Design of Reconfigurable SW Modules for Mobile Manipulators in the Small-Scale Flexible Plants

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I. INTRODUCTION

It is very important for the small-scaled local production companies to respond with current trend of product life cycle where they are forced to move up the release date of the new items and maintain the quality of their existing ones.

It is advantageous to product more than two types of items in the production line at the same time over small quality batch production or mass customization for the market requirement.

There have been many attempts at building their flexible production system based on the robots with the following features and functionalities:

- Human-Robot Cooperation: it is inefficient to provide the robots with high degree of autonomy in the view of cost. Wiring harnesses or seals are, for example, limp components that cannot be controlled properly by today's automation techniques [1]. Instead it is practical to make the robots work with human operators who have the right to make decisions of suitable actions considering work procedures and their experiences.
- Robot-Robot Cooperation: it is necessary to make robots work with one another for complex tasks such as assembling small parts. KUKA introduced a key feature in a set of products that can be applied across cooperating standard controllers. This is important for flexible factory systems, especially where different types of cooperation are needed among different groups [2].
- Environment-Robot Cooperation: A Robot is supposed to be integrated with machine tools with PLC language or G-code. For the functionality, a robot can play a role of master in the production line.

These functionalities can be achieved with various hardware modules and software modules which can be reconfigured properly according to working conditions. However, it is difficult to respond with a change of mechanical structure or relations with external players including human operators, other robots, and environmental apparatus because industrial robots have been designed to be equipped with special tools and their software focuses on reliability, precision, and time constraint property.

In this paper, we suggest reconfigurable software modules for a mobile manipulator which can respond with various changes of external or internal conditions. For the purpose, we explain a mobile manipulator in section 2 and core functional software modules in section 3.

II. MOBILE MANIPULATOR

A. Robot Mechanism

In this paper, we assume that a mobile manipulator has a mobile base and an articulated manipulator with more than four degree of freedom like OmniRob and youBot[3], and X-WAM[4].

The manipulator may be equipped with one of various types of grippers on its end-effector using automatic tool changer. The manipulator has an ability of measuring force/torque applied to its end-effector.

The mobile base is a holonomic or non-holonomic wheel typed system and has a ranging sensor such as LRF (Laser Range Finder) and a vision camera.

B. Robot Controller: Electrical/Electronic Hardware

The manipulator has a real-time communication such as EtherCAT for communicating with other robots or peripheral devices coupled closely in the production line. And the system communicates with loosely coupled devices via wireless communication medium and has an io-channels for PLC communication.

A main computer supports reconfiguration of robot software modules while the robot working. For example, when the robot is a master of a certain production line, robot invokes some part in the environment-robot cooperation module. For the purpose, the robot is assumed to have multi-calculation cores, multi-processors or multi-boards such as Sitra Processor AM5728 from Texas Instruments [5].

III. RECONFIGURABLE SOFTWARE MODULES

A. Human-Robot Cooperation Module

Human operator takes the initiative to work together with a robot. He/She decides something to do and suitable method for completion of the mission. So, it is very important to recognize human operator's intention for the robot.

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Some his/her intentions are related to physical meaning such as force and torque which informs the robot of his/her motion information and behavioral know-how related to handling objects. And other intentions are related to logical meaning such as work procedures.

There are several methods to recognize human operator's intention such as 'kinetic teaching', 'indirect teaching with wearable sensors', and 'learning from demonstration'. The first two methods are suitable to obtaining physical meaning and the last method is adequate to the logical meaning.

B. *Robot-Robot Cooperation Module*

It is necessary to make robots work with one another for complex tasks such as assembling small parts. The robots are coupled loosely, closely, or mechanically linked to each other. In the case of close coupling

- Loosely coupling: robots work together with weak constraints related to the logical sequence. They communicate with each other via the non-real time medium.
- Closely coupling: robots have strong communication methods including io-signal channel or real-time communication such as EtherCAT and share sensor information and planned motion trajectories. One of them takes some decision as a master, and the other robots follows the orders from the master or take their corresponding actions to master's decision.
- Mechanical linkage: one robot is the parent of the other robots such as mobile manipulator and dual arm robot. In recent, mechanical linkage between the robots may be reconfigurable while working. For example, robots may change gripper or even the manipulator on the mobile base according to their roles and robots.

C. *Environment-Robot Cooperation Module*

When the robot has to play a role of master in the production line, it approaches the production line and connects its own PLC connection port to the predefined spot. After completion of connection, the robot loads the PLC master software module. It scans peripheral instruments and downloads work plans from a main server. And the robot controls work processes according to the plans.

D. *Some Common Modules*

There are some software modules for a mobile manipulator as follows:

- Ranging sensor module: the software module obtains ranging information from a sensor module such as LRF and calculate ego-centric local distance map.
- Object recognition module: the software module obtains vision streaming data from camera and recognize/identify objects.
- Map management module: the software module build up and revise geometric maps including 2-dimensional map and 3-dimensional map.
- Localization module: the software module localize the robot itself and other robots.
- Calibration module: in the case of closely coupling cooperation and mechanical linkage, the software module figures out precise mechanical relations between robots.
- Others: Path planner module, Motor interface module, and I/O interface module.

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