International Conference on Economic Engineering and Manufacturing Systems
Braşov, 24 – 25 November 2011

A MULTI-ROBOT SYSTEM FOR ASSEMBLY TASKS IN WOOD PRODUCTS MANUFACTURING INDUSTRY

Mariana FRATU, Aurel FRATU
Transilvania University of Brasov, Romania

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 a case study based on a simplified virtual assembly line realized in Delphi programming environment. The paper describes 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 program is developed.

Keywords: manual handling, flexible assembly systems, virtual robotic assembly systems

1. Introduction

Generally, process of assembly involves manual handling. Manual handling means any activity requiring the use of force exerted by a person to lift, push, pull, carry or otherwise move, hold or restrain any object. For the wood products assembly industry, manual handling covers a wide range of activities such as handling wood, in and out of machinery, transport of materials within the workplace, loading finished product for delivery, delivery and on-site installation. However, manual handling is unsafe.

In wood industry, unsafe manual handling refers to manual handling with any of the following characteristics:

- repetitive or sustained application of force;
- repetitive or sustained awkward posture;
- repetitive or sustained movement;
- application of high force;
- exposure to sustained vibration;
- unstable or unbalanced loads or loads which are difficult to grasp or hold.

There is a legislative framework around controlling risk and consultation in the workplace. Under these regulations the employer has a legal duty to:

- identify tasks involving unsafe manual handling;
- evaluate the risk and;
- control the risk by eliminating it or reducing it so far as is reasonably practicable by the automation of the manual operation.

A person who designs, manufactures or supplies any plant for use at a workplace must ensures that any risk of physical disorder occurring when the plant is properly used at a workplace. If a person is required to carry out identification or risk assessment of tasks involving unsafe manual handling, that person may carry out the identification or assessment for a class or type of tasks rather than for individual tasks.

2. Problem statement

Under new market conditions characterised by high-level dynamics it is necessary to change the conceptual engineering design paradigm to incorporate ideas of intelligence, co-operation and networking.

Many technical processes and products in the area of mechanical and electrical engineering are showing an increasing integration of mechanics with digital electronics and information processing.

In environments unsafe to humans, having robots perform assembly tasks could replace the workers for manual operation and save human lives. The assembly process with robots systems is faster, more efficient and precise than ever before.

To ensure success with robotic assembly, engineers must adapt their parts, products and processes to the unique requirements of the robot. Those that handle tools and those that handle work can differentiate industrial robots. When equipped with gripper arms or tool changers, they can serve both functions.

Assembly automation with robots aims to reduce cost and increase the quality and efficiency of the operation. Assembly has long been not only an important but also one of the most challenging applications for robotics.

There are many significant research issues related to the extensive scope of assembly automation, from design for assembly, to tolerance analysis, assembly sequence planning, and assembling design [1].

This paper is only focused on the issue of robotic motion for assembly in a virtual environment.

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 [2].

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 [3].

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.

The unit effort costs in the manufacture of parts have been decreased by new materials and simplification of products. The new production technologies based on assembling with robots have occurred the augmentation of the productivity into the final product.

3. Assembly motion

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 a*ssembled 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 (DOF) of the held part, compliant motion is desirable in assembly.

Therefore, a successful assembly motion has to move the peg out of such an unintended 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, for example, 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.

4. Learning control for assembly

The essence of most of the actually 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. The successful of the assembly process is assured by using a proper control for a particular assembly operation, through stochastic or neural-network-based methods.

A different approach observes assembly tasks performed by human operators through vision or in a virtual environment and generates a motion strategy. This strategy consists in a sequence of recognized contact state transitions and associated motion parameters.

4.1. Constraint-based manipulations

For every object is attached the attributes element and an event list is held out. An action list is connected to every event in the event list of the object [4]. 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.

Examples for the basic interactive events are the grasping event, the moving event and the dropping event. The framework of constraint-based manipulations for the grasping event is shown in figure 1.

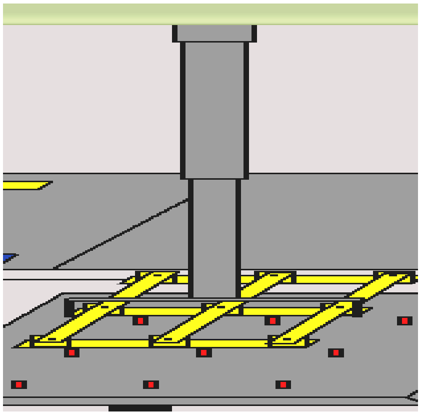

Figure 1. Virtual structure for constraint-based manipulations for the grasping event

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.

As soon as to grip an object, the grasping event occurs and the current allowable motions of this object are derived from the hierarchically structured and constraint-based data model through constraint solving.

Once a constraint is recognized during the constraint recognition, it will be highlighted and will await the user'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.

The control system will be capable to identify the mechanical interaction between the robotic system and her work space. Depending on how this interaction is established, the trajectory might be a collection of successive positions of the robotic system, parameterized by time.

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 DOF, the constraints applied to an object can be mapped to the DOF of this object.

In fact, the relationship from constraints to DOF can be extended to the relationship from a set of constraints to the combination of DOF. Therefore, the representation of constraints can be obtained by analyzing and reasoning the DOF of an object, and constraint solving can also be regarded as a process of analyzing and reasoning the DOF of an object.

