Smart Sensing Devices for Logistics Application

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Abstract. This paper provides an abstract view of the Industry 4.0 as the next industrial revolution. Cyber Physical Systems (CPS) as smart connected solutions are considered to be the key answer to the needs of future industry. Effects of this revolution on the logistics sector is analysed and integration of CPS in this field is presented.

To evaluate the quality of CPS solutions in the field of logistics, PhyNetLab and its subcomponents are presented as a physical testbed for testing CPS nodes, structural designs, communication platform and protocols in addition to the energy challenges for materials handling and warehousing application.

inBin and P-ink as two CPS solutions are reviewed in the context of the order-picking. Also, iCon as an alternative outdoor asset tracking solution is presented.

Keywords: Smart sensing · Logistics · Industry 4.0 · Wireless sensor network · PhyNetLab · inBin · P-ink · iCon

1 Introduction

Industry as a major part of the economy, responsible for production and manufacturing have seen different paradigm shifts since the beginning of industrialization. Mechanization, electrification and automation (or digitalization) are the three past revolutions. Future technologies are orienting into the direction of making machines and services more "smart", resulting in a new shift in industry [1]. This transfer is pushed by the development of new technologies and forced from application and costumer side for better solutions [1].

In a traditional system, several sensors provide data to a central decision making unit. After deciding about the required action, it propagates them to actuators. However, the current need of fast changing products and systems pushes industries towards more flexible solutions. Therefore, future systems have to be easily reconfigurable. Preference is in less central structure and more use of multi-agent solutions which communicate with each other [2]. This helps to avoid complex and tedious task of central reconfiguration after system modifications. Hence, intelligent modularity and communication are the two critical aspects of the next industrial revolution named Industry 4.0.

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1.1 Industry 4.0

In the Industry 4.0 vision, an efficient smart manufacturing system or production line is made of multiple modules. These modules communicate not only with each other and the environment, but also products communicate with them as well to influence the manufacturing configuration and control the production scenario [3]. This is mainly required to realize the individual production in the batch size of one single product while still maintaining the economic condition of the mass production [1]. It makes topologies to be more fluid to automatically reconfigure instead of having a production process with fixed rules [3].

Smart networking of multi entity system will make the future systems more mobile and flexible. It also makes the integrity of the costumers easier and opens new business model innovations [4]. This costumer integrity can be from a simple action such as automatic brewing of a coffee when the costumer enters the coffeehouse till halt of an assembly line by clicking on a button [5].

Recent developments made the future modules for the Industry 4.0 such as sensors, data acquisition systems and networks more available and affordable [6]. For instance, a smart sensor is not only responsible for the sensing, but also it processes the data and analyses it independently as a complete entity. This information can even lead into a decision directly made by the sensor unit. It transmits this data via network to a smart actuator to do the proper action [4].

Although there are different understanding and definition of *smart* in the context of the Industry 4.0, most of them are focusing on two main aspects: first, they are all embedded devices and second, they are able to communicate. This communication can be within different levels; from closed local Wireless Sensor Networks (WSN) to globally spread devices communicating over the internet. These two aspects lead into the definition of the Cyber Physical Systems (CPS). Unlike traditional embedded systems mostly designed for the stand-alone operation, CPS is focusing on the networking of multiple devices. Also, this data exchange possibility is the key differentiation of devices in this new era [4].

1.2 Cyber Physical Systems

Although CPS consists of two main aspects of the connectivity and intelligence (including computational power and data management), there is a 5C structure to explain the work-flow of CPS construction [6]:

- **Smart connection:** easy setup (plug&play) and reliable network connection
- **Data/information conversion:** converting available data into meaningful and useful information
- **Cyber machine:** collecting data from the network and understanding the status of the node among the whole fleet
- **Cognition:** presenting proper monitoring information for the higher levels (or experts) to define priorities, optimization points and maintenance needs
- **Configuration:** feedback from cyber level to the physical level

Exploitation and integration of CPS with such specifications in the industry would transform today's factories into Industry 4.0 factories with significant potentials. A report from Fraunhofer Institute and the industry association Bitkom predicts that introducing Industry 4.0 will boost the German gross value by a cumulative 267 billion Euro by 2025 [6].

Although transition into this direction will bring new potentials for the industry, it amplifies the already existing complexities in the supply chain. All compartments of the supply chain have to be extremely flexible with the shortest reaction time while still acting reliable to assure costumers' needs [3]. Logistics as a major section of the supply chain need to grow hand in hand with this revolution to avoid problems and bottlenecks in the supply chain.

