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# RELEASING THE SYNERGY OF HUMAN-ROBOT COLLABORATION – REDUNDANT ROBOTICS IN PRACTICE

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***Abstract:*** *The later year's evolvement to a more commonly open innovation model [1] have laid a fundament for a rapid growth of Small and Medium Enterprises (SMEs). While large enterprises often have large production lines with low variation, the task for the industrial robot is predictable and highly repetitive, SMEs have more often small batch production with high variation. The SMEs have in the most recent years begun to adopt industrial robots in their production. While SMEs rarely have their own expertise on robotic installation the use has been made possible by more user friendly program editors and remote service and operations. To further enhance the flexibility and overcome the challenges of complex niche production, redundant industrial robots should be introduced to a larger extent. The challenges with redundant industrial robots have so far been the complexity related to solving the inverse kinematics with reasonable secondary tasks. This paper presents advantages of using redundant industrial robots, and aim to motivate more research on user friendly, "easy-to-use" redundancy resolutions for redundant industrial robots.*

***Keywords:*** *Redundant Industrial Robots, Human-Robot Collaboration, Industrial Applications, SMEs*

## INTRODUCTION

*As an effect of the rise of the SMEs more robotics companies have developed, and started to offer more user-friendly systems, and systems that bring the humans closer to the robot. Rethink Robotics™ have developed the Baxter system [2]. Baxter is a double seven-axes arm, with a fully integrated control system. It can be installed in one hour and does not require any safety installations beyond the built-in safety system. But with only 2.3 kg payload per arm the work is limited to very light operations. ABB have introduced the SafeMove system which is designed to bring the operator closer to the industrial robot [3]. SafeMove operate with zones in which the operator can move safely, and allow a more efficient use of the robot. The robot will automatically slow down as the operator approaches, and go to a full stop if the operator is too close. The SMErobots™ initiative have done extensive research on, and developed systems to simplify both the programming of and safety issues related to industrial robot installations [4]. However, the challenge for many SMEs is still the complexity of the product in low volume series. Processes that involved work pieces with complex geometry that require accurate processing with heavy tools are at best cumbersome to automate and the long term effects of having a human operator do the task may result in serious injuries. A system where the repeatability and strength of the robot is combined with the sensing and flexibility of the human is combined is therefore still longed for. This would require a safety system good enough to have the operator work besides the robot. A sensor system must not only protect the operator but give enough information about what is going on in the robot's environment for it to make a decision on how to configure its arm.*

## IMPROVING WITH REDUNDANT ROBOTICS

*In many applications, there is no need for more than a six-axes robot, as it is sufficient to define any pose of the end-effector in space. The gains of having more than six axes can mostly be attributed to more flexibility in the robot arm configuration referred to as self-motion (Figure 1). In terms of*

*using a seven-axes robot, it can increase the working space of which the robot is able to operate, i.e. easily grind under a table or picking and placing in more complex environments. This also reduces the environmental space needed for the industrial robot since it can reach further in a complex environment. In addition, by introducing more joints, one can distribute the total joint motion on more joint. This way it is possible to reduce cases where some joints would move considerably more than others.*

*The level of redundancy R, defined as R=N-6 where N is the number of available joints, always is a limiting factor when introducing secondary tasks. One should always assign priorities between the primary and secondary tasks to ensure the desired behavior.*

