Collaborative Estimation of Environmental Parameters

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Abstract: - Mobile autonomous platforms are considered as mobile nodes in a collaborative wireless sensor network to estimate environmental parameters like temperature, humidity, pressure, sunlight and position. These small robots are equipped with cheap and energy efficient sensory module, based on MTS420 environmental sensor board. For a better approximation of the reality, statistical indicators like sample average, sample standard deviation and confidence interval are used. Experimental results in a real outdoor application show that the method gives good results both in useful data presentation and erroneous data elimination.

Key-Words: - wireless sensor network, environmental monitoring, mobile robots, collaborative robots, data estimation, outdoor localization, node architecture.

1 Introduction

In terms of communications, a team of mobile robots or platforms endowed with sensorial capacities for external data acquisition can be considered as a mobile wireless sensor network. These networks are based of the most promising technologies for the 21st century, with wide range of applications [1] (including environmental and habitat monitoring, precision agriculture, surveillance, medical diagnostics and healthcare, and urban terrain mapping). Perhaps one of the most common applications of mobile WSNs is the environmental monitoring, which involves collecting readings over time across a volume of space large enough to exhibit significant internal variation.

The mobile autonomous robots utilized to a data acquisition in outdoor or indoor applications can be considered as mobile nodes in a mobile WSN. For example, a distributed modular robot system for parameter identification is proposed in [2]. A modular robot was defined as a mono-functional robot (either a sensor or an actuator) with a radio communication unit and a processing unit. Such robots were usually small and could be easily attached to operational objects or dispersed into the environment.

Because in broad areas of investigations the information is incompletely or affected by errors, for an efficient estimation of the environment parameters, a collaborative work between the mobile robots is necessary and data fusion on different stage of data processing is performed.

For example, Liang and Zhu [3] present a probabilistic algorithm to collaborate distributed sensors for mobile robot localization. They use a sample-based version of Markov localization - Monte Carlo Localization (MCL), capable of localizing mobile robots in an indoor office.

One of the advantages of deploying a wireless sensor network was identified by Zeng et al. [4] to be its low deployment cost and freedom from requiring a wired communication backbone, which is often infeasible or economically inconvenient.

On the other hand, in real applications of mobile robot teams there are times when some robots fail and cannot collect or transmit data. Therefore it is necessary that the remaining robots to work together to estimate more accurate parameters. In this respect, Pan and Li [5] adopt linear regression model to describe the spatial correlation of sensor data among different sensor nodes and a k-nearest neighbor based missing data estimation algorithm is proposed.

Also, due to sensor accuracy or robot position, robots from a small area can indicate different values for the same, relative stable parameter (for example, temperature). Again a collaborative estimation of this parameter is necessary. Cattivelli et al. [6] studied the problem of distributed estimation in order to evaluate some parameters of interest from measurements in an adaptive network and they proposed a distributed diffusion algorithm based on recursive least-squares.

Mendez-Polanco and Munoz-Melendez [7] design and implement a robot team consisting of three homogeneous mobile robots and an external server with the main goal to update a map or representation of an indoor environment based on collective exploration.

In [8] the authors proposed a mobile wireless network for indoor applications of parameter monitoring, based on mobile platforms.

In this paper, a WSN is deployed, by means of mobile platforms [9], in the outdoor to collect the environment variables such as temperature, humidity, atmosphere pressure, sunlight etc. The mobile nodes are wireless connected to a gateway in order to collect data, process them and transmit to the users (Fig. 1).

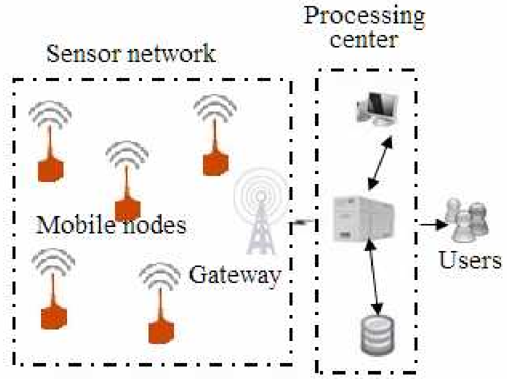

Fig.1. Mobile WSN (robot team) for data collection in an environment monitoring application.

This paper is organized as follows. In Section 2, the architecture and the implementation of the sensory module of an individual robot are introduced. Section 3 presents the algorithm to estimate the real values based on information coming from more environmental sensors. Experimental results are shown in Section 4. Finally, in Section 5, the conclusions of the work are derived.

2 Sensory Module Architecture

The mobile platforms for estimation of environmental parameters are endowed with complex programmable equipments, low power consumption, able to acquire and to process data, to interact with other nodes in order to identify the position and to communicate wireless. As can be seen from Fig. 2, the mobile robot has five functional modules (traction, power, data acquisition, data processing and data communication) which are arranged on four levels. The equipment is positioned on a four-wheel drive platform (Fig. 3).

