Development of methods that support exploration of simple and low-cost IoT-aided improvement solutions at manufacturing plants

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1. Introduction

Internet of Thing (IoT), often regarded as a network of physical objects having their own digital identities and the ability to transfer data over a network [1], has brought various opportunities for manufacturing companies to advance their plants toward the era of information-intensified plant operations. Various kinds of sensors, Information and Communication Technology (ICT) devices, and cloud data storage and computing services have become ever more easily accessible. An effective application of them can integrate and share rich, accurate, and timely information on the operations, leading to achieve higher responsiveness and agility in the operations. However, introducing IoT in manufacturing plants is still often regarded as a complex and expensive investment requiring high technological entry threshold [2]. A technology -driven and top-down approach of the introduction may cause the sense of uncertainty or even fear among persons working close to the operations.

We, a research team, are currently conducting a research project seeking a simpler, more bottom-up, and more human-centric approach of introducing IoT in manufacturing plants. The approach aims to unleash creative power of persons working close to the plant operations. As a part of the project, we are developing methods that help those persons to explore simple and low-cost IoT-aided improvement solutions. The purpose of this paper is to discuss the development of these methods. The methods have been applied at some Swedish manufacturing companies. This paper also reports the use cases and our reflection upon them.

2. Context of the method development

The method development is undertaken under the aforementioned research project whose purpose is to enable plant workers to easily build and implement simple and low-cost IoT-aided improvement solutions at the shop floor by us developing and providing them with a modular hardware and software system. Hardware and software modules can be sensors, communication devices, and cloud services. We call this project as "Karakuri IoT" [3]. The development of the modular system is conducted by three research institutes in close cooperation with five manufacturing companies in Sweden. An overview of the modular system development process is shown in the upper side of Fig.1. The methods in discussion are developed to serve the purpose of the first and second stage of the process (A and B in Fig.1).

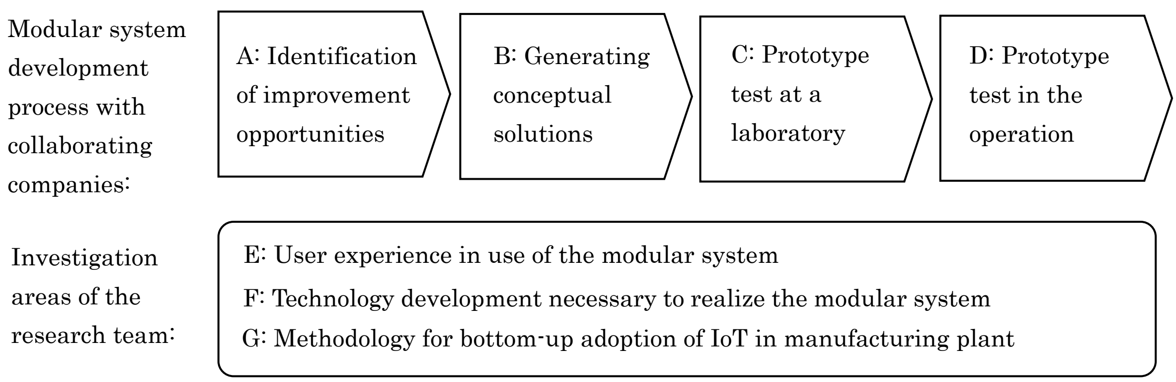

Fig.1 An overview of the research project

The first stage of the process (A in Fig.1) is to identify improvement opportunities that can be possibly addressed by the modular system. At the second stage (B), conceptual solutions to the identified improvement opportunities are generated. At the third stage (C), early prototypes are built and evaluated at a laboratory environment. The fourth stage (D) involves higher fidelity prototypes being built and tested in the operational environment. In all of the stages, prospect users of the system are to be deeply involved in the development as "the experts of their experiences" [4], as we being inspired by co-design approach [5]. Here, prospect users are mainly shop floor workers but also persons from supporting functions such as production engineering, logistics, maintenance, and IT. The development process is also aimed to be agile, being inspired by Scrum approach [6]. The development is undertaken by frequent interaction of the users and the development team. The system is also to be developed through subdivided deliveries of partial systems to the users.

Along with the development process, we aim to develop the knowledge in the following three areas (lower part of Fig.1). The first area concerns gaining deeper insight as to the user experience, especially in terms of how users can perceive the potential of the modular system, how they experience the actual use of system prototypes, and how they experience a human-centric and bottom-up approach of introducing IoT in manufacturing plants facilitated by the modular system (E in Fig.1). The second area involves what technology can be adopted or needs to be developed to realize the modular system (F). The third area concerns the development of a methodology that supports a seamless adoption of IoT in plants in a bottom-up matter with help of the modular system (G).

3. Method development

The main purpose of the first stage of the process shown in Fig.1 is to identify, as many as possible, improvement opportunities that prospect users think relevant to the idea of the modular system. The identification is a valuable input for the development of the system. To meet the purpose of the first stage, a workshop have been organized with prospect users at the companies. At the workshop, the researchers explain a general concept of the modular system to the participants, and they are asked to generate improvement opportunities that they think could be addressed by the system. It is considered that the workshop can be an opportunity for the participants to start to be familiar with the introduction of simple and low-cost IoT in the plant. The workshop is also considered beneficial for us to observe how the participants perceive the potential of the modular system. For the modular system development, it is considered important to capture as many improvement opportunities as possible. Therefore, several measures are used in the workshop to stimulate the participants' exploration. Examples are, presentation of actual use-cases of simple and low-cost IoT implementation in manufacturing plants, adoption of brainstorming rules (e.g. seeking quantity in idea generation than quality, no critic to ideas), and use of storyboard [7] in which drawing pictures of problem situations are encouraged than describing them in texts.