In the remaining of this paper, first the effect of Industry 4.0 on the future logistics is seen. To analyse possible CPS with focus on the logistics, PhyNetLab as a testbed platform is presented. Then, two types of CPS nodes operating in this testbed are presented. Subsequently, two CPS solutions for the order-picking application are discussed. And finally an energy-neutral logistics asset-tracker called iCon is presented before a short conclusion.

2 Logistics

Logistics in its general substance can be considered as all set of services covering the planning, organization, management, control and execution of flowing goods and information. It includes multiple tasks, from purchasing, production, warehousing and freight transport to added value services, distribution and reverse logistics in the whole supply chain [7,8]. Based on this definition, logistics is a vital section for the industry and supply chain. The estimated potential market volume of the logistics sector of the 28 European Union member states in 2012 was about 878 billion Euro. However, transport and warehousing are representing the majority of the added values in this sector [8].

According to the latest investigations published in [8], the existing European logistics sector is dealing with three clear problem areas as:

- continuous rise in costs
- external (non-logistics) effects such as energy and emission
- the quality and quantity of the relevant staff

moreover, there are some not critical issues pushing this sector to improve. Some of them are [5]:

- transparency and integrity control along the whole supply chain
- real time detailed shipment tracking
- integrity control for sensitive goods
- assets control and monitoring for analysis and optimization

In addition to the available concerns pushing for new solutions, influence of reconfigurable manufacturing systems foreseen in the Industry 4.0 revolution demands special solutions as well. On the other hand, advances in the networking solutions and protocols, energy efficient and energy aware hardware in addition to the maturity and affordability of the smart sensors provides new opportunities to fulfil the Industry 4.0 in the logistics sector.

Flexibility of a system have always been an asset in the logistics [9,10]. Modularization as a priority for flexibility requires to decompose the logistics system into its basic functions and introduce proper module for each of them able to communicate with each other. This will reduce the operating challenge in the highly dynamic Industry 4.0 environment [11]. Therefore, using these systems able to understand their condition and react based on that will tackle the flexibility issue [12].

Modularization of logistics tasks using CPS will also reduce the need for central systems and make them much more dynamic [9]. This will reduce the need for human interaction required for continuously reconfigure the system based on new needs. In addition, in those cases where operators have to be available, these solutions can improve the human working quality or reduce the injury risks at the work space. They also help them to decide more efficiently and reduce the chance of failure. A simple example would be a connected forklift which can alert all other entities in its surrounding about its driving path [5].

Among the logistics modules heavily intermeshed with cyber technologies are sensors, data acquisition and actuators. These modules are directly in the front line of application. Therefore, any improvement in them will bring added value and help to optimize the utilization of available resources [4]. Some of these modules are presented hereafter as examples.

3 PhyNetLab

In the logistics application, different physical analysis have to be done before deployment of a new system into the operational field. Though simulation and emulation tools provide understanding of system's subsections, they are not able to mimic all the complexities and dynamics of a working network. Some of these dynamics in addition to the logistics scenarios complexities are: radio interferences, resource limitations, energy harvesting potentials [13]. These dynamics has to be analysed before a large-scale deployment which can be in the size of some hundred thousand of CPS entities.

PhyNetLab, is a research testbed platform with more than 1,000 m^2 surface, with a section as an automated warehouse for the storage of materials. It replicates a real world industrial materials handling and warehousing facility [13]. In addition to its physical space, its hardware platform provides a variety of wireless communication possibilities with protocols on the sub 1 GHz band in addition to the 2.4 GHz band [14]. It is developed to deploy an ultra-low-power WSN to test different decentralized in-house materials handling scenarios in addition to the evaluation of different logistics CPS modules in operation [14].

In addition to the evaluation of the logistics CPS modules, PhyNetLab provides the opportunity to test different technical aspects of WSNs such as radio configuration and routing algorithms. Moreover, different debatable topics such as security, privacy, business structure and integration to other available IT infrastructure can be analysed in the PhyNetLab under real-world constraints [13].

Although this platform represents the real physical environment, introducing the same number of entities acting in a real application will conquer the limitations for experimentation. Therefore, PhyNetlab is deployed in three tiers [14] which an abstract view of them can be seen in Fig. 1.

