ONLINE MOVEMENT CORRELATION OF WIRELESS SENSOR NODES

Mihai Marin-Perianu, Raluca Marin-Perianu,
Paul Havinga, Hans Scholten [1])

Abstract
Sensor nodes can autonomously form ad-hoc groups based on their common context. We propose a solution for grouping sensor nodes attached on the same vehicles on wheels. The nodes periodically receive the movement data from their neighbours and calculate the correlation coefficients over a time history. A high correlation coefficient implies that the nodes are moving together. We demonstrate the algorithm using two types of movement sensors: tilt switches and MEMS accelerometers. We place the nodes on two wirelessly controlled toy cars, and we observe in real-time the group membership via the LED colours of the nodes. In addition, a graphical user interface running on the base station shows the movement signals over a recent time history, the latest sampled data, the correlation between each two nodes and the group membership.

1. Introduction

Smart sensor nodes can become aware of being *together* by observing that they share a common context [5], such as the movement pattern. This paper describes the demonstration of the online correlation of movement data presented in [6], which was accepted for publication in Pervasive 2007. A large range of applications can benefit from this solution: sports and entertainment (people hiking or skiing together), healthcare (body area networks), and transport and logistics (smart vehicles carrying smart goods). In this paper, we are interested in two specific problems derived from the latter scenario, which can be solved by achieving movement-based group awareness:

- Sensor nodes attached to goods carried in rolling containers (also called RTIs) can group together and discover/signal order picking errors.
- Sensor nodes attached to RTIs loaded in transportation trailers can group together and prevent delivery errors.

With respect to this scenario, we focus on the correlation of sensor nodes which are attached to vehicles on wheels. The sensor nodes acquire the movement information from tilt switches or accelerometers and periodically transmit the sampled data to the neighbours. When receiving the movement data from one neighbour, a sensor node calculates the correlation coefficient between its own sampled data and the received data, which represents a confidence value that the two sensor nodes are moving together.

The demonstration of our prototype system consists of two wirelessly-controlled toy-cars outfitted with sensor nodes, which organize in two groups, depending on the car they are attached to. The

[1] University of Twente, Department of Computer Science, 7500 AE, Enschede, The Netherlands

decision of the nodes is shown both locally, by means of the LED colours, and on the base station, through a graphical interface.

The remaining of this paper is organized as follows. In Section 2 we present the hardware sensor node platform, together with the movement sensors used in our demonstration. Section 3 gives the software details of the implementation. We explain the demonstration setting and interface in Section 4. Section 5 concludes the paper.

2. Hardware

We use the Ambient µNode 2.0 platform [1], with the low-power MSP430F1611 microcontroller from Texas Instruments. The microcontroller is equipped with 48kB of FLASH memory and 10kB of RAM. The radio transceiver on the µNodes operates in the 433/868/915 MHz ISM band and has a data rate of maximum 100 kbps. We use AmbientRT [4], a multi-tasking real-time operating system.

The sensor nodes acquire the movement data either from tilt switches or from MEMS accelerometers. In the first case, we use the the ASSEMTECH CW1300-1 tilt switch [2]. The price is below 2 EUR and the typical power consumption is approximately 2µW. The movement data is given by the number of contacts made by the switch ball per time unit, as the node is moving. The second solution uses the three-axis LIS3LV02DQ accelerometer from STMicroelectronics [7], with the price range around 15 USD. The typical power consumption is around 2mW. We operate the accelerometer in the ±2g scale and we retrieve the data on the three-axis through the I^2C interface. The correlation algorithm uses the magnitude of the acceleration vector ($\|a\| = \sqrt{a_x^2 + a_y^2 + a_z^2}$), which is the same in any frame of reference, no matter of the alignment and orientation.

3. Software

We implement our proposed correlation algorithm [6] on sensor nodes. The algorithm updates the correlation coefficient based on the movement data received from neighbours and the most recent local data. Implicit synchronization is therefore achieved, which is essential for a correct evaluation of the correlation. The algorithm operates on a circular buffer corresponding to approximately 16s time history. The execution time measured on the µNodes is in the range of 6ms.

Figure 1 shows the general software architecture. AmbientRT operating system [4] allows to modularize the code into tasks that communicate among themselves through publish/subscribe mechanisms. The *Sampling* task is triggered by an interrupt (data ready to read on the I^2C interface in the case of accelerometers, or ball contact in the case of tilt switches, respectively). The sampled data is stored in the circular data buffer, from where the *Radio* task periodically broadcasts the most recent sequence to the local neighbours. For regulating the access to the wireless medium, we use LMAC [3], an energy-efficient TDMA-based protocol designed for wireless sensor networks. When data is received from a neighbour, the *Correlation* task is triggered and the local correlation coefficient is updated accordingly.

