Efficient Real-Time Monitoring of Multimodal Transports with Wireless Sensor Networks

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***Abstract*—The application of wireless sensor network technology is very promising to meet the demand for real-time monitoring of multimodal transport processes. In such an application context, requirements like energy efficiency, cost efficiency, and satisfying users' information needs have to be met. Within the demonstration proposed with this paper, we outline the basic application potential of wireless sensor networks for real-time monitoring of multimodal transport processes. To address the requirements in this context, we particularly exhibit our approach of local data filtering with scoresheets. Furthermore, we demonstrate different other monitoring approaches and alternatives to detect and transmit events during a multimodal transport process with wireless sensor network technology. This allows for a direct comparison between these approaches and our scoresheet-based approach. It can be shown that the scoresheet-based monitoring approach permits real-time event notification and local data filtering for energy efficiency and cost efficiency, while providing sufficient user information.**

I. Introduction

During transport processes, goods can experience several events influencing their condition. Examples are exceeding temperature or tilt thresholds, sudden shocks, etc. To realize real-time monitoring of transport processes that enables an early detection and warning of such events, applying wireless sensor network (*WSN*) technology is very promising. Thus, in the demonstration proposed here, we exhibit the application potential of WSN technology for real-time monitoring of multimodal transport processes with containers, using a model landscape with model container ships, trains, and trucks and a WSN infrastructure based on SunSPOTs. To meet the demand of energy and cost efficient operation and customer orientation in this context, we have proposed a scoresheet-based monitoring approach in our paper accepted for publication in 2011's LCN [1]. In our demonstration, we realized and exhibit this approach. In order to provide for a comparison between the scoresheet-based monitoring and other approaches, we additionally implemented and present a periodic monitoring approach and a business rule-based approach and provide an RFID-based monitoring infrastructure in the demonstration.

II. Applying WSN Technology in Logistics – Potential and Requirements

Wireless sensor nodes (*motes*) possess the capability to monitor a diversity of environmental parameters influencing the condition of transported goods, like temperature, shocks, tilts, humidity, etc. Further, they provide wireless communication capabilities which allow to transmit gathered data via a corresponding gateway to user backend systems. Thus, WSN technology provides a promising basis to realize real-time monitoring of transport processes, allowing for an early detection and information of critical situations during a transport. In [1], we focus on container transports, which is as well the focus of the demonstration proposed here. Particularly, in our demonstration, we focus on multimodal transport processes with containers as application scenario. This means, that we investigate the deployment of WSN technology in a container which passes through different modes of transport. In our demonstration, we exhibit this exemplary by incorporating transshipments of a container equipped with a mote from sea transportation to rail transportation and to road transportation.

To successfully apply WSN technology in logistics, and particularly for the monitoring of transport processes as briefly described above and in more detail in [2], different requirements have to be taken into account. In [1] and [2], we have differentiated four major requirement categories relevant in this context:

- *Technological requirements*: properties and constraints of WSN technology, e.g., energy constraints.
- *Economical and organizational requirements*: properties and constraints from general economical and organizational context, e.g., need for integrated IT infrastructure or sufficient cost-benefit ratio for a WSN deployment.
- *Regulatory requirements*: properties and constraints from laws or standards, e.g., available frequency bands for wireless data transmission within a WSN deployment.
- *Logistics market specific requirements*: properties and constraints from the specifics of the application domain of logistics, e.g., massive cost pressure or urgent need to fulfill customer demands.

Several interdependencies exist between these requirement categories. Hence, they must not be viewed isolated. We take advantage of these interdependencies and proposed a local data filtering approach employing scoresheets to reduce data transmissions by transmitting only relevant data [1]. This contributes to enhancing energy efficiency, cost efficiency, and customer satisfaction and thus addresses the four above mentioned requirement categories simultaneously.

