Design of a Modular Node for Tracking, Localization and Data Acquisition for WSN Applications

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Abstract: The goal of the equipment which is proposed for research and developed in an experimental version is to associate, based on DSP architecture, several procedures of signal processing (data acquisition, tracking, localization and communication). These procedures are meant to transmit numerical data through un-wired support, especially over wireless sensor networks (WSN). The technical advantages of the proposed scheme are discussed, together with two new procedures for optimizing network topology and for tracking mobile nodes in this network, both ensuring minimum power consumption. The proposed solution for node navigation consists in two levels implementation: a low level section (the sensory level) and a high level section (the fusion data level). In order to realize the sensor fusion, the path following concept was adopted. Some details on the mechanical, electrical and functional characteristics of this intelligent sensor network node and future possible applications are finally discussed.

Key-Words: Mobile sensor networks, Localization, Wireless channels, Moving estimator, Sensor fusion, Middleware, Energy comsuption.

1 Introduction

Wireless sensor networking (WSN) is one of the most essential technologies for implementation of ubiquitous computing. Sensor networks are applied in variant environments, i.e. health care, military, environment, warehousing and transportation management [1], [2], [3], [4], [5]. The sensor networks usually share the same communication channel. Sensor nodes have limited in power, computational capacities, memory and short-range radio communication ability. The limited battery life of sensor nodes raises the efficient energy consumption as a key issue in wireless sensor networks. The main objective of our research consists of a conceptual model and architecture elaboration for mobile sensor nodes based on internal processing theory by complementary data fusion, and a functional model, embedded system type, for tracking, localization, data acquisition and processing, communication and remote vizualization. The functional model which is a demand configured one, has high technical and economical performances.

The network is composed by moving objects (modular nodes) with time depending topology, and therefore, with geometrical and temporal node coordinates. They are endowed with complex programmable equipments, low power consumption, able to acquire and to process data, to interact with other nodes in order to identificate position, and to communicate wireless. The abbreviations in Fig.1 are the following: NMN - network management node, IMN - intelligent mobile node, REF – reference system for tracking and localization, IVN - interactive visualization node (mobile type).

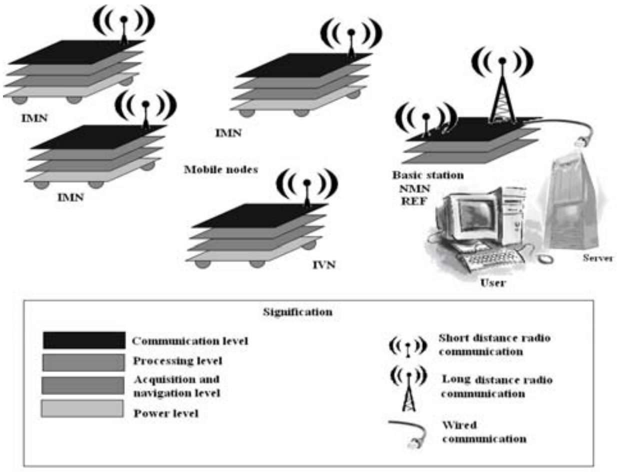

Fig.1. Mobile sensor network.

The paper describes the modular implementation of a wireless sensor mobile node (IMN) with specific facilities for integration in a sensor network. The design offers an association between the data acquisition function, the tracking and localization function, the communication function based on a DSP structure, and the radio modem. The performances of this device (low power consumption, reduced error bit rate, high computational capacities) are fair enough to recommend it for use as a node in a wireless sensor network.

When the node moves, we can consider some objects namely obstacles that can obstruct the node's driving path. The obstacle detection functionality is important even for the path following conception. For this reason, a complete data interpretation and a fusion by correlation between sensor data are necessary. The data fusion method consists in the association between a video-camera (to obtain a 2-D field image) and other sensors (laser, sonar or tactile) to evaluate the distance to various objects in the motion space.

