Mobile Materials Handling Platform Interface Architecture for Mass Production Environments

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***Abstract*-Industrial manufacturing systems achieve production stability due to near constant production processes e.g. mass production. Passive methods such as production flow analysis can produce plant layouts which optimise material flow within the processing environment. Due to the operational structure of mass customisation, passive methods alone cannot facilitate customer influenced production dynamics. This is due to the fact that every product is different from the last.**

Active methods such as flexible materials handling systems can be used to achieve production stability in mass customisation production environments. This paper presents a mobile platform architecture that can act as an active stability component in customer influenced production environments. This architecture consists of many hierarchical levels of abstraction spanning from the physical domain up to the platform management.

I. INTRODUCTION

A flexible materials handling architecture for Mass Customisation manufacturing should be responsive to changing production dynamics. This would ensure smooth and stable material diffusion through the manufacturing plant. It is reasonable to assume that many passive measures would be taken by production planners, in order to facilitate Mass Customisation [1]. These passive measures could consist of simulated Production Flow Analysis in order to design feasible plant layouts which optimise material flow on near-standard manufacturing conditions i.e. Products with only slight customisation. It would then be up to the active components, such as flexible materials handling systems, adaptive process control and flexible machine tool infrastructure to accommodate off standard production and materials handling requirements.

In any complex system it is important to develop a good policy vs. mechanism structure, where policy represents *what we want to do* and mechanism represents *how we are going to do it*. The architecture described here tries to establish a formal policy versus mechanism structure for materials handling in Mass Customisation.

The structure of this paper follows the following format. In Section II a discussion on production stability and a control theoretic framework for Mass Customisation is presented. Section III describes a proposed materials handling platform architecture designed to establish a good policy vs. mechanism structure in flexible materials handling systems. Section IV presents two different platforms based on this architecture that will provide future research platforms. Section V ends with concluding remarks and a discussion of future research.

II. MASS CUSTOMISATION PRODUCTION DYNAMICS

Fig. 1 encapsulates Mass Customisation in a control theoretic framework.

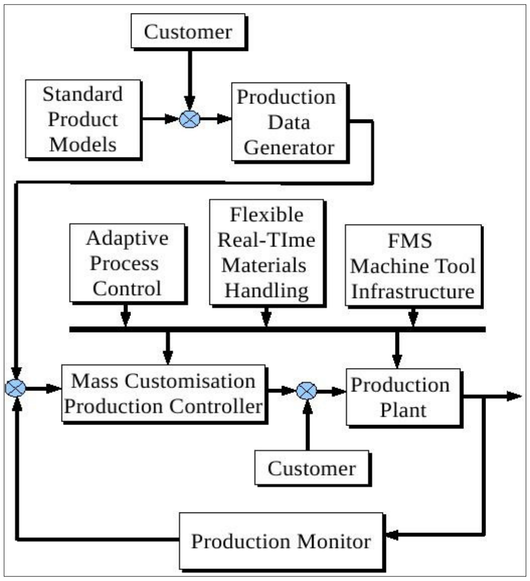

Fig. 1. Mass Customisation in a control theoretic framework.

In this framework, the customer is interpreted as an input disturbance, which offsets standard production signals developed from standard product models. The objective of the Mass Customisation production controller is to minimise production sensitivity by regulating customer-induced process variations. The controller has access to Adaptive Process Control, Flexible Real-time Materials Handling systems and Flexible Manufacturing Systems in order to facilitate off standard materials handling and processing requirements. The focus of this paper is on Flexible Real-time Materials Handling systems and their role in the facilitation of off - standard production.

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Using passive measures, such as Design For Mass Customisation, DFMC [2], and simulated PFA, production plant layout structures can be designed so as to enable static materials handling infrastructure, such as material conveyor networks, to facilitate a large range of material flow and routing requirements imposed by customised products. These passive measures would reduce production sensitivity. However, in the cases where off standard real-time material routing is required in order to facilitate the production requirements of a customised product, flexible real-time material transportation devices would need to be called into commission. By referring back to a control theoretic description of the materials handling characteristics generated through custom production requirements, the application of a flexible real-time materials handling system is elegantly summarised. A control statement follows:

An off-standard materials handling request, generated through a customer input disturbance causes the Mass Customisation production controller to initiate regulation primitives, through the actuation of a flexible real-time materials handling system, in order to regulate the off-standard material routing request thus maintaining economical material diffusion, production rates and production stability.

