

Wireless Locating and Data Communication in Harsh Industrial Environments

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Abstract

In this paper, a concept of a system for wireless locating and data communication for industrial applications is proposed. The proposed system employs ultra-wide band radio for decentralized spatial localization of mobile sensor nodes and for communication. Due to the robustness UWB radio transmissions, it can be used in shop floor environments, e. g. for self-tracking of automated ground vehicles in factory plants. A prototypical implementation of the proposed system is presented and verified by experiments in an industrial environment.

1 Introduction

1.1 Motivation

The widespread adoption of robotics has significantly enhanced the efficiency of industrial production plants in recent decades. The employment of automated guided vehicles (AGV) for in-plant material handling and for warehouse logistics has been subject of continuous improvement through the last 50 years [4]. Keeping track of automated vehicles and monitoring the assets they carry is essential for an optimized time management with as little pauses as possible. Exact locating of AGVs is also required to ensure the safety of humans working on or near to the route of the AGV.

The approach presented in this paper combines accurate self-locating of arbitrary assets in the production plant with high accuracy offering a high level of flexibility in route selection with robust data communication suitable for harsh environments. The focus of this paper is put on locating functionality. The aspect of communication is discussed in detail in another publication presented at INDIN 2012 [11].

1.2 Related work

Today, the most common AGV systems use laser triangulation [6], an optical guideline, a magnetic ground matrix or an inductive guidance system. Another existing approach on wireless sensor based locating em-

ployes WLAN RSSI, measurement of the signal strength of WLAN access points already employed in the production area [5]. In strip mining operations, radio distance measurement is used to track the position of machines within the basin [9]. All these systems only address localization, but not data communication. In contrast, the proposed system incorporates locating, communication and the aggregation of sensor data in a single modular architecture with the same set of hardware infrastructure.

1.3 Requirements for wireless sensor networks in industrial environments

The actual conditions on the factory floor are challenging for wireless communication because of electromagnetic interferences and metallic obstacles degrading communication through signal reflection and signal absorption. Requirements for wireless sensor networks in industrial environments - especially for the proposed system - can be divided into the following items:

1. integrated and highly precise real time locating system (RTLS)
2. resistant to harsh conditions in an industrial environment such as EM interference, corrosive agents, vibrations
3. sensor data acquisition and forwarding (temperature, humidity, illumination, acceleration)
4. self organizing system architectures for ease of setup and expansion
5. low energy consumption for mobile nodes through the use of limited processing power

The choice of a suitable wireless communication standard to fulfill all the refereed requirements above represents an essential challenge. Established industry standards are ZigBee PRO, WirelessHART, ISA100.11a and other proprietary solutions such as the DUST wireless communications protocol from DUST Networks [10]. All those approaches are based on the IEEE 802.15.4 standard. However, so far none of these established communication infrastructures implements an integrated accurate

real-time locating system as specified in IEEE 802.15.4a standard.

1.4 Radio technology

A suitable solution for the refereed requirements is UWB (ultra- wide band radio), which implements a precise distance measurement and simultaneous communication in moderate ranges with low energy consumption (in respect to the usage of an optimized transceiver ASIC).

A radio system belongs to the category UWB if a frequency bandwidth of 500 MHz is used, or if at least 20% of the center frequency are used. [3]. The motes are equipped with radio modules which are working in the frequency band 3.1 - 5.3 GHz, therefore using a bandwidth of 2.2 GHz. With a transmit power of only -14.5 dBm the radio modules are conform to the regulations of the FCC Part 15b. At a distance of 88 m, the raw data rate between these modules is specified with 159 kbps. The main advantage of this broadcast technique is that the information is not modulated on a carrier wave, but instead transmitted as a sequence of pulses. Each pulse has a period of about 500 ps as illustrated in Figure 1.