III. WSN-based Monitoring Approaches for Logistics

Several approaches are possible to utilize WSN technology for the monitoring of transport processes as described in Sec. II. First, a periodic monitoring approach can be realized, which relies on regular data transmissions of current sensor samples in given time intervals. Second, making use of the computation and storage capabilities of motes, some intelligence can be shifted into the WSN. This is realized within business rule-based approaches, e.g., proposed in [3] or in [4]. In this context, thresholds concerning the monitored environmental parameters are typically specified. A mote compares its sensor samples against these thresholds locally and only in case they are violated, transmits a message. Finally, to better address the requirements of energy efficiency, cost efficiency, and customer orientation, we proposed a scoresheet-based approach in [1]. This scoresheet-based approach allows to evaluate detected events with individual criteria and individual weights, enabling a more fine-granular, local decision on a mote whether to transmit data or not. Thus, a local data filtering is realized, which reduces the amount of data transmission, while maintaining the qualities of real-time transport monitoring concerning data fidelity and early warnings.

IV. Demonstration

In order to demonstrate the application potential of WSN technology for multimodal transport processes with containers and furthermore to compare the different monitoring approaches in this context (cf. Sec. III), we provide a small-scale landscape with transport infrastructure for sea, rail, and road transportation with containers and means to simulate different environmental influences during a transport (cf. Fig. 1).

A. Demonstration Components

The main component of our demonstration setup is the small-scale landscape. Within this landscape, different transport routes between a container port and a warehouse, each route with individual characteristics, are provided. To model multimodal transportation processes with containers on these routes, we use small-scale models of container ships, trains, and trucks and a model container, which can be transported with these. The WSN functionality in our demonstration is realized with SunSPOTs [5], because they possess sufficient sensing, computing, and communication capabilities for our needs, are easily programmable, well supported and documented, relatively cheap, and exhibit a reasonable dissemination within the community.[1] One SunSPOT is deployed in a model container and a corresponding basestation is connected to a PC with a monitor for visualization purposes. The in-container SunSPOT monitors the relevant environmental parameters and can be configured to execute one of the monitoring approaches mentioned in Sec. III. To be able to influence the monitored environmental parameters during a transport and demonstrate their detection (and local evaluation) by a mote, we deployed a model bridge to incorporate different tilt values, an infrared lamp to provide sudden temperature risings, and "potholes", which cause sudden shocks. Furthermore, we deployed an RFID infrastructure consisting of six RFID reader devices and four RFID tags attached to the model container with the SunSPOT. This allows us to exhibit the more classical, checkpoint-based tracking & tracing monitoring approach in logistics transport processes. However, by using RFID technology, we provide a realization with a technology rather upcoming at the moment in the logistics domain. For the RFID infrastructure, we use High Frequency RFID reader devices and tags from touchatag [6], because they provide sufficient performance for our needs, are relatively easy to use, and possess a good availability at reasonable costs.

[1]Nevertheless, it is obvious that SunSPOTs are generally not suited for deployment in a real-world logistics scenario, but in our opinion they are sufficient for a prototypical demonstration environment like the one we are aiming at.

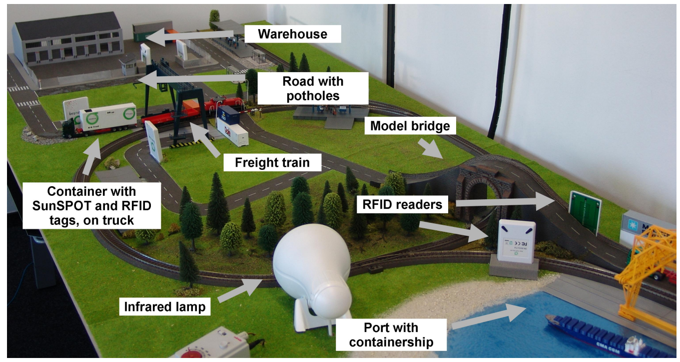

Fig. 1. Demonstration components within model landscape

B. Demonstration Goals

A basic goal of the demonstration is to make practitioners and researchers sensitive to the application potential of WSN technology in multimodal container transport processes and point out potential benefits. This is realized by providing people with a hands-on experience and letting themselves conduct the multimodal transport. They can transport the model container equipped with a SunSPOT by moving the train, the truck, and the container ship with the attached container; they can transship the container themselves and influence the different monitored environmental parameters. To let them experience direct feedback and the immediate detection and wireless transmission of changing environmental parameters by the deployed mote, the in-container SunSPOT is initially set to the periodic monitoring approach. This allows to constantly visualize the monitored parameters (cf. Fig. 2). In order to provide users with a first impression of the potential of wirelessly updating a deployed WSN infrastructure during a transport process, the sampling rate of the in-container SunSPOT can be adjusted in real time to users' preferences via a GUI.

