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Generative design in the development of a robotic manipulator

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Abstract

The emergence of cyber physical production systems has brought with it an increased utilization of robotics in collaborative manufacturing environments. An approach to meet this demand is to democratize robotics by making cheaper more customizable robots that can be implemented by small and medium enterprises. To tackle this problem this research looks at using rapid prototyping techniques for the development of customizable robotic manipulators which can be implemented in cyber physical production systems. This research therefore contributes an approach for designing connected and rapid prototyped robotic manipulators. This approach considers both the software and hardware development required for implementing a robotic manipulator. Furthermore generative design, an evolutionary and artificial intelligence based approach, is used to design the link modules between the robot joints. This component has been identified as the ideal to be designed with this approach as it benefits most of the generative design approach coupled with rapid prototyping. This paper also explores a robotic manipulator control structure based on Ethernet control technology for implementation within cyber physical production systems.

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1. Introduction

1.1. Cyber Physical Production Systems

CPPS consist of autonomous and cooperative elements (e.g. Smart Machines) and sub-systems (e.g. Smart Factories) that are connected with each other in situation dependent ways, on and across all levels of production, from the processes level up to factory and production levels [1].

One of the main drivers for the implementation of CPPS is the need for continuous adaptability and evolution of the production system [1]. Evolving production system requirements can trace their origin in volatile customer behavior and evolving products [2].

The need to adapt to customer requirements has implied that production systems utilize technologies and machines which provide high levels of efficiency whilst being adaptive to the needs of the manufacturing environment. Since robots provide high efficiency and precision, whilst not sacrificing flexibility, the emergence of cyber physical production systems has brought with it an increased utilization of robotics. That said, trends in robotics are changing with the emergence of collaborative and connected robotics. This trend has also been highlighted at the World Economic Forum in Davos, which identifies advanced robotics as one of the main technological drivers behind Industry 4.0.

1.2. Collaborative and Connected Robotics

That said, this does not mean that humans will be completely eradicated from the shop floor. In fact based on detailed studies and experimentation conducted, Pfeiffer [3] argues that human experience will be still needed on the future shop floor. Based on this, the need for humans and robots to collaborate together on manufacturing operations will increase in the coming years [4]. To substantiate this claim Bloss [4] carried out discussions with key managers of robot companies and based on this concludes that collaborative robotics technology "will become the dominant robot technology in decades to come".

In response to this growing need, it can in fact be seen how all major robot manufacturers are introducing to their lineup

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collaborative robots who are capable of working hand-in-hand with human operators.

In order to be implemented into CPPSs these robots need to be easily connected to the control system which manages the manufacturing operations. A characteristic which is central to CPPS is the decentralized, or glocalized control. This vision of glocalized CPPS [5] is achieved by using machines that have embedded processing and networking capabilities. These capabilities allow the possibility for the third characteristic of distributed and cognitive control. This distributed control is gaining further popularity with the capability to use cognitive processing to analyze data gathered from machine sensors which allows for the decentralization of the CPPS control.

The need for continuous adaptation has also driven the development of approaches that implement the concept of plug-and-produce. Plug-and-produce allows for different elements of a production system to be added and removed from the production system depending on the needs of production.

This concept of plug-and-produce also allows for the development of modular production systems. As explained by several authors, Schleipen et al [6], Onori [7] and Maeda [8], the concept of plug-and-produce must be supported not only from a mechanical function, but also by the development of new and improved software and control paradigms.

1.3. Democratization of Robotics

Large companies have dedicated development teams and also the investment potential to implement such technologies. As has been reported by the International Federation for Robotics [9], 2015, has seen an increase of worldwide robot sales of 15% to 253,748 units, the highest level ever recorded for one year.

The same take up of these advanced manufacturing technologies cannot necessary be said of Small and Medium Enterprises (SMEs), even though SMEs make up a largest percentage compared to large companies [10]. Therefore if as described by Sommer [10], SMEs are not to be the first victims of Industry 4.0, then there is a need to democratize the use of robotics.

Democratization of technology refers to the process by which more people rapidly gain access to technology. An approach to meet this need is to facilitate the implementation of robotics by developing cheaper and more customizable robots that can be easily implemented by small to medium enterprises.

Since the readiness to invest in Industry 4.0 technologies by SMEs is low [10], providing cheaper robots would possibly increase the take up of robotics. Moreover making robots easy to connect and train would also address any reservations by SMEs on the use and implementation of robotics. These approaches together with providing the possibility of a single robot platform which can be customized for the widely varying needs of SMEs would also increase the take up of robotics and Industry 4.0 technologies.

1.4. Research Aims

To tackle these challenges this research aims to utilize rapid prototyping techniques for the development of customizable robotic manipulators which can be implemented in cyber physical production systems. To minimize the weight and cost of the robotic manipulator this approach utilized a generative design technique to design the links between the robot joints. Generative design is an evolutionary and artificial intelligence approach and is further discussed in Section 2. Other state of the art approaches which tackle similar challenges are then presented in Section 3. Section 4 describes the methodology utilized to develop the robotic manipulator. Section 5 then presents the prototype design and implementation. The conclusions and future work relating to this research are presented in Section 6.

2. Generative Design

Generative design is not a new concept, and is sometimes referred to by the term evolutionary design with reference to the search techniques and evolutionary algorithms which are used in this computational process. In [11], Bentley and Wakefield describe a prototype design system which uses a genetic algorithm to evolve new conceptual designs from scratch. In this approach the prototype system creates new designs and iteratively optimizes these designs using a genetic algorithm. Genetic algorithms utilize the principles of evolution found in nature to first generate a population of solutions, and then 'reproducing' the fittest solutions. Offspring are generated by combining the genotypes of these fit parents using random crossover and mutation operations. The design system contributed by Bentley and Wakefield [11] consists of three elements:

- A suitable representation of solid objects to allow the computer to manipulate candidate designs effectively during the design process.
- A modified genetic algorithm to *evolve* such represented designs from scratch.
- Evaluation software to guide the evolution process.

As explained by [12] the process of conceptual design can be presented as an optimization process. In order to arrive to a solution and identify a set of rules is required to evaluate the fitness of a solution to a particular design problem. These type of approaches make the best use of the inventiveness of evolutionary computation in order to discover solutions which may have not been found by human designers. Hence such design techniques may be used to enhance design exploration support for human designers whilst maintain the designer at the center of the design process [13]. This co-development approach is also described by Krish in their generative design process [14]. Krish explains how the designer explicitly defines the constraint envelopes within which define the geometric viability of solutions. As explained by Sun et al. [15], the use of such evolutionary techniques for design automation can lead to not only an improvement in the functionality of the designs but also to a reduction in the development time and thus