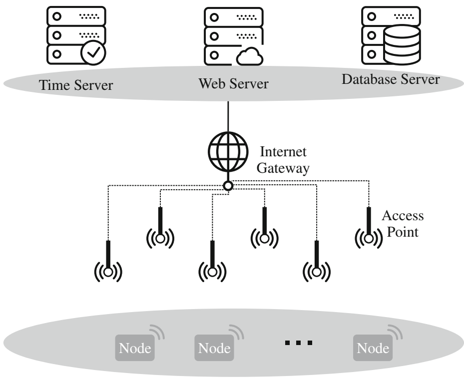

Fig. 1. An abstract overview of the three tiers structure of the PhyNetLab

By looking back into the 5C structure for the CPS development, it can be seen that the middle layer of the PhyNetLab provides the infrastructure for *simple connection* of any new node added to the system. Moreover, it is the back-end for the *cyber machine* in the nodes. It feeds them with the required data from the rest of the system. The two upper layers provide *cognition* from the field to users and experts. Moreover, the web server has options for a system designer to develop and roll-out new *configuration* for the system.

In the PhyNetLab different type of CPS nodes can be operating in the field level which two current types of them are introduced here.

3.1 Cellular Transport System

Traditionally, conveyors were responsible for the in-house materials handling. However, the best logistic area is in theory an empty room with flexible transport options. By the advancement in the field of robotics, mobile transport systems are able to replace the fixed conveyors. These devices are able to freely move in the whole area without blocking a part of the system as the conveyors do.

Cellular Transport System (CTS) is a mobile robot for materials handling in the PhyNetLab. It is designed in a way that can also enter the warehouse section and be lifted to any desired level. Therefore, it is able to pick a handling unit (a standard size bin in the PhyNetLab) from any source and deliver it to any destination in the system.

In addition to the normal operational sensors, logic and actuators, each CTS is equipped with a laser scanner that continuously scans its surrounding to avoid collision with other devices or human operators. By means of wireless triangulation, each CTS finds out its current location and plans its path internally with an acceptable accuracy using artificial intelligence. However, they send this information into the system's higher levels, but only for monitoring purpose and it is not propagated into the other nodes.

Within the PhyNetLab, there are 50 CTSs operating as CPS nodes in the field level to accomplish any task requiring movement of objects. Some CTSs operating in the PhyNetLab are shown in Fig. 2.

Fig. 2. Cellular Transport Systems (CTS) in PhyNetLab courtesy Fraunhofer IML, Dortmund

3.2 PhyNode

The main operational research goal of the PhyNetLab is evaluation of different logistics CPS nodes in diverse structures and scenarios. In one hand, a large number of them are needed to replicate a real scale system; on the other hand, thy have to be modifiable to represent different nodes and applications. Therefore, a design with two sections is considered. Each system is made of a main board (MNB) enabling the *configuration* aim of the 5C structure. An abstract view of the PhyNode's MNB can be seen in Fig. 3.

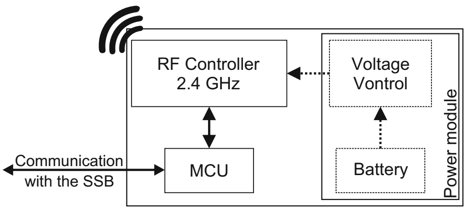

Fig. 3. Schematic structure of the PhyNode's MNB

In addition, a Swappable Slave Board (SSB) makes integration of different hardware designs to be implemented in the platform easily by changing the SSB. A general design of the SSB is shown in Fig. 4.

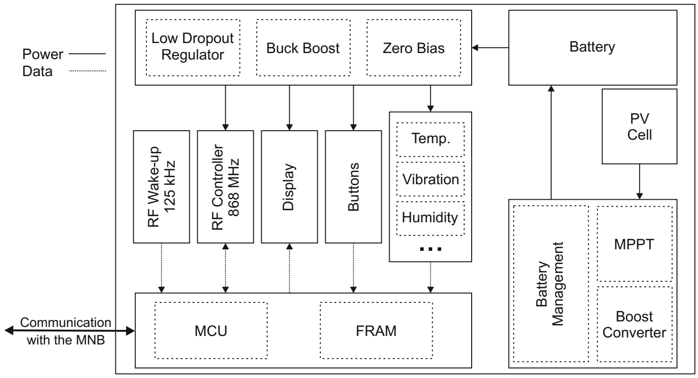

Fig. 4. Schematic structure of the PhyNode's SSB

Five different versions of this SSB with differences in the hardware (replicating dissimilar nodes) are designed and produced. A complete PhyNode including both MNB and the full version of SSB is shown in Fig. 5.

