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DEVELOPMENT OF AN INTEGRATED DOMAIN REPRESENTATION FOR CONFIGURATION, ACTION PLANNING, AND LAYOUT PLANNING OF ASSEMBLY SYSTEMS

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ABSTRACT

During the past fifteen years, robot work cells have become a standard component of many industrial production systems. Up to now, the design of a robot work cell or a automated work station for a specific manufacturing process is a demanding task, although tools have been already developed for different design steps. The problem is that each tool is suitable only for one design step such as assembly planning, cell configuration, layout planning, and robot programming. The mutual effect among these design steps cannot be considered, although it is necessary for a high quality design. Thus, the common way is the manual design by human designers who have to work cooperatively for this task. This paper presents a new theoretical approach for an integrated design process consisting of process planning, component selection and work station planning.

1. Introduction

This article presents the structure of a domain representation for an integrated planning system for assembly stations. This domain representation allows to integrate the main steps of the design: configuration, action planning and layout planning.

Each selection of a manufacturing resource constrains the selection of further manufacturing resources of the same assembly station or influences the course of action which has to be taken. For example: A specific joining process requires specific manufacturing resources and a defined course of action. In addition, it must be possible to arrange all the manufacturing resources in the working space of the handling system. The selection of manufacturing resources and their spatial arrangement has strong influence on cycle times and the investment costs of assembly cells. Therefore, the planning of assembly systems is a combined configuration, action planning and layout planning problem. In order to achieve optimal results, it is required to deal with these dependencies during the planning process.

Action planning is a classical application area of artificial intelligence. Therefore, a number of methods and systems have been developed. STRIPS [1] is the classic action planning system. Afterwards, non-linear planning, hierarchical planning [2], resource availability [3], and formal checks for correctness and completeness [4, 5] were introduced. Ongoing research work focuses on proves for the correctness of plans and the development of powerful representation of real problem domains.

The area of configuration focuses more on knowledge acquisition aspects. This is often caused by the complex structure of the application domains of configuration systems. In a lot of cases, rules are used to represent expert knowledge: R1/XCON [6], SYLLOGIST [7] and PLAKON [8]. A further method for configuration problems is the 'propose and revise' method applied in VT [9] and SALT [10] and 'resource oriented configuration' [11].

For layout planning, there are in principle three approaches available: Robot simulation systems are used in industry to design manufacturing cells. The second group applies operations research methods to layout planning but these approaches do not take into account the kinematics of manufacturing resources. Knowledge based systems belong to the third group. An overview on these systems is presented in [12-18], (FADES [19], EXIST [20, 21], KBML [22], QLAARP [23]). These type of systems use often strongly idealized models and none of them is applied in industry to solve layout planning problems. Lueth [24] introduces an approach based on a Cartesian configuration space which allows a collision free spatial arrangement of manufacturing resources.

Only very few research results are known, which deal with the integration of these aspects. Köhne [25] and Ganghoff [26] propose approaches which integrate action planning and configuration. On the other hand, there are approaches available which try to embed the layout planning problem into configuration systems [27]. But it remains open, how kinematics of manufacturing resources and collision detection can be performed with this type of knowledge representation.

Our overall research objective is to develop an integrated planning methodology which deals with the dependencies between the main steps of the design of a robot assembly cell: configuration, action planning and layout planning. The following paragraph describes the domain representation of the integrated planning system.

2. Development of an Integrated Domain Representation

2.1. Overview

An integrated approach to action planning, configuration and layout planning must deal with the dependencies between each area. In order to achieve this goal, our planning system will have the following structure:

- The *domain representation* provides the static knowledge of the application domain. In our project, we take advantage of the approach developed by Köhne (Köhne, 1992). It represents common knowledge on the domain and integrates generic concepts of action planning and configuration.
- The *problem representation* allows to model the individual planning problem. It contains the planning problem and sums up all effects of the design decisions made during the planning process so far.
- The *planning guidance* controls the planning process. The *plan analysis* supports the selection of plan operators which are the only means to modify the problem representation.

