

A System Architecture for Smart Sensors Integration in Avionics Applications

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ABSTRACT

With the next generation of avionics systems, more sensors and actuators will be required for an ever increasing number of functions. In this paper, we propose a system architecture based on several enhancements to the IEEE 1451 standard, granting it a wider application range, improved resource efficiency and a generic and reusable character. This architecture facilitates the integration of next generation smart sensors with a wide range of avionics data communication networks and allows the specification of generic features to be respected. In order to meet the requirements of avionics applications, this architecture that provides a design framework offers customization of features such as bandwidth, reliability, resources utilization and compatibility with different types of transducers, especially smart sensors. The resulting resource utilization and reliability are analyzed for several configurations that provide a basis for comparison. To validate the proposed architecture and the benefits it offers, we have designed and implemented a transducer network inspired by representative avionic needs. The implementation reported in this paper targets a LX45T Xilinx FPGA board. The transducers are connected to the data network through field buses based on the ARINC 825 protocol, while the backbone of the network is based on the AFDX specification. The analysis of the ensuing prototype shows an important increase in reliability that result from using the proposed architecture. We also show that this architecture enables important complexity reduction over a typical transducer network based on the same communication protocols for the same level of reliability.

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INTRODUCTION

With the next generation of avionics systems, more sensors and actuators will be required for an ever increasing number of functions. Future avionics platforms will also need to manage communications from different application domains, inducing an important increase of the information flow throughout an aircraft [1]. Moreover, stringent safety and reliability requirements are also complicating the situation, by demanding at least the duplication of most on-board avionic systems. Based on the current state-of-the-art in the avionics field, the design of a suitable network meeting all constraints would be very time and effort consuming [2]. The ever increasing diversity in the transducer market makes it even harder to meet the requirements, since most of them are tailored for some specific class of applications. Although some control network and field bus architectures are available to interface these transducers, they still lack the capability to

easily support different types of transducers. The process of integrating transducers to these networks requires significant effort and is thus very costly. These considerations set a requirement for a more effective and systematic approach to design transducers and their associated network interfaces.

The IEEE 1451 standard has been developed several years ago to propose a reference model for the control of smart transducers [3]. Although this promising standard provides guidelines to facilitate the integration of a smart transducer to any type of network interface, analysis has shown that some key features were missing for avionics application. In particular, concerns about setting and respecting reliability targets are the main considerations lacking with the basic application of the standard. This is the main motivation for this paper in which we propose a system architecture based on several enhancements to the IEEE 1451 standard granting it a wider application range, improved resource efficiency

and a generic and reusable character. This architecture facilitates the integration of next generation smart sensors with a wide range of avionics data communication networks and allows the specification of generic features to be respected. In order to meet the requirements of avionics applications, this architecture offers customization of features such as bandwidth, reliability. The proposed design framework allows optimizing resources and offers compatibility with different types of transducers, especially smart sensors.

The rest of the paper is organized as follows. The “Related Work” section first presents the basic concept of the IEEE 1451 for further reference throughout this paper. The advantages and limitations of the architecture are highlighted, which forms the comparison basis for the proposed architecture. This section also reviews some variations on the basic IEEE 1451 introduced by other researchers to provide points of reference. The “System Architecture” section presents the proposed architecture and the improvement over the typical IEEE 1451 architecture. Reliability issues are addressed in the “Reliability” section. The first part of this section recalls the method used to predict the reliability of each of the elements composing the network. Based on these last predictions, the second part of this section presents the guidelines to obtain reliability estimates for the considered network architecture. The results obtained based on a prototype implementation, as well as observations and analyses, are presented in the “Results” section. Finally, concluding remarks and discussion on the improvement offered by the proposed solution are provided in the “Conclusions” section.

