FoFdation
The Foundation for the Smart Factory of the Future

Grant Agreement Number	:	**260137**
Project Acronym	:	**FoFdation**
Project Start Date	:	**1st June, 2010**
FoFdation Consortium	:	**AIRBUS OPERATIONS SAS - IP Coordinator**
		CADCAMATION KMR SA
		CHARMILLES TECNOLOGIES SA
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		POHANG UNIVERSITY OF SCIENCE AND TECNOLOGY FOUNDATION - POSTECH

Title	:	***FoFdation SMC Architecture (FSMC)***
Type	:	*White Paper*
Dissemination level	:	*PU*
Date	:	*6 December 2012*
Lead/Author organization	:	*ECN*

Content

1 Introduction & Objectives

One of the objectives of FoFdation project is to develop a “Smart Machine Controller” that is an emerging topic of interest and is the focus of recent industry discussions. Some of the characteristics of a SMC include:

- the system learns from experience and future performance is improved based on stored knowledge and science based simulation;
- machining conditions are automatically selected to produce parts of the desired quality with maximum efficiency;
- models and sensors work synergistically to improve both the machining process and the accuracy of the models themselves through on-line calibration;
- a high level language is used to communicate the part requirements, control the machining process, describe the physical components and store the history.

Taken together, these qualities allow the system to produce parts of the desired quality with the first part produced and every subsequent part.

2 Definition of ‘Smart’ in the context of the SMC

The original vision in FoFdation for the SMC is to implement an advanced machine controller based on an open-architecture and standards such as a PC driven by Linux RTOS and Enhanced Machine Controller (EMC2), including the XML standard enabling data access, and data visualization application. Additionally, the extended STEP standard [2, 3, 4] will be seamlessly integrated to bring CAD-CAM data down to the shopfloor level, thus enabling intelligent and self-learning manufacturing process as defined by “Smart machining”. A smart machine is defined here as a machine equipped with an advanced controller that knows the capabilities of the machine to be driven. Such a machine is able to come up with the most efficient method, e.g. based on closed-loop machining and genetic algorithms, to produce “first part correct” every time. Such a machine will do this all while monitoring itself and utilizing data to assist “closing the gap” between the designer, manufacturing engineer, and the shop floor. The supervising HMI will work like the “brain” of a smart machine and will propose a knowledge-based system to collect information from individual thrust areas and to make a decision based on predefined business logic. It also addresses the need for an encompassing system that is responsible for the coordination of manufacturing activities, monitoring technologies, construction inputs, thus enabling an optimal machining solution for desired quality and maximum productivity. Therefore, in summary, the smart machine controller can be characterized by the following:

- Open, efficient and scalable PC-based hardware architecture
- Embedded “point SCADA” features
- User-centric supervising HMI
- Intelligent planning based on richer information (STEP-NC)
- Access to machine geometry and performance data repository
- High-level algorithms based on embedded CAM for direct interpolation
- Enabling toolpath interpolation based on biparametric formalism S(u,v)
- Enabling closed loop machining and scrap reduction strategy
- Tool condition monitoring
- Health diagnosis and maintenance management
- Metrology and on-line probing
- Waste reduction strategy
- Sustainability
- Modular architecture with low cost common communication

Regarding the sustainability issue, the SMC will provide means and visibility tools to perform:

- Energy monitoring at the machine level
- Monitoring of energy directly used by manufacturing
- Definition of performance indicators to monitor energy consumption at the machine level
- Real-time follow-up of the machine tools
- Measurable indicators for planning & effectiveness predictions
- Support zero-defect strategy

3 SMC Architecture

In order to accomplish the above SMC requirements, the following generalized Architecture in Figure 1 & 2 (simplified and detailed views respectively) is proposed focusing mainly on the structure required to realize the FoFdation Smart Machine Controller. Interfaces between the SMC and the SMO are established through realtime and non-realtime access provided by Profibus/Powerlink and Powerlink Ethernet.

