AMBIENT INTELLIGENCE IN MANUFACTURING INDUSTRY: CONTROL SYSTEM POINT OF VIEW

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ABSTRACT
The paper intends to contribute to understanding and definition of the paradigm of Ambient Intelligence (AmI). The paper specifically focuses upon AmI application in manufacturing industry. The new definition of AmI systems in industry is proposed intending to indicate a clear correlation between AmI systems and 'classical intelligent control'. The so-called Reference Architecture for AmI systems, serving as a tool for the development of the AmI based control systems, is initially proposed as well. The typical control schemes for AmI based control system (in industry) are defined and analysed intending to identify the key aspects that differentiate the AmI control systems from classical schemes. The analysis has indicated that an increased observability of the whole system and specifically of human operator and his/her environment (ambience) is the key element leading to a more effective control and higher intelligence of AmI systems. The possible applications of the proposed Reference Architecture for different processes and plants in industry are considered.

KEY WORDS
Ambient Intelligence, Intelligent Control, Observability, Reference Architecture, Collaborative Environments, Automation and Robots, Industrial Automation

1. Introduction

AmI technology is currently attracting a high interest of RTD society, as it is believed that it may bring considerable improvements in both business and public domain. The full application of AmI in manufacturing industry is still to be achieved within the next 4-7 years. As explained in [1], from the industrial perspective, a less human- and more system-centred definition of AmI is considered. However, the modern manufacturing concepts turn to human-centred approaches. Therefore, the application of AmI technologies is promising to effectively meet needs of such concepts. Possible applications of AmI based control schemes in manufacturing industry are numerous. Two typical applications are control of Automation & Robotics (A&R) systems (e.g. smart devices [2]) and assembly processes.

Many RTD issues still have to be solved in order to bring the AmI technology to industrial sectors, such as robust, reliable sensors and context-sensitivity, intelligent user interfaces, safety, security etc. The RTD on AmI covers numerous aspects such as interaction with the user, e.g. multimodal interfaces [3], fundamental aspects of user experience [4], analysis of user behaviour [5], context analysis and many others (see [6-7]. In spite of the intensive RTD activities, the control aspects of AmI are still insufficiently explored.

According to the definition of the Expert group of the EU commission on IST [8], 'the concept of Ambient Intelligence provides a vision of the Information Society where the emphasis is on greater user-friendliness, more efficient service support, user-empowerment, and support for human interactions. People are surrounded by intelligent intuitive interfaces that are embedded in all kind of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way'. AmI obviously includes very different aspects and technologies, however the key issue is that it provides a more effective control as it focuses upon interaction between the system and human operators in different processes.

The problem arises to identify, from the control point of view, which are the key improvements which AmI approach may bring in industry w.r.t. classical intelligent control, in order to drive development of the AmI based control systems. In other words, the question is what are the essential aspects of AmI leading to more effective control and higher intelligence.

The objective of the paper is to provide a basis for defining the RTD area on AmI solutions, from the control system theory point of view, in order to minimise overlapping with other approaches and by this avoid unnecessary repetition of previous work on classical intelligent control solutions. Obviously, a clear understanding of the specific AmI based features is essential in the development of such AmI based control schemes. Further, it is necessary to provide the tools to support the development of such new control systems.

The approach applied is to provide first a definition of AmI systems relevant for manufacturing industry which will serve to understand how AmI systems 'upgrade' classical intelligent systems. In order to provide a basis for the development of the AmI based control schemes in industry, an initial Reference Architecture is defined pointing a key structure of the AmI control systems in industry (i.e. identifying the key control blocks and their relations which an AmI based control system has to include) – see Section 3. The typical control schemes of AmI systems are studied and compared with the classical control schemes, aiming to identify the key differences which lead to higher intelligence of the AmI based control systems (Section 4). Based on this comparison the further ways for elaboration of the Reference Architecture are indicated, as well as usage of this architecture for the two typical applications (Section 5).

2. Definition of AmI in Manufacturing Industry

In spite of intensive RTD work on AmI, a clear definition of AmI systems in industry is still missing. The main assumption is that the AmI systems in industry can be considered as control systems of A&R and processes, which include human operators in control loop. The proposed definition of AmI system in manufacturing industry is based on the definition of DG Information Society, [1] and definition provided by Riva [9], addressing psychological modelling of human operator within an AmI system, i.e. it is a combination of a system approach and a psychological framework for the concept of Ambient Intelligence.

In order to propose such a definition, first a definition of 'Ambience' is provided.