RELATED WORKS

As mentioned before, the proposed architecture for the integration of transducers for avionics applications is an extension to the IEEE 1451 standard. The suite of IEEE 1451 smart transducer interface standards was developed several years ago to address issues related to the need for plug-and-play smart transducers. Nowadays, sensors and actuators are ubiquitous in many engineering and scientific systems. Since transducers are used in so many different scenarios, their design is often tailored to a specific class of applications. The integration of transducers within a network based on a current field bus technology may require significant efforts and may lead to different advantages or weaknesses depending on the characteristics of transducers and of the system where they are used. Supporting various types of networks and protocols or producing multiple transducer versions for every relevant network specification on the market would require significant efforts and cost from a manufacturer. This can be mitigated through universally accepted sets of open standards.

The goal of the IEEE 1451 standard is to allow access and control of smart transducers through normalized interfaces. The use of microprocessors or any other dedicated electronic hardware to handle digital communication has also opened

the opportunity for adding intelligence to sensors and actuators. According to IEEE 1451, in order to be qualified as a smart transducer, the device needs to fulfill three specific features. The transducer itself must be defined by a machine-readable transducer electronic data sheet (TEDS). The TEDS is a nonvolatile memory, located in the transducer, used for storing transducer identification, calibration, correction data, measurement range, and manufacture-related information. The second feature states that control and data associated with the transducer must be in a digital format. Finally, triggering, status, and control must be provided in accordance with the TEDS's information to support the proper operation. The type of transducer, either actuator or sensor, does not affect its qualification as a smart transducer. Nowadays, smart sensors are slowly starting to make their way in some applications, mostly in less restrictive fields. They are currently been considered in avionics, but have not yet been adopted [5]. The proposed interfaces allow transducers to be connected to a processor, an instrumentation system or any other control network. The reference model, shown in Figure 1, is completely independent from communication protocols and hence, it is also applicable to wireless networks. We note that this reference model is very similar to structures found in avionic transducer networks with the exception of the interoperability inherent to the use of the standard.

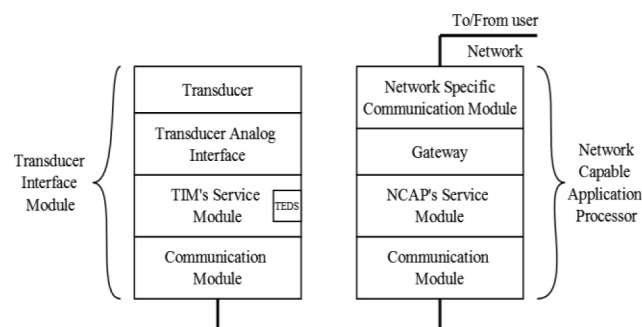


Figure 1. IEEE 1451 Reference Model, adapted from [3]

The functionality proposed in the standard is separated into two main modules. The transducer interface module (TIM) has the following responsibilities: analog signal conditioning, digital conversion, command processing, data transfer, and TEDS storage. The transducers, from a single sensor or actuator to many heterogenous units, are enclosed within the TIM. The second part of this model is the network capable application processor (NCAP) linking the TIM to user networks. The NCAP is responsible for interface control, command routing, data correction, and message coding and decoding. The physical interface between TIM and NCAP is left to the designer's choice and is not covered by the standard. The third part of the standard (IEEE 1451.3) is applicable for the definition of an interface for a multi-drop system using distributed communication architecture, regardless of the selected field bus technology. This scheme globally allows a NCAP to offer services to several TIMs

sharing the same communication link. A simplified version of this rather specific reference model for a distributed architecture is presented in [Figure 2](#).

The adoption of this standard provides several advantages in the design of transducer networks. The main benefit is to ensure compatibility between any combination of transducers, network protocols, and manufacturers. Having a reference model and a framework to follow for the control of transducers and the data management enables another important gain in productivity by reducing the design effort and the development cost. The multi-drop portion of the standard also guarantees a plug and play capability making it easier to install, update, replace, and move any component in the system. For avionics applications, the use of data buses and communication networks can eliminate wiring burdens as the current on-board architecture relies on a multitude of point to point connections. However, our preliminary research has shown that the basic framework provided by the IEEE 1451 standard lacks the ability to reach the reliability requirements for the stringent aerospace environment. This drawback will be demonstrated in the “Results” section. Although one can readily benefit from the generic aspect, improving the reliability, as we propose in this paper, is essential for the adoption of this standard for avionics applications.

