Time-Triggered Communication Architecture for an Autonomous Mobile Robot System

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Public Final Project Report

Abstract

The project *Time-Triggered Communication Architecture for an Autonomous Mobile Robot System* has been carried out between 2005 and 2008 at the Vienna University of Technology and the University of Klagenfurt, both being located in Austria. This document is a shortened, public version of the final project report and is intended to give an overview to the project and its results.

1 Project summary

Autonomous robots interact with their environment via sensors, actuators, and a, possibly decentralized or hierarchical, control system. Even when considering a small robot, such a system can become a very complex distributed system. Moreover, typically there exist strict real-time constraints between the components due to the existence of distributed closed control loops or important tasks such as counting odometer signals in order to infer about the robot's movement and position. Current ad-hoc implementations of communication systems, as they are pre- sent in many robot designs, do not fulfill the upcoming requirements on maintainability, manageable complexity and performance. When considering groups of interacting robots, the communication design brings up even new challenges. Such a system will have to cope with the breakdown of a robot or the incomplete broadcast of data via wireless links between the robots. Therefore, it is required to coordinate the robots in a robust manner. In order to address these problems, we have designed a generic, time-triggered communication architecture for the interconnection of components within a robot. As a case study we have implemented this system to network components in a small but modular soccer robot. The logical "wiring" between the components is supported with automated configuration tools that release the system designer from prosy, cumbersome, and error-prone tasks which reduces the probability for configuration errors and enables a quicker change or extension of the system. Furthermore, we have identified the interface between naturally inaccurate and limited sensor data and the main application as critical for the system design. To mitigate this, we have shown how sensor fusion algorithms can be integrated with the time-triggered communication system, which comes with the advantage of simplified and standardized interfaces for the application programmer. The time-triggered nature of the system supports a global interpretation of sensor data. Thus, the sensor fusion algorithms become simpler, easier to verify and better apt for implementation on low-cost embedded hardware. Finally, we have investigated methods for designing inter-robot behavior based on a self-organizing paradigm. These self-organizing systems are expected to show robustness against incomplete communication nets and breakdown of robots. Thus, we propose an overall system architecture consisting of robots with a rigid time-triggered local communication system, while the cooperation between different robots is coordinated via a weaker coupling with self-organizing behavior.

2 Research development

The goals of the project Time-Triggered Communication Architecture for an Autonomous Mobile Robot System (TTCAR) were twofold: first we wanted to examine how well the time-triggered approach can be applied to the networking of components within autonomous small robots. Complimentary to this work was the creation of configuration processes and their implementation in a tool chain. This research was important towards creating the technology based on the research work on lightweight time-triggered communication protocols.

The other target was to do basic research in the area of networking small autonomous robots, particularly the sensing, data processing and control paradigms. Furthermore we elaborated models to extend the time-triggered paradigm to a wireless environment. In this part, also new directions and methods have been explored, like for example self-organization, bio-inspired synchronization, neural networks, and genetic algorithms.

As a consequence, the project was a source for reference implementations and tools as well as for new scientific ideas. The research methodology was very diverse, covering experiments with real hardware, simulations up to theoretical work on mathematical models. Although the work in this project was not easy, we think this mixture was a healthy situation for creating good scientific work.

3 Project results

The results are very satisfying, especially when considering the small size of the project. There was a constant dissemination via publications. The quality of the publications increased significantly towards the end of the project. In the beginning, preliminary results were mainly presented as short papers and posters, while in the last two project years we have several conference and journal publications.

The following table gives an overview on the project results in form of publications and theses with a mapping to the defined work packages[1]:

[1] Work package WP7 is not listed here, since it is a Meta-work package on documentation

WP1	Communication system architecture
WP2	Development System
WP3	Generic communication protocol
WP4	Management tools
WP5	Sensor fusion and data processing
WP6	Wireless inter-robot communication

	WP1	WP2	WP3	WP4	WP5	WP6
Year 1		[31]	[34, 23, 21]	[18, 19]	[15, 36, 35]	
Year 2	[12]	[29]	[?]	[33, 26, 20, 14]	[2, 3]	[25]
Year 3	[6]			[16]	[10, 5, 11]	[27, 38]
Year 4	[9]	[7]		[17, 22, 30]		[28, 24]

The project evolved around the needs for networking and controlling the parts of a mobile robot and therefore required to some extend, an interdisciplinary approach intersecting the fields of real-time communication, configuration, sensing, data processing, distributed control and wireless systems.

The main contribution to real-time communication was the design of the time-triggered sensor bus protocol and its adaption to the heterogeneous components of the Tinyphoon robot [21]. Thus, it provided a generic state-of-the-art implementation of the TTP/A protocol, which is part of the OMG Smart Transducer Interface Standard. The protocol is available as open source implementation at `http://www.vmars.tuwien.ac.at/ttpa/`. This page also contains tools and configuration approaches which were developed for designing a time-triggered system [29, 7]. Another contribution in this area is an extendable generic graphical design tool [33, 26].

In the field of sensing and data processing, the project yielded two main approaches. First an approach where the sensors' behavior is integrated with the sensor fusion [2, 10] and second a generic approach which abstracts from the sensors using a statistical model [15, 2, 11]. Moreover, the project results implemented and validated the time-triggered sensor fusion model [13] and the real-time monitoring architecture described in [32].