The following paragraphs focus on the domain representation. An integrated domain representation for action planning, configuration and layout planning encompasses various types of knowledge. Action planning knowledge and configuration knowledge are usually represented in a symbolic manner. Layout planning requires the representation of spatial relationships which cannot be usefully represented in a symbolic manner. Therefore, we decided to divide the knowledge representation into two parts:

- Knowledge belonging to action planning and configuration will be represented in a symbolic way. This part of the domain representation will be used to detail assembly steps, assign manufacturing resources to assembly steps, and to deal with the dependencies between both.
- Knowledge belonging to layout planning will be represented separately in a robot simulation system. This part of the knowledge base contains spatial models of available manufacturing resources as well as its kinematics.

During the planning process, the robot simulation systems receives the selected manufacturing resources and a course of action. Based on this information, the spatial knowledge on manufacturing resources is retrieved and planning operators allow to define location and orientation of the manufacturing resource. After the position of an manufacturing resource is defined, a simulation of the assembly task will be performed.

2.2. The Different Levels of Task Decomposition

Action planning requires that an assembly task is hierarchically decomposed and refined through various levels in order to come from an task description (the precedence graph) to a planning level which allows to be executed in an robot simulation. The precedence graph is one important input to our integrated planning system and its nodes represent assembly activities like assembling an sealing ring on a piston. On the next lower level of decomposition, these assembly activities are refined into subactivities. These subactivities describe tasks which are basically different like to feed an part, to join two parts, to move parts or to check the quality but they cannot performed for example by one manufacturing resource on its own. In our example, our assembly process is divided into feeding of required parts, the joining process itself, movement of the part to the measuring device, and so on. On the next level, these subactivities are refined into assembly steps. They represent activities which can be accomplished by a specific manufacturing resource or a fixed set of cooperating manufacturing resources. On this level decisions on different technical implementations have to be taken. In our example, the joining process of the sealing ring is divided into putting on the sealing ring which is done on a specific manufacturing aid and to orient the sealing ring which is done by this manufacturing aid in cooperation with the robot. On our lowest level of decomposition so-called assembly actions are represented. This refinement process separates the coarse of action to be taken by each manufacturing resource. This is why assembly actions show the coarse of action an individual manufacturing resource to implement an assembly step.

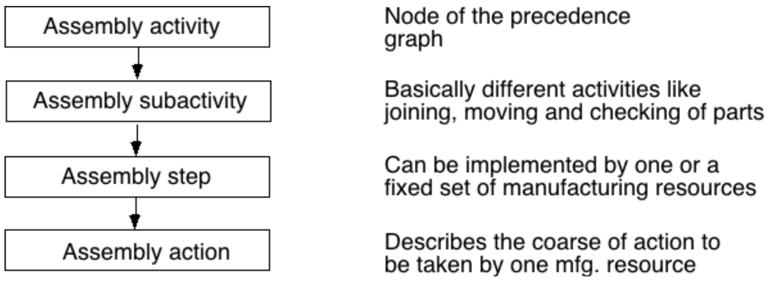

Fig. 2: Hierarchical decomposition of an assembly task

2.3. The Symbolic Part of the Knowledge Representation: Action Planning and Configuration

Planning flexible assembly systems comes with a considerable complexity of the domain knowledge involved. In order to cope with this we have differentiated our domain representation into three layers of decreasing abstraction:

- Generic representational structures: This layer contains general concepts of action planning and configuration whose applications are not limited to the domain of assembly system planning.
- Common concepts of assembly system planning: The common knowledge about the domain, such as standard classifications of component types for configuration or assignments between assembly methods and related resource types, is given here.
- Task specific concepts: This layer covers descriptions of specific configuration components and process steps which may be performed by these components. A typical example would be the representation of a supplier‘s catalog.

The integrated planner uses a frame formalism for representation. Following the well-known state of the art (see (Cunis, 1989) for example) the domain concepts are described by objects (frames) and their specific characteristics by attributes of these objects. Knowledge about connections between the domain concepts is expressed by relations between the corresponding objects. The domain representation is build upon the formulation of object classes, the planning process manipulates the instances of these classes contained in the integrated plan description.

