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On-line knowledge acquisition and enhancement in robotic assembly tasks

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ABSTRACT

Industrial robots are reliable machines for manufacturing tasks such as welding, panting, assembly, palletizing or kitting operations. They are traditionally programmed by an operator using a teach pendant in a point-to-point scheme with limited sensing capabilities such as industrial vision systems and force/torque sensing. The use of these sensing capabilities is associated to the particular robot controller, operative systems and programming language. Today, robots can react to environment changes specific to their task domain but are still unable to learn skills to effectively use their current knowledge. The need for such a skill in unstructured environments where knowledge can be acquired and enhanced is desirable so that robots can effectively interact in multimodal real-world scenarios.

In this article we present a multimodal assembly controller (MAC) approach to embed and effectively enhance knowledge into industrial robots working in multimodal manufacturing scenarios such as assembly during kitting operations with varying shapes and tolerances. During learning, the robot uses its vision and force capabilities resembling a human operator carrying out the same operation. The approach consists of using a MAC based on the Fuzzy ARTMAP artificial neural network in conjunction with a knowledge base. The robot starts the operation having limited initial knowledge about what task it has to accomplish. During the operation, the robot learns the skill for recognising assembly parts and how to assemble them. The skill acquisition is evaluated by counting the steps to complete the assembly, length of the followed assembly path and compliant behaviour. The performance improves with time so that the robot becomes an expert demonstrated by the assembly of a kit with different part geometries. The kit is unknown by the robot at the beginning of the operation; therefore, the kit type, location and orientation are unknown as well as the parts to be assembled since they are randomly fed by a conveyor belt.

1. Introduction

Part assembly accounts for over 50% of total production time according to various surveys [1]. It is therefore easy to understand why this assembly process contributes to 20% of the unit production cost as stated in [2]. Furthermore, despite the technological progress in automation, it is recognised that approximately 50% of all labour work in the mechanical and electrical industries is involved in work closely related to assembly, handling and fitting processes [3]. Nevertheless, this high percentage has a direct impact on total production costs. A reason that assembly plays a crucial role in manufacturing may be due to the diverse variety of products in the market, whose production is driven by consumer's choice. Nowadays, a wide variety of product is needed so a rapid change in product design and therefore assembly planning is required. This is perhaps one of the reasons that assembly is not fully automated by industrial robots. The wide variety and the rapid changes in product characteristics require a variety of fixtures and rigs to carry out the complex manufacturing processes. This could be mitigated through enabling self-adaptive intelligent robots within this dynamic manufacturing environment, which is the main motivation in our research.

There are multiple manufacturing areas where industrial robots are currently used like in the automotive sector, which is undoubtedly where most industrial robots are used today. In terms of use; tasks such as handling, welding and assembly are the most demanding operations for industrial robots around the world according to the International Federation of Robotics IFR [4]. Statistics show that the trend in robot population growth is expected to continue and has a direct impact also on increasing the number of human skilled jobs related to robotics [5]. This promising scenario in conjunction with the acceptance of skilled workers' interaction with robots will undoubtedly bring new

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paradigms to solve related to human-robot collaboration. New programming methods are needed; robots have to coexist with skilled workers. Consequently, it seems natural for robots to acquire human-like behaviours to solve human manufacturing tasks. Robots have to adapt to new conditions in unstructured environments and to be self-adaptive making an effective use of their intelligence founded in a solid knowledge representation to accomplish a manufacturing task. Specifically in our research, we are interested in studying the *acquisition, representation and enhancement/refinement* of this knowledge during complex manipulative robot tasks such as kitting and assembly operations. We expect to contribute to the understanding of how robots can effectively use their knowledge to accomplish these tasks. The aim is to contribute towards the development of a unified ontology in the area of manipulative tasks for industrial robots considering the complexity of knowledge data present in unstructured scenarios such as the one presented in this paper. Ontology of this type should comprise a set of terms and definitions specified in a machine-readable language and shared by a given community as pointed out by Prestes et al. [6] who propose methodologies to encompass this knowledge to enable and facilitate data integration and information exchange between industrial robots systems. Within the Industrial Robots subgroup the kitting operation is recognised as a good candidate for ontology application [7]. In the current research it is expected to contribute at the lower level of the ontology application in terms of the location of the assembly parts, recognition of the mating pairs and insertion as well as the overall skill acquisition.