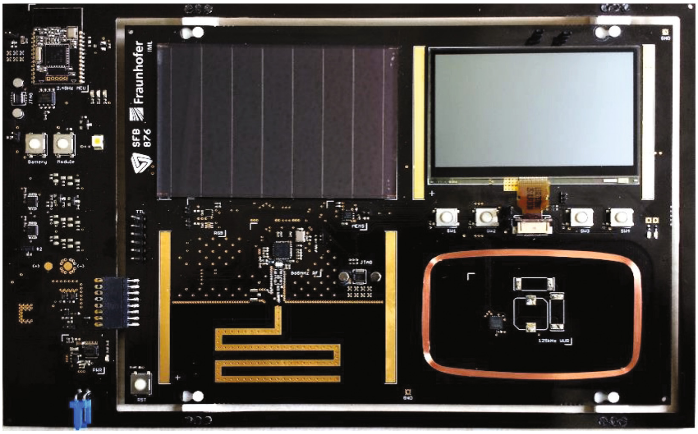

Fig. 5. Overview of a complete PhyNode

In the PhyNetLab, 350 PhyNodes are mounted on transport bins operating in the field level. Therefore, overall 400 nodes are operational as a combination of CTSs and PhyNodes.

4 Order-Picking Application

Order picking as a major section of in-house logistics is getting more and more momentum specially with the raise of online stores. Traditionally, there are two type of strategies for this task as:

- **goods to operator:** ordered good travels from the storage space into the picking station
- **operator to goods:** operator moves in the storage to access the item

Two examples of Industry 4.0 solutions for order picking task using CPS are presented hereafter.

4.1 inBin: Intelligent Bin

In the in-house application, the nun-bulky materials are mostly flowing in a standardized unit which can be a pallet or a bin. Traditionally, these units are only a carrier of the materials and all the related data is stored in a central system. With the advancements in the low-energy electronics and energy harvesting, an electronic board with the concept of PhyNode can be mounted on a normal bin. This intelligent module stores all the related data locally and makes them available all the time travelling with the bins. This will make an intelligent bin (inBin) which its evolution over the time can be seen in Fig. 6.

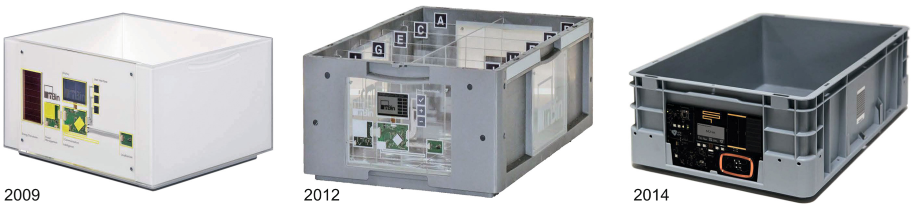

Fig. 6. Three generations of inBin over time

By storing the content data in the inBin, there would be no need for a central warehouse management system. As soon as a new picking order is triggered by user through the web server, a request of picking propagates in the whole system. Those inBins able to fulfil the order, reply to the request and build up a subgroup. They communicate to each other within their group and select the best matching solution based on their own criteria. It can be the longest storage time, products expiry date, lowest distance to pickup or any other criteria. The selected inBin starts communicating about its selection.

In the *operator to goods* concept this signal would be received by the operator's interface which can be a hand-held device or a voice signal through its related gadget. Operator moves to the storage place and meanwhile a lighting signal on the inBin helps the operator to find the bin easier. After picking the item, operator acknowledges the number of picked items and inBin updates its internal database and logs the pick's data.

In the *goods to operator* concept, for instance in the case of using PhyNetLab, communicated signal from inBin reaches the CTSs. They do also an intelligent selection internally and the chosen CTS starts communicating with the inBin. CTS picks the inBin and brings it to the operator's station. After confirmation of operator, inBin communicates with the CTS for return into the storage.

4.2 P-ink: Pick by Ink

In the *operator to goods* order-picking strategy, operator can be informed in different ways where the desired item is stored. It can be by use of an order-picking list, using a voice commanding system or a light alerting mechanism. Generally, systems based on the visual sense are easier for the operator to work with. However, typical visual solutions require long cabling in the whole warehouse for communication. This cabling makes them expensive and system structure would be reluctant to any change.