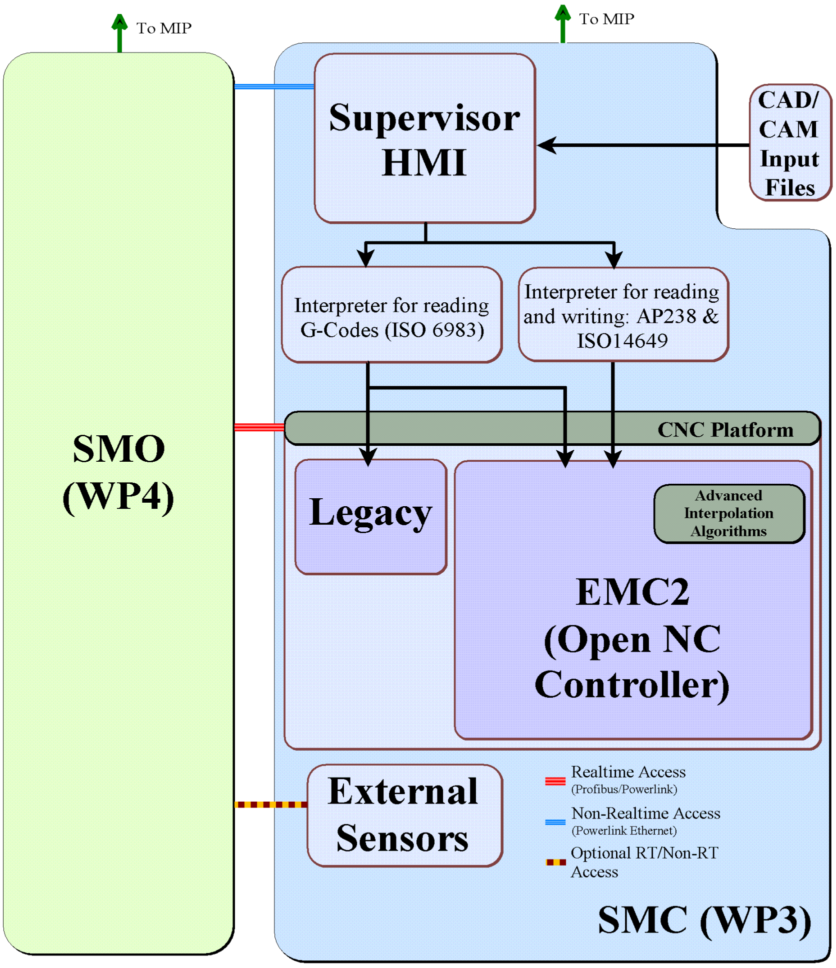

Figure 1: Generalized FoFdation SMC (FSMC) Architecture- Simplified View.

Within the Simplified Views that follow, it should be mentioned that they do not at all include detailed description of the interconnection between modules or between Work Packages. They are supposed to be considered as a general overview of the FoFdation Architecture and that the detailed links between Work Packages are planned as shown in the Detailed Images.

