Ambient Intelligence Technologies for Industrial Working Environments in Manufacturing SMEs

Sebastian Scholze, Harald Sundmaeker, Uwe Kirchhoff

ATB - Institute for Applied Systems Technology
Wiener Str. 1, 28359 Bremen, Germany
Tel: +49 421 220 92 0, Fax: +49 421 220 92 10
{scholze, sundmaeker, kirchhoff}@atb-bremen.de

Abstract

This paper presents an innovative approach how to bring AmI technologies to the industrial sector of manufacturing SMEs and how to develop and validate business process innovations based on the Ambient Intelligence philosophy. Furthermore a Building Block concept to develop reusable components which are required to realise an intelligent human operator support is elaborated and developed, as well as a software architecture providing the required runtime environment and infrastructure to support the realisation of human-centric solutions is developed. The Building Blocks and the Software Architecture are applied and verified in 5 business cases in 4 European countries.

Keywords

AmI Technology, Collaborative Environments, Human Centric, Mobile Devices, SOA

1 Introduction

AmI technologies are nowadays in the focus of the research domain [1, 2, 3] but their implementation especially in manufacturing SMEs is still in the beginning. In particular constraints like limited investment potentials and investment risks, limited amount of staff and qualification to drive business process innovations often create a strong objection to innovations. Therefore, SMEs need specific approaches on how to address the successful utilisation of these new technologies to create measurable business benefits on short to medium term, enabling SMEs to keep pace with the innovation speed at large companies [4].

The main objective of the presented results is to enable manufacturing SMEs to actively take part in this revolution by proposing a new scheme for systemic innovation of industrial working environments in SMEs by applying AmI technology.

The results presented in this paper are elaborated in the scope of the EU-funded project "Revolution in Industrial Environment: Ambient Intelligence Technology for Systemic Innovation in Manufacturing SMEs", contract nr. 017120 (AMI-4-SME) [7].

2 Relation to existing theories and work

The current approach of implementing the AmI concept is oriented on surrounding people with electronic environments, sensitive and responsive to their wishes [5]. AmI based solutions are expected to combine concepts of ubiquitous computing and intelligent systems putting humans in the centre of technological developments. However, in spite of intensive research activities on specific AmI technologies, besides the a.m. generic formulations on AmI, there are no widespread accepted definitions of AmI systems in manufacturing industry.

In [6], based on the definition of AmI systems relevant for manufacturing industry, a reference model is presented starting from the main assumption that the AmI systems in industry can be considered as control systems of Automation & Robotics and processes, which include human operators in the control loop. The elaborated reference model indicates where AmI technologies offer potentially optimization of the interaction of human operators within their working environment.

The reference model indicates the different areas of required AmI based solutions to enable a human centred interaction of the worker with his ambience. Thereby, the ambience is split up in a manufacturing related ambience, covering process, plant, machines etc. and an ambience representing a wider human operator environment, not directly (however indirectly) related to the manufacturing process. The intelligence of interaction of the human operator with the environment is managed by the AmI system (see Figure 1).

As presented in Figure 1, the reference model covers the input and output areas of the human operator with the AmI system comprising implicit (1.1) and explicit (1.2) inputs from human operator to the AmI system and the explicit outputs of the AmI system to the human operator (1.3). Additionally input/output areas address the interaction of the different ambiences (environment (2) and process (3)) with the AmI system.