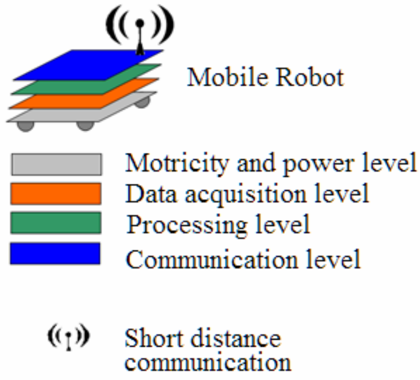

Fig.2. Functional levels of the mobile robot for environment monitoring.

Fig.3. Mobile platform equipped with wireless sensor and GPS antenna.

Having in plan to use our robot team as an environmental monitoring system, the first step in designing our solution has been to choose the needed sensors. In order to achieve a good monitoring level for the environmental conditions outdoor, we needed to have our nodes equipped for gathering the following parameters: temperature, sunlight, humidity, barometric pressure and position (using a GPS module).

The solution we agreed on has been to use the MTS420 sensor board (Crossbow) [10].

Thus, MTS420 environmental sensor board offers five basic environmental sensing parameters and an optional GPS module. One of the main characteristics is that they are energy-efficient devices so that they can provide extended battery-life and performance wherever low maintenance field-deployed sensor nodes are required. These

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versatile sensor boards are intended for a wide variety of applications ranging from a simple wireless weather station to a full mesh network of environmental monitoring nodes. Applicable industries include agricultural monitoring, art preservation, environmental monitoring, sensor location mapping.

According to the MTS/MDA Sensor Board Users Manual [11], some of the environmental sensor characteristics are as follows:

- Dual-axis accelerometer (ADXL202JE): acceleration range: ±2g; resolution: 2mG RMS; sensitivity 167 mV/g, ±17%; operating range 3.0 to 3.6 V;
- Barometric pressure sensor (Intersema MS55ER) : pressure range: 300-1100 mbar; accuracy: ±3.5%;temperature range: -10 to 60 ˚C; accuracy: ±2˚C; operating range 2.2 to 3.6 V;
- Ambient light sensor (TAOS TSL255D): spectral response: 400-1000 nm, similar to human eye; operating range 2.7 to 3.6 V;
- Relative humidity and temperature sensor (Sensirion SHT11): humidity range: 0-100%; accuracy: ± 3.5% RH; temperature range: -40˚C to 80 ˚C; temperature accuracy: ±2˚C; operating range 2.4 to 3.6 V;
- GPS Module (uBlox LEA 4-A): chipset: ANTARIS 4; meters: 3m CEP; reacquisition time: <1 sec; protocol NMEA-0183; current: 35 mA at 3.3 V; operating range 3.3 to 3.6 V (recommended)

The average operating range for the described sensors is between 2.7 and 3.6 volts without GPS and between 3.3 and 3.6 with a running GPS.

The sensor node (MicaZ), manufactured by Crossbow, has a 7.3 MHz Atmega128L processor, 128Kb of code memory, 4Kb of data memory, and a Chipcon CC2420 radio which supports the 802.15.4/ZigBee WPAN protocol (transmits up to 250 kilobits per second and an outdoor transmission range of approximately 30-50 m) [12]. The dimensions of the node are 58 mm x 32 mm and have reduced weight, making them ideal for mobile platforms (Fig. 4).

3 Data Estimation

Because the information from sensor is incomplete and uncertain, it is essential for the system to provide redundant information from more sensors [13]. Generally there are distinguished three types of sensorial data fusion:

-Complementary fusion: fusion of incomplete sensorial measurements from several separate sources;

-Competitive fusion: fusion of redundant sensorial measurements from more sources;

-Cooperative fusion: fusion of physical measurements after or during conversion time.

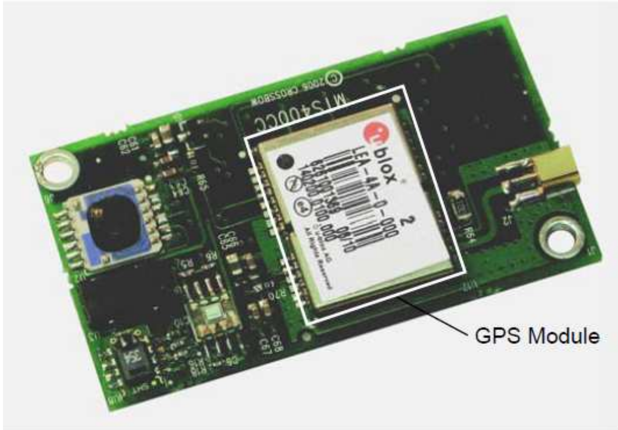

Fig.4. MTS 420 sensor board.