The architecture presented here is a proposed method of implementing such flexible actuation mechanisms.

III. MATERIALS HANDLING PLATFORM ARCHITECTURE

The layered materials handling platform architecture is shown in Fig. 2.

At the highest level of abstraction lies a Materials Handling Agent Architecture or MHAA. The MHAA operates in two functional scopes. Firstly as a software mechanism that allows for the structured storage, in materials handling specific data structures, of local materials handling task information. The materials handling task information is passed in from higher level management frameworks, [3]. Such data structures hold information regarding material routing destinations as well as information about the payload instance associated with the assigned task. The MHAA also holds maps of the production plant layout, for navigation and path planning purposes.

The second operational aspect of the MHAA is to utilise an Agent Toolbox in order to operate a communication subsystem as well as access the interface specifications of the underlying Robotic Middleware, discussed shortly.

The communications subsystem implements two protocol structures. Firstly a global protocol structure which is used to communicate with the higher level management framework. The global protocol structures facilitate the communication of completed task information and provide data marshalling for the materials handling task instances. The local protocol structure enables robust transmission of environmental and local task information between cooperating mobile materials handling platforms. This protocol structure is designed to facilitate multi-platform cooperative materials handling in which the stability of material payload transportation is dependant on the degree of robust information exchange between the relevant platforms [4].

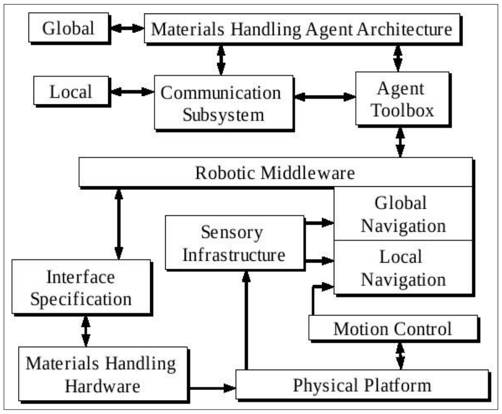

Fig. 2. Materials Handling Platform Architecture

The Agent Toolbox also provides the MHAA with access to Robotic Middleware. The middleware abstracts the underlying physical aspects of the mobile materials handling platform into higher-level device interfaces which the Agent Toolbox can access and use to control the motion of the mobile platform. This motion control is not explicit, control is provided implicitly through global and local navigation facilities, provided by the Robotic Middleware. The Sensory Infrastructure layer feeds the data fusion primitives used in the implementation of the global and local navigation facilities and constitutes part of the physical hardware layer of the platform architecture. At the lowest level of the mobile platform architecture is the Physical Platform subsystem. This subsystem encapsulates the mechanical architecture and drive system used by the platform as well as any motion constraints imposed through the drive kinematics.

The kinematics environment of most mobile robot platforms in use today is nonholonomic, which requires the development of non-linear or time-varying motion controllers in order to facilitate path tracking and posture stabilisation motion requirements, [5].

The motion requirements for the majority of materials handling tasks can be considered as point-to-point along a reference path, i.e. tracking motion and posture stabilisation. Point-to-point motion primitives are required in order to facilitate a request to transport material from one section of the production plant to another. Posture stabilisation motion primitives would be required to converge the platforms' pose onto a goal pose that best suites the transfer of material from manufacturing infrastructure to the mobile platforms' materials handling infrastructure or vice-versa. The Motion Control layer, shown above in Fig. 2 is a specification on these above mentioned motion primitives and controllers must be implemented in order for the underlying physical platform to facilitate such motion primitives regardless of kinematic environments.

Lastly the physical materials handling infrastructure used to carry out the materials handling procedures is encapsulated in the Materials Handling Hardware subsystem and presents an abstract interface for the MHAA and associated Agent Toolbox to operate, through the Robotic Middleware.

IV. PLATFORM ARCHITECTURE REALISATION

Discussed below are two different platform configurations based on the proposed platform architecture. The first platform is discussed on a systems scope and the second platform is discussed on a hardware scope.

A. *Architecture Realisation #1*

Fig. 3 shows one of the mobile materials handling platforms developed based on the above mentioned platform architecture.

