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Knowledge driven robotics for kitting applications

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HIGHLIGHTS

- Work supports the IEEE's Ontologies for Robotics and Automation Working Group.
- Knowledge methodology/model allows agility, flexibility, and rapid re-tasking.
- Ontology focuses on the subset of manufacturing automation problem.
- Case study of kit building presented.

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ABSTRACT

This article presents a newly developed knowledge methodology/model that was designed to support the IEEE Robotics and Automation Society's Ontologies for Robotics and Automation Working Group. This methodology/model allows for the creation of systems that demonstrate flexibility, agility, and the ability to be rapidly re-tasked. The methodology/model will be illustrated through a case study in the area of robotic kit building. Through this case study, the knowledge model will be presented, and automatic tools for optimizing the knowledge representation for planning systems and execution systems will be discussed.

1. Introduction

Today's state-of-the-art industrial robots are capable of sub-millimeter accuracy [1]. However, they are often programmed by an operator using crude positional controls from a teach pendent. Reprogramming these robots when their task is altered requires that the robot cell be taken off-line for a human-led teaching period. For small batch processors or other customers who must frequently change their line configuration, this frequent down time may be unacceptable. The robotic systems of tomorrow need to be capable, flexible, and agile. These systems need to perform their duties at least as well as human counterparts, be able to be quickly re-tasked to other operations, and be able to cope with a wide variety of unexpected environmental and operational changes. In order to be successful, these systems need to combine domain expertise, knowledge of their own skills and limitations, and both semantic and geometric environmental information.

The IEEE Robotics and Automation Society's Ontologies for Robotics and Automation Working group is striving to create an overall ontology and associated methodology for knowledge representation and reasoning that will address these knowledge needs. As part of the Industrial Subgroup of the IEEE Working Group, the authors have been examining a novel architecture that allows for the combination of the static aspects of the ontology with dynamic sensor processing to enable the construction of a robotic system that is able to cope with environmental and task changes without operator intervention.

This article presents the first steps in the formation of a formal knowledge model and implementation methodology that is being developed by the industrial subgroup of the IEEE Working Group. The knowledge model will eventually allow for the compact representation of the world knowledge required to successfully plan for and carry out a variety of industrial applications. Currently, the model has been focused on automated kit building. The methodology presents sample techniques that demonstrate how this knowledge can be transformed into representations that are optimized for planning systems and robotic operations. When possible, these transformations are accomplished in an automated fashion, without the need for intervention from the user. In addition, sensor

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processing is utilized to provide late-binding of detailed information about the environment to the control process. This allows for generalized plans that reside in the knowledge model to adapt to a changing environment.

The knowledge methodology/model proposed in this article is not designed to act as a stand-alone system architecture. Rather it is intended to be an extension to well developed hierarchical, deliberative architectures such as 4D/RCS [2]. The methodology relies on the robotic system to be able to carry out specific robot motions such as Cartesian moves, avoid collisions, and pick up objects. The knowledge methodology/model proposed in this paper is designed to work in conjunction with the existing robotic architecture to allow the system to be more agile, flexible, and easily re-tasked.

The organization of the remainder of this paper is as follows. Section 2 describes the domain of kit building which is a simple, but still practically useful manufacturing/assembly domain. Section 3 presents an overview of the knowledge driven methodology that has been developed for this effort. Section 4 describes our knowledge model for the kitting domain. Finally, Section 5 gives conclusions and future work.

2. Industrial kitting

Material feeding systems are an integral part of today's assembly line operations. These systems assure that parts are available where and when they are needed during the assembly operations by providing either a continuous supply of parts at the station, or a set of parts (known as a kit) that contains the required parts for one or more assembly operations. In continuous supply, a quantity of each part that may be necessary for the assembly operation is stored at the assembly station. If multiple versions of a product are being assembled (mixed-model assembly), a larger variety of parts than are used for an individual assembly may need to be stored. With this material feeding scheme, parts storage and delivery systems must be duplicated at each assembly station.

