

A Concept for a user-friendly first Communication Initiation between Stationary Field Devices and Mobile Interaction Devices

Florian Floerchinger*. Mathias Schmitt**

*SmartFactoryKL, P.O. Box 3049, Kaiserslautern, D-67653
Germany (Tel: +49-631-2053708; e-mail: floerchinger@smartfactory.de)
**German Research Center for Artificial Intelligence,
Kaiserslautern, Germany, e-mail: mathias.schmitt@dfki.de

Abstract: This paper presents a concept for a user-friendly way to establish ad-hoc physical communication connections between industrial field devices and mobile control devices supporting several communication standards. For the human user in the future factory, this concept allows for more flexibility, mobility and safety. Hence it represents the basis for the nomadic user.

Key of the presented concept is a reference model that specifies all communication relevant information of a field device, attaching this information to the device by using an inexpensive passive data carrier. Furthermore, this reference model manages data like multi-user behavior and user-rights, enabling a flexible user-centered device interaction which satisfies the needs of industrial environments in future factories. With a reference model like that most ubiquitous technologies will be much easier to use in ad-hoc linked environments. The concept presented in this paper has been tested and evaluated in the *SmartFactory^{KL}*, the intelligent factory of the future. The results of this evaluation, which focus on the acceptance of users with regard to usability, show that there is a significant enhancement in compare to the state of the art identification methods.

Keywords: Industrial communication protocols, RFID and ubiquitous manufacturing, Protocols and information communication

1. INTRODUCTION

Visionary research forecasts adaptive industrial environments linked up ad-hoc in the factory of tomorrow (Jovane, 2009), (Zuehlke, 2009). Smart technologies will turn our factories in intelligent environments. Ubiquitous computing (Weiser, 1991) will affect our future factories in a whole and especially in terms of the human-machine-interaction. Over the last decade industry has recognized the demand for mobile interaction devices promising to enable the seamless control of different devices in a flexible industrial setting. In visionary future factories, devices might be connected without any configuration effort and the operator will be able to control all functions according to his qualification appropriately. Today, industrial reality is still far away from this desired Plug & Play behavior.

To let this vision become reality, a generic reference model on a passive data carrier is required which describes the different direct and indirect communication connections for industrial field devices. In addition, it has to be possible to reference information about operating-specific data, like user requirements, multi-user behavior and security demands to satisfy the needs of an industrial environment. This reference model can be stored directly in form of a binary data representation on a passive data carrier linked directly to the field device. Reading this data carrier with the mobile control device the field device will be identified and the

communication will be established without any additional configuration effort after checking the operating-specific data (see Fig.1). For the human user in the future factory, this concept allows for more flexibility, mobility and safety. Hence it represents the basis for the nomadic user.

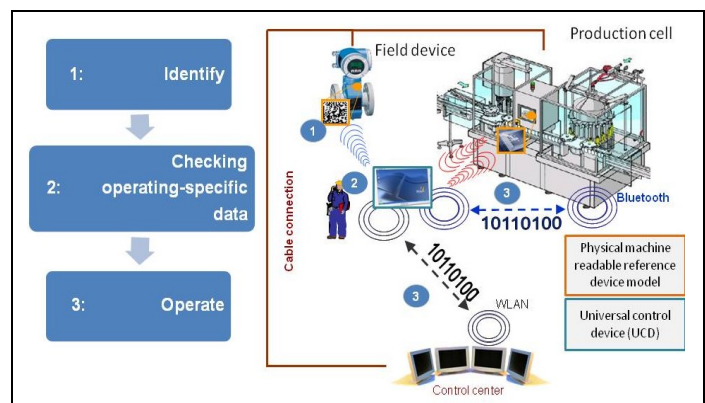


Fig. 1. Concept for an intuitive way of establishing physical communication connections

2. PRELIMINARY WORK AND LESSONS LEARNED

The number and complexity of technical devices in industrial plants are constantly growing. What is common are thousands of field devices and plant modules integrated in a

single facility. All of them can be connected through different communication connections and have to be configured and managed by different workers with various qualifications. Without reducing the configuration effort these complex field devices will become less manageable which will have an impact on the flexibility of future factories.

