Sanderson, David and Chaplin, Jack and Ratchev, Svetan (2018) Common shared system model for evolvable assembly systems. In: Model-Based Enterprise Summit 2018, 2-5 April 2018, Gaithersburg, Md., USA.

MBE2018-###

COMMON SHARED SYSTEM MODEL FOR EVOLVABLE ASSEMBLY SYSTEMS

David Sanderson
University of Nottingham
Nottingham, UK

Jack Chaplin
University Of Nottingham
Nottingham, UK

Svetan Ratchev
University Of Nottingham
Nottingham, UK

ABSTRACT
A vital aspect of distributed control in an adaptable production system is coherence between each system resource. The Evolvable Assembly Systems project addresses this challenge using a common shared system model. This paper provides an overview of the project and the shared system model approach as implemented in a real world demonstration cell.

Motivation

Assembly of final products in sectors such as automotive, aerospace, pharmaceutical and medical industries is a key production process in high labour cost areas such as the UK. In order to respond to current challenges manufacturers need to transform capital-intensive assembly lines into smart systems that can self-heal, self-adapt, and reconfigure in response to external and internal changes [1]. This need is dictated by:

1. demand for rapid ramp-up and downscale of production systems;
2. lack of autonomous responsiveness to disruptive events and demand fluctuations in current assembly systems;
3. an economical and societal drive towards "manufacturing as a service".

Consequently, there is a need for new development approaches for assembly systems able to continuously evolve in response to changes in product requirements and demand. They must provide short set-up times, low cost of maintenance and reconfiguration, and easily integrate emerging new technologies.

Vision

There is a significant body of research in reconfigurable manufacturing systems [2], automatic and adaptive control [3], and manufacturing systems modelling and simulation [4]. The fractal factory concept [5] proposed an integrated approach to manufacturing systems that adapts to changes at different levels of the enterprise. Holonic Manufacturing Systems [6] use loosely coupled holons to represent resources such as robots, machines, orders, or even factories that cooperate to achieve their goals [7]. Building on techniques such as evolutionary computation and swarm intelligence, manufacturing systems capable of collectively optimising their performance in changing environments have been proposed [8, 9], as has the concept of co-evolution of products, processes, and production systems [10].

Achieving balance and harmony between products, processes, and systems in their continuous development and evolution is a key challenge for future successful cost-effective manufacture. Adaptation of a system can be triggered by different factors and driven by a variety of selective forces including breakdowns, changing product requirements, mutability of processes and equipment components, performance characteristics, and other indicators. Key knowledge gaps are in: finding the best model and architecture for product, process and system adaptation; finding the most appropriate levels of integration; understanding how and when configurations are updated; and understanding how disturbances in the system are managed and controlled [10]. There is also limited research and a lack of generic evolvable systems approaches that can be applied at different manufacturing system hierarchical levels.

Despite achievements to date, the above fundamental challenges remain and new theoretical foundations are urgently needed for next generation manufacturing systems. To achieve this, manufacturing systems require new levels of context-awareness, standardised "plug and produce" configuration methods, equipment module design and, crucially, new multi-stage/multi-scale algorithmic capabilities and interfaces capable of delivering this new behaviour.

Our research addresses these needs with the concept of "Evolvable Assembly" built upon the principles of autonomous distributed decision-making, ubiquitous context-aware equipment and systems, multi-agent control, learning, swarm intelligence and self-adaptation [11, 12]. This programme is complementary to recent theoretical developments in subject areas such as complex networks, machine learning, intelligent systems, distributed control, data processing and ubiquitous computing. This is also matched by the opportunity to shape future manufacturing systems by fusing current IT capabilities for sensing and control and infrastructure that could match and exceed the level of product and process complexity in modern manufacturing.

Challenges

As such, the research has adopted the methods of context-awareness, multi-agent intelligent control, and self-adaptation. Context-awareness provides each individual element with an understanding of the surrounding environment; multi-agent intelligence supports system self-organisation based on a community of autonomous and cooperative entities; and self-adaptation allows the development of goal-driven collective behaviour leading to purposeful system evolution. The programme is a departure from the previous philosophy of reconfigurable manufacturing – it creates a framework for autonomous, context-aware, and adaptable assembly and manufacturing systems that can co-evolve with products, processes, and the business and social environment. This transformational approach presents theoretical, technical and social challenges that demand new fundamental multidisciplinary research.

These challenges fall into three main areas:

1. **Infrastructure**: The morphology of future production systems in the project is based on intelligent resource objects. These are connected in a distributed architectural infrastructure inspired by flexible and reconfigurable manufacturing systems.
2. **Decision-making**: The evolution of the system structure and behaviour is based on context-awareness, learning, planning, and adaptation techniques. This enables decision-making across the entire spectrum from fully human-based, through hybrid, to fully-automated.
3. **Instantiation**: The core principles and methods developed by the project are instantiated at fixture, end effector, workstation, and assembly cell levels.

Crossing across these three areas is the requirement for a common "**shared system model**". This model is built across the infrastructure, enables distributed decision-making, and integrates across real-world instantiations.

