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Industrial robotic system with adaptive control

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Abstract

In this paper an adaptive multiagent robotic assembly system is presented. State of the art industrial equipment is utilized to perform various assembly tasks in a highly unstructured environment without the need for central control. The emphasis is given to the developed methods that address particular issues in such robotic assembly systems. Close collaboration and intertwined work with human operators is one application under development, possible due to complex sensorial inputs on the robots. Active voice commands and prompts additionally contribute to human-robot interaction. Encounter with unknown objects is another issue that has been addressed and can be solved autonomously for simple case scenarios. Actual assembly applications as well as applications under development are presented. The operation in unstructured environments has been facilitated with vision systems, F/T sensors and other sensorial devices.

Keywords: Multiagent systems; robotic assembly; human-robot interaction

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1. Introduction

In order to cope with current trends of dynamic changes in market demands, shortened product life cycles and large number of product changes a new approach in system design is required. Assembly technology can be stressed as one of the key factors in almost every industrial application ranging from automotive to electronic industry. A continuous development in assembly technology is present. New sophisticated tools and machines ranging from industrial robots, vision systems, handling and measuring devices have been developed [1, 2]. The level of system complexity in assembly technology is undoubtedly increasing. Functions are added to products where they never existed in the past. Technological development requires an associated development of novel system control methods. Today, utilized system control principles within industrial applications vary from simple centralized single-purpose systems to distributed flexible and adaptive systems.

A multiagent robotic assembly system is presented with embedded capabilities for adaptive behavior. State of the

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art industrial equipment is utilized to perform various assembly tasks in a highly unstructured environment without central control mechanisms. Emphasis is given to developed methods that address particular issues in such robotic assembly systems. Assembly technology has always been vulnerable to machine failures and part defects. A classical industrial system usually operates in a highly deterministic environment. Each step is governed by central system controllers that synchronize actions for all units. In complex systems this approach increases time and resources for part preparation. Even a small modification in the process will cause serious disturbances. Therefore various methods and principles [3, 4] have been developed in supporting such systems to become more autonomous and reliable in nondeterministic conditions and environments.

A self-adaptive control method for tuning intrinsic vision parameters is developed in [4]. The adaptive vision system is able to produce desired results in fluctuating light conditions and has been facilitated in actual assembly applications. Huge efforts are present in the development of intelligent robots [5]. An integrated system with acting and sensing capabilities has a wide potential of applications. One persistent issue in robotic handling applications is introduced through underdeveloped grippers. The development of grasping capabilities can be seen as a separate research direction. Today there are various attempts to provide a universal gripper [6] adequate for a number of applications. Tool changing capabilities [7] are more obvious to solve grasping problems for the majority of undefined working parts. Giving the possibility to every agent in the system to choose an appropriate tool for an action produces satisfactory results.

In this paper a synergy of adaptive methods in all enumerated fields is present. A continuing research is presented with an overall goal of providing a fully adoptable technical assembly system. Intelligent robots (agents) are used as the backbone in the presented multiagent system. Use of diverse sensors and actuators allows these intelligent agents to build an actual representation of the environment. Through various communication mechanisms [8] agents interact and are able to reach consensus.

The developed multiagent robotic system is not confined with single-purpose machines and is suitable for varying environmental conditions. Therefore it can be used in various production scenarios. The central part consists of cognitive agents [9] (robots and machines) which acquire information from the environment using sensors and through communication with other agents. By delivering appropriate actions in unknown scenarios the multiagent system is able to respond to unexpected changes. Developed system approach with embedded cognition and action capabilities in every component (agent) produces added value in compared to traditional control principles. A turnover toward intelligent solutions in industrial environments is a crucial step for creating autonomous technical systems. A series of determined actions are needed in order to provide these solutions. Two isolated issues concerning such systems have been addressed. An adaptive method has been implemented for solving occurrences of unknown objects. In addition an initial version of the human-robot interaction scheme is presented.

2. Developed adaptive methods

2.1. System setup

The developed multiagent architecture has been tested and verified on an actual industrial setup consisting of 8 industrial robots, 4 transport systems, 7 vision systems, 2 F/T sensors, 3 PLC’s and automatic tool changers as presented in Fig. 1. Supported with essential communication protocols such as DeviceNet, Profibus, and TCP/IP allows integration of diverse technical components into the system.

At present the system is capable of complete assembly operation for two different products [10]. The assembly system utilizes sophisticated sensorial capabilities including 2 F/T sensors, 6 cameras and a 3D laser projection vision system. These agents include mechanisms for resolving occurrences of unknown objects, human-robot interfaces and interaction schemes. Diverse sensorial devices allow agents to create a representation of the environment.