An alternative to continuous supply is known as kitting. In kitting, parts are delivered to the assembly station in kits that contain the exact parts necessary for the completion of one assembly object. According to Bozer and McGinnis [3] "A kit is a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order". In the case of mixed-model assembly, the contents of a kit may vary from product to product. The use of kitting allows a single delivery system to feed multiple assembly stations. The individual operations of the station that builds the kits may be viewed as a specialization of the general bin-picking problem [4].

In industrial assembly of manufactured products, kitting is often performed prior to final assembly. Manufacturers utilize kitting due to its ability to provide cost savings [5] including saving manufacturing or assembly space [6], reducing assembly workers walking and searching times [7], and increasing line flexibility [3] and balance [8].

Several different techniques are used to create kits. A kitting operation where a kit box is stationary until filled at a single kitting workstation is referred to as *batch kitting*. In *zone kitting*, the kit moves while being filled and will pass through one or more zones before it is completed. This article focuses on batch kitting processes.

In batch kitting, the kit's component parts may be staged in containers positioned in the workstation or may arrive on a conveyor. Component parts may be fixtured, for example placed in compartments on trays, or may be in random orientations, for example placed in a large bin. In addition to the kit's component parts, the workstation usually contains a storage area for empty kit boxes as well as completed kits.

For our sample implementation, we assume that a robot performs a series of pick-and-place operations in order to construct the kit. These operations include the following tasks:

1. Pick up an empty kit and place it on the work table.
2. Pick up multiple component parts and place them in a kit.
3. Pick up the completed kit and place it in the full kit storage area.

Each of these may be a compound action that includes other actions such as end-of-arm tool changes, path planning, and obstacle avoidance.

It should be noted that multiple kits may be built simultaneously. Finished kits are moved to the assembly floor where components are picked from the kit for use in the assembly procedure. The kits are normally designed to facilitate component picking in the correct sequence for assembly. Component orientation may be constrained by the kit design in order to ease the pick-to-assembly process. Empty kits are returned to the kit building area for reuse.

The knowledge methodology/model presented in this article is designed to allow for more agility and flexibility in the kit preparation process. This includes the ability to easily adapt to variations in kit contents, kit layout, and component supply as well as the ability to work in environments where components are not fixtured to precise locations.

3. Design methodology

The design approach described in this article is not intended to replace sound engineering of an intelligent system, but rather as an additional step that may be applied in order to provide the system with more agility, flexibility, and the ability to be rapidly re-tasked. This is accomplished by assuring that the appropriate knowledge of the correct scope and format is available to all modules of the intelligent system.

The overall knowledge model of the system may be seen in Fig. 1. The figure is organized vertically by the representation that is used for the knowledge and horizontally by the classical sense-model-act paradigm of intelligent systems. On the vertical axis, knowledge begins with Domain Specific Information that captures operational knowledge that is necessary to be successful in the particular domain in which the system is designed to operate. This information is then organized into a domain independent representation (an Ontology) that allows for the encoding of an object taxonomy, object-to-object relationships, and aspects of actions, preconditions, and effects. Aspects of this knowledge are automatically extracted and encoded in a form that is optimized for a planning system to utilize (the Planning Language). Once a plan has been formulated, the knowledge is transformed into a representation that is optimized for use by a robotic system (the Robot Language).

It is acknowledged that sensing and action are important parts of a robotic system. However, this article focuses on knowledge representation, and thus the modeling section will be described in the most detail.

3.1. Domain specific information

The most basic knowledge that must be gathered for a knowledge driven system is domain specific information (DSI). This appears along the bottom row of Fig. 1. DSI includes sensors and sensor processing that are specifically tuned to operate in the target domain. Examples of sensor processing may include pose determination and object identification.

For the knowledge model, a scenario driven approach is taken where the DSI design begins with a domain expert creating one