Examples for such a challenge are human machine interfaces (HMI) of industrial field devices. Since these devices often stem from multiple vendors, they possess heterogeneous User Interfaces (UIs) with different interaction paradigms. Since users often have to adapt their mental model to these different UIs, operation errors often occur. In contrast this means that workers can benefit from having a nomadic universal control device (UCD) which allows a uniform access of different devices.

To show the feasibility of a UCD within ambient intelligent production environments several demonstrators have been developed. In a first feasibility study several mobile phones have been used as a UCD to control a core module of the *SmartFactory*^{KL} demonstration plant via a proprietary Bluetooth connection (Goerlich, 2007).

Due to the very positive feedback of the initial UCD prototype and based on the lessons learned a new UCD – the unipo[®] UCP450 control device – has been developed in a follow-up project in collaboration with two industrial companies (Meixner, 2010), (Schnurrer, 2010).

Although the UCP450 allows a broad access of the various field devices located in the *SmartFactory*^{KL} it doesn't consider the users' context of use. This information allows the run-time adaption of the user interface. This challenge is currently addressed within the research project "GaBi" where a prototype of a run-time adaptive UCD – called SmartMote – for ambient intelligent production environments has been developed (Breiner, 2009). To enable the adaption of the user interface during run-time a model-based approach is used. Core of this approach is a use model, specified in the Useware Markup Language (useML), which allows the specification of detailed information about users' tasks, like task structure, task types, conditions and temporal relationships between the different tasks (Meixner, 2009).

One lesson learned from all these projects is, that several preconditions have to be fulfilled to describe an adaptive UI in an ad-hoc combined industrial environment. First step is the unique identification of the field device which should be connected to. Subsequently, a physical communication connection has to be established, which is rather complex with regard to all the different industrial communication standards, whereby the main focus lies on wireless technologies due to the nomadic mobile character of the control devices. After establishing a communication connection questions dealing with user rights, multi-user behaviour and security demands have to be answered before an adaptive UI can be built up and a worker is allowed to operate a device. Currently there is no known research project (as far as we know) which focuses on the question, how these context information sources can be referenced in real-time for the demands of industrial devices. Today,

context information is widely used within static industrial environment that do not change over time. Future factories will need all information to be dynamically referenced in real-time from different sources (see Fig.2), that implies in an adaptive and flexible factory, production lines change quickly. Because of security reasons user rights related to a specific field device will depend to the produced product in future factories. From this it follows that user rights have to be managed highly dynamical and cannot be secured through static logins and passwords stored directly on the field device.

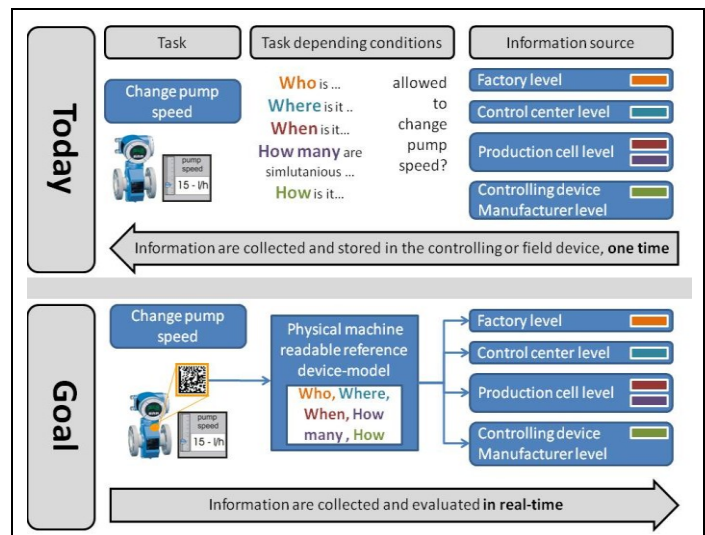


Fig. 2. Context information of the generic device reference model

The generic reference model is one reasonable approach to store all relevant device and context references directly on the field device, which is extended by an inexpensive passive data carrier (e.g. re-writable like RFID, NFC or read only like Data matrix, QR Code).