2 Configuration of a Sensor Node

A sensor node (IMN) consists of several functional blocks as seen in Fig. 1: power, data acquisition and navigation, data processing, and communication. The specific requirements for a particular block can differ depending on the application:

- A large-area low-density sensor network deployment will require a more powerful radio than a short range indoor or sensor application.
- Applications where high data rates and complex signal processing functions are required will benefit from a more powerful signal processor.
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- Sensors and associated sensor electronics will vary from application to application.
- For some applications the power can be provided by an appropriate primary battery, whereas others call for a complete power management system that can scavenge energy from the environment.

Therefore, if the wireless sensor module architecture is to be suitable for a broad range of applications, it should be designed in a modular fashion. The blocks in Figure 1 was implemented as distinct hardware layers which can be plugged together like Lego blocks to obtain a sensor module with the desired functionality. The data processing and control block can be reprogrammed in-system to provide this application-tailored functionality.

The target hardware architecture consists of power sources, SRAM memory, CPU core, general purpose I/O, RF communication unit and digital logic for the embedded operating system. We decide to prototype the architecture using DSP technology to implement the CPU core, digital logic and general purpose I/O. The digital logic of the DSP device can be used to interface to general purpose I/O, this will be necessary to connect sensors, actuators, memory and network interfaces to the CPU. It can also be used to implement custom hardware accelerated user-instructions for the CPU core. Processing that does not map well to the CPU instruction set, or whose computationally requirements make it difficult to meet real-time performance constraints are candidates for implementation in hardware logic. Nodes requiring digital signal processing of audio/video data may require such functionality. The ability to add new functions based on the DSP capacities is specific for the chosen architecture

The IMN software architecture responds to the requirements of the software framework of the whole network. The components of the framework provide the functionality of single sensors, sensor nodes, and the whole sensor network. According to these components, applications are classified into *sensor applications*, *node applications* and *network applications*. The software implemented on IMN corresponds to the first and the second levels. A *sensor application* contains the readout of a sensor as well as the local storage of data. It has full access to the hardware and is able to access the operating system directly. The sensor application provides essential basic functions of the local sensor node, which may be used by the node application. The *node application* contains all application specific tasks and functions of the middleware to build up and maintain the network e.g., routing, looking for nodes, discovering services, and self localization.

Primary objective of the middleware layer is to hide the complexity of the network environment by isolating the application from protocol handling, memory management, network functionality and parallelism. A middleware for sensor networks has to be scalable, generic, adaptive and reflective. Resource constraints (memory, processing speed, band width) of available node hardware require an optimization of every node application. Thereby, the application is reduced to all essential components and data types and interfaces are customized (*scalable middleware*). The components of the middleware require a generic interface in order to minimize customization effort for other applications or nodes (*generic middleware)*. The mobility of nodes and changes of infrastructure require adaptations of the middleware at runtime depending on the sensor network application. The middleware must be able to dynamically exchange and run components (*adaptive middleware*). Reflection covers the ability of a system to understand and influence itself. A reflective system is able to present its own behaviour. Thereby, two essential mechanisms are distinguished – the inspection and the adaptation of the own behaviour (*reflective middleware)*. In contrast to an adaptive middleware, a reflective middleware does not exchange components but changes their behavior. An example of reflective behavior is the modification of the routing strategy depending on mobility.

3 Procedure for Mobile Object Tracking

The sensors are used to collect information about mobile target position and to monitor their behavior pattern in sensor field. A mobile object tracking system is a complex mechanism that is accompanied with collaborative works between nodes. Tracking of the mobile targets has lots of open problems to be solved including target detection, localization, data gathering, and prediction. In the localization problem, excessive sensors may join in detection and tracking for only a few targets. And, if all nodes have to always wake up to detect a mobile target, there are a lot of waste of resources such as battery power and channel utilization. Actually, power conservation is one of the most critical issues in object surveillance and tracking since the sensor nodes that are once deployed in the sensor field would be difficult to replace a battery. Energy dissipation in sensors is various depending on condition of each sensor, for basic sensing operations, for powering the memory and CPU, and for communication between nodes or sink. So, if each node uses timely its energy to execute tasks, the network lifetime may be extended as a whole. Therefore, each sensor must minimize its battery power usage for desired longevity of network operation, which can be accomplished by properly managing sensor's operation. When a target moves around far away from the sensing range of a certain node, the nods does not need to keep wake up for participating in tracking of the mobile target. This raises the necessity for prediction of the moving path of the mobile target to maintain the number of participating nodes in tracking as small as possible [15], [16].