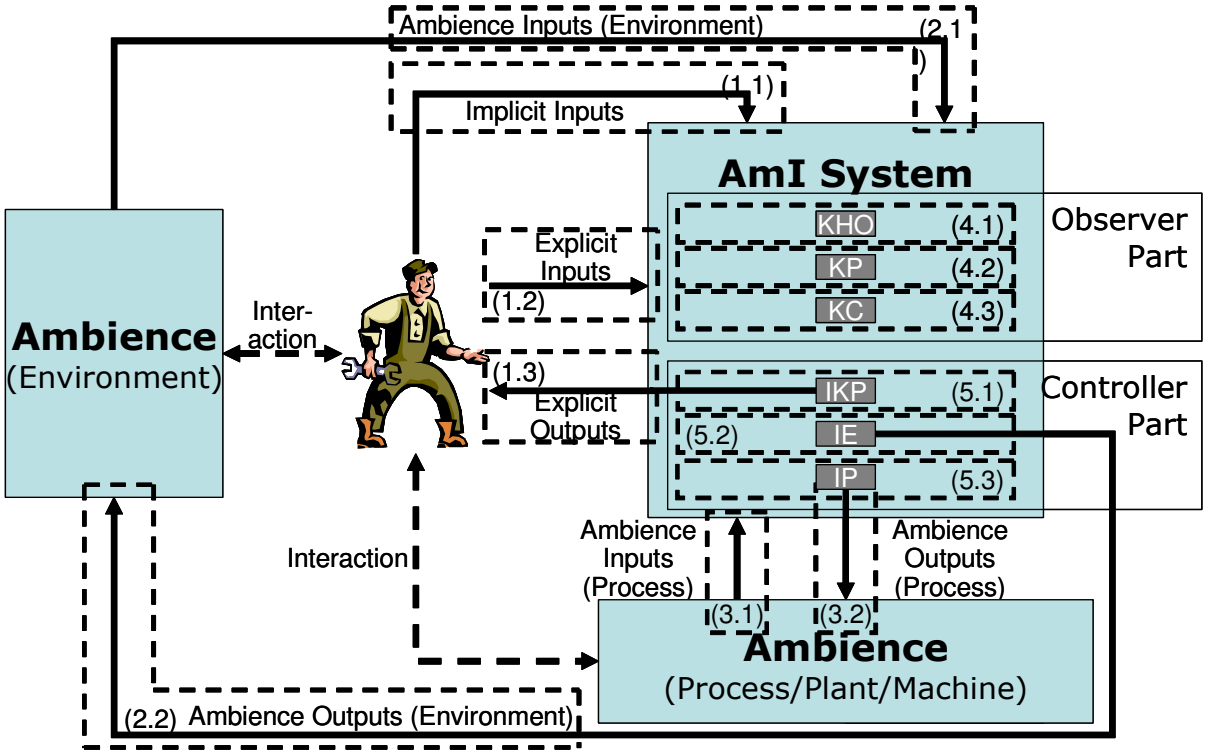

Figure 1: Reference model for AmI in manufacturing industry.

Based on the control engineering approach in [6], the AmI system is separated in an observer and a controller part. The observer part is creating, based on input information and other existing knowledge and information, the knowledge about human operator (4.1), the knowledge about ambiences (4.2), covering process, environment and interactions, as well as the knowledge on context (4.3), based on knowledge and information provided by the two mentioned observer modules and other systems.

Based on knowledge and information provided by the observer part, the controller part of the AmI systems covers the information/knowledge provision to human operator (5.1 - IKP), the intelligent interaction with ambience (environment) (5.2 - IE) and the intelligent interaction with ambience (process) (5.3 - IP) [4].

2.1 The AmI Features Concept

The objective must be to enable SME end-user, representing "non-experts in AmI technology", to identify most appropriate AmI technologies for a human centred business improvement, not requiring any expertise on AmI technologies. This statement implies a contradiction. To overcome this contradiction, the concept of "AmI features" is introduced. AmI features represent a solution independent formulation of AmI technology potentials offered to the human operator when interacting with the ambience. These AmI features must be expressed in a form understandable by non-expert and must posses the following characteristics:

- It must be technology independent,
- It must indicate the functional and/or non-functional requirement(s) relevant for the user which can be provided by AmI technology and
- It must correspond to one or more SPECIFIC characteristics of AmI according to the above definition of reference Model of the AmI systems.

Therefore, a feature defines **what** an AmI system may offer, but not **how** it may achieve.

The grouping of the AmI Features in respect to the structure of the AmI Reference Model (see Figure 1) represents the key approach to bridge the gap between identification of processes to be improved, identification of the required AmI potentials and the AmI technology required to create an AmI based solution realising the intended improvements. For each of the five areas of the AmI reference model one or more AmI features are defined, formulating specific AmI characteristics in this area. However, the proposed classification represents a structure which is open for further extensions and/or refinements. In Table 1 the elaborated AmI features and related AmI technologies required for the implementation of these features are presented for the explicit input of the human operator (HO).

Table 1: Example for the relation between AmI features and technologies.