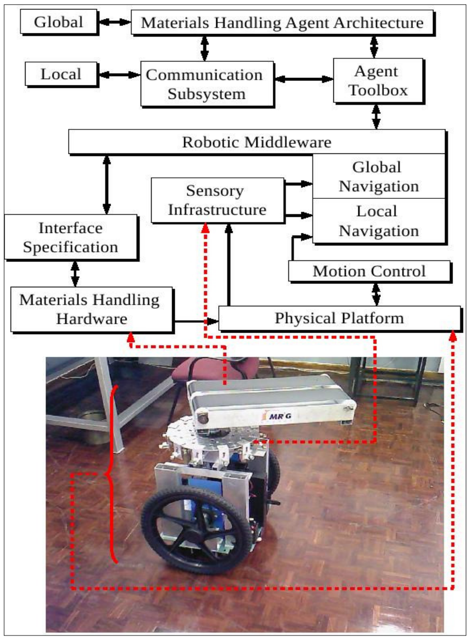

Fig. 3. The RollerMHP Mobile Materials Handling Platform

A bottom up, i.e. hardware to software description of the mobile platform shown in Fig. 3 follows:

The platform implements, as its “Materials Handling Hardware” infrastructure, an articulated material conveyor. The conveyor can rotate 360 degrees and is driven by an underlying DC motor. The motor is fitted with a quadrature encoder and is controlled through an embedded microcontroller and H-bridge driver. This provides the underlying physical platform with the relative orientation of the conveyor. This allows the platform to execute highly directional materials handling primitives without using high power consuming platform orientation adjustments as well as provides and extra degree of freedom and “sensed articulation” during cooperative materials handling tasks where the cooperating platforms effectively form closed kinematic chains, [6].

Fundamentally, the mobile platform is a differential drive mobile robot, and has associated nonholonomic kinematic constraints. A non-linear posture stabilisation algorithm was implemented based on a polar coordinate state transformation, taken from [7]. The algorithm provides satisfactory performance in stabilising the mobile platforms state configuration.

Fig. 4 shows a sample response.

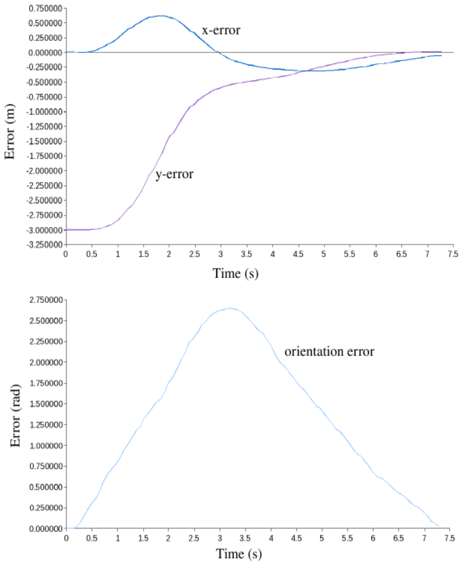

Fig. 4. Parallel Parking Manoeuvre

The point to be made here is that regardless of the constraints imposed by the physical implementation of the mobility system, the materials handling platform can still perform the motion primitives specified in the architecture.

The platform uses the Player Server, [8], as its Robotic Middleware layer. The interface specifications supported are shown in Fig. 5.

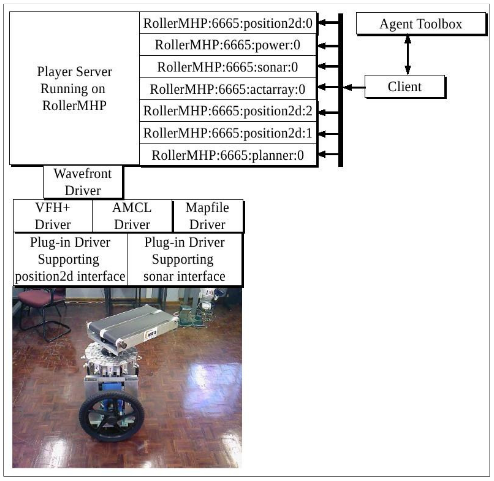

Fig. 5 Middleware Configuration

Utilising Robotic Middleware allowed for the development of generic non-linear control algorithms. This allows for easy porting of motion controllers to other differential drive platform configurations, such as the one presented shortly.