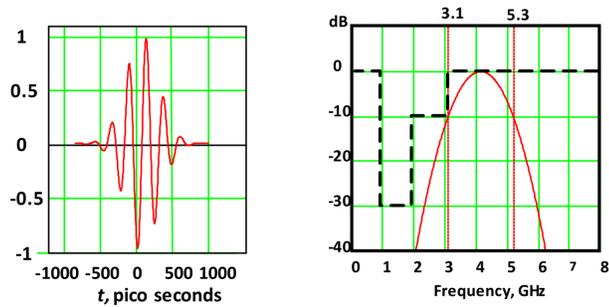


Figure 1: Example of an UWB pulse (left) and the related frequency spectrum (right) which is used by the radio modules (Graphic: [8])

2 Solution

2.1 System overview and network topology

The architecture for the wireless locating and communication system proposed in this work-in-progress paper is modular, consisting of a small number of fixed position sensor nodes ('anchors') and mobile sensor nodes ('motes') attached to the assets to be tracked. Each of the motes has the capabilities to calculate its position from distance measurements to the anchors. The architecture is based on the proposals in [6].

The position information is combined with data gathered from on-board sensors and sent to a special anchor serving as data hub and gateway to existing Ethernet infrastructure. This is facilitated through the use of the Sensor Conguration, Aggregation and Interchange (SCAI) protocol, a XML-based protocol designed to utilize and configure a heterogeneous sensor network [1]. The network topology is a flat peer-to-peer infrastructure suitable

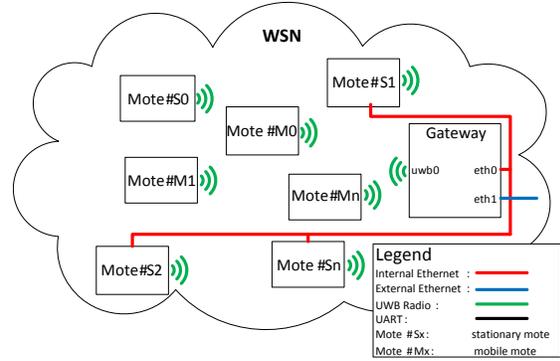


Figure 2: Ad-hoc network topology consisting of mobile motes, stationary anchors and a gateway

for ad-hoc self-configuration for motes joining and leaving the sensor network dynamically.

Our working prototype uses this architecture to provide locating of assets or personnel in three dimensional space with a deviation of less then 0.5 meters over ranges of up to 100 meters with an update rate of about 4 Hz. It is currently equipped with a sensor load-out of a 3-axis accelerometer and a temperature sensor (which monitors circuit board health), but can easily be expanded with other types of sensors, such as an inertial measurement unit.

2.2 Localization

The localization algorithm applied is quadrilateration: the calculation of a mote's position in space from distance measurements to anchor nodes with known coordinates [11]. Accurate distance measurements are provide by the UWB radio transmissions: By transmitting very short pulses ($t_{pulse} = 500$ ps) it is possible to differ the direct path pulse from the multi-path pulse, although the amplitude of the multi-path impulse is higher than that of the direct path pulse [7]. Hence, it is possible to calculate an exact time of flight (TOF) and thereby the exact distance between the motes up to an accuracy of a few centimeters.

The lateration algorithm was selected over other algorithms such as *Extended Kalmann Filtering (EKF)* or *Particle Filtering (PF)* because it is suitable to be employed on a mobile platform with restricted resources since it

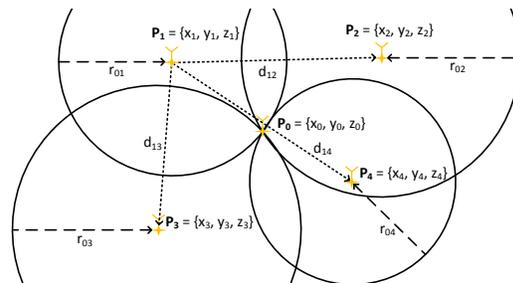


Figure 3: Geometric dependencies at the localization via quad lateration

does not incur high cost in neither memory footprint nor processing power. Furthermore, the accuracy possible with lateration can outperform other approaches in certain circumstances [2].