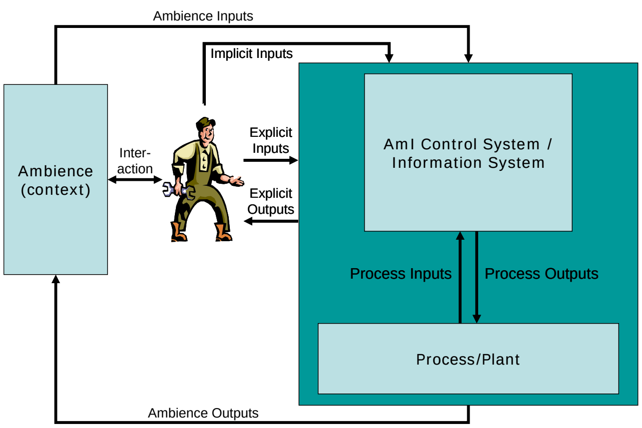

Fig. 1 AmI System

Definition of Ambience: Under Ambience is understood the environment both physical (e.g. room, with its physical features: temperature, humidity, etc.., manufactu-ring process, e.g. assembly line) and contextual (e.g. pur-pose of a Human Operator (HO) actions, business pro-cesses, situation dependence etc.) in which HO acts [13].

Proposed definition:

I. main characteristics (mandatory) - see Fig.1:

An AmI system in manufacturing industry exists only in a scope of interaction(s) with HO(s). A system is AmI if it possesses at least the first three of the following characteristics:

(a) 'Multimodal and easy interaction' with HO [3][1] including explicit and/or implicit interaction[2]

(b) Knowledge on ambience and HO based on extensive models (a' priory knowledge) and 'increased' sensory to observe the ambience and 'multimodal and easy' interaction with the HO (dynamic knowledge)[3], i.e. knowledge on:

- HO (e.g. location, context, intensions, etc.)
- (process) environment in which the HO is working and interaction among the HO and (process) environment
- the system itself and its interaction with the environment (context surrounding its use)

(c) Transparent[4] support to the activity[5] of HO regarding processes (disburdening the task execution by tending to overtake higher level tasks as far as possible) using the system intelligence which can be based on the knowledge on ambience (b)[6] related to different HOs involved in the business process(es)[7]

(d) implicit actions in processes[8] (i.e. actions not visible to HO)

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[1] As a 'multimodal and easy interaction' are understood new forms of seamless and user friendly interactions (information exchange) between HO and the AmI system which enables HO to easily provide and obtain information/knowledge (i.e. to communicate with the system at higher level), as well as to easily collaborate with other HOs. [10].

[2] In manufacturing domain HO / avatar interaction is primarily driven by the process needs. Therefore, in manufacturing domain explicit interaction has to be designed with highest priority compared to implicit interaction. The explicit outputs are e.g. information provided to HO etc.

[3] Reformulation of the definition [1]: 'know' itself, its environment and the context surrounding its use and act accordingly. The knowledge on ambience, therefore, is defined as: knowledge on HO, environment, context, and interaction.

[4] Acc. to [9] under 'transparency' it is understood that the activity is experienced without breakdowns.

[5] The psychological concept of "activity", see [9], is used here to indicate any actions of HO which can be done on different levels: strategic level, tactical level, execution level. The activity support may include e.g. 'higher' level mode of communication (allowing the HO to request/obtain data/knowledge on the level which is the most appropriate for her/him), decision support, behavioural support, etc.

[6] One of the key differences to the 'classical' intelligent systems: intelligence could be based on 'increased' knowledge on HO and environment. Intelligence may provide e.g. a higher level mode of commutation between HO and the system.

[7] Please note that it is assumed that intelligence uses the knowledge on 'all' ambience and HOs involved in the processes.

[8] Under 'implicit actions' in process are assumed actions which an AmI system makes in the process without explicit information to the HO and without his explicit involvement.

(e) implicit actions in ambience (i.e. actions not visible to HO) – adapting ambience to the HO needs.

II. Additional characteristics – (see [1]):

- Ability to find (and generate) its own rules on how best to interact with neighbouring systems and HO, while always looking to optimise its own workings and its own relations with the environment.
- be dynamic - able to configure and reconfigure under varying, and even unpredictable, conditions.
- be resilient and able to recover from routine and extraordinary events that might cause some of their parts to malfunction.
- be trustworthy, able to handle issues of safety, security and privacy
- be traceable.

NOTE 1: Obviously, the above presented definition assumes that HOs may interact with the AmI systems at different levels of process hierarchy (e.g. AmI can be for the HO making strategic production planning decisions, AmI can be for a foreman or for an operator at the shop-floor). For each HO, at whatever level, the same above listed characteristics must/may apply.