2.4. The Interface between Symbolic and Geometrical Knowledge

One very important point in designing the hybrid knowledge base is to define the interface between the two parts of the knowledge base. The symbolic part of the knowledge base is designed for integrated action planning and configuration of an assembly system. The planning process is able to deal with the dependencies between action planning and configuration. When detailing assembly steps to assembly actions, decisions have to be made according to strict rules, which are cumbersome to represent in our frame based approach but can be easily represented in a formal language. Therefore, this is a suitable level for leaving the action planning and configuration part of the knowledge base and transferring required data to the geometric part of the knowledge base. There, it has to be further processed before the data can be used for a simulation of assembly cell.

2.5. The Geometric Part of the Knowledge Base: Converting Action Plans and Resources into Executable Tasks for Manufacturing Resources.

In this part of the knowledge base, geometrical information has to be represented. For this, we use the ROBCAD robot simulation system. In ROBCAD each active mechanism (our manufacturing resources) is controlled by its own task. The various tasks of manufacturing resources are synchronized via signals. Therefore, the integrated plan description has to be converted into an equivalent task of each active manufacturing resource of the considered manufacturing cell.

In the first part of this section, we will outline how this conversion can be accomplished. In the second section we present our way to describe the robot movement independent of the position of the manufacturing resources.

The conversion of the integrated plan description into tasks

As mentioned above, the tasks of the active mechanisms have to be generated based on our integrated plan description. The integrated plan description represents the coarse of action on the level of assembly steps. This description, for example, does for example not contain approach and depart motions of a robot. Therefore, tasks need to be described on the level of assembly actions and our assembly steps have to be decomposed once again. The result is a coarse of assembly actions describing the task of an individual manufacturing resource on the level of assembly actions. Each of these assembly actions has a corresponding task element, which describes the action in the syntax required by the simulation system of ROBCAD. The task of a manufacturing resource is composed out of task elements.

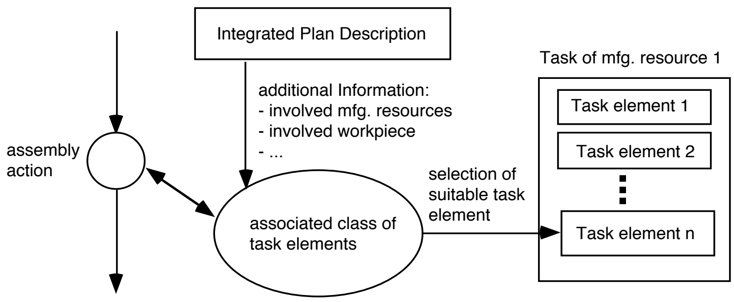

Fig. 3: Interrelations between assembly actions and tasks of mg. resources

This decomposition process follows strict rules. For example the task to orient the sealing ring of our piston is assigned to a robot. This assembly step must be decomposed into six parts: 1. transfer motion from the starting point to the approach frame of the manufacturing resource where the piston is fixed, 2. approach motion, 3. orienting the sealing ring, 5. depart from the piston, 6. transfer motion to the final position. Each of the motion parts belong to a specific class of movement types. These motion types are in the case of the robot: transfer motion, approach motion, grasp the part, detach the part, other interactions between the robot and an other manufacturing resource and depart motion. This division of the robot movement ensures a high reusability of the task elements defined. Independent of which workpiece has to be gripped and where the workpiece lays, the robot has first to do a transfer movement to the approaching point, has to approach afterwards, and now it can grasp the workpiece.

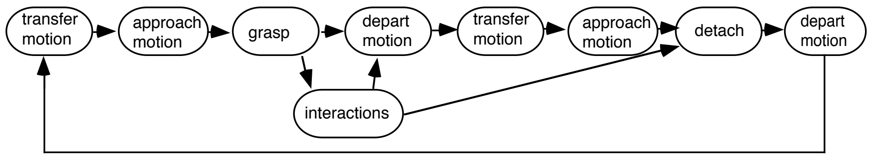

Fig. 4: Strongly simplified grammar for a robot presenting allowable sequences of assembly actions

The allowable actions can be easily described using a grammar. Each class of manufacturing resources has its own grammar describing the allowable course of action. In Fig 4 we show a strongly simplified example for such a grammar. The letters of the alphabet represent classes of actions which can be performed by a manufacturing resource. In the figure, the letters of the alphabet are depicted as nodes.