AmI Features	**Related Technologies & Functions of Supporting Applications**
(1) Human Operator I/O	
(1.2) Explicit inputs from HO to the AmI system • Natural HO inputs: i.e. spoken language, handwriting, touch screen, gesture, gaze to forward unstructured information and observation to the AmI system • Simultaneous exchange of information over multiple channels at different levels of abstraction, e.g. speech, gesture, animation, non-speech audio. • Provision of observations and experiences of the HO on the status and problems in process and environment to the AmI system • Request for data without knowing specific file names, location or format. • Automated user identification and authentication and authorisation. • Forwarding unstructured communication needs with collaborating partners • Mobile or nomadic access • ...	• Digital pen, touch screen, handwriting recognition, speech recognition technologies. • Wireless handheld devices like PDAs, tablet PC or mobile phones. • Wearable input devices like e.g. key boards sewed in cloth, data glove etc. • Biometric authentication and authorisation technologies • Video conference technologies • Mobile communication and interoperability technologies (Bluetooth, WLAN, GPRS, UMTS etc.) • Collaborative working environment – core services • Network interoperability and ubiquitous communication • ….

3 Research approach

With respect to the reference model the work will focus in the following upon the support of the human operator. Therefore a Building Block concept to develop reusable components which are required to realise an intelligent human operator support is elaborated and developed. Furthermore a software architecture providing the required runtime environment and infrastructure to support the realisation of human-centric solutions is developed.

3.1 The AmI Building Blocks

The idea behind the Building Block concept is to develop three Building Blocks to provide radical innovation in three technology domains:

- **Mobile Communication** providing a middleware required for a mobile interaction of mobile devices and AmI based ICT services with legacy ICT system environments for the variety of mobile communication techniques (e.g. UMTS, GPRS, Bluetooth, WLAN, WiMAX, etc.).
- **Speech Recognition System** providing a configurable natural human interaction via speech linked to a server via a standard interface.
- **RFID** represents a specific type of sensor system for the assessment of process status information or for worker identification linked to a server via a standard interface.

These blocks aims at being reusable components which can be easily incorporated in the specific solution at each SME shop floor. The presented work targets the realisation of "AmI Building Blocks", which are required to realise an intelligent human operator support, since these building blocks are a key component to realise AmI based ICT Services, where mobile access represents an essential issue.

3.2 The AmI Software Architecture

This chapter aims at presenting a general software architecture overview. Based on the Business Case specific static views of the run-time configurations, the overall Software Architecture was elaborated as presented in Figure 2.

The software architecture is separated in two main parts – the server side and the mobile device. On the server side it includes particularly the following components:

The **Service Execution Environment (SEE)** is a key enabler of a Service Oriented Architecture, a framework capable of managing all the operational aspects related to (Web) Services. It can be seen as an execution environment which enables discovery, selection, mediation, and invocation of (Web) Services.

The **Orchestration Module** provides an environment to combine Core Services Building Blocks and support modules in order to fulfil business case specific needs. In this line, reconfiguration of shop floor lines can be performed by the composition of fine grained services into coarse grained services or applications.

Core Services are a group of services which represent the basic functionality each AmI system uses to realise the specific AmI based ICT solutions. These core services represent the core business functionality and are grouped into the categories Reasoning Services, Search Services, Monitoring Services and Control Services.

Building Blocks aim at being reusable components which can be used at each SME solution without too much effort. On the server-side of the software platform, additional interfaces are implemented to integrate the building block within the software architecture.