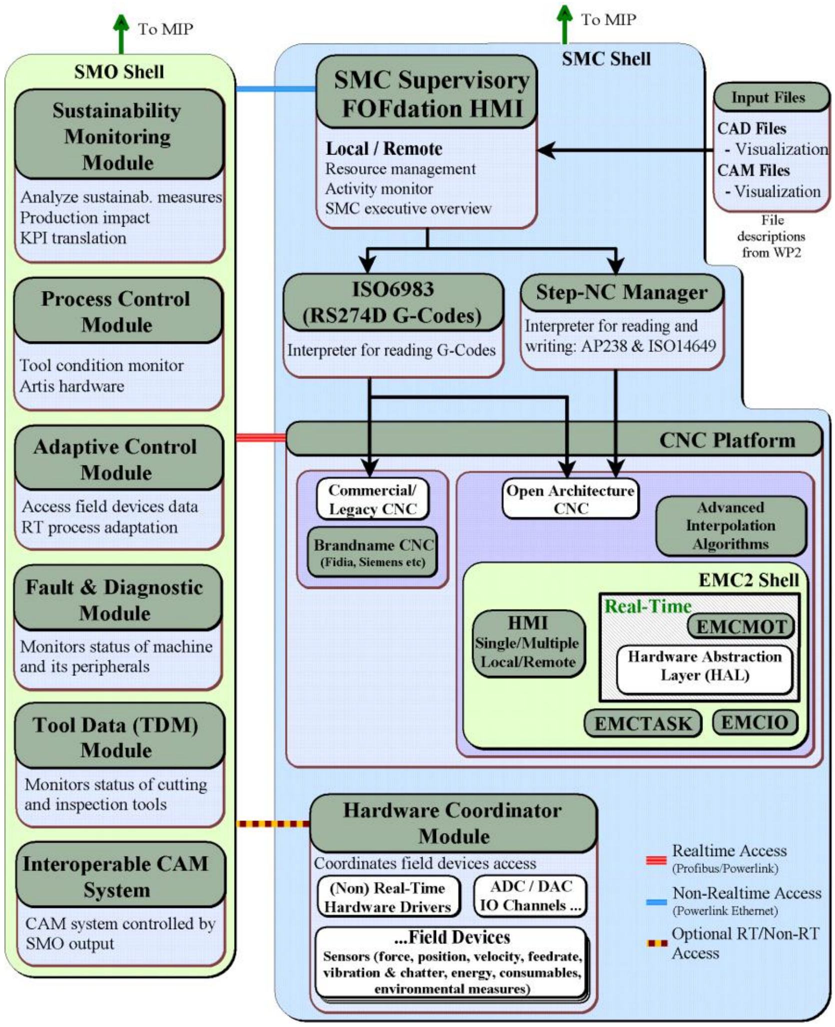

Figure 2: Generalized FoFdation SMC (FSMC) Architecture- Detailed View

3.1 SMO Shell

The SMO Shell is comprised of the defining characteristics of FoFdation dream. These modules are designed for key value addition.

3.1.1 Sustainable Monitoring Module

Through direct input from field devices such as power, flow rate and other sensor data, defined sustainability measures will be analyzed within the scope of this module. The results will be translated to real KPI (Key Performance Indicators) values showing the sustainability impact of the current process. Data from this module can be stored within the SMC supervisory module in an SQL database.

3.1.2 Process Control Module

Functionalities such as tool condition monitoring will be performed in this module in real-time. Potential module to be interfaced with tool management modules such as ClassCAD TDM system.

3.1.3 Adaptive Control Module

This module will be able to directly access field devices in order to obtain real-time process data. From these data, real-time adaptations of feed rates, spindle speeds and axis positions can be performed to improve the process. It can be interfaced with the ClassCAD TDM system for managing actual tool data.

3.1.4 Fault & Diagnostic Module

Within this module, the status of the machine components as well as its peripherals are monitored. Faults are diagnosed and recorded inside the component. Possible resolving actions are taken to communicate and correct the problems.

3.1.5 Tool Data (TDM) Module

This module is responsible for the management and organization of cutting tools, fixtures and jigs. Its main output will be to higher functional modules that are in charge of process planning and production.

3.1.6 Interoperable CAM System

Using optimized process data and methods, the process is updated to improve performance, and reliability.

3.2 SMC Supervisory Module

This module's primary function is to act as a supervisor and information repository for the SMC. It is also the primary HMI for this architecture and details for this HMI are given in the description of each Scenario presented in Section 8.1 It can be accessed both locally and remotely and will provide an executive overview of the SMC. Systems resources will also be managed by this supervisory module.

3.3 Hardware Coordination Module

This manager-type module will be a hub that contains all the field devices that are expected to be supported by the SMC. Devices such as sensors that provide process data for other upper hierarchy modules will be contained in this module. Sensors measuring force, position, velocities, feed rates, vibration/chatter, energy, consumables and environmental parameters are all supported by the SMC through this module. It should be noted that the goal of the SMC is to provide enough data and usable signals directly from the controller itself so that expensive external sensor requirements can be minimized which will in turn minimize the cost to the costumer. Support in this module is reserved exclusively for data that cannot accurately be retrieved through the controller.

3.4 Part Description

This component contains the incoming part information as a CAD model. The description of this data type is expected to come from another Work Package (WP2) group within FoFdation.