In general, the target localization is estimated successively based on the predicting of the next location, which is a result of the current measurement at a sensor and the past history at other sensors. The goal of this paper is to propose an efficient tracking method that can minimize the number of participating nodes in mobile target tracking to extend the network lifetime.

Our sensor can operate under the three different conditions: Active, Idle and Sleep. It is important to completely shut down the radio rather than put it in the idle mode when it needs not sensing. Power management of sensor components is very important because energy consumption is depends on their duties. To save energy resource and thus extend the network lifetime, it is desirable that only the nodes that surround the mobile target are responsible for observing the target (Fig. 2). Instead, it is more energy efficient for only the nodes *S* around the mobile object to join in collecting information of the target and performing collaborative work among them. Other nodes located far from the target do not need to waste their powers to monitor the target. If we can predict the next location of the mobile object in advance, we can organize the group membership dynamically which should join in tracking mission. The number of participating nodes may be minimized, which allows us to further extend the whole network lifetime if we predict future location of the mobile target accurately.

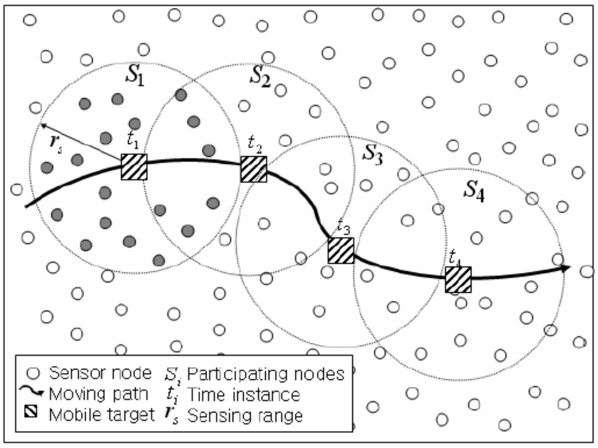

Fig.2. A concept of tracking of a mobile object

As the mobile object moves, the tracking nodes may migrate to the moving direction of the target to keep on monitoring as shown in Fig.2, where a thick line indicates the moving path of the mobile target and the blacked circles inside the dotted circle are tracking nodes at time t_1. Thus, sensor nodes need to control their states by themselves based on prediction of target's movement.

We assume a sensor network where N sensors with a different communication and sensing range are distributed randomly in the environment that is being monitored. We also assume that each node knows its own location by using GPS or other location awareness techniques. And we utilize triangulation for localization of a mobile target. Consequently, at least 3 sensors join the target detection and tracking with surveillance. Also each node keeps information about its neighbors such as location through the periodically message change and each individual sensor node is equipped with appropriate sensory devices to be able to recognize the target as well as to estimate its distance based on the sensed data. Further, we assume that we predict the location of the mobile targets every one minute and each sensor records the movement pattern of the mobile object. Basically, we use a *moving average estimator* to predict the future location of the mobile target based on the measurement of direction and the velocity of the mobile target. Therefore tracking in our system is performed by the following procedure:

1. Discovery: When a sensor node around the mobile object detects the target and initializes tracking, it becomes 'estimation node' which acts as a master node temporarily.
2. Localization: A set of nodes those become aware the appearances of the mobile target compute the target's current position. The coordinates of the mobile target may be accomplished by the triangulation and their collaborative works.
3. Estimation: An estimation node predicts the future movement path of the mobile target, and transmits message about the approaching location to its neighbor nodes. The prediction is carried out by two steps: approximate a prediction and correction step. The moving factors of a mobile target, such as direction and velocity, can be obtained by sensor nodes through collecting moving patterns of the tracked target.
4. Communication: As the mobile target moves, each node may hand off an initial estimate of the target location to the next node in turn. At that time, each node changes its duty cycle along the movement of the target.

