The 4th International Conference
"Computational Mechanics
and Virtual Engineering"
COMEC 2011
20-22 OCTOBER 2011, Brasov, Romania

A MULTI-ROBOT SYSTEM FOR ASSEMBLY TASKS IN AUTOMOTIVE INDUSTRY

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Abstract: *This paper describes the virtual assembly automation systems as decision support systems, for the better knowledge of assembly operation. The study of this procedure is described as well as the necessity for assembly systems design. The work draws on research into product and manufacturing knowledge models, and uses the cases study based on a simplified virtual assembly lines realized in Delphi programming environment. A virtual prototype has been implemented to testify the feasibility of the presented methodology for the assembly of mechanical objects. The paper describes with enough detail the adopted solutions used to perform those tasks, giving special attention to the software designed to supervise the system. To support robot work simulation, a simulator environment is developed. In this paper, the authors have proposed the virtual prototype models for assembly systems architecture of robotic assembly automation in automotive industry.*
Keywords: *flexible assembly systems, virtual robotic assembly systems, automotive production line*

1. INTRODUCTION

Automation of an assembly operation in an automotive production plant is described in the paper. The operation assembly is automated using robot technology. To design an automatic assembly system the assembly operation is considered as a problem of multiple peg-in-hole insertions. The paper investigates the basic principles of a multiple part assisting task with special regard to the finish assembly. The theoretical and experimental conclusions are presented enabling improved understanding of the assembly process.

On this basis, the robot work cell is built and assembly strategy is proposed. The work cell peripheral devices are presented and also the incorporation of the work cell into the existing automotive production line. The assembly line, where the automobiles are manufactured, encompasses several working operations organized along a linear conveyor.

The problem of the assembly operation, treated from a robotic assembly point of view as a peg-in-hole insertion problem, is investigated with theoretical background and virtual laboratory evaluation. For successful automation of operation, the system should be able to detect, adequately distinguish and react to the assembly faults.

The robot cell setup is presented incorporating for this task specially designed robot gripper and peripheral feeding devices. When a round peg is being inserted into a round hole, the peg may be in contact with the hole owing to positional inaccuracy. The positional inaccuracy may be caused by many sources, such as positional inaccuracy of the manipulator, tool wearing and most common, variation of part tolerances and position error of both parts after being fed. During mating two objects with positional inaccuracy, undesired and possibly harmful reaction forces can appear. In such a moment, the motion of the peg is constrained by the geometry of the hole, and some compliance in the system is needed to successfully accomplish the mating task. The limits of non-parallelism for rigidly connected pegs when avoiding the instance of wedging were derived.

The robotic assembly system is a veritable “mechatronic” system, as its performance depends on the highly coordinated real time behaviour of mechanical/electrical/electronic and control software components. Designing of each part of an automation assembly system can have significant results on the general efficiency of the whole system.

The designers use modelling and simulation technology as part of the manufacturing design process. This effort proves to be very much helpful to the designers, helping them to understand important component interactions between subsystems as well as to assess system-level performance correction options.

This paper describes the creation of models and simulation of the behaviour of the virtual assembling system. Virtual prototype improves knowledge and provides understanding of the behavioural of the assembly system as system with Discrete Event.
To ensure success of the assembly process assisted by the industrial robots, engineers must adapt robots, products and processes to the unique requirement of the market. Manufacturing automation with robots aims to reduce cost and increase the quality and efficiency of the operation.