NOTE 2: The above definition implicitly assumes that AmI systems provide improved collaboration environment for HOs within a process. Interactions among HOs are addressed over interactions with the AmI system.

Rational for the proposed definition: The key aspects by which the AmI technology 'upgrades 'classical' intelligent systems:

- 'new', 'multimodal and easy' interaction between HO and the system, including implicit interaction allowed by new technology (mobile, embedded computers etc.) [3]
- radically 'new' knowledge on ambience based on new sensory, multimedia and other technology and based on 'multimodal and easy' interaction with HO i.e. radically increased observability of the holistic system: process, HO, environment
- higher intelligence possibilities allowed by the increased knowledge on ambience/HO and by different technologies to better utilise/manage these knowledge
- possibility to provide higher (more appropriate) communication level between HO and the system based on a.m. higher intelligence
- increased possibilities to overtake activities of HO (psychological definition of activity) on as high as possible (hierarchical control/planning) level by the system based on a.m. higher intelligence (i.e. the system may overtake not only lower level tasks but also (a part) of higher level tasks)
- implicit actions by the system both towards the process and ambience (as explained above actions about which the HO is not explicitly informed) based on new technological potentials to perform actions with higher reliability and safety.

Based on the above definition it is clear an AmI system from system point of view may have different functionalities, e.g.:

- it may be (only) an observer which provides increased knowledge (on HO, process, environment) and intelligence to different other (control or information) systems (e.g. an AmI system can be an add-on to Production Planning system or Leitstand system or to Maintenance Planning system; this add-on provides better interaction between these systems and HO and provides new knowledge and intelligence about HO and ambience)
- it may, besides the observer part, include information/knowledge provision part i.e. it provides activity support by providing information in more adequate way (e.g. provision Diagnostics results in more effective way, via multi-media etc.)
- it may provide higher level of communication between HO and the system (e.g. the system may allow for easy commands by HO based on context awareness and intelligence) as well as among HOs within collaborative working environments
- it may (besides observer part) include a control part which controls either different business processes (e.g. AmI system may be a new AmI based Process control system, or new AmI based Robot programming/control system) or ambience (e.g. a system for controlling environment in which HO is acting), or is used to provide information (e.g. control of actions to obtain requested information).

3. Reference Architecture

In order to enable efficient design of control systems for different systems (e.g. A&R, processes), it is necessary to establish consistent development methodology. A key tool of such a methodology is a definition of reference architecture for control systems of such devices/processes which should provide a unified representation of essential control features of these devices. The basic objective is to provide a simple unified architecture for control systems enabling traceability between the solution independent requirements and final implementations, as well as achievement of minimum control complexity and simplification design, support of interfacing and re-usability of control modules, etc. This reference architecture may serve as a tool for the comparison of different control concepts/implementations, their evaluation and an integration of modules developed within different control approaches. It shall enable and efficiently support the communication process between people involved in this development process. This means, it shall serve as a mean to ensure a common unified, unambiguous and widely understood terminology between people interested, from a utilization point of view, in the behaviour of the devices/processes, and people, being the experts in the different technical domains, realising a specific functionality of the devices to achieve the required behaviour. To reach this objective reference architecture shall be easily interpretable and applicable and, therefore, it shall represent a structure of limited complexity [11, 12].

Based on the above proposed definition, and based on study of several AmI based control systems for A&R and manufacturing processes, the top-level structure of the Reference Architecture for AmI based control systems in industry, i.e. for AmI based control of A&R devices and processes in industry must include following areas:

(4) KP knowledge on (process) environment and interaction

(5) KC knowledge on context

(6) I – Intelligence

As explained related to the definition of the AmI system in manufacturing industry, the reference model has to be seen at multiple levels of businesses process in which they are involved. In other words, the HO on Fig.2 represents **a set** of HOs (vector) involved with the considered AmI system (i.e. AmI system may represent collaborative working environment for a set of HOs).