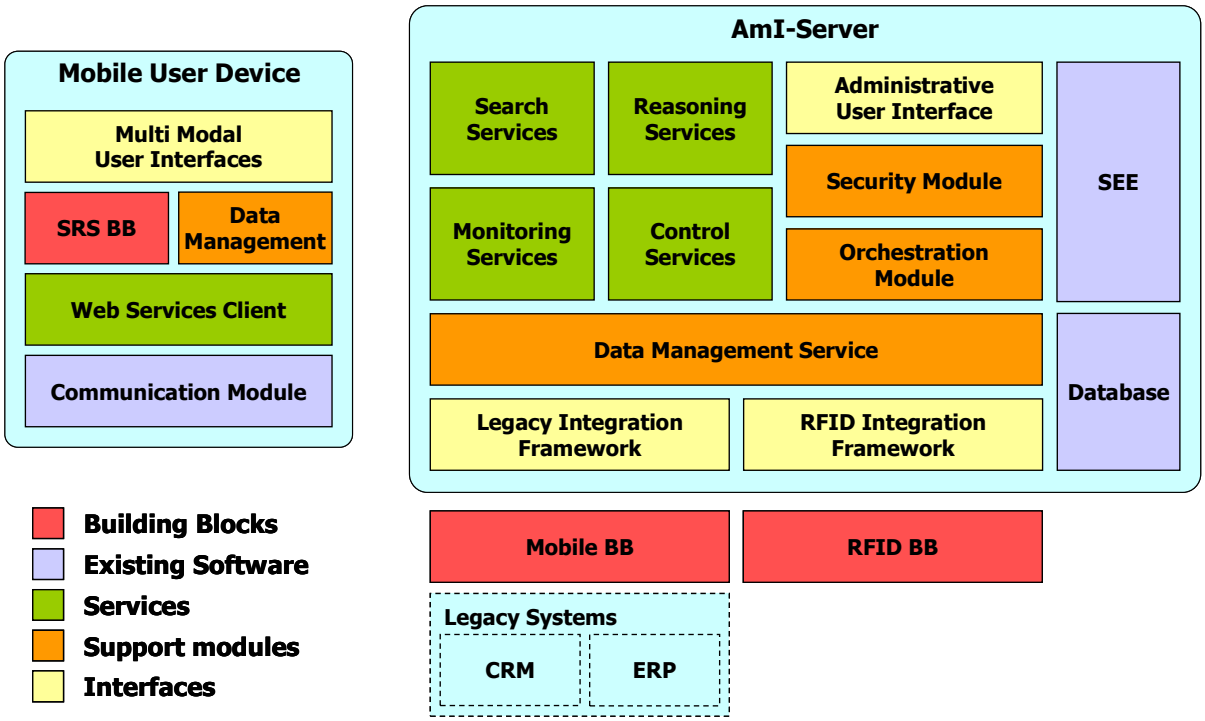

Figure 2: AmI Software Architecture.

The mobile device part of the architecture is specifically built on the following components:

The idea behind the **Multimodal User Interfaces** is to provide the user with multiple modes of interfacing with a system beyond the traditional keyboard and mouse input/output. The advantage of multiple modalities is increased usability: the weaknesses of one modality are off-set by the strengths of another.

The **Web Services Client** comprises the software clients in charge of invoking the services provided by the server. Because of limited runtime environments and limited system resources, this module will provide a tailored framework/set of libraries, which is focusing to the specific demands of mobile devices.

4 Findings

The Building Blocks and the Software Architecture are applied and verified in 5 business cases (BC) in 4 European countries; Germany, Ireland, Poland and Spain.

- BC 1: Dynamic reconfiguration of build-to-order-driven assembly processes with high product diversity in an Extended Enterprise environment
- BC 2: Improvement of management and control of mobile maintenance services for process industry
- BC 3: Enabling experience-based and dynamic calibration of highly precise measuring systems at the end-user site
- BC 4: Rescheduling and update of product specification due to evolving customer requirements, in parallel to product realisation
- BC 5: Dynamic reconfiguration of workers' manufacturing tasks, based on current order progress and available human resources and expertise

Based on the application of the developed feature concept the elaborated results for an AmI based improvement process is presented in the following for one of the five business cases in more detail.

Company A and company B are cooperatively producing in relatively small batches special, customised, chassis and change over platforms for lorries, where company B is responsible for all welding activities. There is normally a high variation in volume of different product variants. The delivery time is currently 5 days, and the main business objectives is on one side to cut the delivery time to less than 4 days, and, on the other hand, to increase number of variants, i.e. achieve higher customisation following the total Built-To-Order philosophy. Furthermore, quite often a rescheduling of orders on customer demand is required. As an additional Quality/Cost/Schedule-objective an increase of the overall productivity in the cooperation is targeted, as well as a decrease of wasted materials.

Based on the company objectives, the analysis of the business processes indicated the following most critical weak points to be eliminated with highest priority.

- Production Operations Management:
    - Delayed update of the production progress information by foremen.
    - Production problems and delays are sometimes detected too late, reducing the reaction time for problem elimination.
    - The coordinated rescheduling of the production order sequence and related reconfiguration of the assembly lines are too slow.
- Materials Management:
    - Semi-finished products are not delivered order related to the welding areas, causing sometimes missing material or waste of material.

