changed much in the past decades. Several approaches with the basic strategy of moving away if the robot is too close to the human operator have been proposed. Systems like these are also needed to realize safe HRC, but it can be a strain on the human co-worker if the robot blatantly moves around and suddenly moves away it the human is too close. Moreover, even when these safety system works properly, it is not avoiding human-robot conflicts, they simply react when a danger is imminent. These conflicts are disturbing for the human operator and interrupt his/her concentration. Furthermore, the robot is not even able to complete its task if it is forced to avoid the human. A new safety strategy for safe and productive HRC is therefore needed. This system should act proactive against dangers and aspire to maintain the productivity of the system. Three problem statements were formulated, in no particular order. The statements were criteria to be considered when developing the new approach to safe and productive HRC. The goal of this research was thus to fulfill the listed statements.

List of problem statements:

PS1: *The developed system should act proactive against dangers.*

PS2: *The developed system should be able to solve the necessary tasks to main-*

tain its productivity.

PS3: *The developed system should be designed to improve the effect the collaboration has on the human operator.*

Responsible Robots

This thesis proposes a novel strategy for safe and productive HRC called Responsible Robots. A Responsible Robot is a robot that shares the responsibility for the productivity and the safety in the collaboration. While it has traditionally been the full responsibility of the human to set proper safety rules for the robot, this should be a joint venture. The Responsible Robot acts proactively against dangers and it can in this way plan when to execute its different tasks to ensure the safety of the human operator while being productive.

A study of how human beings are able to make safe and productive decisions is conducted. The importance of situation awareness (SA) in the human's decision making process is discussed, and the three levels of SA are investigated. With level 1 SA a human will only have a perception of the status of the elements in the system, this perception alone may result in poor decisions as the status of the elements are perceived separately, e.g. an elements position and velocity. At level 2 SA the human starts to comprehend the situation and gets a new understanding of the situation. The elements in the system can be seen in relation to each other, e.g. the perceived positions of two elements at level 1 SA can now be comprehended to a distance between the to elements. This comprehension at level 2 SA thus lead to more proper decisions. Reaching level 3 SA involves a perception of the future status of the system and is the highest level of SA. At level 3 SA, a projection of the elements position in the future is possible based on the elements position and velocity and the humans knowledge about basic physics. Reaching this level of SA is vital for the human to make proper decisions.

These levels of SA can be related to current research and available safety systems in HRC. The most widespread safety strategy in the industry today is to enable an emergency stop if an unwanted state is detected, thus level 1 SA (Table 1). In research, the general strategy towards safe HRC is to move the robot away from the human if an insufficient separation is detected, thus using level 2 SA information. Further, it is found that a proper safety system exploiting Level 3 SA information is missing. The Responsible Robots are thus introduced as a term to describe robotic systems with a Level 3 SA with respect to safety. These robots will make decisions that keep the human safe while being productive. Risk perception was identified as a means of enhancing the SA to Level 3. A risk analysis is the product of the likelihood and the consequence of an unwanted event. The likelihood analysis gives a projection of the future status of the system, thus enhancing the SA to level 3.

SA Level	Safety Strategy	Appropriate Action	Consequence
Level 3	Proactive safety systems	Task Selection, proactive planning	None
Level 2	Reactive avoidance systems, separation monitoring.	Augment task, Task Suspension	Human-Robot Conflict
Level 1	Contact based emergency stop, Emergency stop-button, Door switch, light curtains	Stop the Robot	Production Stop

Table 1: Safety strategies related to the level of SA with appopriate action and consequence of action.

Realizing Responsible Robots

The model to realize Responsible Robots enhance the systems SA by adopting a risk perception (Figure 1). The system observes the human operator and learn from his/her work patterns. The risk perception enables the system to estimate the risk associated with each of the robot's tasks. The system can then select the task with the lowest risk and postpone high risk task in case the risk is reduced later in the operation. Urgent tasks that are considered to have too high risk can be augmented to lower the associated risk by e.g. reducing the execution speed and increase its alert to the human operator of its intentions.