2. ASSEMBLING AUTOMATION WITH ROBOTS

The assembly process with robots systems is faster, more efficient and precise than ever before. Invention of robots has brought about revolutionary changes in the field of industrial manufacturing. Robots are used in the manufacturing industry for parts handling, component insertion, assembly, and inspection when required a high degree of repeatability.
Robots have saved workers from tedious and dull assembly line jobs, and have increased production. But, what's easy for a human assembler can be difficult or impossible for a robot. To ensure success with robotic assembly, engineers must adapt their parts, products and processes to the unique requirement of the assembly process - the precision. Assembly automation with robots aims to reduce cost and increase the quality and efficiency of the operations. Assembly operation has long been not only an important but also one of the most challenging applications for robots.
There are many significant research issues related to the large scope of assembly automation, from design for assembly to assembly sequence planning [1].
The principal target for assembly automation with robots will be applications involving high demands on flexibility. The flexibility and the reprogramming ability of robots will contribute to their expanded use in assembly operations. The robots are flexible in the sense that they can be programmed to assemble different products.
The robot should be able to pick up a part and insert it without any further manipulation. The parts should have self-aligning features, to help the robot insert them.
An informal analysis of manufacturing engineers in the automatic assembly indicates that the most remarkable applications for robots in automatic assembly are given by the capabilities of today's robots and the maturity of the off-line programming software.
This paper is only focused on the issue of robotic motion for assembly in a virtual environment. Studying the virtual robot systems and detecting the movement of part assembly in the virtual environment and transforming this movement into symbolic language will sustain the control decisions making.
Automatic assembly is a computerized production control technique used in the production of manufactured goods to balance output of production with demand. Robotic automatic assembly offers many important features and advantages that are not achieved with traditional fabrication techniques. These features include inserting, pressing, rolling and consolidation of the manipulated object, all in the automatic mode, precise control of object placement and orientation. Furthermore, the use of a robot manipulator increases the flexibility of the pieces placement process and allows for the fabrication of more complex structures.
Compared with other operations in industrial manufacture, the application of robotics to assembling operations is the area where the biggest potential for the robots' utilize is seen to be more exploited.
While unit effort cost in the manufacture of parts have been decreased by new materials, simplification of products, numerical control of machines and new production technologies, the robotic assembly has occurred in assembling the some delay growth into the final product. Among other things, the example to which assembly of parts can be automated will strongly determine the competitiveness of industry. Automation of assembly can only take place through more flexible assembly systems.
More flexible assembly systems are needed to preserve the existing high level of automation in high-volume production over the long term. In this connection, high hopes are placed in assembly robots as the principal element in new flexible assembly systems.

3. ASSEMBLING SRATEGIES

An assembly task defines the process of putting together manufactured parts to make a complete product. It is a major operation in the manufacturing process of any product.
The concerned assembly motion is that of a robot manipulator holding a part and moving it to reach a certain assembled state, i.e., a required spatial arrangement or contact against another part. The main difficulty of assembly motion is due to the requirement for high precision or low tolerance between the parts in an assembled

state. As a result, the assembly motion has to overcome uncertainty to be successful. Assembly motion strategies can incorporate compliant motion.
Compliant motion is defined as motion constrained by the contact between the held part and another part in the environment. As it reduces uncertainty through reducing the degrees of freedom (DOFs) of the held part, compliant motion is desirable in assembly. Therefore, a successful assembly motion has to move the held part out of such an unplanned contact situation and lead it to reach the desired assembled state eventually. To make this transition, compliant motion is preferred. Often a sequence of contact transitions via compliant motion is necessary before the desired assembled state can be reached.
Assembly motion strategies that incorporate compliant motion can be broadly classified into two groups: passive compliance and active compliant motion, and both groups of strategies require certain information characterizing topological contact states between parts. Often a set of contact configurations share the same high level contact characteristics.
Such a description is often what really matters in assembly motion as it characterizes a spatial arrangement that could be either an assembled state or just a contact state between a part and another part. For contacting polyhedral objects, it is common to describe a contact state topologically as a set of primitive contacts, each of which is defined by a pair of contacting surface elements in terms of faces, edges, and vertices.
From the viewpoint of contact identification via sensing, however, both representations can result in states that are different by definition but indistinguishable in identification due to uncertainties.
Passive compliance refers to strategies that incorporate compliant motion for error correction during the assembly motion without requiring active and explicit recognition and reasoning of contact states between parts.
As an alternative to the passive compliance based assembly strategies, the different strategies were proposed incorporating the active compliance control. The active compliance is a controlled robot motion as a response to the measured reaction forces. A kind of active compliance to the multiple peg insertion is based on the perturbation of the robot end-effector as a result of contact forces and implementation of the algorithm reacting to the measured contact forces. The successful multiple part mating can also be achieved by utilizing a simple differential touch sensor and a behavior-based insertion algorithm.

4. LEARNING CONTROL FOR ASSEMBLY

The essence of most of these approaches is to learn to map a reaction force upon the held object, caused by contact to the next commanded velocity in order to reduce errors and to achieve an assembly operation successfully. An important approach maps combined sensory data of pose and vision obtained during human demonstration of assembly tasks to compliant motion signals for successful assembly by using a proper control for a particular assembly operation through automatic control methods.
A different approach observes assembly tasks performed by human operators through vision or in a virtual environment and generates a motion strategy necessary for the success of the task that consists of a sequence of recognized contact state transitions and associated motion parameters.