In the scope of the elaboration of the solution concept for the optimisation of the process dimension the targeted changes in the execution of the business activities were identified, as well as an envisaged extension of existing legacy systems, as presented in Table 2.

Table 2: Results of the optimisation of the process dimension.

Sub-process	**Activity Execution**	**ICT Support of Activity Execution**
Production Operations Management	Organisational measures for production status control to be applied strictly A defined procedure for production rescheduling and line reconfiguration to be followed.	Installed PC (Personal Computer) based software for production status control to be extended for the support of the rescheduling and reconfiguration activities.
Materials Management	Order related delivery of commissioned semi-finished materials by company A to the welding area of company B. Delivery event to be recorded as part of the production status control.	Software support for the order related commissioning of semi-finished materials. Installed PC based software for production status control to be extended to manage delivery events.

In respect to the human centric optimisation dimension an “AmI vision” is created targeting, in reference to the AmI features scheme, at the identification of required intelligent AmI System Services to overcome the identified weak points in the different business processes (see column 2 of Table 3). This will be realised for all actors in the company involved in different processes. Furthermore, to operate intelligent AmI system services the targeted interaction and sensor technologies to manage the specified interaction between Human Operator, Ambience and AmI system have to be identified, representing an essential design dimension of an AmI system for AmI based Input/Output services.

As presented in column 3 of Table 3, this covers the identification of the required AmI technologies, as well as their interaction with the existing and planned ICT infrastructure, identified in the scope of the previous process oriented optimisation step.

Table 1: Results of the optimisation of the human centric dimension.

Sub-process	AmI System Services	AmI based Input/Output Services
Production Operations Management	Based on an access to the ERP (Enterprise Resource Planning), supervision and automatic identification of critical production delays. Rescheduling and reconfiguration of the production from any place at any time possible. Automatic generation of optimal re-scheduling proposals.	Automatic mobile information of the production managers in case of a delay at any time at any place. Automatic information of the foreman on rescheduling at any time at any place. Mobile multi-modal information access (visually and via voice information) to production data. RFID (Radio Frequency Identification) technologies for automatic recording of truck chassis production status; forwarding info to status control software to disburden foreman.
Materials Management	Intelligent guidance of the worker, executing the order related picking process.	Mobile multi-modal support of the worker (visually and via voice I/O) for order picking. RFID technologies for the automatic recording of delivered transport units leaving the storage area and forwarding info to status control software.

The identified intelligent AmI System Services and AmI based Input/Output Services (speech recognition systems, RFIDs, Wireless LAN and multimedia), interoperating with existing Enterprise Resource Planning (ERP) systems will support quick responses to different problems in the shop-floor, including possible order rescheduling, assembly line reconfiguration in case of problems. This will allow an optimal coordination of work of two assembly lines and their optimal reconfiguration in both SMEs. The benefits expected include considerable reduction of efforts and time needed to reconfigure the lines, enabling faster manufacturing/assembly of different product variants and effective smoothing of the manufacturing processes in both companies.

The identified human centred system solution provides a highly intelligent production status control and decision support system to assure an efficient collaboration of human operators in both companies in charge of the reconfiguration and rescheduling process. The identified solution concept was developed and implemented and will be verified in the real production environment.

5 Conclusions

The presented work intensively analysed the SME innovation needs within the business cases, clearly indicating the SMEs' need for highly tailored turn-key solutions, required to guarantee the realisation of business benefits and competitive advantage. To effectively serve those SME needs with turn-key solutions in a suitable price range, the presented work elaborated the following results:

- Building blocks as enablers for realising innovative "AmI" as well as human centred solutions (RFID based sensor system; speech recognition system for implementing configurable natural human interaction on mobile devices; AmI system adaptor for mobile device, service and system integration).
- Software platform to easily set up the required runtime environment as well as the software infrastructure to provide a cost- and time-efficient realisation of a human-centric turn-key solution.

- Methodology providing clear instructions, guidelines and templates for realising the successful utilisation of new AmI technologies.

The main innovation of the work, presented in this paper is the realisation of a new SOA based software platform including a set of AmI Building Blocks which are required to realise an intelligent human operator support. This is one of the first attempts to provide novel AmI technologies in manufacturing SMEs. Although the presented results are applied and verified in the SME manufacturing domain, they can also be applied in larger companies as well as in other domains.

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