Shared System Model

The “type problem” for the EAS approach is the “batch-size-of-one” problem – how to produce a given unique product on a given set of manufacturing resources. Our solution to this can also be leveraged to provide resilience, robustness, and general adaptability in the face of disruptions or changes in requirements [11, 12]. When considering the set of available manufacturing resources, they are characterised based on the *capabilities* they provide to the system. The products to be manufactured is defined by *recipes* that capture the product requirements. These capabilities and recipes are both modelled and the models are subject to a distributed adaptable analysis of manufacturability used to automatically plan a control approach that can produce the specified product on the specified set of resources.

The overall approach is shown in Figure 1. At the local level, each resource is controlled by an agent which maintains a local model of the system and environment, based on the BDI paradigm [13]. These agents interact via a common shared system model, maintained using a publish-subscribe approach [14], on which the distributed analysis and planning operates. This shared model can further be used as an integration point for other enterprise-level operations, and can be mined for large-scale data processes.

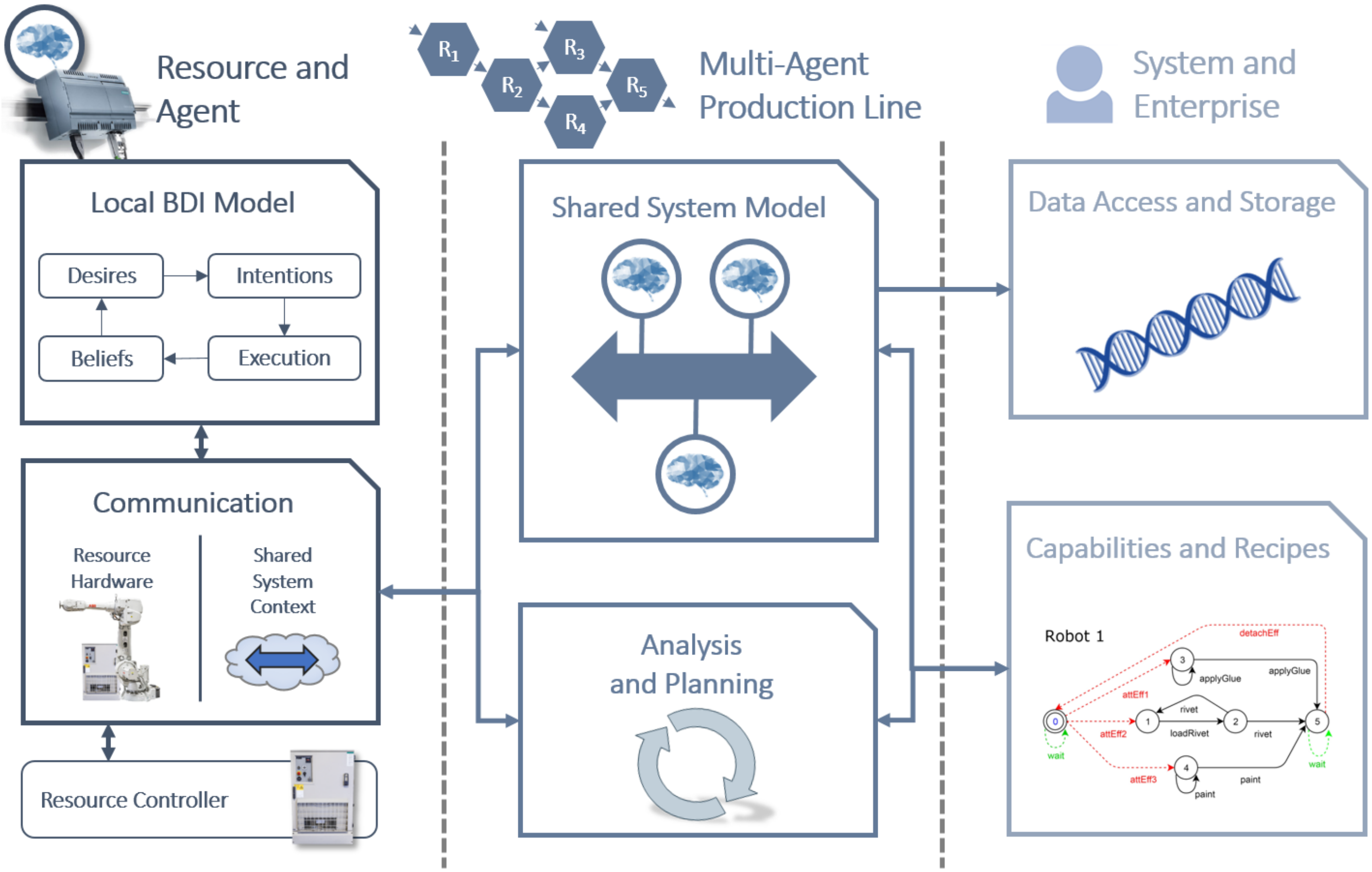

Figure 1: EAS Agent-oriented Layered Architectural Model

Implementation Example

This system has been implemented in a proof of concept demonstrator at the University of Nottingham shown in Figure 2. The demonstrator consists of two ABB IRB6700 robots, a shared central workspace, a tool rack accessible by one robot, and both a shared tool/part rack and a part loading conveyor belt accessible by the other robot. Each robot has access to a number of different end effectors on their respective rack and is equipped with an automatic tool changer.