P-ink is a CPS alternative pick by light order-picking solution. It uses a large flexible segmented e-ink display to show the meta-information such as the items details relevant for the order-picking operator. Flexibility of the display makes it easy to be integrated in the available standard systems (Fig. 7).

Fig. 7. A P-ink system easily mounted on a standard size bin courtesy Fraunhofer IML, Dortmund

It is using ultra-low-power logic and communication hardware. The industrial grade hardware with compliant wireless communication standards using 868 MHz ISM band bidirectional communication removes the need for cabling and brings flexibility to easily restructure the storage area. Local storage of data reduces the communication overhead compared to the centralized systems. Also, a node density of up to 4,000 nodes with latency of up to 3 s (for requests from the top most layer) per industrial warehouse can be reached. The wireless connectivity makes over the air programming possible and it is easy to update the logistics softwares interacting with the system.

P-ink can be also used as a decentralized warehouse management system and increase the traceability of the items in a warehouse. It helps to create better allocation of storage spaces in real time with close integration to other controlling (normative) layers of industrial software.

MEMS sensors such as a vibration sensor embedded in the P-ink, provide data that can be integrated into the process. For example, critical state detection of an article from the container when a specific kind of vibration is detected.

5 iCon: Intelligent Container

In the not-enclosed logistics applications, asset state and tracking has a very high priority. According to a report [5] published by Cisco, it accounts for about 25% of the total value stack of the whole IoT. For most active components of the logistics sector such as vehicles, trucks, airplanes and ships, integration of tracking solutions is roughly easy. However, number of passive modules is much larger than the active ones and their tracking is much harder mainly because of the lack of energy supply.

iCon is a CPS system designed to be installed on the passive logistic modules such as air-cargo containers. In addition to its ultra-low-power electronic logic system, it localizes itself using GPS and GSM roaming data. Also geo-fencing with automatic alarm is integrated in it. iCon integrates different sensors including temperature, humidity, sun exposure, air pressure, dew point and three axis accelerometer. It is able to communicate using 4G LTE, UMTS and GSM network to transmit its data using the available infrastructure to its tracker (Fig. 8).

Using large combined PV panels (for sun and artificial lighting) it assures reduced harvesting time from one side and helps to reduce the battery size (already enough for 6 to 8 months) which is a critical point for the air transport. Moreover, by using e-paper display it can show up to 100 pages of stored documents such as container's contents, delivery info or even customs documents. Not only this will reduce the fright weight, but also enables the user (such as customs officials) to request an update of data via an app. The container owner can transfer new data through the network to be shown on the display.

iCon is able to do short range communication (up to 300 m) with other intelligent logistics modules. This can even reduce the energy requirements by collecting the data from multiple iCons and transmission through only one single data link.

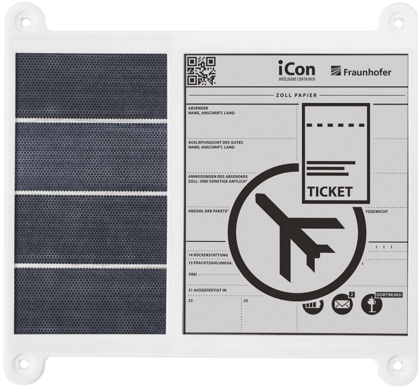

Fig. 8. An iCon device showing customs documents courtesy Fraunhofer IML, Dortmund

6 Conclusion

It had been shown that the next big change in the manufacturing and production or in general, industry is going to be happening in the context of Industry 4.0. This advancement is mostly seen by breaking the available industry into its fundamental sections and provide intelligent modules responsible for each. These modules have to communicate among each other to enable self reconfiguration to adapt the industry to the current dynamics.

Cyber Physical Systems as intelligent devices with communication possibilities are considered as the key pile of this revolution. The 5C structure for development of CPS was reviewed.

The effect of Industry 4.0 revolution on the logistics sector was shortly analyzed. To fulfill the requirements of the future industry and also overcome the current challenges in the logistics, integration of CPS would be the key solution.

Structure of PhyNetLab and its nodes as a real physical testbed for evaluation of the future CPS nodes in the materials handling and warehousing application showed a strong basement for other solutions.

inBin and P-ink as two outcomes of the PhyNetLab experiment were explained in the context of the order picking application. Moreover, iCon as an outdoor asset tracking solution of the passive component was presented.

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