EVOLVABLE SKILLS FOR ASSEMBLY SYSTEMS

Evolvability by automatic configuration and standardization of control interfaces and state models

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Abstract: The Eupass project (www.eupass.org) proposes to develop assembly systems, especially in the field of ultra precision assembly, with evolvable skills to fit a wide range of products being assembled by applying a "Zero-Engineering" approach for the switch-over from one product to another. The Eupass partners are currently developing a machine line network with new and additional machine and device discovery mechanisms, synchronization and data exchange capabilities. By means of a common behavioral model, machines and devices connected to a network can jointly be discovered, commanded and execute any programmed activity in a collaborative way – developing evolvable skills exceeding the skill set of the singular machines.

Key words: Control, Communication, Assembly, Eupass, Skills, UPnP, Evolvability, Publisher / Subscriber, ADS, EtherCAT

1. INTRODUCTION

In today's manufacturing environments, the return- of- investment (ROI) gap between short product life cycles and expensive fully automated manufacturing systems grows even larger. Whereas there is no alternative to largely automated manufacturing systems due to continuously growing product quality requirements, the traditional way of achieving ROI for an assembly line by extending its life cycle over many product generations results in numerous re-engineering phases for products being manufactured sequentially on the particular assembly line.

The Eupass partners are currently developing an assembly line technology with new and additional machine and device discovery mechanisms, synchronization and data exchange capabilities. By means of a common behavioral (state) model, machines and devices connected to a network can jointly be commanded to start, stop, hold, etc. and execute any programmed activity in a collaborative way to use machining capabilities more freely.

Programmed “skills” of machines and devices are exposed to a planning tool for the assembly sequence via a publication method (blueprint publication), so that assembly steps are being planned within the capabilities of machines being used from a Eupass machine repository. Planning tools are subsequently capable of designing an assembly sequence within the geometrical workspace of the machine modules using the “skill-set” of its devices. As the combination of singular skills is random, new assembly skills evolve even beyond the original capabilities of the set of machinery.

1.1 Engineering is the issue

Assembly processes in manufacturing are characterized by an expensive engineering process spanning a variety of segregated tools for creation of products and subsequently assembly equipment. The lifecycle of the investment in machining lines and the product marketing span are in mismatch, as a result the product cost are higher as needed due to underutilizing investments at the end of the product marketing cycle. To overcome the situation and better utilize the unused investment remaining, it is advantageous to utilize the assembly equipment for ramping up the next product while still producing the fading volume of the previous product.

Therefore, the Eupass project proposes to develop assembly systems, especially in the field of ultra precision assembly, with evolvable skills to fit a wide range of products being assembled by applying a “Zero-Engineering” approach for the assembly line conversion from one product to another.

1.2 Concept

To achieve a Zero-Engineering approach in product conversion, the gap between Automation Equipment (Controls, Networks, Drives, Motors, I/O Sensors and Actuators) and Product Design Tools (CAD, 3D-CAD, Modeling Software etc.) needs to be closed. To avoid multiple recurrent loops in engineering, the product designers should be aware of manufacturing limitations such as dimensional restrictions of assembly machinery for the new product under design.

If design tools would have not only information about limitations of an assembly process, but also have knowledge about the entirety of available assembly process capabilities (skills of the assembly line); the CAD Tool could compile the assembly sequence itself by means of a post processor. Pre-assembling the product in a simulation before the assembly line and even the physical product exists would become reality.

In order to form a connection between the design tool level and the (assembly) machine line, a tri-directional exchange of information is necessary:

- (Assembly) machines must communicate (publish) skill sets and limitations of those,
- Design Tools and postprocessors must communicate the sequence of executing skills and parameters of execution,
- (Assembly) machines must exchange information with the exchange of products to organize the flow of products throughout the line and vertically.

In order to achieve this, the state-of-the-art approach to programming machine lines requires a new structurization and separation of generic capabilities (skills) from product-specific parameters. Also, the organization of machine behavior and communication systems requires separation of organizational program levels and standardization in order to seamlessly function:

- To connect machines in a "Plug-and-play" behavior, a common network, protocol, communication behavioral model (state machine) are required,
- To operate machines in a "cluster", a common operational behavioral model (state machine) is required,
- A separation of "managerial code" from "functional code" is required,
- All machining functions must operate on parameters provided by the engineering tools, so that all functions behave in an abstracted fashion,
- All machining capabilities must be published as skills within a certain operating area and parameter limitations, such as physical parameters etc.,
- Skills of machinery must be accessible by means of a command interface in form of an API (application programmer interface) via network so that
- Tools are capable to command execution of skills,
- Machinery is capable to interact with each other.