The main purpose of the second stage of the process in Fig.1 is to, based on the idea of the modular system, generate conceptual solutions of some of the improvement opportunities identified in the first stage. The current state of the modular system development is at an early phase (at the beginning of the third stage in Fig.1), thus it is still not clear how the system will exactly appear. We also consider that prospect users shall generate conceptual solutions by themselves, since we employ the co-design approach in the modular system development. This have led us to devise mock-up modular system cards (Fig.2). In a workshop, prospect users are asked to use those cards to generate conceptual solutions. The mock-up cards are provisional modules of the modular system. Approximately 40 hardware and software modular cards are created. Joker cards, for instance joker sensor, are also made in order to leave the participants freedom to create their own modules. Generating as many solution as possible during the workshop is considered important. Therefore, the participants of the workshop are asked to generate high variety of solutions having different combination of the cards with different complexities.

Fig.2 Examples of the mock-up cards

4. Use cases and reflection

The workshops for the first and second stages have been so far applied three times and one time respectively at some of the collaborating companies. More workshops are planned to be conducted.

As to the workshop for the first stage, more than 80 improvement opportunities have been identified by the participants. Generally, their perception of the idea of the modular system and the form of workshop were positive. Concerning the workshop, the participants found that drawing picture of improvement opportunities was particularly enjoyable and stimulating the discussion (Fig.3). The identified opportunities were of high variety. Examples of the types of the opportunities frequently appeared in the workshops were; taking time to find something (e.g. empty carts, material at inventory), important information does not reach relevant persons immediately (e.g. machine stop, short of material), richer information of problem situation (e.g. small stoppages of machines, defects), and richer current and/or historical information of a certain activity (e.g. machines status, object locations). When the framework of process maturity level of IoT-based manufacturing system [8] is applied, which consists of six levels from lower to higher – Visualization, Connection, Analysis, Measurement, Prediction, and Symbiosis, the most of the identified improvement opportunities are related to the first two levels. It is to some degree understandable because the participants were asked to generate opportunities that can be easily solved by introduction of simple and low-cost IoT. The companies' current maturity level of the IoT-based manufacturing system may have affected the result, however more investigation is needed to verify this.

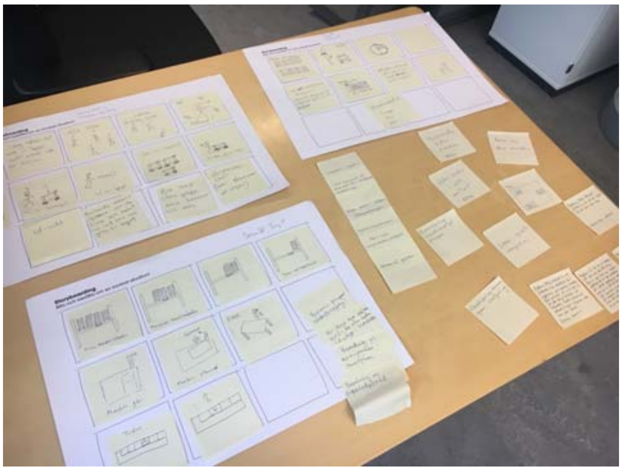

Fig.3 A result of one of the workshops

The workshops for the second stage has been undertaken one time at one of the collaborating companies where six conceptual solutions were generated for one specific problem identified in the workshop for the first stage (Fig.4). Generated solutions had a difference in complexity. For instance, a simpler solution had push buttons and color lights as main components (using a few modular cards). While, a more complex solution employed multiple layers of sensing, real-time information display, and trend analytics (using ten modular cards). General impression of the participants on the workshop was positive. They perceived that the modular cards helped them to focus on the conceptual phase and generating various alternatives. Some participants commented that the cards helped to avoid the discussion going into technical details, which tented to be dominated by technical experts. The participants also perceived that the cards facilitated multi-disciplinary work in generating solutions. The cards functioned as "a common language" for them with different expertise and technical knowledge to discuss solutions at a similar abstract level. Further, the performed workshop has demonstrated the potential of the scalability and reconfigurability that the modular system can entail. The use of the mock-up cards has shown that the complexity of a solution to a certain problem can be easily changed by adding or removing cards. This implies that the modular system, when realized, can help to identify a right level of system complexity through experiments with different combinations of the modules resulting in different complexities. The reconfigurability that the cards have demonstrated also implies that the modular system can be used in some situation as a prototype of a larger, more permanent and tailored system in order to estimate the effectiveness or weakness of the permanent system.

Fig. 4. Use of the mock-up modular cards

5. Final thought

The methods presented in this paper are still under development. They can be further refined through the iteration of workshops at collaborating companies. Considering the generality of the methods, a thought is that, although they have been developed in the context of using the modular system, they can be applied in more general situations with minor modifications. They can be applied in situations, for instance when a company wants to explore improvement opportunities that can be realized by an introduction of simple and low-cost IoT. Exploring different combinations of sensors, communication or computing devices, and cloud services is still needed regardless of the use of the modular system.

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