The cell is designed to assemble aerospace components defined through a variety of recipe files. As such it is capable of the following processes, which map to the highest level of capabilities (sub-behaviours are defined hierarchically beneath these):

- Load and unload parts via conveyor
- Pick, place, and manipulate a variety of trailing edge ribs and non-structural skin panels from a common single-aisle aircraft
- Apply sealant
- Store parts in rack for curing
- Scan parts with a line scanner
- Apply temporary fasteners (semi-manual process)

Each resource in the system is controlled by an intelligent agent deployed on an embedded computer – in this case a Raspberry Pi 3 Model B, although other options such as the Siemens IOT2040, Intel Galileo, or National Instruments RIO are possible – that allows the distributed agent control layer to interact with the relevant PLC or hardware controller.

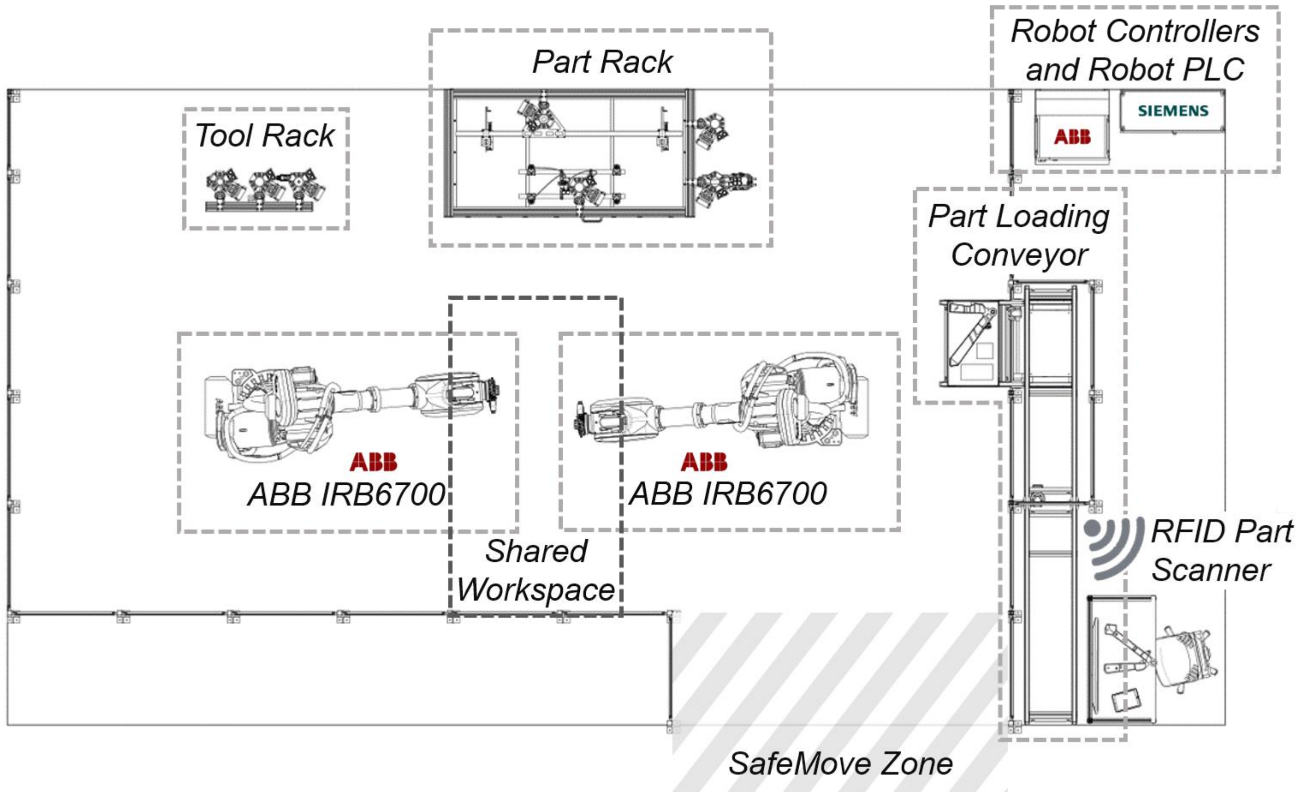

Figure 2: Assembly Cell Layout

Conclusions

Responses to current challenges in the manufacturing domain must address challenges in three main areas: infrastructure, decision-making, and instantiation. Solutions to these all rely on a common shared system model which is built across the infrastructure, enables distributed decision-making, and integrates across real-world instantiations. This paper has presented the overall approach to this shared system model used by the Evolvable Assembly Systems project in the context of a proof of concept demonstrator designed to assemble aerospace components.

Acknowledgements

The authors gratefully acknowledge the support provided by UK EPSRC Evolvable Assembly Systems (EP/K018205/1).

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