Reliable Fault-Tolerant Sensors for Distributed Systems

Sebastian Zug, Michael Schulze, André Dietrich, Jörg Kaiser
Department for Distributed Systems
Otto von Guericke University Magdeburg
Universitätsplatz 2, 39106 Magdeburg
Germany
{zug, schulze, dietrich, kaiser}@ivs.cs.uni-magdeburg.de

ABSTRACT

Providing reliable fault-tolerant sensors is a challenge for distributed systems. The demonstration setup combines three sensors and allows to inject different faults that are reliably detected by our system.

Categories and Subject Descriptors

B.4.5 [**Reliability, Testing, and Fault-Tolerance**]: Diagnostics, Error-checking; C.2.4 [**Distributed Systems**]: Distributed applications; I.2.9 [**Robotics**]: Sensors

1. INTRODUCTION

Modern sensor/actuator applications in automotive, automation, or robotics are usually built as distributed systems, depending on faultless perception of the environment and dependable communication. However, assuming a faultless data acquisition, processing, and dissemination is unrealistic in real environments or either requires a high effort to guarantee correctness of all participating parts. In [2] we described different origins of faults that may arise in a distributed system. We distinguish between four types: External faults are injected if the environmental conditions change in a way that the measurement process is disturbed. Imagine ultrasonic distance measurements during changing pressures as an example for such incorrect results. This influences the sound velocity and the sensor produces untrustworthy distance measurements. The second fault type are transducer faults. They occur while mapping physical values to an electrical signal. The transformation process may be affected by inherent electrical or mechanical problems within the sensor. The third category is related to processing unit faults, which may arise from software or hardware as either software bugs or failures in hardware like a defect in an internal register. The forth fault type considers problems within communication networks. Data transmissions are delayed, have a variable jitter, or even may be corrupted or lost. Reasons for network problems are congestions, broken links, electromagnetic disturbances, etc.

All fault types disturb the correct interpretation of physical values in different ways e. g., by sporadic, continues, constant, or stochastic modifications. The varying impact and possibly combined occurrences challenge the fault detection process in general.

To develop reliable fault-tolerant sensors for distributed systems, we have to tackle all of the described faults that may arise during the information flow from the data acquisition up to the consuming node. Our MOSAIC (fraMework for fault-tOlerant Sensor dAta processIng in dynamiC environments) approach treats external and transducer faults by providing mechanisms for fault detection and classification. Furthermore, it allows to enrich data with a validity value, and fusion nodes use these to determine results with a higher reliability [6]. Our publish/subscribe communication middleware FAMOUSO (Family of Adaptive Middleware for autonomOUs Sentient Objects) is responsible for the information dissemination and offers means to detect delayed or lost data [3, 4, 5]. Faults related to the processing are not considered as far (neither software nor hardware problems), due to the large number of existing research that bother with this topic (e. g., formal software verification).

The demonstration setup described in the following section illustrates how reliable fault-tolerant sensors can be implemented by layering the two abstractions MOSAIC and FAMOUSO.

2. DEMONSTRATION

We integrated our fault-tolerant sensor mechanisms and middleware in a mobile robot platform that is equipped with a five degree of freedom manipulator arm. To demonstrate the fault-tolerance mechanisms in detail, we use the multi distance sensor system in front of the robot shown in Figure 2.

Precise positioning and reliable obstacle avoidance requires a dependable perception of the environment. To enable such services, we fuse different distance sensor measurements (i. e., infrared, ultrasonic, laser) in the *Fusion* node, that is depicted schematically in Figure 1. The different sensors are mounted in the front of the robot and oriented towards the same direction. Due to their different operation ranges (up to 3 meters), resolutions, reactions on external disturbances, and complementary behaviors on varying obstacle materials (e. g., transparent, reflecting or rough surfaces), the sensor array is the base for a reliable decision-making for robot's next actions. Each distance value is enriched by MOSAIC with a validity value, than transferred via FAMOUSO, usually in a timely manner, and eventually

DEBS'10, July 12–15, 2010, Cambridge, UK.

combined with the other distance values within the *Fusion* node. Instead of calculating majority results, the *Fusion* node combines all measurements related to their validity values. If an information is late or lost, FAMOUSO will notify the application, which adapts the fusion strategy automatically.