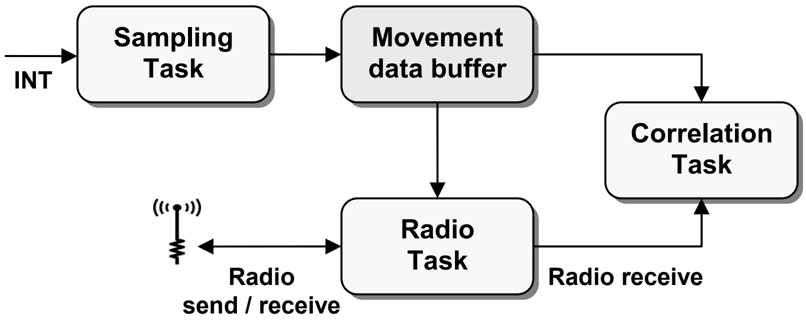

Figure 1 – Implementation of the correlation algorithm

4. Demonstration

The demonstration shows how the sensor nodes group based on movement information. We use four sensors nodes with tilt switches and four sensor nodes with accelerometers. During a demonstration, only four sensor nodes of the same type are active. The nodes are placed on two wirelessly controlled toy cars, as shown in Figure 3. The nodes convey their grouping decision by using different LED colours. In addition, a gateway node collects the correlation coefficients periodically broadcast by each moving node, together with the movement data, and logs them to the base station through a standard RS-232 interface. The base station provides a graphical user interface (see Figure 2), which shows the movement signals over a recent time history, the latest sampled data, the correlation coefficients between each two nodes and the group membership. Figure 2 displays a situation where the nodes 1 and 2 are part of the same group, being attached to the same car, while the nodes 3 and 4, which are on the other car, form a different group.

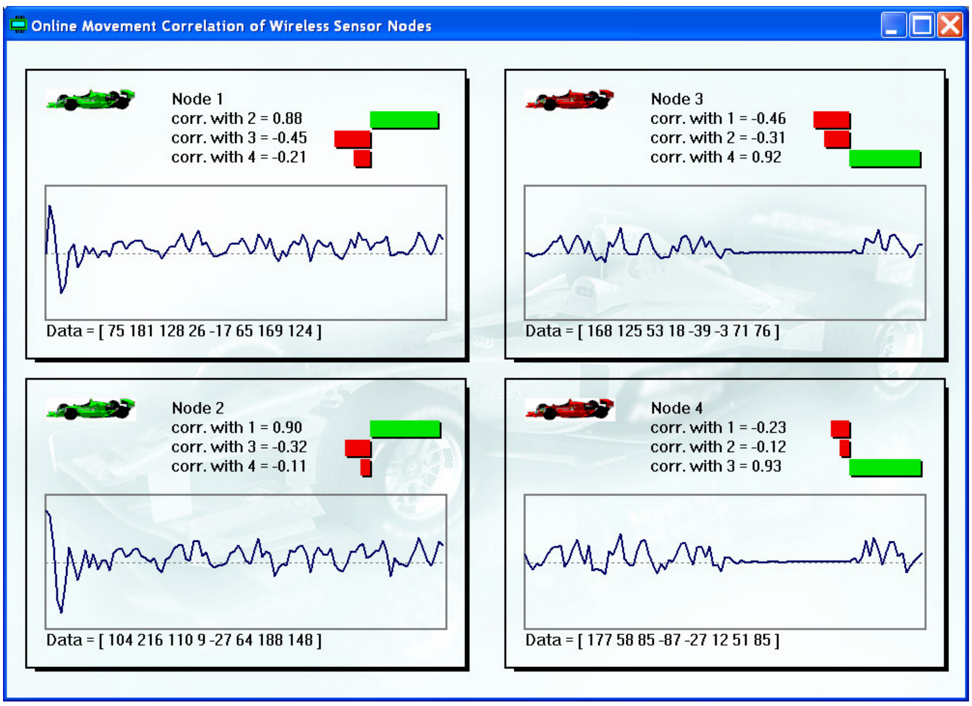

Figure 2 - Demo interface

Figure 3 - Two sensor nodes with accelerometers attached to a wirelessly controlled toy car

5. Conclusions

This paper demonstrates an autonomous way of interaction between sensor nodes that can establish groups based on their common movement context. The proposed solution can be implemented on resource-constrained hardware, aiming thus at a low price range that would make it feasible in real world applications, such as transport and logistics. Initial experiments with our system prototype show reliable distinction between ensemble and separate movement, as well as robustness to constructive differences of sensors and to occasional packet loss.

For future work, we plan to extend our solution to a larger-scale, multihop network, and fuse information from multiple types of sensors in order to improve the decision reliability.

6. References

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