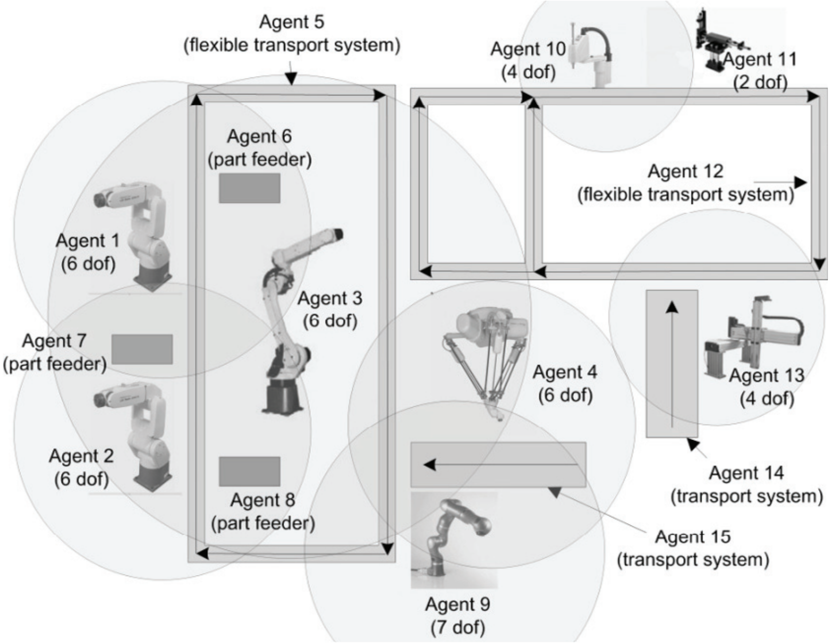

Fig. 1. The multiagent architecture [8]

2.2. Human-robot interaction

Close collaboration between humans and robots is a feature of this system that is under development. Looking at the future of automation, robots will not only be stupid machines carrying out dull and dangerous work and being caged behind fences, but work as robot assistants in close proximity of, and in cooperation with humans [2]. Moreover robots could be programmed through haptic and voice interaction making the human robot interface more accessible and eliminating the need for expert programming knowledge. Above all the level of safety has to be maintained. Special sensors for collision detection are integrated. Traditional industrial robots provide this functionality through measuring current flow in their joint motors. It can be determined if the robot came across an obstacle by the current flow increase. An opposite direction utilizes force/torque sensors that produce better results due to higher level of sensitivity. Industrial robot manufacturers are responding to these demands and producing robots that have sensors in one or even in every joint [2]. These sensorial capabilities allow human operators to work very close to the robot and also are the main precondition for future interactive behavior. The worker can simply push the robot away if it presents an obstacle. High precision force sensors also allow fine tuning of programmed positions.

In addition to haptic feedback the most intuitive way of interaction is speech. A background running speech recognition module is analyzing spoken commands. For safety reasons the speech recognition module is trained to respond only after a specific word is spoken. The voice commands have the highest priority level (strictly reserved) where the robot responds promptly. Depending on the issued command the robot performs a certain task. Preprogrammed tasks can be executed or a mode for creating new programs and routines can be activated.

A natural way in which humans communicate is mostly oriented toward gestures, speech and sense of touch. In the ever increasing complexity of technical systems only skilled and highly competent operators are able to "communicate" with robots using special languages and interfaces. Designing a human-robot interface intended for operators without expert programming knowledge will provide them with the ability to work with robotic systems through a more intuitive interface.

2.3. Unknown objects

Common issue in industrial robotic handling applications is inadequate possibility for handling various parts. Manipulation with unknown objects is moreover an issue that hasn't been given much attention. Today, the environment suited for industrial robots is strictly arranged. Every process is separated from human interference, the workspace and working parts arranged in great detail. These requirements pose limitations in aspect of flexible behavior.

A probable factory of the future will have the ability to produce various products in a nondeterministic environment. Constant changes and customizations of products will demand an endeavor toward fully adaptive technical systems. One of the issues regarding these possible solutions are unknown objects for the robot (agent). In a system where numerous products are being assembled and robots encounter a variety of different parts it is possible that an unpredictable situation occurs. A deadlock arising from this kind of scenario would significantly reduce system efficiency. A "debugging" decision made by the robot on the other hand could save time and boost productivity.