This level of abstraction and interaction is achieved in single manufacturer's installations; however, today no standards exist for open connectivity of systems, especially between design & engineering tools and machinery. With EUPASS; the novelty is the standardization of interfaces for an entire industry, the micro-assembly world. As an achievement, an ecosystem of service providers and service consumers may boost the machine builders (OEM) and possibly even manufacturing industries in Europe to gain weight against competitors in this field.

1.3 Interaction of Design and Execution

In order to interface the design layer and the execution layer of a manufacturing system, a bidirectional interface is proposed to create knowledge about abilities on both sides – the design layer and the control layer.

As shown in Figure 1, the Design System Tools include additional layers between the Product Design Tool (CAD) and the production systems to create an Assembly Sequence, simulate such sequence including all steps executed, time spent, materials consumed and geometries and tools utilized during such assembly sequence. The final result will be a "cookbook recipe" of steps and parameters such as geometries, forces applied, tools utilized, separation into machine modules and more.

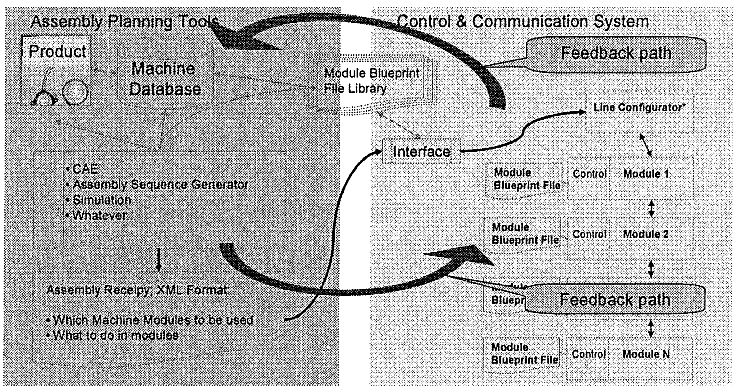

Figure 1 Feedback between Assembly Planning Tools and Assembly Control System

In order to apply useful steps of assembly actions, the Assembly Planning Tools will need to know the specific abilities of machines used to build an assembly line: the "skills". EUPASS compatible machinery will therefore include and publish a "Blueprint File" as electronic datasheet containing - next to other items - the specific skills and their physical limitations for any planning tool. By contacting a storage site, the "Eupass Module Blueprint Library", a virtual repository containing such information plus availability and location of any machinery compatible to such repository information, an assembly line can automatically be planned, simulated, and allocated for commissioning.

On the other side, machinery linked together to an assembly line by mechanics, communication and logic will proceed to form a configuration to a line and then consume the "cookbook recipe", distribute it to module controllers and trigger execution of the assembly recipe step by step and parameter by parameter to invoke assembly of products – so far, a straight forward approach to assembly line control; however, with some structurization, the capabilities of the machinery may develop (evolve) beyond the total sum of singular skills.

1.4 Skills and evolving Skills

Each station or module controller will participate in EUPASS communication via the EUPASS backbone. "Plug & play" capabilities will allow to automatically connect and start up a machine module; additionally, a discovery mechanism will expose an XML scheme to any higher layer computer system, including but not limited to the Line Configurator to publish information about assembly abilities with the Line Configurator and to the Design System Tools.

As additional benefit of the project, the abstraction necessary for this level of standardization allows to combine skills to new "super-skills", creating an evolvement of capabilities of the combination of machinery to a line. Skills may evolve by combining skills of sub-modules; and, beyond the boundaries of a station or module across the assembly line.

This development of features is not only a "Superposition of features" but creates in best evolutionary terms complete new capabilities from interaction of existing (singular) skills; therefore "Evolvability" was chosen for best characterization. In order to create "evolved" skills beyond the combination of two prior existing skills, a planning tool must know the set of all available singular skills for compilation into new skills. Additionally, the planning tools must be capable of combining the published machine skills in any meaningful way for assembly of products within the limitations of the physics of the machinery system.

With advanced software technologies, the planning tools may bridge the gap between a product design tool (CAD, 3D-CAD) and the machinery assembly execution logic. With the ability to know all the requirements for an assembly sequence and the machine skills, algorithmic approaches may solve the problem of combining the skills to other skills that could not be formed by machinery itself by communication: the detailed knowledge about the product to assemble is missing at the production control level.

1.5 Control and Communication

In order to combine skills and utilize machinery for randomly changing products to be assembled down to batch size of quantity 1, the control system must be able to link functionality within a module and across module boundaries within the real-time control environment. A deterministic powerful Publisher/Subscriber technology based on Ethernet was chosen to achieve real-time execution even for complex multi-axis motion control across equipment boundaries.

