GLAC-14,S4A,4x20428

ADVANCED SENSOR BASED POSITIONING AND MONITORING SYSTEM

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As an integrated approach, we have proposed a monitoring network which is based on a satellite segment and a wireless sensor based ground network. The developed architecture can localize its elements with minimal required resources. For the position estimation process among the sensors, we used a recursive technique that extends the accessible coverage area deploying only three high performance devices with accurate positions that are used as initial references. We developed new algorithms to improve the precision of the recursive positioning scheme utilized in the proposed sensor network. In order to analyze the introduced sensor network architecture and evaluate its operation, a simulator tool was implemented. In the evaluation of the proposed model, we analyzed and compared the performances of different positioning algorithms in our simulator. Based on our results, an integrated service for satellite based remote sensing and positioning could be implemented for Earth environment and space exploration as well.

I. INTRODUCTION

Positioning and monitoring services will have emergent role in the next years. As part of these services, the wireless sensor networks could play a critical role. With advancement in research and technology, many mobile sensor systems have been developed with different geometries, sizes, and configurations. Our advanced concept for sensor based positioning and monitoring system could be applied either in Earth environment (as an integrated satellite based services) or in exploration missions beyond Earth. The combination of satellites and mobile sensors makes the remote monitoring of non-easily accessible areas in Earth environment possible. As for the exploration, very expensive and sensitive multifunctional robots with wheels or tracks were sent to other planet up to the present day. However, in the future hundreds or thousands of cheap sensors can be dropped on the surface of distance orbits.

The Wireless Sensor Networks (WSNs) could play an important role in different environments, e.g., vehicles, scientific measurements, meteorology, monitoring. The simple and cheap sensor devices have ability to remotely monitor non-easily accessible areas and can be used to ensure the safety of actual human or robotic missions. In WSN, the sensors have low dimension resulting in low price as well. This is why high number of these sensors can be dispersed at the investigated area to monitor atmospherical, terrestrial, electromagnetic features and forward the collected data through their radio interface.

For the successful work of WSN, the efficient deployment of sensors is very important. A sensor may move independently from others or in group, but usually uniform dispersion is preferred to minimize the uncovered area in the monitored environment. Several studies are dealing with movement control methods [1]. Most of these strategies [2], [3], [4] assume that the environment is sufficiently known and under control. However, in unknown or hostile environment such as distant planets or disaster areas sensor deployment cannot be performed manually. The devices are scattered from great distances (e.g., airplane, space capsule), therefore the actual landing position cannot be precisely controlled due to the existence of wind or other obstacles. In a centralized approach, a powerful cluster head collects the sensor location and determine the target location of the mobile sensors [5]. However, the centralized approach is not always acceptable, because it may suffer from the problem of single point failure. In case of special conditions self-controlled methods are preferred.

In this paper, we propose a monitoring network which is based on a satellite segment and a wireless sensor based ground network. The network is based on our previously published results [6]. The developed architecture can localize its elements with minimal required resources. For the position estimation process among the sensors, we used a recursive technique that extends the accessible coverage area deploying only three high performance devices with accurate positions that are used as initial references. New algorithms were developed to improve the precision of the recursive positioning scheme utilized in the proposed sensor network. Two types of sensors are used in the ground network. The first type is deployed in large number and it is responsible for collecting and forwarding environmental data, while the other type of devices consists of high performance sensors, which are able to communicate with satellites. The environment of data measurement is a significant issue, so the positioning of sensors is a central subject in this research. The position estimation is mainly based on received signal strength values of the radio communication that is influenced by terrain obstruction therefore the Deygout propagation model was used. The surface and environmental characteristics that influence the mobility and communication of mobile device were taken into account as well.

In order to analyze the introduced sensor network architecture and evaluate its operation, a simulator tool was implemented. In the evaluation of the proposed model, we analyzed the performances of different positioning algorithms in our simulator. Based on our results, an integrated service for satellite based remote sensing and positioning could be implemented.

II. PROPOSED MODEL

II.1. Sensors and supersensors

The general overview of our network is illustrated in Fig. 1. Our monitoring network is based on a satellite segment and a wireless sensor based ground network. The ground network contains sensors which perform different measurements. The central data collector device will serve as a gateway, which forwards the collected records to a command center via satellites.

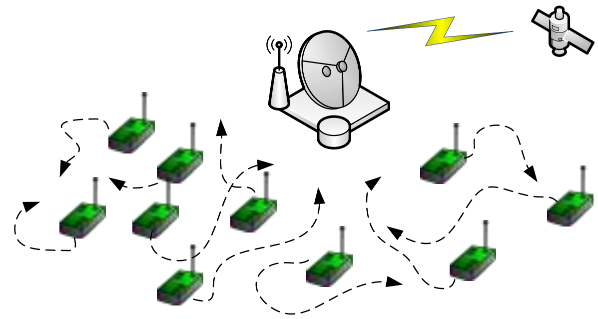

Fig. 1
General overview of the monitoring sensor network

We use some special sensors, named supersensors in our model as well. The supersensors collect the data from the other sensors and forward to the command center via satellites. Their actuation is more expensive because the communication with satellites needs more energy that must be produced using bigger solar cells, compared to other regular sensors.