Knowing these rules and knowing that the robot has to grip a specific workpiece at a specific place, we can complete our course of assembly actions by selecting the appropriate task elements out of this class and adding it to the task. Afterwards, we identify the action to be performed next and we look for the corresponding class activities in our grammar. After this, we know again which actions have to be taken in-between and we select the appropriate task elements out of the corresponding classes an add them to the task. In this way, we work the whole assembly actions of this manufacturing resource and get the complete task.

In a manufacturing cell usually a number of active manufacturing resources are available and cooperate. Therefore, their activities have to be synchronized. To accomplish this, we distinguish between local communication in which two task elements are involved and a global communication which starts parallel processing of two or more tasks.

- Local communication is usually used for synchronized communication. This means, a process one starts a process two and waits until it receives the competion signal of process two. Typical representatives of this class of movements are putting a work piece into a chuck. The typical flow of signals for this action is shown in Fig. 5.
- The task elements of the two manufacturing resources are strongly interconnected. In order to ensure, that the activities and the signals exchanged are consistent, these task elements will be generated in parallel with the help of a special tool.
- Global communication usually initiates parallel processing of two or more manufacturing resources. In this case, the task elements cannot be predefined, because the partners involved in the communication are not known before. Therefore, these task elements are generated in each situation when an global communication occurs. In the integrated plan description, global communication takes place, when an assembly step has more then one successor.

The procedure which generates the tasks of the manufacturing resources analyzes the predecessor and successor relationships between assembly steps. The tasks of the active manufacturing resources are compiled in parallel. When the last assembly step is processed, the tasks are nearly completed. A automated final editing has to be done in order to fulfil syntax requirements. Afterwards the simulation has to be compiled and executed.

During layout planning, manufacturing resources have to be placed and moved. Therefore, the description of the movement of active resources has to be independent of their location. We reach this by defining a number of frames relative to the manufacturing resources and the workpieces which allow to describe the required robot motions.

Now we have reached a stage which allows us to integrate the planning process. With this domain representation it is possible to represent action planning and configuration knowledge as well as geometric knowledge. We can also use the action planning data for simulation of the assembly task and to do collision checking and optimization of the robot movement. . The description of the robot motion is independent of ht location of the manufacturing resources. Therefore, after changes of the layout a new simulation can be performed again. The tasks generated for simulation can be also used to generate programs for real robots.

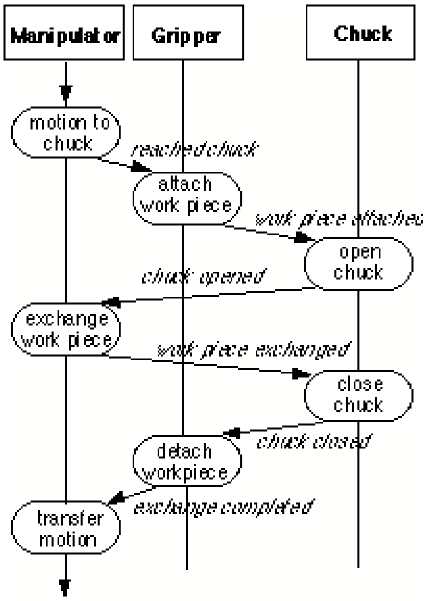

Fig. 5: Flow of signals when putting an workpiece into a chuck (local communication)

3. Future work

We introduced the design of the integrated knowledge base. In the next steps, the planning guidance has to be developed. This work is divided into two parts: First, the planning analysis has to be enhanced in order to detect deficits, conflicts and inconsistencies in the problem representation. Second, the planning guidance has to be developed to deal with the dependencies between action planning, configuration and layout planning.

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