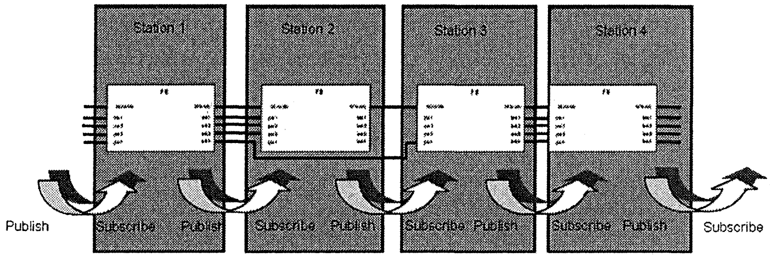

Figure 2 Eupass backbone communication by Publisher/Subscriber Technology

1.5.1 Communication Model

The Eupass communication must support both the hard real-time communication within the machine control environment as well as background, database-level communication of no hard real-time requirements. A model of cyclic and acyclic communication services was chosen to best represent a solution to this requirement: cyclic communication covers axis synchronization and inter-module logic signaling, whereas data transfer and status exchange is handled by the asynchronous or acyclic communication. Based on these two generic types of communication, all other Eupass-specific services may develop by means of the Eupass Communication Library to handle status control, recipe transfer, product tracing services, etc..

1.5.1.1 Interfacing cyclic data

Handling of handshakes and data transfer is established by distributed objects and Network variables in the communication layer by means of cyclic data communication: to transport products between EUPASS stations, a data link between these stations is necessary. Additionally other information, e.g. parameter values, must be exchanged. Because the characteristic of this information can be very dynamic and is used for synchronization tasks, a distributed real-time capable cyclic data transfer is used.

As shown in Figure 2, this is achieved by an open Publisher/Subscriber model on the Ethernet layer that is configured by the EUPASS Line Configurator.

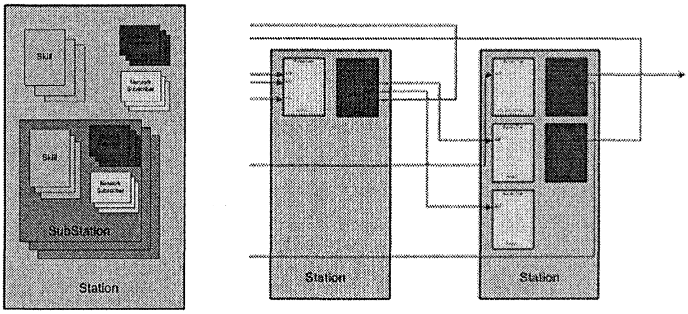

Figure 3. Skills, combined skills within a module (left) and across module boundaries (right) by means of Publisher / Subscriber Technology

Each of the stations (and substations) is capable to publishing and subscribing to distributed objects to and from other stations. Data exchange within a station is not executed over the network, instead, a controller internal Publisher/Subscriber-model data mapping is used to optimize resources.

Synchronization of the independently operating controllers and their network access is accomplished by publishing and subscribing of distributed objects in Publisher and Subscriber Objects.

1.5.1.2 Interfacing acyclic data

All other traffic is either of no real-time nature or no cyclic nature and is mapped to acyclic communication services whenever bandwidth allows, e.g. file transfer, operator commands, HMI display information, communication between User Applications and real-time control environments. etc..

A protocol-layer independent published protocol was chosen as an access and abstraction layer to various fieldbus protocols and for transportation over Ethernet protocols to transparently access different controllers, different processes and devices independently of the underlying protocol: the open ADS (Automation Device Specification) API. A distributed acyclic data exchange service allows communication In-process, In-device, via UDP, TCP/IP or SOAP / Web Service - even via Java.

The EUPASS controller platform already contains the ADS API and is easily accessed by User Applications and/or PLC programs. To facilitate device communication within the Eupass project by communication services, the Control & Communication Workgroup provides a Eupass Communication Library including updates to the partners throughout the project.

1.5.2 Behavioral Model

Also, abstraction of code into organizational and functional layers is required: for all machinery linked to an assembly system, a common communication and behavioral model (state model) should facilitate the application of assembly by distribution of assembly steps and recipe parameters.

Other industries have a long-time history of research and application of behavioral models to equipment, e.g. the process industry with it's batch control state machines defined in ISA S88 (Modes) and S95 (Enterprise Integration) standards. Recent industry initiatives show that these batch state models can be successfully applied to discrete product manufacturing, e.g. by the OMAC Packaging Workgroup. For reasons of convenience, the OMAC PackML state model was chosen for modeling the operational behavior of assembly equipment.