Calculating the unknown position P_0 (shown in Figure 3) of a mote is based on the geometric dependencies between the known positions of four reference anchors $\{P_1, \dots, P_4\}$, the unknown position of mote P_0 and the distance from the mote to each of the anchors. The approach is to basically calculate the intersection point of four spheres in space. These can be expressed as a system of linear equations, which is solved using the approximate measurements through the well known least squares fitting algorithm.

2.3 Prototypical implementation

The proposed concept has been realized prototypically to validate our approach. The major components will be described in the following sections.

Sensor mote The current state of development is an evaluation model to test the functionality (see figure 4). The hardware consists of a transceiver module for communication and a base-board, which controls the mote's components. It employs a 32 bit ARM Cortex M3 microcontroller clocked at 100 MHz running the real time operating system (RTOS) FreeRTOS for the calculations required for self-localization, for gathering and processing of sensor data and for network communication. The implemented protocols ensure aspects like routing of data, energy efficiency, self organization and fault tolerance.

In this approach, ultra-wide band technology is used in form of commercially available radio transceiver modules¹ to get started rapidly. This transceiver module is connected to the base-board via UART. Packets generated on the base board are forwarded to the radio module for transmission. Incoming transmissions are likewise forwarded to the base board for processing.

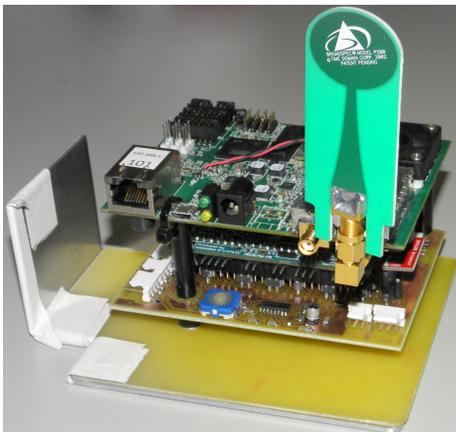


Figure 4: Picture of the current evaluation model

¹Time Domain PulsON 400 Ranging and Communication Module (P400 RCM)

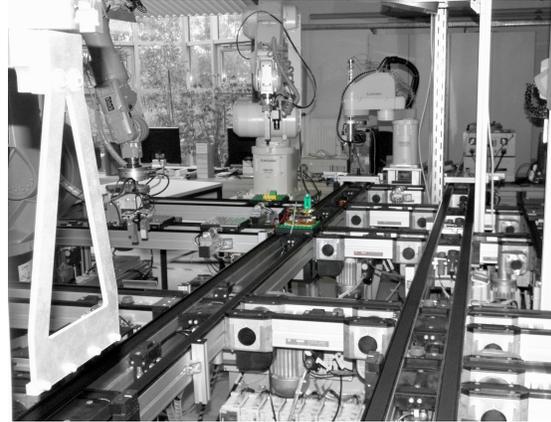


Figure 5: Test setup in an industrial environment

Gateway A network gateway forwards the collected data to other applications for subsequent analysis. The motes of the WSN are technically homogeneous and have a fixed set of sensors but offer digital interfaces for application specific add-ons. The gateway's hardware consists of an industrial PC (IPC), suited for installation in industrial environments. This IPC is connected to the WSN in two ways: A standard mote is connected via UART and an Ethernet connection can be established to the stationary WSN motes. The gateway is equipped with an additional Ethernet interface providing third-party access to the data gathered by the WSN.

3 Experiments

In order to determine the accuracy of the proposed localization system, tests were performed within a model of a factory hall, placed in a technical center on our campus. In this environment there were many large metal constructions like high racks and robots, which where partially blocking direct line of sight (LOS) connections and thereby leading to multi path propagation of the electromagnetic waves (see Figure 5).