Besides this basic goal, a major goal of the demonstration is to present our scoresheet-based monitoriong approach and allow for its direct comparison to other monitoring approaches for WSN deployments in multimodal transport processes as

Fig. 2. On-screen presentation of the periodic monitoring and the business rule-based monitoring approach

described in Sec. III and exhibit the corresponding benefits and drawbacks. Therefore, in addition to the periodic monitoring approach, we provide users with the possibility to specify different individual business rules based on thresholds for the monitored environmental parameters, like a maximum or minimum temperature, via a GUI. Such specified rules can afterwards be wirelessly deployed and changed in real time on the in-container SunSPOT. This way, the mentioned business rule-based monitoring approach is realized within the demonstration. In consequence, when the mote is set to this monitoring mode, it stops transmitting continuous data, evaluates the deployed business rules locally and transmits data only in case a rule is broken. Accordingly, this can be seen directly on-screen as the trend visualization stops and continues only in those cases a predefined business rule has been violated. Additionally, an according alert message pops up on-screen (cf. Fig. 2).

Finally, to realize and demonstrate our scoresheet-based monitoring approach for efficient and customer-orientated data transmission [1], we provide users with a Web frontend which lets them define individual scoresheets according to their preferences (cf. Fig. 3). These scoresheets can afterwards be wirelessly deployed to the in-container SunSPOT, which evaluates its current sensor readings based on the deployed scoresheets and only transmits data when the scoresheet evaluation reveals a transmission-relevant event. Thus, after setting the in-container SunSPOT to the scoresheet-based monitoring approach, no more continuous data transfer is provided and visualized. Instead, events are only transmitted and visualized with corresponding pop-up messages, when the local scoresheet evaluation on the mote yields a transmission-relevant event.

C. Demonstration Requirements

Our model landscape with the attached PC occupies a floor space of about 260×160 cm. An additional table with dimensions of at least 100×70 cm is needed to place our monitor besides the model landscape. For power supply, one power outlet is required. Finally, stable Internet access (wired or wireless) and space for a poster is required. The initial setup, particularly the assembly of the model landscape and the re-wiring of the technological components, will take approximately two hours. Afterwards, starting up the PC and the SunSPOT and RFID infrastructure with the corresponding programs should not take more than 15 minutes.

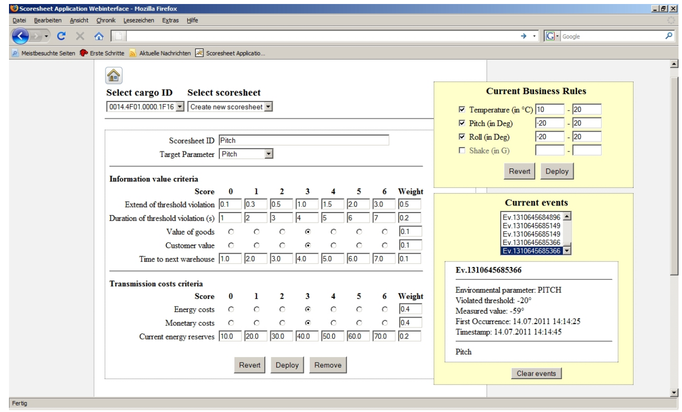

Fig. 3. Web frontend and on-screen presentation for the scoresheet-based monitoring approach

V. Conclusion

Wireless sensor network technology is a promising means to realize real-time monitoring of multimodal transport processes. The proposed demonstration provides users with a hands-on experience on how WSN technology could be applied in this context and exhibits the corresponding potential and benefits. Nevertheless, WSN deployments in logistics have to take several requirements into account, like energy and cost efficient operation and user satisfaction. To better meet these requirements, we already proposed a scoresheet-based monitoring approach. In the described demonstration, this scoresheet-based approach is implemented besides a periodic monitoring approach, a business rule-based approach, and an RFID infrastructure, which represent currently prevalent monitoring approaches in the logistics domain. Thus, these monitoring approaches can be directly compared with each other and their different advantages and disadvantages are exhibited and can be directly experienced with the proposed demonstration.

Acknowledgment

This work was partially funded by the German Ministry of Education and Research in the context of the research project ADiWa (www.adiwa.net).

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