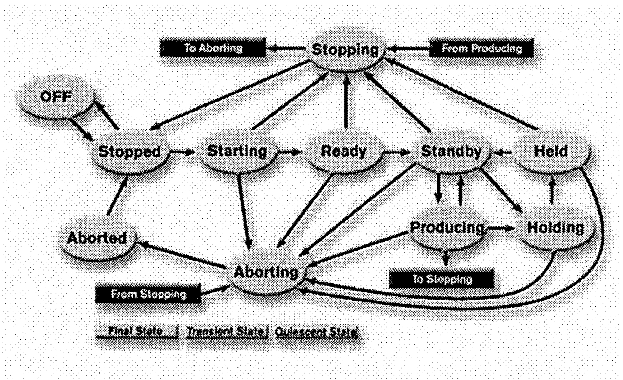

Figure 4. OMAC PackML State Model describes Eupass module behavior and facilitates linking of machinery and common behavior

Other than the machine module, the network communication for each backbone-connected controller itself requires its own state machine to facilitate discovery, operational and non-operational states. The Eupass backbone communication system utilizes the state model of the underlying EtherCAT network technology.

1.5.3 Evolving new Skills

By combining the advantageous design of structured software technology and abstraction of functionality from the behavioral model and communication subsystem, linking of objects can be achieved in a new way to create skills that go beyond the numerical combination of skills of the machines combined to a network. For this achievement, the boundaries of a single skill and a single machine module must become transparent to operate this equipment with a new skill, planned by matching the newly product and its requirements in assembly with the set of machinery available. Figure 5 shows the skill instance with all the elements necessary for skill evolvement: cyclic and acyclic communication interface, state model, recipe interface.

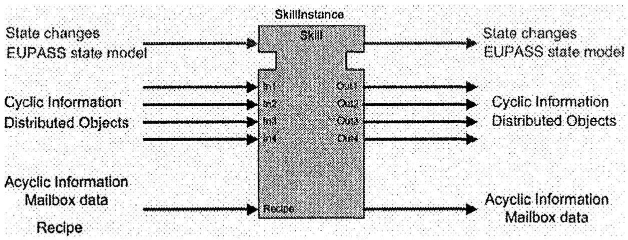

Figure 5. Complete Eupass Skill instance

By linking of skills beyond module boundaries, the project creates a new and open way of linking instances of functionality across hardware boundaries and with exposed software interfaces to allow intelligent planning tools to create new skills.

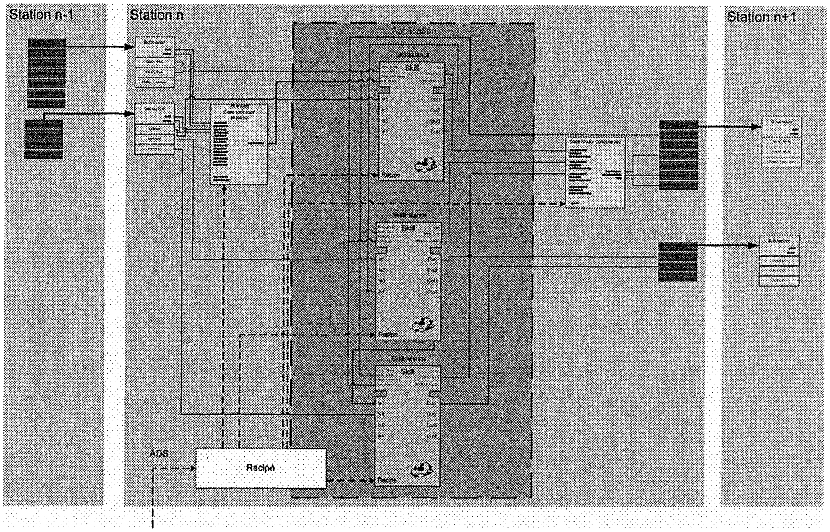

Figure 6. Eupass system with new skills created y evolving from pre-existing skills

2. CONCLUSIONS

The Eupass project targets to implement a new ecosystem of machine module producers and consumers with innovative new distribution models for a user community comprising of Eupass databases, virtual repositories of machinery and their published skill sets. In order to facilitate the deployment of equipment while driving down capital cost for assembly, standardization of equipment and random utilization of skills by automatic assembly line commissioning becomes customary state of the art.

With new technologies on the horizon, the standardization of assembly systems must go far beyond physical interfaces, communication protocols and functions o achieve this goal. Eupass proposes to drive the inventive creation of assembly skills by means of abstraction and layered, object oriented design. The achievements can ultimately lead to a fully computerized workflow from the product design concept to its assembly in an industrial environment with full toolset support to supervise, simulate and finally even create the assembly process from the product design tools to generic machinery elements publishing their capabilities as Eupass skills.

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