B. *Architecture Realisation #2*

Tasks that are allocated to this platform by the management systems can be defined as tasks that are required to defend the production rate and stability due to circumstances beyond the control of the management systems such as bottlenecks and buffer overruns. These are not essential to complete the production process, but are necessary to uphold the rate and stability of production. This platform however can also be used to facilitate the off standard routing requirements as discussed earlier as well as for cooperative materials handling tasks.

The platform discussed in this section can be seen in Fig. 6. This is a self-balancing materials handling platform. The impact of this fact on the proposed platform architecture will be discussed shortly.

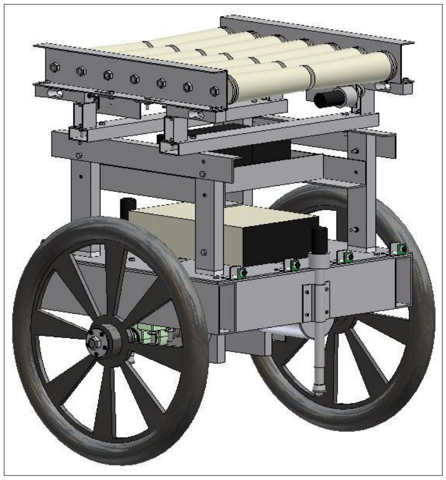

Fig. 6. CAD model of self-balancing materials handling platform

The physical realisation of this platform as related to the proposed platform architecture can be described as follows:

The Player robot server software represents the Robotic Middleware as discussed earlier. The robot server is installed on an on-board Single Board Computer (SBC) running the Fedora 7 distribution of the Linux operating system. The robot server realises the global and local navigation through Wavefront Propagation and Vector Field Histogram algorithms, respectively [8].

Communication between this platform and other materials handling platforms as well as management systems is realised via the wireless Wi-Fi communication protocol. The on-board SBC is fitted with a USB Wi-Fi adapter for this purpose.

An array of eight ultrasonic transducers are mounted on the base of the platform, four ahead and four to the rear. They are mounted at such angles as to maximise range and minimise crosstalk without creating blind areas. These ultrasonic transducers constitute the sensory infrastructure of the platform and are abstracted as a device known as “sonar”. As discussed earlier these sensors also constitute part of the physical hardware layer of the platform.

The drive system of this platform consists of two wheels each driven by a DC motor, as seen in Fig. 6, this implies that the drive system can be described as a differential drive system. This drive system forms part of the Physical Mobile Platform subsystem. From the point of view of the Agent Toolbox this differential drive system is abstracted as a “position2d” device by the Robotic Middleware.

As discussed in Section III the motion controller that is implemented on this platform for path tracking is based on nonholonomic kinematics, due to the constraints enforced on the platform by the differential drive system. The control system tasked with maintaining the dynamic stability of this platform is embedded on the motor controllers that command the drive motors. This control system can thus be assumed to form part of the Physical Mobile Platform subsystem, as any commands communicated by the motion controller for path tracking are overlaid on the stability control commands. The stability control commands however enjoy highest priority due to the importance of their function.

The actual Materials Handling Hardware, which will physically be interfacing with materials, is abstracted as an “actarray”, or actuator array. As seen in Fig. 6 two rows of rollers, each individually actuated by a DC motor constitute the Materials Handling Hardware of this platform. This Hardware forms part of the Physical Mobile Platform subsystem. The requirements and capabilities of this Hardware are abstracted by the Robotic Middleware for use by the Agent Toolbox and MHAA for task allocation purposes.

Another “actarray” abstraction is realised by two retractable stabilising posts, one at each end of the platform, see Fig. 6. These stabilisers are extended whenever a part is loaded or unloaded on the platform. This is necessary due to the fact that the material may cause an imbalance and cause the platform to capsize. After loading is done, the part is manipulated by the rollers in order to align the centres of gravity of the part and the platform. Once this is achieved the stabilisers can be retracted and the platform can depart for its next destination. This second actuator array also forms part of the Physical Mobile Platform subsystem.

The number of these platforms required in a specific manufacturing plant depends on the size of the plant as well as the degree of customisation allowed by the design of the products produced by the plant.

V. CONCLUSION

In conclusion two separate platform implementations have been presented based on a proposed mobile materials handling platform interface architecture. The architecture is designed to provide a policy vs. mechanism structure for materials handling in Mass Customisation environments, where policy in this regard represents a request to route materials between manufacturing infrastructure and the associated mechanism represents the distributed control of autonomous mobile materials handling platforms.

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