The scope of the research presented here needs to define some aspects as to build up a sounded understanding. The task domain of our investigation refers to the assembly of parts having two well defined tasks, the peg-in-hole task and the kitting task. In this investigation the kitting task is composed by more than one assembly operation. In general sense, the work domain is in the assembly of parts, which is the action of putting together manufactured parts to make a completed product or subassembly. In particular, in this paper we will deal with a special type of assembly composed by a peg and its counterpart named hole and referred to as the peg-in-hole (PIH) task. The kitting task can then be understood as the practice of assembling components (pegs in our case) in predetermined quantities that are placed together in specific container (kit). The term of assembly parts, assembly components and mating pairs are used interchangeably within this paper.

The investigation is related to intelligent robots, specifically autonomous industrial robots. An autonomous robot can solve complex tasks by itself and has intentions of its own to produce changes in the world as pointed out in [6]. Accordingly, a robotic agent should emerge from the interaction between the real-world and the robot manipulator itself. This agent should demonstrate its “intelligence” by using new knowledge, refine and apply it autonomously during skill learning showing the required skill during real world tasks as demonstrated by Lopez-Juarez et al. [8]. The research is founded on previous approach by Lopez-Juarez in terms of creating intelligent robotic agents for assembly using force sensing in conjunction with an image processing method called the boundary object function (BOF) to describe invariantly an object using object's features as initially presented by Peña Cabrera et al. [9]. Although the work was centred on the PIH operation, the method can easily extend the robot's capability in more complex processes like for instance, the kitting process under high uncertainty.

In real-world scenarios, robots deal with high uncertainty in the environment due to modelling, sensing and control errors. Uncertainties come from a wide variety of sources such as robot positioning errors, gear backlash, arm deflection, ageing of mechanisms and disturbances. Controlling all the above aspects would certainly be a very difficult task; therefore a simpler approach based on reactive learning control is preferred. By using force control the overall effect of the contact force between the environment (assembly parts) and the manipulator are considered as a whole. In order to cope with these situations, we propose the robot to learn the manipulative tasks using multimodal information, i.e. vision templates and force sensing.

The proposed learning approach considers a multimodal assembly controller (MAC) and an artificial neural network (ANN) based on the adaptive resonance theory (ART) [10] in conjunction with a knowledge base which is created by the task. At the beginning of the operation, the robot moves with limited initial knowledge, henceforth named the primitive knowledge base (PKB), which is related to the mapping of contact force information and the robot's motion direction that produced such force condition. Related to vision, it only considers clues on what to assemble. During the operation, the robot learns the skill that includes the acquisition of knowledge to recognise the mating part geometry using a template matching approach based on similarity to grasp the required assembly part and insert in the kit. The assembly skill is evaluated based on the number of elapsed steps to complete the assembly, length of the followed assembly path and the compliant behaviour. The compliant behaviour is observed by the reduction in contact force during the insertions. If the respective force/torque pattern in the current assembly trajectory favours the assembly, then this pattern is considered for enhancing the initial knowledge base, hence forming an enhanced knowledge base (EKB).

The article is organised as follows. After this introduction, Section 2 presents the related work and original contribution. In Section 3, the methodology that includes the description of the test bed, image processing, task description and knowledge acquisition is presented while the results are explained in Section 4. Finally, Section 5 provides the conclusions and further work.

2. Related work

Uncertainties due to manufacturing tolerances, positioning, sensing and control errors make it difficult to perform the assembly. Compliant motion can be applied using passive devices such as the remote centre compliance (RCC) introduced by Whitney [11]. Other alternative is to use active compliance, which actually modifies the position of the manipulated component as a response to constraint contact forces. A detailed analysis of active compliance can be found in works by Mason [12], De Schutter [13] and more recently, using contact based assembly for real industrial assemblies and kitting processes [14]. Alternative solutions using active compliance are based also on connectionist approaches that rely on the information given during the network training stage which implicitly considers all insertion parameters. The use of connectionist models in robot control to solve a canonical assembly task like the PIH operation under uncertainty has been dealt in a number of publications along the years. The reinforcement algorithm implemented by V. Gullapalli demonstrated the ability to learn circular and square peg insertions. However, the network was unable to generalise over different geometries [15]. Cervera used SOM networks and a Zebra robot (same as used by Gullapalli) developing similar insertions improving the autonomy of the system by obviating the knowledge of the part location and used only relative motions [16]. Other interesting approaches have also been used for skill acquisition within the framework of robot programming by demonstration (PbD) that considers the characteristics of human generated data. Work carried out by Kaiser and Dillman [17] shows that skills for assembly can be acquired through human demonstration. The training data is first pre-processed, inconsistent data pairs are removed and a smoothing algorithm is applied.