4. Object localization

For object localization and navigation, we utilize a dual system based on sensor data fusion. The sonar detects the well defined objects with high confidence but the angular resolution is low. From this point of view it is necessary a complementary sensor (CCD camera). The dual sensor system must be assisted by a knowledge-based system using a dynamic data base with rapid access and a dedicated hardware structure for rapid data processing. In order to explore the space in the close neighborhood of the mobile object (assimilated with a mobile WSN node), a priority window is selected from the complete field. Every object which appears in the priority field – for example, Ob_1 in Fig. 3 – is considered as a virtual obstacle. The notation significances are the following: PW – priority window; Ob– obstacle; M – lane marks, A – the nearest point of an obstacle; O – the origin of the priority window and also of the image field; α_1 - vector radius angle

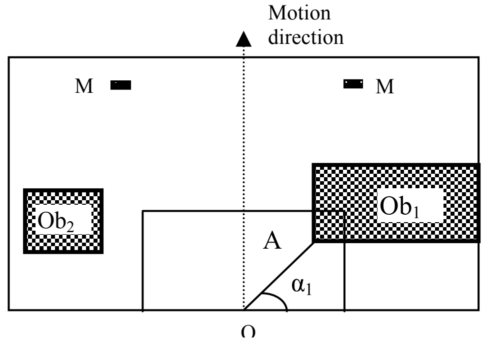

Fig.3. Moving objective path configuration

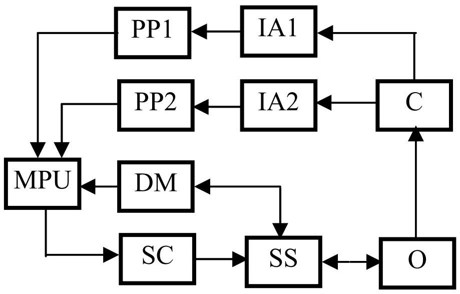

Fig.4. Block diagram of the data sensor fusion based system for object detection

In Fig.4 it is presented the block diagram of the system build around a central processing unit. The block significances are as follows: C – CCD camera, obliquely oriented with respect to the motion plane; O – object (obstacle) in the motion space; IA1 – image acquisition block for a priority window; IA2 – image acquisition block for the complete field; PP1 – primary processing block of the image corresponding to the priority window; PP2 – primary processing block of the image corresponding to the complete field; SS – multisonar configuration; DM – distance measurement block; SC – sonar control block; MPU – main processing unit. The architecture presented in Fig.4 offers the possibility to perform a fast parallel primary processing at the level of the hard units PP1, PP2, DM, which diminishes the computing time and discharges the main processing unit from these costly processing tasks. The main processing unit ensures the sensor data fusion and processing of sensor information already refined as above mentioned by using dedicated operational tasks under the coordination of a supervising module.

5 IMN Implementation

There are three main hardware units incorporated in the IMN structure: the communication unit, the central processing unit and the data acquisition unit. Each unit is single board implemented around a dedicated chip.