3. PROJECT OBJECTIVES & GOALS

The goal of the presented work is to create a framework which allows a task-based initial communication to industrial field devices. The device operator should be supported the best way in his workflow, without considering how to configure devices. The user-friendly unique identification of the field device is the first step to a generic device identification regarding the needs of ad-hoc combined industrial environments. A particular challenge is the linking of reference model based identifiers (NFC, RFID or 2-D barcode) to a specific field device. The necessity is recognizable in (Fig.3). Some field devices are in hard-to-reach or in several cases not reachable areas. Therefore, mounting the identifier directly onto the field device won't make sense in all cases. This would mean that some advantages of an UCD would get lost. From this it follows that simple user-friendly linking methods of industrial field devices to identifiers (NFC, RFID or 2-D barcode) have to be developed. Those device identification methods will be

described henceforth as “touch and connect” (t&c) based methods.

The description of the communication interface and the topology are the next challenges, because a physical communication connection is a precondition for operating a field device. A generic model has to be developed which is able to reference the typical industrial interfaces e.g. ProfiNet, ProfiBus, RS232, RS485, IWlan, Wlan and Bluetooth. Establishing a communication must be enabled solely on the information stored in the generic model. Therefore, common communication-relevant attributes of widespread communication standards have to be evaluated. On the basis of this information it will be possible to configure physical communication interfaces. To enable the automatic processing of the generic reference model, the identified attributes have to be stored in a machine-readable data format.

The generic reference model, which describes the device-specific communication attributes, is stored on a passive data memory directly linked to the field device. In consideration of the research results regarding the establishment of secure communication channels using out of band-canals (OOB) (McCune, 2005), (Kumar 2009), passive data memories seem to be the most appropriate data carrier for industrial environments regarding the usability. Therefore the results of the “Semantic Product Memory”-project (SemProM) can be used as a basis for this approach (Wahlster, 2008). Using a SemProM the UCD can read the field device parameters, stored on the memory and establish a connection (see Fig.1). To show the feasibility of the concept a first prototypical implementation of a communication model interpreter has been integrated in different universal control devices. This prototype allows establishing a connection to different industrial field devices, using the communication information stored on RFID, NFC, or 2D-barcode identifiers.

4. USABILITY EVALUATION

The whole concept of the first communication initiation between stationary field devices and nomadic interaction devices depends on the user acceptance. Therefore, the usability of the reference model based identification concept has to be evaluated. Our goal is to evaluate and compare identification methods with respect to following factors:

Robustness: How clearly does the identification method establish a communication connection to a specific device in our test environment?

Usability: How does each method fare in terms of successful completion, completion time, ergonomic design and user ease-of-use perception and personal preference?

Besides the pragmatic quality factors (PQ) like robustness, effectiveness and usability, hedonic quality factors (HQ) refers to the human need for stimulation (HQ-S) and identity (HQ-I) are captured as well (Hassenzahl, 2003).

The compared device identification methods are divided in two groups. The first group consists of established

identification methods, which are based on proprietary and preconfigured software tools. That means all communication connections to the field devices are already programmed, solely the user has to choose the demanded device out of a representation of available ones.

Drop down list: The user gets a list of available devices and has to choose the demanded device (textual). As identification information, she has got the name, the manufacturer of the device and the exact position in the test-bed (comparable to the challenge to log in the correct Wi-Fi in an unknown office building)

Graphical supported HMI: The user gets schematic diagrams of the industrial environment and has to choose the target device over a touch screen (graphical). As identification information, the name and manufacturer of the device as well as its' exact position in the test-bed is presented to the user (Realised through Siemens Mobile Panel (Joehnsen, 2010), unipo UCP450 (Schnurrer, 2010)).

The second group of identification methods includes different magnetically, electrical and optical identifiers which provide a first version of the generic reference model. As a result they realise an ad-hoc communication connection without the demand for preconfigured software tools. All identification methods require a physical approach of the UCD to the device identifier and are based on the touch & connect principle.