Due to technological process of sensor manufacturing, robot position, and environmental perturbations, data acquired from sensors are different for the same parameter and do not reflect the real values. Therefore the values indicated by the robot team must be processed and interpreted so as to be as closed to the real values.

On the other hand, one of the critical technical problems that need to be resolved in wireless sensor networks is the energy efficiency of sensor nodes with limited battery life [14]. The most frequent cause for a node malfunction is power failure and the power drop can lead to erroneous measurements. The risk management is a great factor to have in mind when designing an outdoor monitoring system. For example, Fig. 5 presents the case of a humidity/temperature sensor from MTS 420 when a drop in voltage from 2.1262V to 2V causes a temperature jump from 22.79 ^{0}C to 124.23 ^{0}C. As it can be seen in Fig.5, the power drops under the 2.4V (the minimum recommended value for the Sensirion SHT11 [15]) and, as a result, the gathered data is no longer valid. Therefore, one of our goals is to predict such a malfunction that may result in erroneous data gathering or even losing precious data.

These situations should be avoided by measuring the voltage permanently or testing if the measured values of the parameters belong to a confidence interval. For this purpose we assume that data achieved from sensors have a normal distribution and for each set of *k* samples of time series, both sample average and sample standard deviation are calculated. Also, we consider that the processes whose parameters are estimated are slow in comparison with the rate of data acquisition (for example, temperature).

Fig.5. Temperature sensor starts sending erroneous data as a result of power drop.

The sample average (1) from n samples, for the parameter S is defined as [16]:

$$\mu_S(k) = \frac{1}{n}\sum_{i=0}^{n-1} S_{k-i} \qquad (1)$$

where the set $\{k-n+1, k-n+2, ..., k\}$ is the observation window, before the moment k, and $S_{k-1}, i = 0,1,..., n-1$ are the measurements (samples) inside the observation window.

Sample standard deviation (2) is defined as [17]:

$$\sigma_S(k) = \sqrt{\frac{1}{n-1}\sum_{i=0}^{n-1}(S_{k-i} - \mu_S(k))^2} \qquad (2)$$

The next sample S_{k+1} is tested if it belongs to a six sigma interval (3):

$$S_{k+1} \in [\mu_S(k) - 3\sigma_S(k), \mu_S(k) + 3\sigma_S(k)] \qquad (3)$$

If the condition (3) is fulfilled, then S_{k+1} is considered as a valid experimental value and a new pair $\{\mu_S(k+1), \sigma_S(k+1)\}$ is calculated.

If the condition (3) is not fulfilled, then S_{k+1} is rejected as an erroneous value. The robot which has transmitted S_{k+1} is investigated for its health.

The parameter S_k will be estimated by the dynamic sample average $\mu_S(k)$.

4 Experimental Results

Implementing a monitoring system for the outdoor environmental conditions offers many challenges but also allows us to use some interesting new tools, such us the GPS module. This helps us keep a better view of the entire sensor topology.

The test bed for our experiments has been our university surroundings and our topology resembles the one in Fig.6.

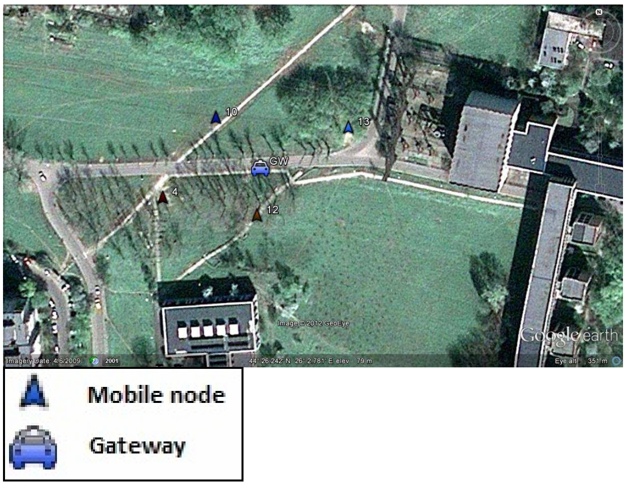

Fig.6. Mobile nodes positioning relatively to gateway

The mobile nodes move in a designated area so that the communication coverage condition could be fulfilled. The communication radius of every node is between 30 and 50 meters and every single node acts like a router for the other adjacent nodes. Therefore, the communication coverage of the multi-hop mobile wireless network is far more extended than the communication coverage made possible by the gateway antenna.

As can be seen from Fig. 7, which represents the temperature outputs of four sensors humidity/temperature, the values are different an have a slow evolution.

Fig. 7. Screen capture of temperature acquisition.