Reference model for system activity support can be further refined based on the Reference Architecture for A&R systems (see [11, 12]):

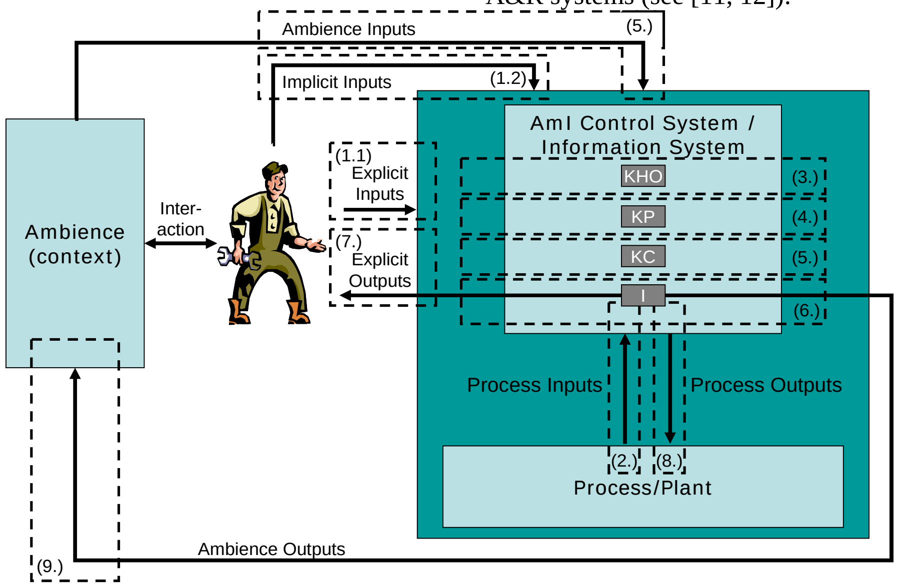

Fig. 2 Reference areas for an AmI System

(1) inputs HO to the system:

(1.1) explicit (e.g. speech, handwriting, touch screen).

(1.2) implicit (e.g. automated generation of coordinated speech, natural language, gesture, animation)

(2) (extended) inputs from ambience/processes

(3) knowledge on HOs (e.g. recording physiological signals such as heart rate, galvanic skin response, electromyography, apply biosensors etc., knowledge on collaboration among HOs)

(4) knowledge on (process) environment and interaction

(5) knowledge on context (see [13])

(6) transparent activity support based on the intelligence (which is in turn may be based on the knowledge on HO, environment, context)

(7) explicit outputs to the HO

(8) explicit and implicit actions in processes

(9) explicit and implicit actions in ambience

Figure 2 presents these areas within the Ami Reference model in industry, where

(3) KHO – denotes knowledge on HO

- Three main paths (feedforward part, nominal feedback path, non-nominal feedback path)
- Three levels (strategic, tactical, executive)

This will lead to further elaboration of the Reference Architecture by the identification of the main interactions between the human operator, process/plant and ambience and different control paths and control levels. The above listed areas have to be specified for interaction at each of the three levels and for each control path.

4. Control Model

Fig. 3 presents the typical classical control schemes, where HO is (vector) of human operator, EN indicates environment (ambience) in which HOs operate and PR indicates process(es) controlled by HOs and the control system K, C. The remaining symbols are obvious and their descriptions are omitted for the sake of space.

In these classical schemes the control system often does not include inputs on interaction between HO and the environment, and on interaction between the ambience and process(es) in both directions. HO normally gets part

of information on process state, part of information on interaction between EN and PR, and additional information on the PR state (j), which the control system does not obtain, and based on these additional information makes decisions, i.e. provides his inputs to control system.
The typical AmI based Control system scheme is presented in Fig. 4.