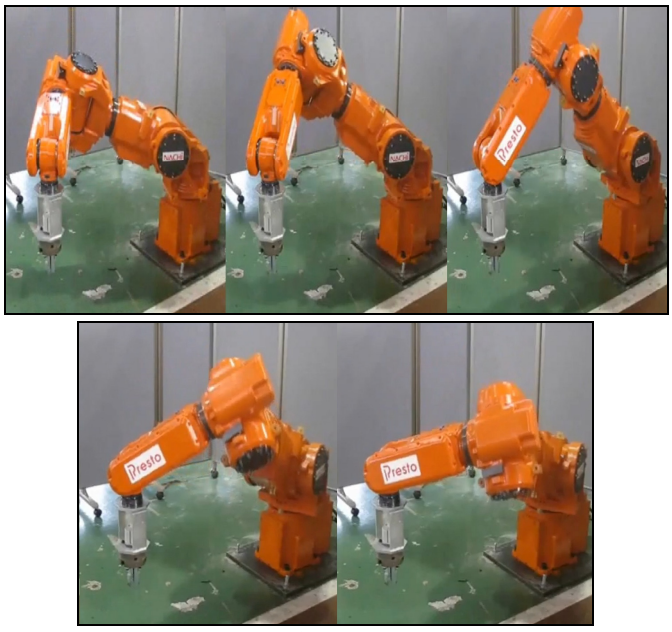

*Figure 1. The NACHI MR20 performing self-motion [5].*

### *Human interaction*

*Human interaction with robots is to some extent in use in the industry today as seen in Figure 2. When an industrial robot is being used as a third hand for a worker, use of a redundant robot will further increase the flexibility of the system. The robot will be able to, for instance, hold a work piece in the same position with several different configurations as it can be seen in Figure 3. This would ease the workers accessibility to the workpiece. This may also reduce the number of required gripping, which in turn reduces time in production.*

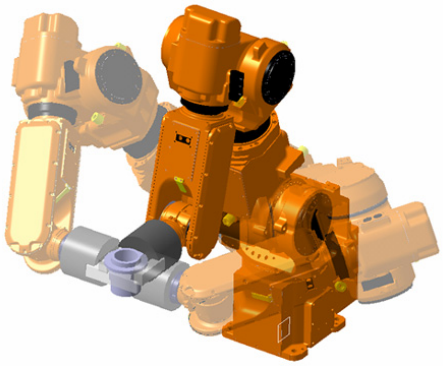

*Figure 2. The NACHI MR20 holding the work piece with different configurations [5].*

*Figure 3. Two workers collaborating and working together with traditional six-axis robots [6] [7].*

### *Process control*

*Since a redundant robot has more degrees of freedom than it needs to perform its primary task it introduces several new possibilities when it comes to implementation of secondary tasks. Axes can also be transfers from the primary task to increase the capabilities of the secondary task. These may include the following.*

- *Obstacle Avoidance: Obstacle avoidance that does not affect the task at hand is simply not possible with only six-degrees of freedom. The redundant robots self-motion ability gives it*

*the flexibility it needs to keep the tool stationary while reconfiguring its arm to avoid an obstacle. This allows a redundant robot to reconfigure to reach places unreachable for a six-axis robot as seen in*

- *Singularity Avoidance: The same reasoning may be applied to singularity avoidance as to obstacle avoidance. While jogging, the control system may detect a possible upcoming singularity, and then reconfigure the arm in a fashion so that the robots configuration never reaches its singular pose. With a six axes robot, there simply no way around the singular configuration.*
- *Joint Limit Avoidance: Due to the extra joint the robot is able to select such an arm configuration throughout a predefined path, so that it does not encounter any joint limits. This will leave the robot more robust to unforeseen motion caused by dynamic tasks.*
- *Energy and Torque Optimization: To reduce the energy consumption of the larger joints the smaller joints may be prioritized when using redundant robots. If the robot is performing short-ranged tasks, it may use the smaller and less energy consuming, ones. When moving heavier objects may the larger joints be used more to reduce the torque and stress in the smaller joints, thus prolonging their lifetime. Reducing stress on the smaller joints can also be achieved through keeping the greater component of the reaction forces parallel to the rotation axis of the smaller joints.*

***Space efficiency***

*Redundant industrial robots also have a great advantage when it comes to required space. A robot with seven axes used in a loading system can be placed on the side of the machines door, as opposed to directly in front of it as a traditional six axis robot would require (see Figure 4). This feature reduces the space required in front of the machine and gives easier access for the operator for maintenance and operation. This also reduces the necessary reach for the robot, allowing a smaller robot to be used. According to NACHI, their MR20 seven-axes industrial robot can reduce the requirement for space in front of the machine with 70% [5].*

*Figure 4. A six axis (left) and a seven axis (right) industrial robot used to load and unload parts [8] [5].*

***CONCLUSION***

*There is a definitive trend towards safer and more user-friendly industrial robot systems mainly aimed at SMEs. Most of the available systems are aimed at simplified robot programming and closing the gap between the operator and the robot, targeting a lower threshold for a company to invest in an industrial robot However, more research is required before the necessary equality between human and robot is achieved. To fully exploit the potential in human-robot collaboration redundant robots should be used. This will extend the flexibility and allow the operator to give more focus on the task, rather than the robot.*

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