Mechatronics 34 (2016) 63–71

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Towards distributed intelligent sensor and information fusion

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ARTICLE INFO

Article history:
Received 16 October 2014
Revised 7 May 2015
Accepted 17 May 2015
Available online 10 June 2015

Keywords:
Cyber-physical systems
Information fusion
Fusion system design
Intelligent sensors
Self-configuration
Intelligent networking

ABSTRACT

Recent industrial applications are implemented in a modular way, resulting in flexibility during the whole life cycle, i.e., setup, operation, and maintenance. This applies especially to larger applications like logistic, production, and printing processes. Their modular character is resulting from the constantly increasing complexity of such installations, which makes their supervision for securing reliable operation a difficult task: the data of hundreds (if not thousands) of signal sources must be acquired, communicated, and evaluated for system diagnosis. In this contribution we summarize the challenges arising in such applications and show that distributed sensor and information fusion for modular self-diagnosis tackles these challenges. Here, we propose an innovative distributed architecture encompassing intelligent sensor nodes, self-configuring real-time communication networks, and a suitable sensor and information fusion system for condition monitoring. New challenges arise in the context of distributed information fusion systems, which are identified and to which an outlook on future solutions is provided. A number of these solutions have already been discovered, implemented, and are evaluated in the context of a demonstrator, which resembles a real-world printing application.

1. Introduction

Mechatronic systems are currently subject to change towards intelligent technical systems. Originating from pure mechanical systems, electrical engineering (characterized by actuator, motion control, sensor, and monitoring technologies amongst others) has found its way into mechatronic systems. Furthermore, the recent years were marked by an increased application of information technology for information processing, extensive networking, and system as well as environment monitoring using sensor and information fusion (SEFU/IFU) systems [1,2]. Thus, these systems become more intelligent in order to assist the operator in handling such complex systems.

Industrial printing processes, like a newspaper printing process depicted in Fig. 1, are typical applications in which the printing presses evolve from mechatronic to intelligent technical systems.

Today's state-of-the-art printing systems are driven by hundreds of actuators in the application, along with a number of sensors in the same order of magnitude. During operation, a massive amount of data is produced, which is used for process/system control. This existing data shall further also be used for condition monitoring using sensor and information fusion systems. On the one hand, the data is produced by electric drives (cf. Fig. 1(b)) moving the conveyor belts, or magnetic valves controlling the print color's application onto the substrate, for example. On the other hand, a vast variety of sensory units in the same amount are applied for acquisition of different types of data. These may be several different basic physical measures like pressure or temperature, but also specific process parameters like the quality of the fluid used to wipe off surplus print color, as well as many others. Of course, the actually deployed actuators and sensors depend on the application at hand, i.e., the printing machine in this example. Furthermore, the printing market is highly customer-specific meaning basic concepts and modules can be developed which are applicable to a series of printing presses, but in the end each printing press is individually configured. Hence, thousands of parameters are to be supervised for the determination of a printing press' state, but each set of supervised parameters changes from one printing press to another, because every press is highly customized. In every case, the sensors must be chosen and parameterized properly (e.g., regarding the appropriate measurement range). Furthermore, novel sensory concepts which turn actuators into sensors get introduced nowadays, e.g., the *Motor as Sensor* (MaS) concept [4]: The trend in the field of electric drives is towards integrated systems, in which the power and control electronics are part

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http://dx.doi.org/10.1016/j.mechatronics.2015.05.005
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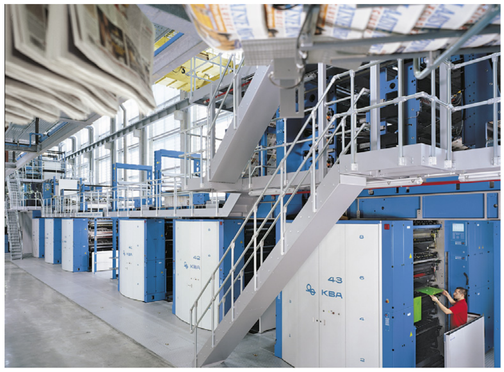

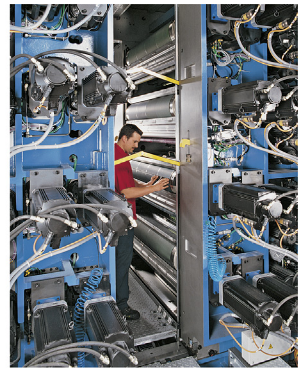

(a) (b)

Fig. 1. KBA Cortina newspaper offset printing press overview (a) and a detail (b) showing its several attached electric drives (with kind permission of KBA – Koenig & Bauer AG, Würzburg [3]).

of the electric motor itself. In these systems, sensors are necessarily built-in for controlling the drive. The conceptual idea of the MaS concept is to make the information obtained by those sensors also available for systems outside the electric drive.