According these, a procedure based DOF combination method occurs for solving 3D constraints [5]. This method combines DOF analysis with 3D direct manipulations in the virtual environment and has an intuitive solving way. The current allowable motions of an object are derived from the current remaining DOF of the object.

The action of grasping an object is interpreted by the constraint solver as requesting the current remaining DOF of the object. The current constraints applied to the object can be obtained from the hierarchically structured and constraint-based data model.

Initially, the object is unconstrained and has six remaining DOF. If there is only one constraint applied to the object, the current remaining DOF can be directly obtained by DOF analysis.

If there are multi-constraints (more than one) applied to the object, the current remaining DOF of the object can be obtained by DOF combination [6].

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

Since DOF are divided into three basic translational DOF and three basic rotational DOF, it is easy to connect a constraint with remaining DOF by analyzing the remaining basic translational and rotational DOF, 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 system framework is illustrated in figure 2. It consists of three modules: constraint-based data model, the constraint processing model and the assembling process model.

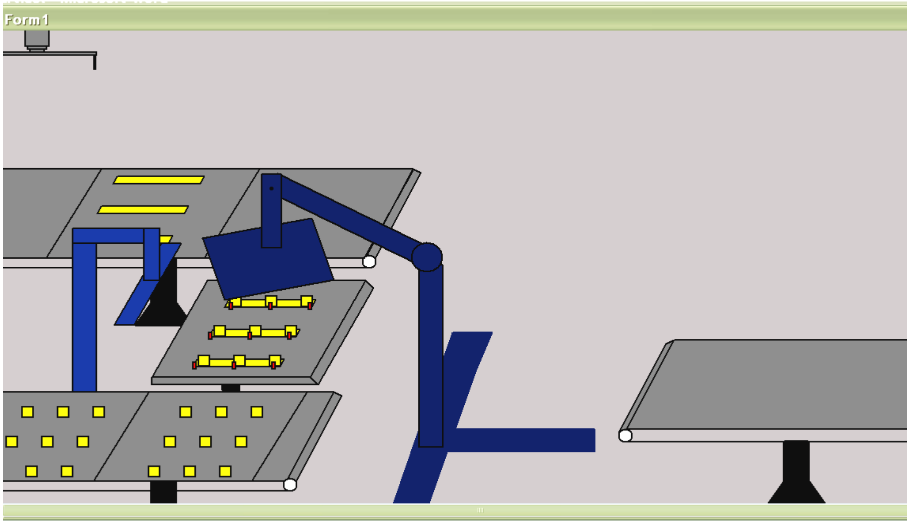

Figure 2. Virtual flexible line for assembly - case study

These models are hierarchically structured. 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.

6. Conclusions

Simulation planning processes simulation at virtual prototype level, have been established to allow planning of the motion control system.

In this paper, the authors use a case study based on a virtual simplified assembly line realized in Delphi programming environment. A virtual prototype has been implemented to testify the feasibility of the presented methodology for the assembly of wood objects.

The paper describes the adopted solutions used to perform the constraint-based manipulations tasks. For the assembling of the wood products in the manufacturing industry, the authors have proposed a virtual multi-robots prototype model.

References

1. Reinhart, G., Werner, J. (2007) *Flexible automation for the assembly in motion.* Journal of Manufacturing Science and Technology, Vol.56, No. 1 (May 2007), p. 25-28, ISSN 0007-8506
2. Ahmadi, M., Stone, P. (2006) *A Multi-Robot System for Continuous Area Sweeping Tasks.* Proceedings of the IEEE International Conference on Robotics and Automation, p. 1724-1729, May 2006, Available from: www.cs.utexas.edu/~pstone/Papers/bib2html-links/ICRA06.pdf, Accessed: 21/04/2011
3. Xiangming, D., Bin, S., Weijun, Z., Ruqing, Y. (2002) *Design of a flexible robot assembly demo system.* Proceeding of the 4th World Congress on Intelligent Control and Automation, vol. 2, p. 1343-1346, ISBN 0-7803-7268-9, June 2002, Shanghai, China
4. Zhong, Y., Ma, W., Shirinzadeh, B. (2005) *A methodology for solid modeling in a virtual reality environment.* Journal of Robotics and Computer-Integrated Manufacturing, Vol. 21, No. 6 (December 2005), p. 528-549, ISSN 0736-5845
5. Kim, J., Kim, K., Choi, K., Lee, J.Y (2000) *Solving 3D geometric constraints for assembly modeling.* Journal Advanced Manufacturer Technologies, Vol. 16, No. 11, (September 2000), p. 843-849, ISSN 0268-3768
6. Li, Y.T., Hu, S.M., Sun. J.G. (2002) *A constructive approach to solving 3-D geometric constraint systems using dependence analysis.* Computer Aided Design Journal, Vol. 34, No. 2 (February 2002), p. 97-108, ISSN 0010-4485
7. Hu, X., Zeigler, B.P. (2004) *Model Continuity to Support Software Development for Distributed Robotic Systems: a Team Formation Example.* Journal of Intelligent and robotic systems, theory and application, Vol. 39, No. 1 (January 2004), p. 71-87, ISSN 0921-0296