The communication unit is based on the TRF6901 chip, an integrated circuit intended for use as a low cost FSK transceiver to establish a frequency-programmable, half-duplex, bidirectional RF link. The multichannel transceiver is intended for digital modulated applications in the free 868-MHz European band and the North American 915-MHz ISM band. The single-chip transceiver operates down to 1.8 V and is designed for low power consumption. The synthesizer has a typical channel spacing of better than 200 kHz and uses a fully-integrated VCO. Only the PLL loop filter is external to the device. The transmitter consists of an integrated VCO and tank circuit, a complete integer-N synthesizer, and a power amplifier. The TRF6901 was easily interfaced to a baseband digital signal processor such as the Texas Instruments MSP430 ultralow-power microcontroller, that is the core of the CPU. The TRF6901 serial control registers are programmed by the MSP430, which performs also baseband operations in the software. According to the application requirements, one can choose the design complexity necessary to implement the system, a data rate and the coding scheme, and one can determine the number of required frequency channels. Wireless transceiver designs can be loosely classified into three groups according to performance and design complexity. Simple designs are often characterized by low data rates (10 kbps), very low cost targets, and short transmission ranges (under 100 m). Cost is the primary driver in making design choices. Complex designs have higher performance goals that may include higher data rates or longer transmission ranges (over 100 m). In the implemented solution the DSP contains an additional software that ensure three optional supplementary signal processing functions: adaptive equalization for canceling intersymbol interference, error correction to minimize the bit error rate and coded modulation (QAM type) for increasing the transmission speed.

The choice of coding scheme has important implications for several parts of the transceiver design, including loop filter bandwidth, frequency deviation, and operating the TRF6901 in learn and hold modes. Systems with low data rates (2.4 kbps to around 30 kbps) are often implemented with Manchester coding. There is a voltage change every bit (or symbol) period, hence the dc content of the data is zero or constant. In FSK systems, this means that the bit rate is the same as the rate at which the transmitter toggles between frequencies (symbol rate, data rate, or frequency modulation rate). If Manchester coding is used, the TRF6901 can be operated in the learn or hold modes when receiving data. The training sequence, used during the learn mode, is still required to establish a reference voltage at the sample-and-hold capacitor. Systems with data rates higher than 30 kbps are often implemented with unipolar Non Return-to-zero (NRZ) coding. There is a voltage change only when the data changes from one to zero or vice versa, hence the voltage content of the bit stream and the frequency modulation rate depends on the data content. In FSK systems, this means that the bit rate is about twice the maximum frequency modulation rate. If NRZ coding is used, the TRF6901 must be operated in the learn mode while receiving the training sequence, and then the TRF6901 must be switched to the hold mode while receiving data.

The data acquisition unit has been realized also as a standalone layer, around a AT90S4433 microcontroller. The ADC is connected to an analogue multiplexer with 6 channels and contains an Sample and Hold Amplifier that maintain the input voltage as a constant level during conversion.

6 Conclusion

The design of radio networks of mobile sensors and their implementation is a modern topic; nowadays developed countries invest a lot of resources to diversify and develop the specific infrastructure and services. The device proposed in this paper is part of a highly performing communication equipment that aims to combine message processing procedures with signal processing procedures and multi-point transmission organisation, which today offers the best performance/price ratio for solutions for information remote transmission based on wireless channels lead to the use of combined techniques of multipoint transmission processing and organisation. We have motivated and presented the design of a new architecture for the nodes of a sensor network. The architecture differs from previous work in being based explicitly on a hardware/software co-design approach in order to improve optimization and adaptability. Because an important objective was the simplification of development of service applications for wireless sensor networks, a key issue was to separate the software from underlying hardware and to divide it into functional blocks. The presented software architecture and design flow facilitates the programming on high abstraction layers. Reducing energy consumption was the aim of other new proposed procedure, representing an efficient tracking method using a moving average estimator to decide the future location of the mobile target. Simulations results show that our estimation method performs accurately, which contributes to saving energy and thus extending the network lifetime as well regardless of mobility pattern of the mobile target by reducing the number of participating nodes in tracking.

Our current research activities concentrate on the realization of the proposed architecture embedded in a framework. It simplifies the development of single sensor, node and sensor network applications. Besides that, it provides functionalities to configure and manage the whole network, whereby the scalability and portability of applications increases. Our immediate research challenges are to determine appropriate abstractions for the construction and deployment of the embedded systems architecture from hardware and software perspectives. We intend to evaluate our work against a range of applications, both to check the qualities of the implemented solution for IMN and to derive methodological understanding that aids the creation of complex sensor networks.

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