4.1. Constraint-based manipulations

For every object in the virtual environment, such as a feature element, a feature and a part, an event list is regarded as the attribute of this object and is attached to this object. An action list is connected to every event in the event list of the object [2]. On the base of this list, in this paper, are created, in a virtual environment, the virtual objects by means of the functions and procedures written in Delphi language. This action list shows the actions that will be done as soon as the event occurs. The constraint-based manipulations are realized by a basic interactive event and the actions being performed when these event occur.
A basic interactive event is attached to every object. Example for the basic interactive events is the grasping event, the moving event and the dropping event. The grasping event has an action for acquiring the current allowable motions of an object that is attached to it. An action for recognizing the constraints between objects is attached to the moving event and the dropping event [3].
As soon as the robot grasps an object, the grasping event occurs and the current allowable motions of this object are derived from the hierarchically structured robot arm and constraint-based data model through constraint solving. The constraint-based manipulations are acquired by constraining the motions of 3D space to the allowable motions. This is done by transferring 3D motion data from the 3D input devices into the allowable motions of the object.
The constraint-based manipulations not only ensure that the precise positions of an object can be obtained, but also guarantee that the existing constraints will not be violated during the future operations.
The framework of constraint-based manipulations for these events is illustrated in Figure 1.

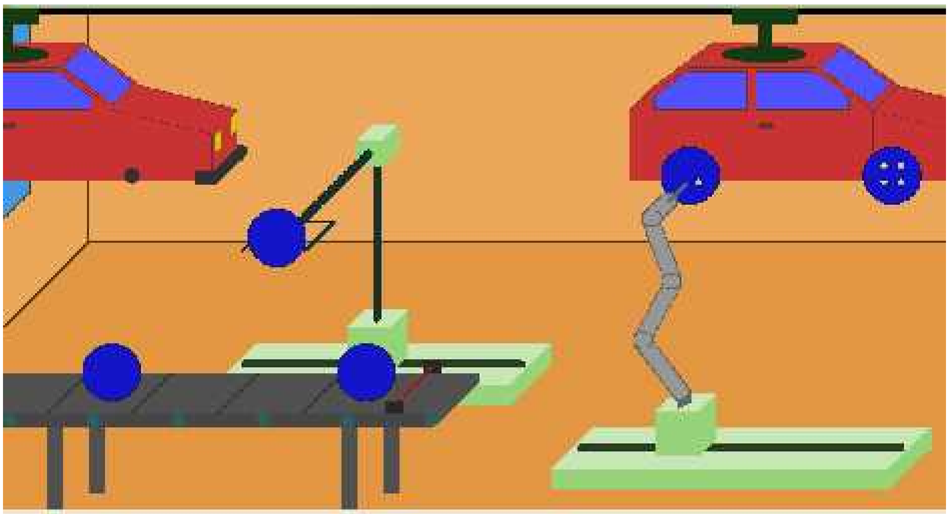


Figure 1: Virtual structure-generated in Delphi environment- for constraint-based manipulations

Once a constraint is recognized during the constraint recognition, it will be highlighted and will await the system's confirmation. Once it is confirmed, the recognized constraint will be precisely satisfied under the current allowable motions of the object and be inserted into the constraint-based data model. The satisfied constraint will further restrict the subsequent motions of the object.

Constraint-based manipulations are accompanied by automatic constraint recognition and precise constraint satisfaction and are realized by allowable motions for precise 3D interactions in the VR environment. The allowable motions are represented as a mathematical matrix for conveniently deriving the allowable motions from constraints. A procedure-based degree-of-freedom incorporation approach for 3D constraint solving is presented to derive the allowable motions. Some special constraint-based manipulations are also implemented as modeling operations for solid modeling in the VR environment.

4.2. Constraint solving for deriving allowable motions

Since most constraints are geometric constraints and they are shown as the limitation of relative geometric displacements between objects, i.e. the limitation of DOFs, the constraints applied to an object can be mapped to the DOFs of this object. In fact, the relationship from constraints to DOFs can be extended to the relationship from a set of constraints to the combination of DOFs. Therefore, the representation of constraints can be obtained by analyzing and reasoning the DOFs of an object, and constraint solving can also be regarded as a process of analyzing and reasoning the DOFs of an object. Based on this, a procedure based DOF combination method occurs for solving 3D constraints [4]. This method combines DOF analysis with 3D direct manipulations in the virtual environment and has an intuitive solving way.

According this procedure, the current allowable motions of an object are derived from the current remaining DOFs of the object. The action of grasping an object is interpreted by the constraint solver as requesting the current remaining DOFs of the object. The current constraints applied to the object can be obtained from the hierarchically structured and constraint-based data model [5].

Initially, the object is unconstrained and has six remaining DOFs. If there is only one constraint applied to the object, the current remaining DOFs can be directly obtained by DOF analysis. If there are multi-constraints (more than one) applied to the object, the current remaining DOFs of the object can be obtained by DOF combination.

The DOF combination for solving multi-constraints is based on the DOF analysis for solving individual constraints. Within the limitation of the current remaining DOFs determined by the current constraints, the object aims at satisfying a new constraint recognized by the current constraint-based manipulations applied to the object.