A solution for handling simple case scenarios when locating unknown objects was developed and implemented on several agents in the system. The principle is described in Fig. 2.

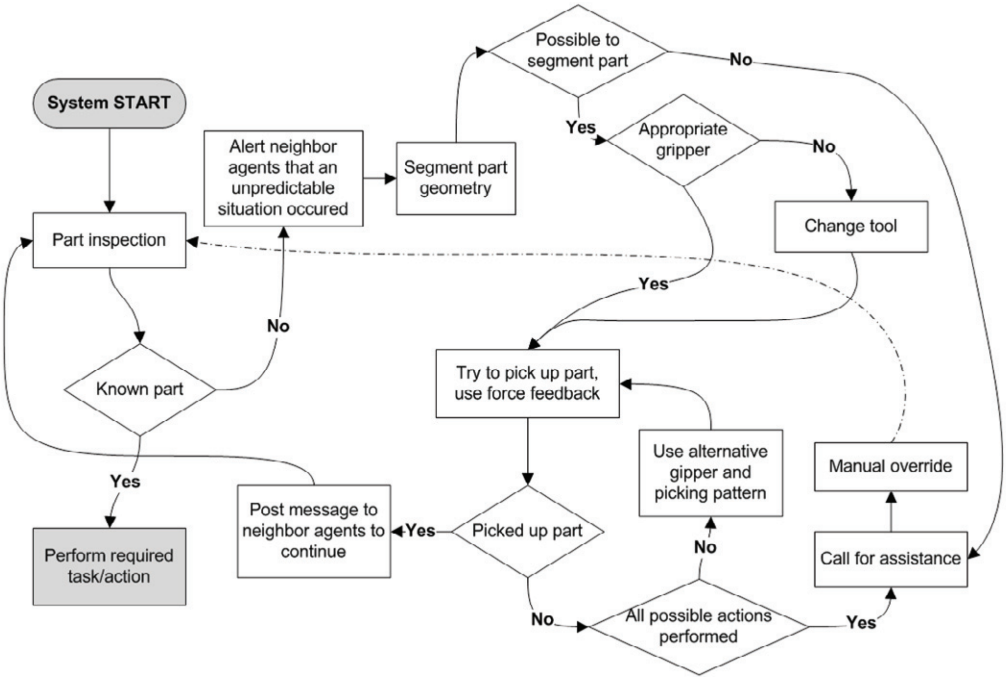

Fig. 2. Workflow chart for resolving unknown parts in the system

Vision system inspects the arrival of a new part. If the identified object corresponds with the agent assembly plan an appropriate action is executed. In a scenario where the agent by visual inspection identifies an unknown or defective part it first alerts all neighbor agents involved in its common workspace. By this procedure the awareness of all agents increase and their working speed reduces significantly. Using a segmentation method the agent attempts to identify the geometry of the part. The geometry characteristics are compared with similar objects in the vision pattern database. If the matching pattern is a defect of a known part the agent attaches an appropriate tool. If there is no appropriate tool and no other neighbor agent can eliminate the unknown part a request for manual override is sent.

When the identified part has similar geometry in comparison with an already defined part the agent uses the most likely tool for grasping. Choice mostly depends on the shape and dimension of an object. The tool which will most likely yield a positive grasping result is attached. An agent can choose from specific parallel grippers intended for picking small objects, grippers for picking medium sized objects, a vacuum gripper which can be used on any (large enough) flat surface and a gripper with a varying finger stroke and angle. After approaching the picking position and picking the part the feedback from the F/T sensor is analyzed. If an increase of the force applied to the sensor is recorded the part has been successfully grasped. If there is no change in comparison to readings prior to grasping an alternative grasping method is utilized. If no alternative grasping method yields positive results the agent sends a request for manual override.

After the issue has been solved all neighbor agents are notified and the system resumes working with normal speed.

3. Coordination and negotiation methods

At global level the system consists of various types of industrial equipment that work concurrently and has task negotiation capabilities. A common “language” is adopted for every agent. The system consists of collaborative agents which share a common global goal. The Contract Net Protocol communication [11] is used to allocate an operation to the best suitable agent. At this point the bidding mechanism has been adopted for several reasons. The cost function is particularly easy to calculate. Investigating their current states and the state of the environment agents calculate the amount of resources for completing a task. This calculation is translated into an interchangeable value comparable among all agents in the system. The agent with the lowest bid is delegated the particular task. Calculated cost can be compared between different types of agent architectures. For this reason it is used as the main negotiation technique in a distributed architecture when industrial hardware with reduced processing capabilities is utilized.