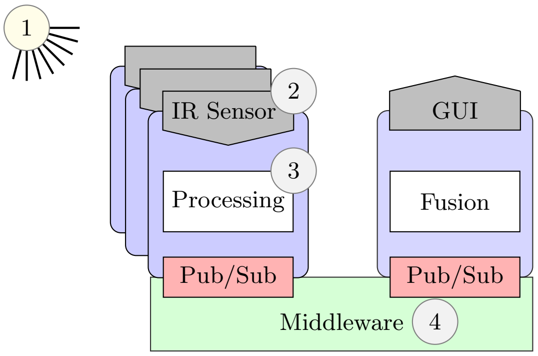

Figure 1: Structure of the demonstration scenario

The demonstration scenario combines three sensor types. For the close area observation we use an infrared sensor, which compensates the blind area of laser distance sensor. The third one, an ultrasonic sensor is responsible for general obstacle avoidance due to its large beam width. Figure 1 shows the structure of the setup. The three sensors are illustrated on the left side. All sensors use 8-bit micro-controllers for processing and connect to an embedded network. On the right, a PC connects with the same network, executing the fusion algorithm. We visualize the results of the fusion as well as the sensor beams with the help of the Augmented Reality (AR) Tool Kit [1]. Figure 2 shows a screenshot of the visualization. It should be noted that additional information like diagrams and textual elements can be easily integrated. We provide AR techniques to recognize sensor states according to injected faults.

As mentioned above, we distinguish between four fault types. The numbers of injectable faults in the following enumeration correspond to the numbers in Figure 1:

① We disturb the measurements of the infrared sensor by a strong external light. The detection method of this fault type is described in [2].

② We simulate a broken connection by intercepting the sensor power or the signal line. Then, signal statistics will change and we use this to estimate the current fault state.

③ For fault type three we are only simulating a crash of the processing unit by switching it off, because software or hardware related faults are out of scope.

④ To inject faults like the loss of information during communication, we simply disconnect nodes from the network. We show that FAMOUSO is able to detect late or lost data reliably [4]. It further enables the seamless reintegration of nodes into the distributed system if disconnection is only temporally.

Our demonstration shows that the combination of MOSAIC and FAMOUSO detects different fault types, and allows building reliable fault-tolerant sensor/actuator applications for distributed systems. For our distance measurement example, the *Fusion* node calculates an appropriate distance result all the time, and with the AR visualization we see what is going on in the system at the same time.

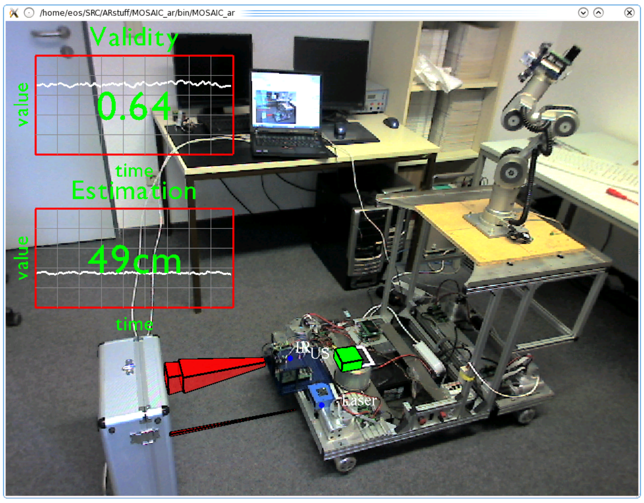

Figure 2: Sensor array in the front of the robot

Acknowledgement

This work is partly funded by the Ministry of Education and Science (BMBF) within the project “Virtual and Augmented Reality for Highly Safety and Reliable Embedded Systems” (ViERforES - no. 01IM08003C).

3. REFERENCES

[1] Artoolkit. `http://www.hitl.washington.edu/artoolkit/`, 2007. [(online), as at: 25.02. 2010].

[2] A. Dietrich, S. Zug, and J. Kaiser. Detecting external measurement disturbances based on statistical analysis for smart sensors. In *Procedings of the IEEE International Symposium on Industrial Electronics (ISIE)*, 2010.

[3] M. Schulze. FAMOUSO project website. online, `http://famouso.sourceforge.net`. [(online), as at: 25.02.2010].

[4] M. Schulze and G. Lukas. MLCCA – Multi-Level Composability Check Architecture for Dependable Communication over Heterogeneous Networks. In *Procedings of 14th International Conference on Emerging Technologies and Factory Automation*, Mallorca, Spain, 22-26 Septmeber 2009. IEEE.

[5] M. Schulze and S. Zug. Exploiting the FAMOUSO Middleware in Multi-Robot Application Development with Matlab/Simulink. In *Proceedings of the 9th Internatinal Middleware Conference (Middleware2008) ACM/IFIP/USENIX*, Leuven, Belgium, 1-5 December 2008.

[6] S. Zug, A. Dietrich, and J. Kaiser. An architecture for a dependable distributed sensor system. *IEEE Transactions on Instrumentation and Measurement*, 2010.