NFC based identification: The user has to contact the NFC identifier linked to the field device with the UCD to read the tag data (t&c electrical).

HF-RFID based identification: The user has to approach the identifier about 10 cm with the UCD to read the tag data (t&c electrical).

2D barcode based identification (t&c optical): Optical identification requires a direct view onto the identifier linked to the field device. The manageable distance between UCD and identifier depends on the camera solution, light situation and barcode size.

The used UCD-devices (Siemens Mobile Panel, unipo UCP450, HTC-G1, SmartMote, Nokia 6280 and Nokia 3132 NFC) provide in sum following features:

Users-input: keypad, touch-pad, microphone, camera

User-output: colour screen, vibration, speaker

Identifier: NFC, RFID, QR-Code

Communication interface: IWLAN, WLAN, Bluetooth, ProfiNet, RS232, RS485, LAN, GSM, GPRS, UMTS

6. TESTENVIRONMENT & CONDITIONS

In comparative usability studies, meaningful and fair results can only be achieved if all methods are tested under similar conditions and settings. In our case, the fair comparison basis is formed by two industrial field devices to which the different identification technologies, established as well as generic reference model based identification methods are

implemented. The *SmartFactory^{KL}* (Fig.3) serves in our case as a realistic test bed for a real production environment. To avoid learning effects and unilateral results different test cases have been developed. Both task sequences and sequences of the starting device have been permuted during the usability evaluation.

For collecting the relevant data we use two methods. Completion time, successful completion, clear identification, user attitude, user actions and performance are captured through participating observation according to ISO 9241-11. Data concerning user-friendliness and acceptability are collected via post-test questionnaires and free discussions. Through the post-test questionnaire, we solicit user opinions about all tested methods. Participants rate each method for its ease-of-use (very easy, easy, hard or very hard) and are asked to order methods from most to least preferred. Additionally the participants have to fill out a background questioner as well as information about their demographic data.



Fig. 3. Process technology part of the *SmartFactory^{KL}*; highlighted exemplary stationary HMI

5. USABILITY EVALUATION RESULTS

In sum 25 participant were recruited for the usability test in the *SmartFactory^{KL}* which lasted over one month. Participants were mostly university students from the engineering field, as well as graduated engineers. The gender was divided in 84% male and 16% female. The relation between male and female can be explained by the nature of the test location. Altogether this resulted in a fairly young and well-educated and technology-savvy group.

The evaluation was continually made considering the specified criteria as well as the objectives. In general the usability evaluation shows a significant enhancement in comparison to the state of the art identification methods. Furthermore there are shown meaningful differences within the group of established identification methods.

Figure 4 shows the so called evaluation portfolio (Hassenzahl, 2003). It corresponds to the visual analysis and

interpretation of the questionnaires and the data collected during the experimental test. According to the users evaluation, the device identification methods can be classified in a defined character section of the portfolio. Whereas on the abscissa the pragmatic quality aspects are shown, the ordinate shows the hedonic quality aspects. The scale of assessment has a range of -3 for the lowest rating to +3 for the highest.

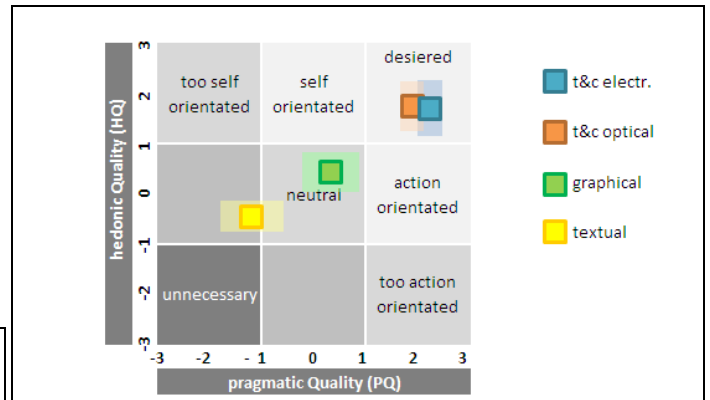


Fig. 4. Evaluation Portfolio of the tested device identification methods

It is obvious that the t&c-based identification methods are clearly better rated, than the established identification methods and show furthermore barely deviation on their average ratings. With regard to this outcome, there are no significant differences between those methods shown. The touch and connect based identification methods are clearly evaluated as *desired*.