4. Implementation of adaptive methods

Implementation of the force control algorithm for manual positioning the robot arm is depicted if Fig. 3. The operator activates force control issuing a voice command. The robot is guided to a desired position in its workspace. Vision system identifies precise position of the working object for executing a pick & place operation. The force control application was used to show how a change in work piece position can be easily solved using the developed interactive human-robot interface. Due to complex calibration issues with actual parts the approach has been tested on simplified objects. A method for visual calibration in actual industrial scenarios is under development.

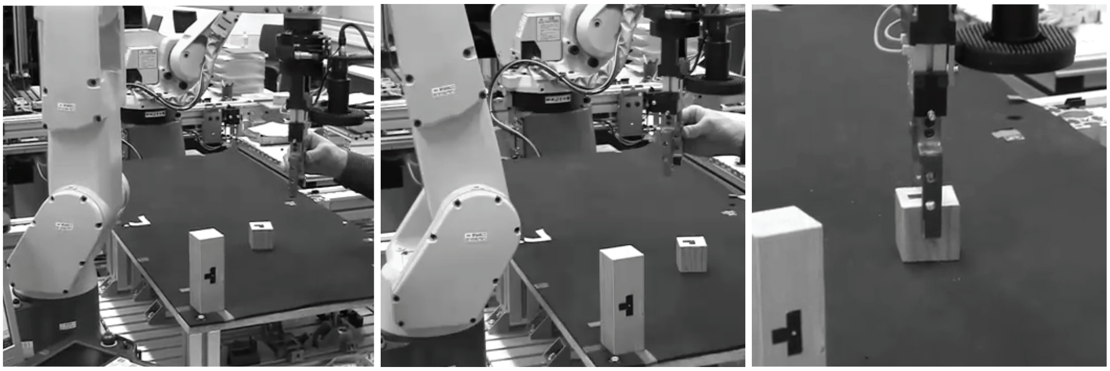

Fig. 3. Open loop control for the robot arm (*Agent1*)

In Fig. 4 an unknown object is introduced into the system. The agent inspects the transport system and identifies an elongated object. An alert signal is issued to neighbour agents. The agent attaches the most appropriate tool for grasping the unknown object. The object is successfully removed from the transport system (*Agent5*) and normal system operation is resumed.

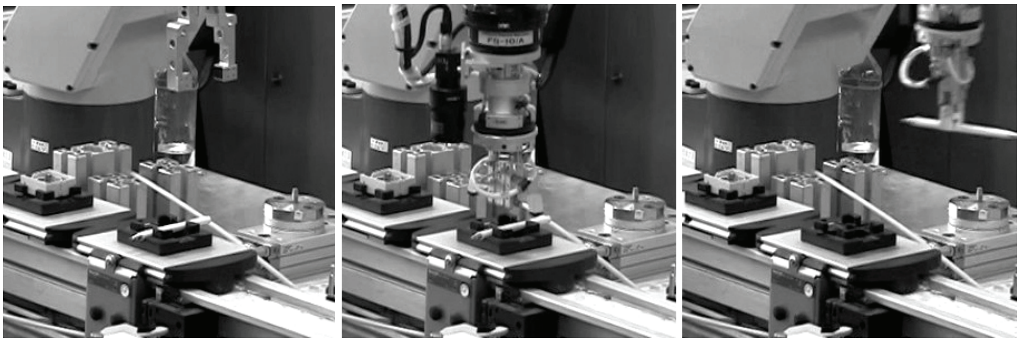

Fig. 4. Introduction of an unknown object (*Agent2*)

5. Conclusion and further research

The constant trend in increase of product diversities and decrease of available space for production facilities has led researches toward creating flexible and adaptive solutions. Bringing toward a system approach where one developed framework has numerous production capabilities can help solve these issues. In the future, the development of similar systems is prominent. Robots represent ideal platforms for facilitating the embodied approach where each unit is a complete entity with acting and sensing capabilities.

The presented system is intended to serve as a research platform for developing new methods for adaptive and autonomous behavior in industrial assembly. An efficient method for resolving occurrences of unknown objects has been presented. Through geometrical matching of object shape and available tools an agent attempts to manipulate an object by applying various grasping patterns. The human robot interaction methods allow the utilization of robots either as assistants or for simple teaching tasks. Future research efforts will extend the application of the framework to new diverse parts as well as deliver novice methods for intelligent adaptive behavior.

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