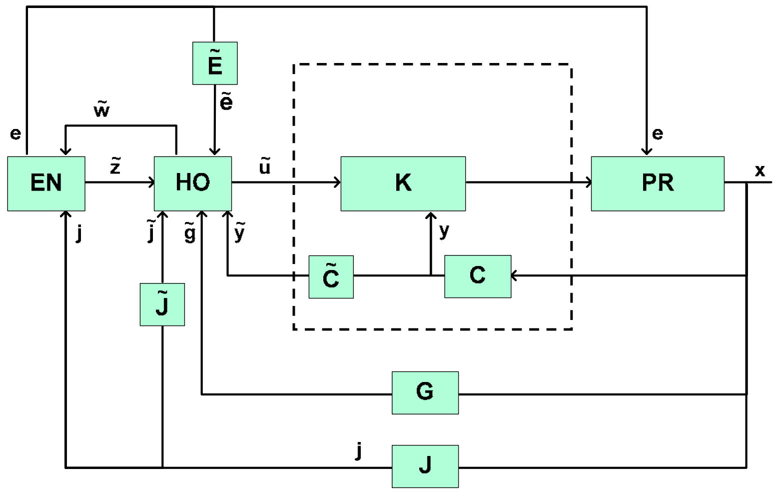

Fig. 3 Classical Control Scheme

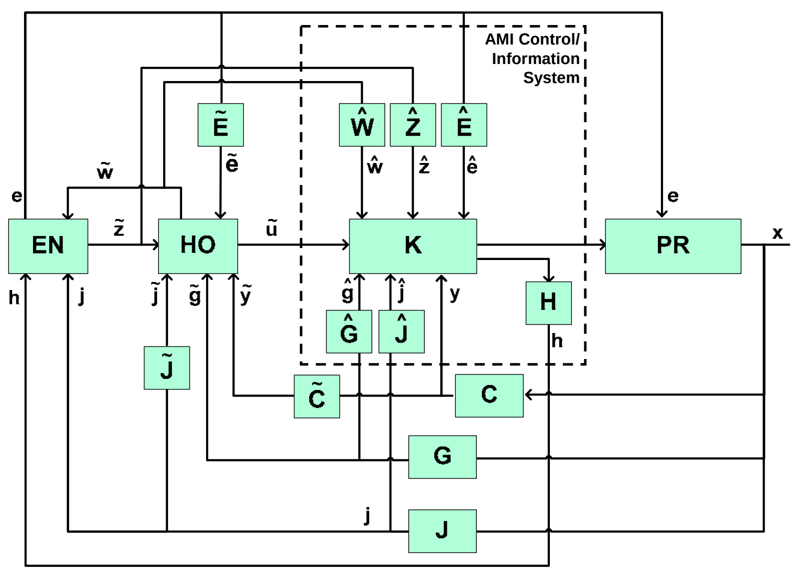

Fig. 4 AmI based Control Scheme

By comparison of these two control schemes, one may easily identify the key differences. AmI based control scheme includes:
a) Explicit control loop to control environment EN – the control block H (e.g. temperature, noise, light).
b) feedback loop from the interaction between HO and EN – the block Z. (e.g. wearable input devices such as key boards sewed in cloth, data glove, realization of user movement profiles and ad-hoc localization by sensors and cameras in the room; based on [13] a set of four context-aware capabilities that applications can support are identified: contextual sensing, adaptation, resource discovery, augmentation)
c) feedback loop from the interaction of EN upon PR – block E (e.g. smart tags)
d) feedback loop from the interaction of PR upon EN – block J
e) feedback loop from the information which HO gets on the process state – block G (e.g. cameras, smell sensors).
This means that AmI based control system receives more information on the interaction between HO and EN and between EN and PR as well as gets additional information which normally HO obtains from the PR and which 'classical' system do not receive (j). As explained above, this increased observability is a consequence of 'increased' sensory to observe the ambience and 'multimodal and easy' interaction with the HO as well as more powerful approaches for processing of these increased information and modelling of these different

interactions in the system which were not available in the classical control systems [14]. In addition, the possibilities of the AmI based control systems to directly control the environment (ambience) of the human operator (control loop H), allow influencing these interactions and, by this, providing possibilities to overtake lower level control tasks from the operator.
The further elaboration of this scheme requires modelling HO and his interaction with different control levels and paths. The model of HO will be based on the psychological model proposed in [9]. This leads also to further elaboration of the Reference Architecture which includes modelling of these interactions, i.e. structuring of inputs H, J, Z, G at each level of the interaction between HO and the AmI based control systems.

5. Applications

As indicated above, the proposed Reference Architecture is intended for the development of AmI based control systems for different applications in manufacturing industry. Within the two European projects the AmI based control systems are to be applied for the A&R systems and assembly lines. The proposed definition of the AmI system and the Reference Architecture will serve as guidelines for development of these systems. The Architecture serves to compare different possible AmI based control solutions and compare them with the classical, already existing solutions and by this effectively identify improvements which can be achieved by the AmI based control systems. The Architecture will serve as a basic control structure and for defining the main functionality and information flow for the key control blocks of the both planned control systems. The systems to be developed will be tested in a control of reconfigurable assembly line and complex automation system at two automotive suppliers.

6. Conclusion

The paper presents a first attempt to propose the definition of the AmI systems in manufacturing industry, from the control system theory point of view, and to specify the Reference Architecture for the AmI based control systems. Up to now, such Reference Architecture has not been developed. To achieve this, the classical control schemes are compared with the typical Ami based control architectures. This comparison clearly indicated that the key features of the AmI based control systems are an increased observability of the interactions among the human operator, his environment and the controlled devices/processes, as well as by direct control of the operator's environment, supporting directly operator to provide his commands at a higher level. This means that in AmI based control schemes key new algorithms/procedures must be defined for the observability of these interactions and for the control of the operator's ambience.

The further work will include an elaboration of the proposed Reference Architecture by modelling the human operator's activities and by further structuring different feedback loops from human operator and environment interaction. This Reference Architecture is intended to serve as a tool for the development of two AmI based control systems for A&R and assembly lines.

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