The model factory's conveyor system was set up to move a mobile node along a rectangular path with a total length of 8 meters (3.88 m length by 0.62 m width). The node's position on the conveyor was sampled every 200 ms and stored on the gateway for analysis. The conveyor system was set to a transport speed of 40 cm / s, and positions were sampled with a rate of 4 Hz

The anchors are located in a trapeze around the model factory at distances between 3 and 10 meters. This geometry (completely surrounding the target area with anchors) has provided the best results in our experiments. The optimal placement of anchors is subject of our current research.

4 Performance

As seen in Figure 6, after the application of a low-pass IIR filter, the localization deviates from the ground truth

by no more than 35 cm over the course of our test run. The unfiltered calculated positions have a standard deviation of 18.5 cm.

Some of the deviation is probably caused by partial NLOS measurements, the obstacle being an industrial robot (massive metallic object) blocking the direct path to one of the anchor nodes. The optimal placement of anchor nodes in or around the area of interest (in which localization shall be performed) is a subject of our research and will be addressed in a future publication.

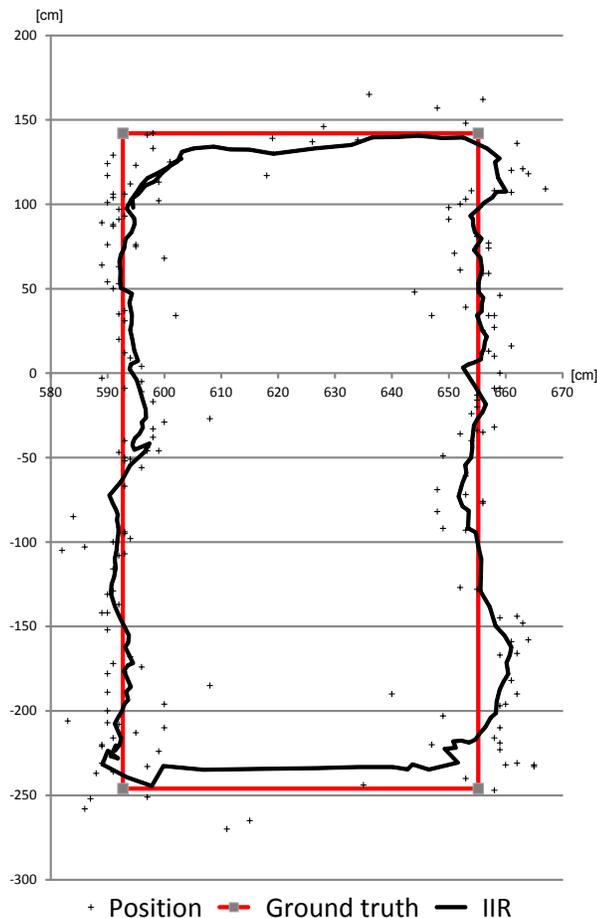


Figure 6: Movement tracking on conveyor belt: unfiltered position, IIR-filtered position and ground truth

5 Conclusion

In this paper we presented a concept of a wireless sensor network which combines localization and communication for industrial use and verify this concept with a working prototype. While being focused on the localization of AGVs and assets on the shop floor, the modular architecture of the proposed approach allows for easy adaption of the WSN to other industrial applications.

Wireless locating and communication in an industrial environment has been presented during the experiments. The positions calculated by the mobile node were transmitted to the gateway system for evaluation without inter-

ference, using SCAI [1].

The measurements taken during the first lab and shop floor tests are promising. The position deviation had an accuracy within the set goal of 0.5 m (see Section 2.1) The next tasks to be completed are the design of a rugged casing for our components, suitable for actual use in harsh conditions and research on an optimized placement of anchor nodes.

Further work of research will be focused on the analysis of intelligent methods and procedures for increasing the accuracy of ranging and localization, enhancing the robustness and optimizing the energy efficiency of the proposed system. The final goal is the development of a self organizing network consisting of intelligent motes which are both network clients and routing nodes.

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