For wireless systems we have treated the problem of finding a robust clock synchronization, which is a prerequisite for a time-triggered communication. Therefore, we investigated on a bio-inspired clock synchronization algorithm and contributed an algorithm that works for typical state-of-the-art wireless nodes [28, 27, 24].

Another significant result of this project is the idea of a shift towards a self-organized control architecture for the inter-robot behavior. From the experiments with different real and simulated robots in cooperation we learned that it becomes very difficult to find the right parameters for a centralized control architecture, moreover, the result is typically fragile. In [16, 17] we propose and exercise a self-organizing approach for this problem – this lays the basis for future research in this area, which we hope to be able to continue after the closure of this project as well.

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and publishing.

4 Effects of the project

4.1 Effects outside the scientific field

A robot assembled within the project was presented to explain the concept of programming and robotics to 7-12 year old kids at the Kinderuni 2007[2]. The participation at the KinderUni was beyond the scientific field, but we hope it had a positive effect on the future generation of researchers.

The design of the sensor nodes (which have been developed in the project) is now used in a lab course on embedded systems engineering at TU Vienna[3].

Some of the project results on sensor fusion are included in a textbook "Embedded Systems Engineering" [8] for lectures on microcontroller programming and embedded systems engineering at TU Vienna.

4.2 Organization of scientific events

The cooperation in the project with the Institute of Computer Technology was a driving force to cooperatively host the Fourth Workshop on Intelligent Solutions in Embedded Systems (WISES'06)[4] at Vienna University of Technology. This was an international event supported by IEEE and IFAC with peer-reviewed publications.

4.3 Particular honours and prizes

The project supported the development of the remote monitoring architecture, which was adopted for a lab course to allow students accessing special hardware in embedded systems lab via Internet [37]. This result was honored was awarded the E-learning award 2006/07 of the Vienna University of Technology for the area of special solutions.

4.4 Relevance of the project in the organization of the relevant scientific discipline

The project results helped organizing the integration of knowledge from several fields. An example for this is the textbook "Embedded Systems Engineering"[8], which grew concurrently to the project and integrates a part of the project results.

The results from the project opened interesting perspectives for future research in the area. The initial target system with a small devices consisting of many interacting components is today even more relevant than it was at the project start. In our opinion, there is a great potential in doing further research on networking devices, configuration and the knowledge from complex systems theory.

[2] see page 2 of `http://www.scifactory.at/smpl/hitech_0703_BuehlerPaschen.pdf`

[3] see `http://ti.tuwien.ac.at/rts/teaching/courses/eselu`

[4] http://www.ict.tuwien.ac.at/wises06/

5 Project-related participation in international scientific conferences

5.1 Invited lectures

- A. Schörgendorfer on "Extended confidence-weighted averaging in sensor fusion" at the Junior Scientist Conference 2006, Vienna, Austria.
- W. Elmenreich on "Fusion of continuous-valued sensor measurements using statistical analysis". Invited lecture at the the International Symposium on Mathematical Methods in Engineering, Ankara, Turkey, 2006.

5.2 Conference participation – lectures

- M. Schlager on "Interface design for hardware-in-the-loop simulation" at the IEEE International Symposium on Industrial Electronics, Montreal, Quebec, Canada, 2006.
- W. Elmenreich on "A review on system architectures for sensor fusion applications" at the 5th IFIP Workshop on Software Technologies for Future Embedded & Ubiquitous Systems, Santorini, Greece, 2007.
- W. Elmenreich on "Interface design for real-time smart transducer networks - examining Cosmic, Lin, and TTP/A as case study" at the 15th International Conference on Real-Time and Network Systems, Nancy, France, 2007.
- W. Elmenreich on "Fixed point library according to ISO/IEC standard DTR 18037 for Atmel AVR processors" at the Fifth International Workshop on Intelligent Solutions in Embedded Systems, Madrid, Spain, 2007.
- G. Klingler on "Genetic evolution of a neural network for the autonomous control of a four-wheeled robot" at the Sixth Mexican International Conference on Artificial Intelligence, Aguascalientes, Mexico, 2007.
- R. Leidenfrost on "Establishing wireless time-triggered communication using a firefly clock synchronization approach" at the Sixth International Workshop on Intelligent Solutions in Embedded Systems, Regensburg, Germany, 2008.
- R. Leidenfrost on "Fusion of heterogeneous sensors data" at the Sixth International Workshop on Intelligent Solutions in Embedded Systems, Regensburg, Germany, 2008.
- W. Elmenreich on "Time-triggered fieldbus networks state of the art and future applications" at the 11th IEEE International Symposium on Object Oriented Real-Time Distributed Computing (ISORC), Orlando, FL, USA, 2008.
- M. Umlauft on "Qos-aware ant routing with colored pheromones in wireless mesh networks" at the Second International Conference on Autonomic Computing and Communication Systems (AUTONOMICS), Torino, Italy, 2008.

- I. Fehervari on "Evolutionary methods in self-organizing system design" at the 2009 International Conference on Genetic and Evolutionary Methods, Las Vegas, NV, USA, 2009.

6 Conclusion

In overall, the project was conducted without major problems, keeping a very good balance between the different work packages. There was a fruitful interaction between the theoretical work (e.g., on the statistical modeling of sensor data fusion) and the practical work where case studies and particular hardware had been designed. The scientific output was properly achieved for all work packages.

Additionally, the project had very positive effects on the careers of the involved researchers. The project also acted as a kickstarter for several careers of young students. We would like to thank all the involved people for supporting us in this research project.

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