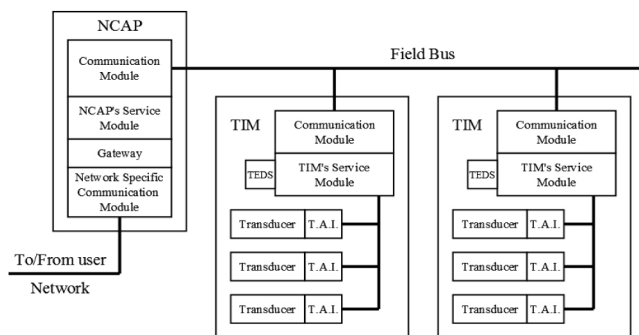


Figure 2. IEEE 1451 Distributed Architecture

Although IEEE 1451 offers clear advantage, several researchers have also found weaknesses inherent to the standard and proposed their own improvements. A dual connection based on a CAN bus is proposed in [7] to improve the reliability of an automotive system. Although this approach is not based on duplication of all key modules, it does increase the reliability of the system. However, that improvement is not sufficient for fulfilling all requirements of aerospace applications. Their proposal is also limited by the specified number of field bus while our proposal makes our architecture completely generic. A method for autonomous self diagnosis in an IEEE 1451 based architecture has also been proposed [9]. Their approach is based on the introduction of a fault detection layer within the NCAP structure. The effect of this improvement on the network's complexity has yet to be analyzed. Other than reliability, energy consumption has been one of the main important

research topic related to IEEE 1451. An improved method for grouping transducer to reduce the power consumption of the network is proposed in [8]. The principles formulated in this last paper were proven for wireless communication, but they are also applicable to a wide range of wired implementation. These works also demonstrate that even though the IEEE 1451 standard provides a generic architecture to ease design and integration, several aspects limit its application to some specific fields, such as avionics systems.

SYSTEM ARCHITECTURE

[Figure 3](#) presents a global view of a version of the proposed architecture. This architecture has been designed to be as generic as possible. In this architecture, our NCAP and TIM modules have the same functionality as the one described in the basic IEEE 1451 specification. The number of field busses is proportional to the number of communication module included in each TIM and NCAP. The number of NCAP is selected in order to reach the required level of reliability. The addition of more NCAPs only results in an increase in redundancy, while the bandwidth remains unaffected since the amount of exchanged data remains unaffected. The number of TIMs is mainly dictated by the number of transducers and their location. Several TIMs are served by one or several NCAPs, as needed to fulfill the reliability requirement. This number of TIMs served by a NCAP is limited by the available bandwidth of the combined field busses.

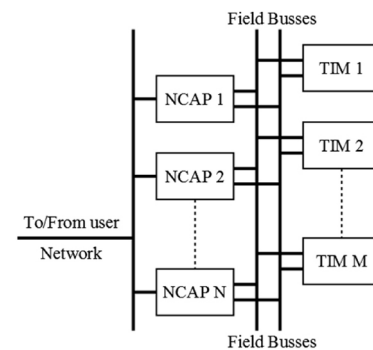


Figure 3. Custom global architecture

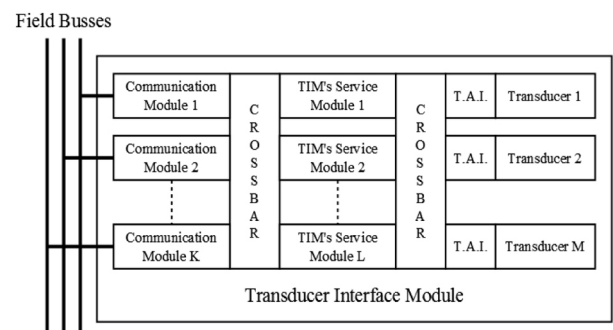


Figure 4. Custom TIM's architecture