Within this exemplary scenario, the challenges arising when it comes to machine condition monitoring can be clearly pointed out. As besides sensors also hundreds of actuators are inside such kinds of systems, the amount of data generated and acquired literally explodes by the addition of those *X as Sensor* approaches. Manual human condition monitoring is therefore impossible and must be carried out by proper SEFU/IFU systems. Since the sensing devices are distributed over the complete application, all the data must be communicated over an appropriate network to the fusion system. When deciding upon the communication technology, the optimal communication solution can typically not be chosen, but trade-offs are made. Either by concurrently using different technologies in one application (e.g., field bus and real-time Ethernet systems), or in case one single technology is used, limits regarding the achievable performance might be introduced. After being communicated, the data can be processed. Here, established signal processing algorithms and systems are at their frontiers, if not even inapplicable in such *Big Data* scenarios [5].

Currently, it is due to the sheer number of data sources a complex, time consuming, and error-prone task to provide such systems manually with self-diagnosis abilities in form of a SEFU/IFU system: The system developer has to select, parameterize, operate, and validate problem-adjusted sensors and evaluation algorithms (for signal acquisition and preprocessing) as well as possible additional information sources. Since the number of possible solutions is most frequently too vast, the developer must be very experienced and will probably create a system based on already existing solutions which in only very few cases represents the optimal solution. Furthermore, setting up a communication network with real-time capabilities is also required comprising several manual steps. These issues are addressed in the Leading Edge Cluster “its OWL Intelligent Technical Systems OstWestfalenLippe”. Its project “Intelligent Networking” [6] deals with *self-configuration* of both the communication and the fusion system enabling *self-diagnosis* for *self-optimization*, hence autonomous recognition and evaluation of the technical system’s status leading to autonomous reactions improving or maintaining the status. This offers the associated possibility to operate intelligent technical systems adaptively, robustly, anticipatory, and user-friendly in terms of cyber-physical systems (CPS) [7].

This paper is structured as follows. Related work and existing research gaps are discussed in Section 2. Based on these findings and the identified challenges of the introduction, an innovative information fusion system architecture and a corresponding design assistance are proposed in Section 3. In Section 4 the architecture and the design flow are preliminarily evaluated in the context of a real setup. The contribution is concluded in Section 5 followed by a brief outlook towards future work.

2. Related work

The main challenges described in Section 1 – or similar challenges – have also been tackled by others. Work leading towards first partial solutions for intelligent technical systems can be categorized in the three classes, (i) *sensor and information fusion*, (ii) *intelligent sensors*, and (iii) *self-configuration of networks*, which are discussed accordingly.

Sensor and information fusion systems appear in various kinds. They all have in common, that the information originating from a number of homogeneous or heterogeneous sources are combined in order to reduce the data’s amount and dimensionality, and obtain information of higher quality. Comprehensive overviews over information sources, general fusion system models, and theoretical backgrounds of the fusion algorithms provides [8].

For modeling the sensor information and carrying out the fusion, one of the evidence theories (probability, possibility, belief theory) as well as concepts derived from them are applied most likely [9–11]. We identified a hybrid approach consisting of a possibility theory-based information model and a belief theory-based fusion as beneficial for machine condition monitoring applications of various kinds and can be efficiently implemented [12–14]. This fusion system, referred to as *multilayer attribute-based conflict reducing observation* system MACRO, is capable of resembling the physical structure of the monitored application in the fusion system, and determines and reduces conflicts between information sources.

As briefly mentioned in Section 1, the design of a fusion system is mainly a time-consuming manual task carried out by an expert. To tackle this issue, Iswandy and König present a framework for the automated design of multisensor fusion systems in [15]. Nevertheless, the proposed framework follows a sequential optimization procedure which aims at replacing the human expert. But as Hall makes clear, a human expert understanding the monitored system or process to evaluate the decisions made by the fusion system is necessary in every case [16]. Otherwise, decisions derived by a sensor fusion-based monitoring system are neither clear, nor understood, or traceable: only phenomenons are recognized, whose causes and interdependencies are hidden. The monitored system shall instead be well understood so that the