II.2. Sensor positioning

Our model works on a minimal infrastructure, so we do not use GNSS-based *(Global Navigation Satellite System)* navigation. For positioning, we use the way of triangulation and reference points as it is illustrated in Fig. 2. We are able to calculate the position of a fourth sensor, if this sensor is visible for three others sensors which position are already known. At the beginning of our algorithm, the first reference points are the supersensors (we assume that their positions always are known).

The *B1*, *B2* and *B3* points are the known position sensors, sensor *A* has the unknown position which need to be calculated. If the cover of sensors *B1*, *B2* and *B3* are bigger than the distance from sensor *A*, then the way is adaptable. Circles, with *d1*, *d2* and *d3* radius and *B1*, *B2* and *B3* centre, define the position of *A*. In this case, the *B1*, *B2* and *B3* are reference points. After determining the position of sensor *A*, it will become a reference point as well.

Using this technique recursively and assuming that there are no lost sensors, the location of the sensors will be known. In the next sections of this paper, we explain what happens if there are some lost sensors.

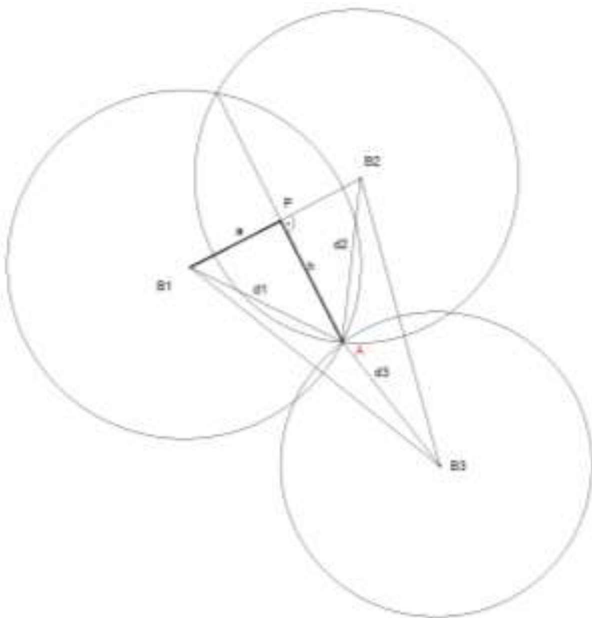

Fig. 2
General schema for calculation the position of sensor *A* using triangulation method

II.3. Optimized positioning algorithms

As previously was discussed, different methods could be used for positioning. In our work, we were interested in the optimization of positioning. In this section, we describe our three positioning algorithms.

a) Basic Position Algorithm without optimization (BPA)

In order to calculate the position of a sensor, three parent sensors are chosen from the list of potential reference devices. The algorithm examines the potential reference sensors in the sensor group and selects the first one that is capable to serve as a reference. After the first three hits, the examination stops and the triangulation process can be started.

BPA is not an effective solution, because if the algorithm chooses three sensors, which estimated position is not accurate enough due to accumulated errors, the new calculation will contain all of these errors, too. This means that the calculated coordinates will be different from the real position. Actually, if the three basic supersensors can be selected as parents, then the calculated value will contain lower error, since the position of supersensors are precisely known.

b) Positioning Algorithm based on Hop Number (PAHN)

In PAHN, the sensors use a hop value that contains how many steps of positioning resulted the calculated coordinates. Hop values of supersensors are zero, because the supernode positions are precisely known and its coordinates are not estimated. Each simple sensor position is estimated from the position of three parent nodes, therefore the average of the hop values of the parents are calculated and set as a hop value of the currently estimated sensor.

For example, if we want to calculate the hop value of sensor *A*, and the parents of this sensor are supersensors *S1*, *S2*, and *S3*, the hop value will be the following:

$$(0+0+0)/3 + 1 = 1 \qquad (1)$$

If sensor *B* is chosen which parents are sensor *A* and two supersensors, then the hop value will be calculated as follows:

$$(0+0+1)/3 = 1/3 \qquad (2)$$

This means that the hop value shows how accurate calculation can be performed in the position estimation. If hop value is small, then the calculation value is probably more accurate. Therefore a sensor chooses its parents on the basis of smaller hop values in order to estimate the position as accurate as possible. An example is illustrated in Fig. 4.

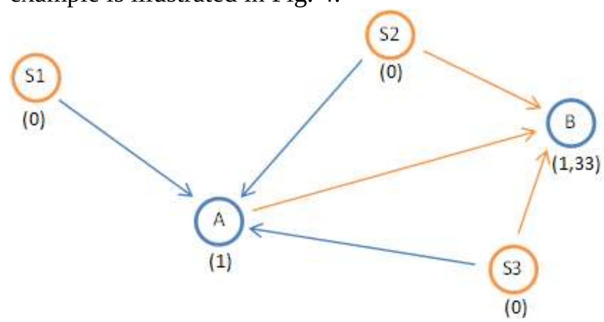

Fig. 4 Hop value calculate example with the PAHN algorithm

c) Extended Basic Positioning Algorithm (EBPA)

We extended the previously described BPA with heuristic optimization. During the positioning process, the sensor sets all combination of reference sensors and calculates the coordinates for each one. The sensor position is calculated as the average of the estimated coordinates based on the examined reference sensor combination.