In contrast the state of the art identification methods are showing considerable differences in their evaluation. While the device identification method with graphical supported HMI can be established in the *neutral* sector the device identification method supported by a drop down list moves to the *unnecessary* sector.

Furthermore, the evaluation results could prove, that the presented results are not stochastic, but obvious and meaningful, which means that the participants shared the same opinion concerning the device identification methods. The average deviation is described by the confidence intervals shown in figure 4.

Building on this, figure 5 shows an average value chart of the tested identification methods. This presentation supplements the precede portfolio. While the abscissa presents the different dimension of the quality aspect, the ordinate is reserved for the scale of assessment. The profile shows additional the hedonic quality factor attractiveness (ATT).

The chart underlines the results shown before and furthermore the users acceptance for the t&c-based identification methods. Furthermore, those methods have a better effect by attractiveness than the state of the art methods. Here again, significant differences between the two groups evaluated are made clear.

Altogether the touch & connect-based device identification methods for industrial environments highlighted as the solution with the highest user-friendliness and usability.

5. CONCLUSIONS & OUTLOOK

The generic device identification for a user-centered, task-based communication connection represents a further step towards a more intuitive human-machine-interaction in future factories. An initial communication reference model for describing the common attributes of communication interfaces has been developed and is evaluated with different industrial field devices from several vendors in the *SmartFactory*^{KL}. The capability of real-time adaptation of mobile interaction devices to their surrounding is a must for changeable production sites in future factories. For the human user in the future factory, this concept allows for more flexibility, mobility and safety. Hence it represents the basis for the nomadic user.

The whole concept of the first communication initiation between stationary field devices and mobile interaction devices depends on the user acceptance. Therefore the usability evaluation shows a significant enhancement in comparison to the state of the art identification methods.

Summing up touch & connect-based device identification methods have proved as a promising approach for industrial applications, which could change the universal and mobile operation in industrial plants fundamentally. Due to this usability evaluation in the realistic environment of the *SmartFactory*^{KL} the user acceptance for the new type of mobile and universal device identification could be proved.

Future work will address the adaption of the UI based on the context information stored within a generic reference model. With the generic reference model it will be possible to connect unknown field devices in ad-hoc linked industrial environments and to calculate the accessibility of devices depending directly to the context of use in real time.

REFERENCES

- Breiner, K. et. al. (2009). *Towards automatically interfacing application services integrated in an automated model-based user interface generation process*. In: *4th Workshop on Model-Driven Development of Advanced User Interfaces (MDDAUI), Intelligent User Interfaces (IUI) 2009*, Sanibel Island, USA.
- Goerlich, D. et. al. (2007). *Demonstrating Remote Operation of Industrial Devices using Mobile Phones*. In: *Proc. of the 4th Intl. Conference on Mobile Technology, Applications and Systems*, pp. 482-485, Singapore.
- Hassenzahl, M. (2003). *AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität*, Mensch & Computer, Stuttgart.
- Joehnsen, O. (2010). *Flexibilität und Verfügbarkeit erhöhen - Anlagenweites mobiles Bedienen und Beobachten*. IT Production, 9.2010.
- Jovane, F. et. al. (2009). *The ManuFuture Road: Towards Competitive and Sustainable High-Adding-Value Manufacturing*, Springer, Berlin.
- Kumar, A et. al. (2009). *A comparative study of secure device pairing methods*, In: *Pervasive and Mobile Computing - Volume 5*, pp. 734-749.