3.5 CNC Platform for Legacy and Open Use Cases

FoFdation is expected to define a unified and open IT architecture at the shopfloor level in order to enable both **progressive and breakthrough innovations** for industry:

- The progressive innovation must be based on an additional component compatible with legacy systems, thus supporting the industry transformation by introducing more IT assisted technology into conventional and existing manufacturing process for better optimization of the manufacturing process. Within the recovery context, the FSMC architecture must be compatible with legacy "brand name NC" controllers . This condition is necessary to support the transformation of prevalent brand name controllers mostly based on ISO G&M code into Step-NC compliant controllers, thus allowing companies to increase their production performance without heavily investing in new expensive machines and time-consuming training. This "Legacy Use Case" will be based on a **Step-NC remote FSMC interface** for part programming tightly integrated with the optimization module (FSMO) and running on a dedicated Windows PC. This will allow the implementation of an intelligent meta-controller system which includes both optimization and supervision, beside any "brand name Controller" and that could be tightly coupled with any brand name CAM system for tool path generation.

- Breakthrough innovation might be based on paradigms shift and science-based integration. With FoFdation we envision the next numerical controller open and smarter, able to be self adaptive with regard to the real status of the machining process. Next controller must be able to generate itself the cutter path and optimize the cutting strategy in real-time. In order to encourage synergy and to easily benefit from a large researcher community's contribution, an Open-source controller based on Linux will be developed. It will be proposed with an **embedded Step-NC Windows-based FSMC interface** (HMI) including its own (experimental) tool-path generator, e.g. for surface milling. This will allow the prototyping development of an autonomous Step-NC compliant Controller fully compatible with the FSMO system.

3.5.1 Commercial Legacy CNC Platform

Figure 1 presents main scenarios that will be present in the SMC architecture in a simplified visualization.

As already mentioned, the proposed FoFdation architecture, allows for 2 types of CNC controllers to be used: current brand name controllers and an open-source controller based on Linux.

It is important to include and use, in this framework, brand name controllers like FIDIA, SIEMENS, etc. because they are prevalent in today's industry. To accomplish the general objectives and long time goals of the project, implementations and innovation done need to be usable in short time in industry to show immediate benefits and to encourage commitment and investments of "big players" in machine tool sector.

The STEP-NC interpreted programming make it possible to use the STEP-NC standard with the existing machine tools and NC controllers, which still understand G-code programming.

Therefore the innovation of the SMC is not a "product" but is an "architecture" that can be implemented in several platforms, existing brand name controllers included.

3.5.2 FoFdation Open CNC

In this platform the CNC software is based on EMC2 Open Source Numerical Control (see description in previous chapters). Two main developments will be performed in this software: the implementation of a STEP-NC task interpreter and the direct interpolation of Nurbs curves trajectories.

3.5.2.1 STEP-NC task interpreter

The implementation of the STEP-NC interpreter will allow the CNC to manage STEP-NC working steps and tasks without degrading the data in RS274 code.

3.5.2.2 NURBS interpolation

Generally free-form surfaces are machined by approximation into a number of smaller straight lines or arcs. This method focuses on the constant speed of cutter location point instead of the constant speed of cutter contact point. The result is a low machining efficiency and accuracy. The interpolation of NURBS surfaces and trajectories based on STEP-NC at CNC level will drastically increase the accuracy of the machined part.

3.6 Data Models (ISO6983 and STEP-NC)

To facilitate the above-mentioned CNC platforms, 2 data models are necessary: G-Code (ISO6983) and STEP-NC (ISO14649). Some work will be performed, as an extra step, to include AP238 as a possible data model available within the FSMC. These data models will ensure that the objectives of the SMC are attained for an enriched and optimized NC controller.

3.7 EMC2 Shell

The EMC2 shell, described fully [1], will be a main component of the FoFdation Architecture acting as the machine controller. The EMC2 controller software runs in the Linux operating systems environment with real-time extensions. Different hardware configuration can be used. At present, there are three major physical interfaces used by EMC2: - Parallel port (SPP and EPP), PCI and ISA. EMC2 uses a Hardware Abstraction Layer (HAL) which is very configurable. One can easily map any signal to any hardware pin, or modify signals with HAL components as if they were real analog or digital electronic signals.

4 Conclusion

The basis of HW/SW configuration of SMC has been defined and will be used in the SMC prototype that will be implemented on an open-source manufacturing environment at the end of FoFdation.

5 References

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