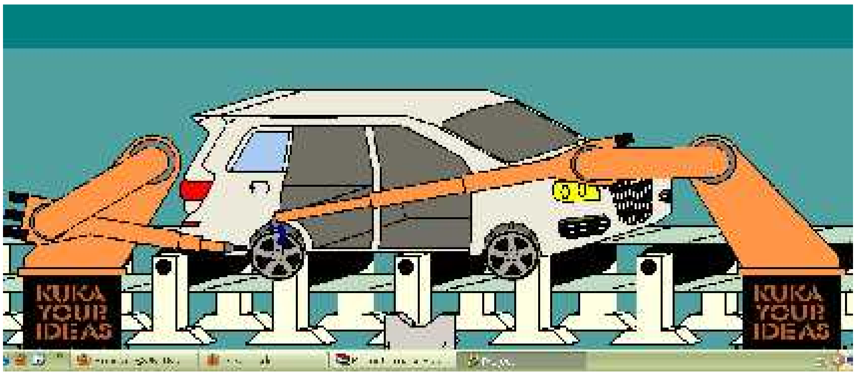
The update of the current constraints results in the update of the current remaining DOFs of the object, and thus results in the update of the current allowable motions of the object [6].

Since DOFs are divided into three basic translational DOFs and three basic rotational DOFs, it is easy to connect a constraint with remaining DOFs by analyzing the remaining basic translational and rotational DOFs corresponding to the constraint.

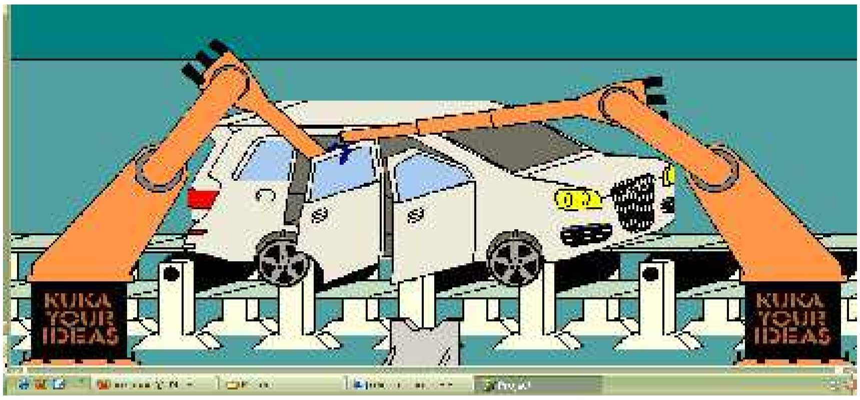
5. IMPLEMENTATION AND RESULTS

A prototype system for intuitive and precise solid modeling in a virtual environment through constraint based 3D direct manipulations has been implemented on the Delphi platform with Reality graphics workstation. The robot work cell is designed in a flexible manner enabling quick change over when changing the car type during production. The assembly system frameworks are illustrated in Figure 2.

a)



b)



c)

Figure 2: Virtual assembly cells for wheels car - a) and b) - and door car - c) - generated in Delphi environment

It consists of three modules, i.e. the hierarchically structured and constraint-based data model, the constraint processing and the modeling process.

During the modeling process, parts are created from feature primitives by constraint based manipulations through locating feature primitives. A feature library for providing some basic primitives is developed to support solid modeling [7].
The hierarchically structured and constraint-based data model represents the entire solid modeling process with various design levels and the constraints at the different levels. It also provides the constraints to generate precise constraint-based manipulations. The new constraint is precisely satisfied under the current allowable motions of the object and is subsequently inserted in the constraint based data model to update the current constraints applied to the object. The software for controlling the robot work cells is written in the robot programming Delphi language and is prepared for the robot controllers. The robot controllers, besides robot motion, also control the operation of the feeding devices and monitor the feedback signals, from the gripper and the conveyor.

6. CONCLUSION

The special structure of modular products provides challenges and opportunities for the design of assembly systems. Given a family of modular products, designing a low cost assembly system is an important issue. In this paper, an approach for design of assembly systems for modular products is proposed. The configuration problem of the assembly system is formulated and solved using the specific algorithms. The algorithm considers concurrent partition of assembly operations and scheduling of products to minimize the total balancing cost of the assembly system.
The assembly system is decomposed into two subsystems based on the structure of modular products.
Simulation planning processes at virtual prototype level have been established to allow planning of the motion control system. The absence of constraints when interacting with virtual objects is one of the major limitations in the current Virtual Reality environments. Without constraints, it is difficult to perform precise interactive manipulations and precise solid modeling in VR environments cannot be ensured. Constraint-based 3D direct manipulations are acquired through incorporating constraints into the VR environment for intuitive and precise solid modeling. In this paper, the author uses the cases study based on a simplified assembly line, realized in Delphi programming environment. The paper presents the adopted solutions used to perform the constraint-based assembly tasks on the assembly lines.

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