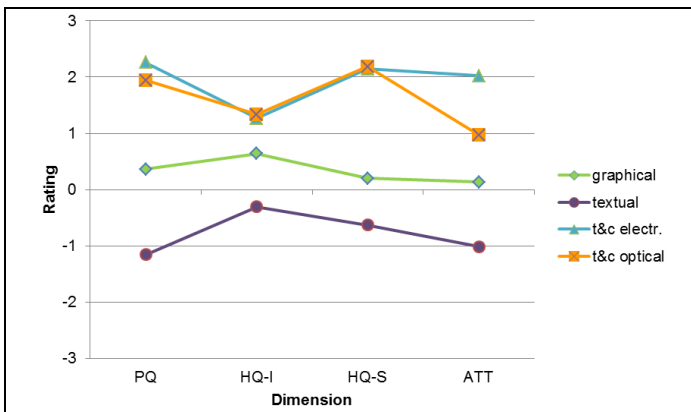


Fig. 5. Evaluation Profile and Attractiveness of the tested device identification methods

In addition to the questionnaire especially effectiveness, as a measure of usability, was collected by timing and logging both user interactions and error rate. The visual interpretation and evaluation of this data is shown in figure 6. The result reflects the average processing time of all participants to complete the tasks accurate.

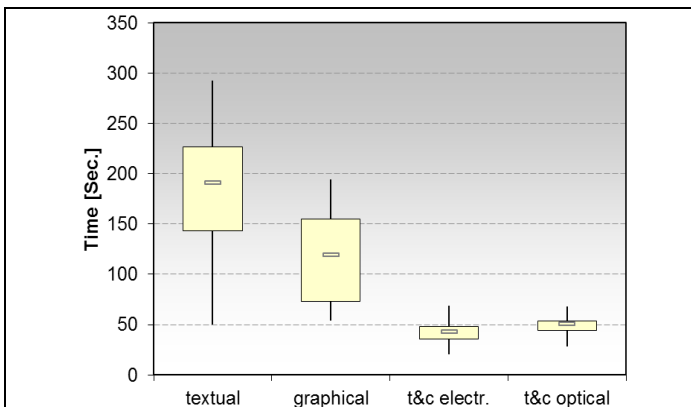


Fig. 6. Processing time over all participants

The users require a clearly higher processing time in average, while evaluating the state of the art identification methods. In contrast the t&c-based identification methods show both a high effectiveness, represented through the processing time.

The significant differences within the group of established methods and the high range of measurement clarify the uncertainty and difficulty the users had during the evaluation.

Again the significant differences between the both groups evaluated are recognizable. The methods based on the t&c-principle highlighted as high effective for industrial use.

- McCune, J.M. et. al. (2005). *Seeing-is-believing: Using camera phones for human-verifiable authentication*, in: *IEEE Symposium on Security and Privacy*.
- Meixner, G. et. al. (2009). *Udit – A Graphical Editor For Task Models*, In *Proc. of the 4th Int. Workshop on Model-Driven Development of Advanced User Interfaces (MDDAUI)*, *CEUR Workshop Proceedings Vol-439*, Sanibel Island, USA.
- Meixner, G. et. al. (2010). *User Interaction Evolution in the SmartFactoryKL* In: *Proc. of the 24th BCS International Conference on Human-Computer Interaction*, Dundee, Scotland.
- Schnurrer, M. et. al. (2010). *Entwicklung eines universellen Bediengerätes zur drahtlosen und mobilen Interaktion; Tagungsband VDI Kongress AUTOMATION 2010*, Baden-Baden.
- Wahlster, W et. al. (2008). *Sharing Memories of Smart Products and Their Consumers in Instrumented Environments*. In: *it – Information Technology 50(1)*, *Special Issue on Ambient Intelligence*, pp. 45-50, Oldenbourg.
- Weiser, M. (1991). *The Computer for the 21st Century*. In: *Scientific American, Special Issue on Communications, Computers, and Networks*. September 1991
- Zuehlke, D. (2009). *SmartFactory - A Vision becomes Reality*. In: *Keynote Papers of the 13th IFAC Symposium on Information Control Problems in Manufacturing (INCOM 09)*, June 3-5, Moscow.