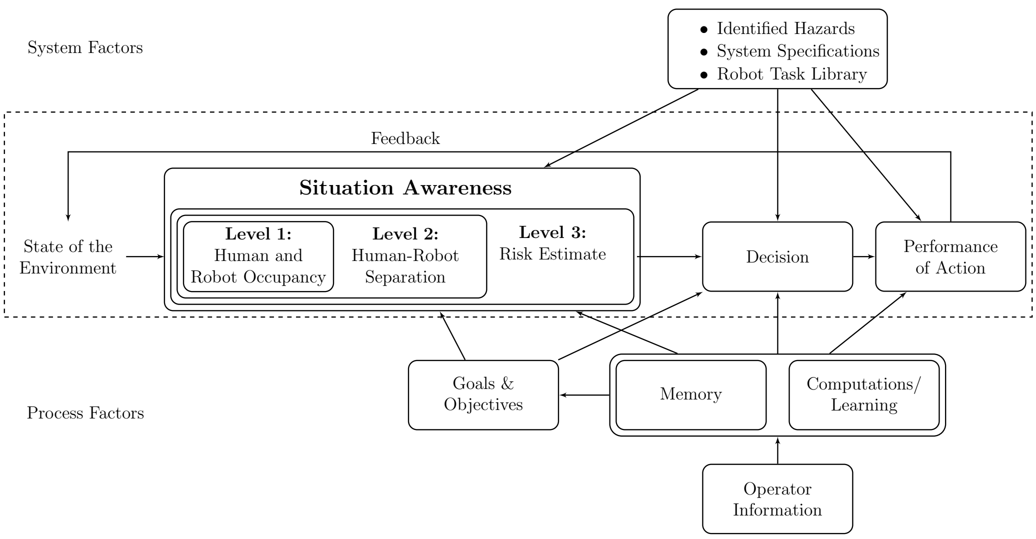

Figure 1: The model developed to realize Responsible Robots based on the human being's decision making process.

This way, the system acts proactively against dangers and may reduce the number of human robot conflicts. The system can plan its tasks better and keep up the productivity to a greater extent than a pure reactive safety system. The reduced number of human-robot conflicts can also have a positive effect on the human operator, as he/she will not be disturbed as often as before.

Experiments

The proposed model was implemented in an experimental setup and tested with several human test subjects. The experimental setup was realized with a heavy-duty NACHI MR20 7-axes industrial robot. The human operator and the robot then collaborated on an assembly task. The test subjects received instructions that could be solved in a variety of ways. This variety represent the flexibility in how humans solve tasks and poses a tremendous challenge for the robotic system. The robot had three tasks, and it was expected to solve each task once for each time the human operator completed one cycle of his/her tasks. The system continuously had to decide to start one of the tasks or wait. Several indicators was used to verify that the system was in compliance with the three problem statements. The system had to reduce the number of human-robot conflicts to show its ability to only start tasks that had an acceptable risk. The precision in its decisions was measured as the rate of true positives. The test subjects workload was measured and compared to the workload of working with a pre-programmed robot co-worker. It was expected that the Responsible Robot would reduce the workload for the human operator.

Conclusion

The experiments demonstrated that the system acts proactively against dangers with a precision of 96%. Moreover, using a Responsible Robot as a robot co-worker reduced the number of human-robot conflicts by 81%, compared to a pre-programmed robot co-worker. This demonstrates that the proposed method is appropriate as a new layer of safety before the currently researched separation monitoring as shown in Table 1.

The human operator's NASA-TLX workload was reduced by 14,5%. Keep in mind that the human test subject was performing the exact same tasks in both cases, only the behavior of the robot changed. The reduced workload both signifies the importance of the robot's behavior in HRC and that the proposed Responsible Robot has a positive effect on the human operator.

It is therefore concluded that Responsible Robots as an approach to safe and productive HRC has been realized and that this approach has a positive effect on the human operator.