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The results measured by the four mobile nodes over a short period of time (21 samples) are presented in Table 1.

Table 1. Presentation of environmental data

No	Id	Volt [V]	H[%]	HT [^{0}C]	P[bar]	PT [^{0}C]
1	13	2.59	38	24.33	996.11	24.7
2	4	3.01	37.9	24.6	996.18	25.05
3	10	3.10	39.6	24.96	995.45	25.45
4	12	2.72	38.8	24.5	996.51	24.75
5	13	2.60	37.9	24.32	996.23	24.75
6	4	3.01	38.3	24.58	996.19	25.05
7	10	3.10	39.5	24.97	995.46	25.46
8	10	3.10	39.5	24.97	995.46	25.46
9	12	2.72	38.8	24.52	996.52	24.76
10	13	2.60	37.9	24.32	996.22	24.74
11	4	3.01	38.1	24.6	996.18	25.05
12	10	3.10	39.5	24.96	995.35	25.44
13	12	2.72	38.8	24.51	996.54	24.77
14	13	2.59	37.9	24.32	996.22	24.74
15	4	3.01	38.4	24.62	996.18	25.05
16	10	3.10	39.5	24.96	995.44	25.44
17	10	3.10	39.5	24.96	995.44	25.44
18	12	2.72	38.9	24.52	996.62	24.76
19	13	2.59	37.9	24.33	996.22	24.74
20	4	3.01	38	24.64	996.1	25.05
21	10	3.10	39.5	24.95	995.43	25.43

The positions of the mobile nodes are fixed for the duration of this experiment. The GPS measured positions of mobile robots and gateway can be seen in Table 2. The robot team configuration is a star one and therefore no parents were utilized in data transmission to gateway.

In Table 3, the parameters $\mu_S(20)$ and $\sigma_S(20)$, for *S* = *H*, *HT*, *P*, *PT* and *PT&HT* (together), are calculated. It can be seen easily that *H*(21), *HT*(21), *P*(21) and *PT*(21) are valid samples, i.e. they belongs to the interval:

$$S_{21} \in [\mu_S(20) - 3\sigma_S(20), \mu_S(20) + 3\sigma_S(20)]$$

The test for randomness is performed by a lag plot [17]. In this respect, Fig.8 presents the lag plot (lag = 1) for temperature. Both diagrams Humidity/Temperature Sensor (HT) and Pressure/Temperature Sensor (PT) are drawn. Separately, HT and PT have a randomness aspect.

Table 2. Presentation of mobile nodes positions

Id	LatD	LatM	LongD	LongM
0	44	26245	26	2761
4	44	26238	26	2724
10	44	26259	26	2745
12	44	26232	26	2759
13	44	26255	26	2795

Table 3. Statistic indicators of environmental parameters

Parameter/ Indicator	H[%]	HT[^{0}C]	P[bar]	PT[^{0}C]	HT+ PT[^{0}C]
μ	38.68	24.64	996.0	25.05	24.85
σ	0.689	0.255	0.437	0.310	0.340

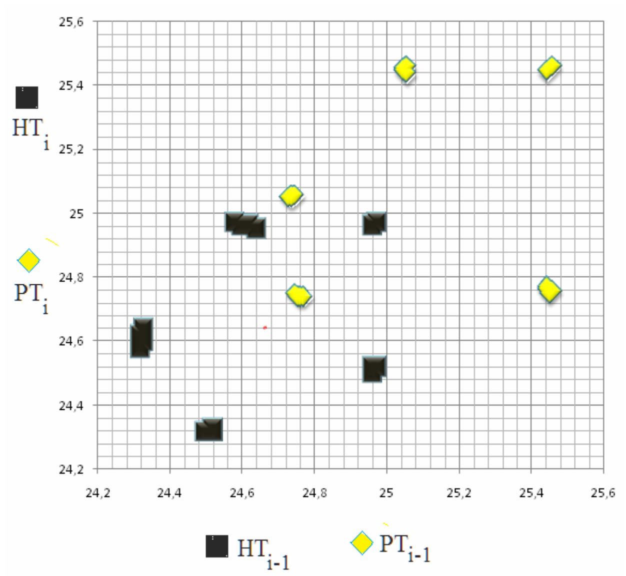

Fig.8. Lag plots for *HT* and *PT* respectively.

5 Conclusion

In this paper we presented an approach to collaborative distributed mobile platforms to estimate different parameters in outdoor environment. Every platform contains an energy-aware module based on *Crossbow* technology able to acquire and transmit information about environmental parameters and location. The collaborative work consists had two components: on the one hand a node (assimilated with a small robot)

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can be a router for another node to transmit its data and on the other hand all the data from the team are utilized to estimate more accurate the real values of the parameters. Finally, the experimental results validate our approach.

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