III. SIMULATION RESULTS

III.1. Parameters

In order to analyze the performance of the proposed solutions, a simulation tool was implemented in C#. The tool is capable to set the type of surface, the number of the sensors, the communication range, the starting point and the final destination, etc. The parameters used in the simulation were the following:

1. Table Simulation default parameters

Name of parameter	Default value [unit]
Number of sensor	200 [p]
Area	400 [m2]
Maximum value of displacement	4 [m]
Range of sensor	30 [m]
Distance of point *D*	400 [m]
Pixel/meter	0.5 [pixel/m]
Color change	1 [m]

We used the above values as environmental parameters. Except the actually examined parameter, the other values do not change during the simulation.

“Number of sensor” shows how many sensors are in the sensor network. The value contains both the sensors and supersensors. In our simulation, we calculated with three supersensors.

“Area” is the selected area for monitoring, where the sensors performs different types of measurement. Borders of this area are the safety boundaries.

“Maximum value of displacement” limits the length of the movement vector. In one step, a sensor cannot move further then the given limit.

“Range of sensor” is the distance in which two sensors can see each other and able to communicate. All the sensors have same value for this range.

“Distance of point *D*”: the simulation ends when a sensor reaches point *D*.

“Pixel/meter” ratio sets the size of a pixel on the map in meters. Our simulator handles two different maps. The topography map contains the height values of coordinates. The other map is a soil map which contains the soil pattern for the given point.

“Color change” parameter gives a relation between the RGB values of the map and the physical elevation represented by the map.

III.2. Number of lost sensors in function of algorithm

In this scenario, we analyzed how many sensors will be lost due to unavailable communication with other sensors. If the position estimation error becomes high, the sensor cannot navigate correctly and move out from the communication (positioning) range. These sensor are assumed to be lost. We analyzed how the “Range of sensor” parameter effects the loss probability of the sensors. The simulation results in Fig. 5 show the sensor loss probability in this case of 30 m and 60 m communication range, According to the obtained results, less than 25% of sensors moves outside the communication range, if increased range is used. If we increase the range, more sensors can see each other, so more sensors can be used as parents for recursive position estimation. The PAHN algorithm proved to be the best choice in this case.

III.3. Analyzing positioning error distance in function of sensor number

Position estimation error is one of the most important feature of an algorithm. In these measurements, we compared the performance of the presented algorithms from the estimation error point of view. Fig. 6 shows how error distance changes in function of the number of the sensors. The error distance means the difference of real coordinates and the estimated coordinates calculated by the proposed algorithms.

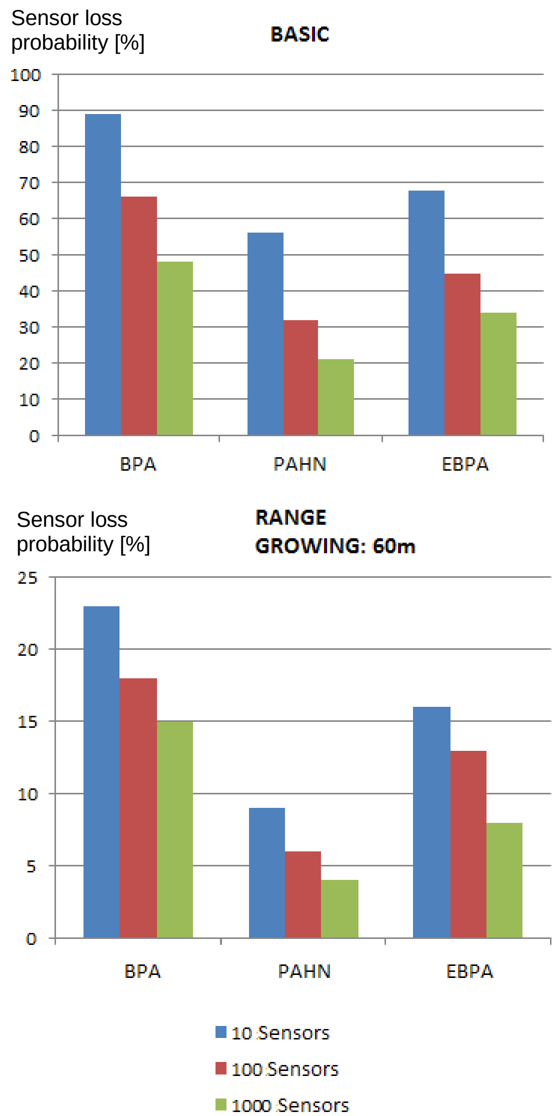

Fig. 5 Number of lagging sensors in function of algorithm

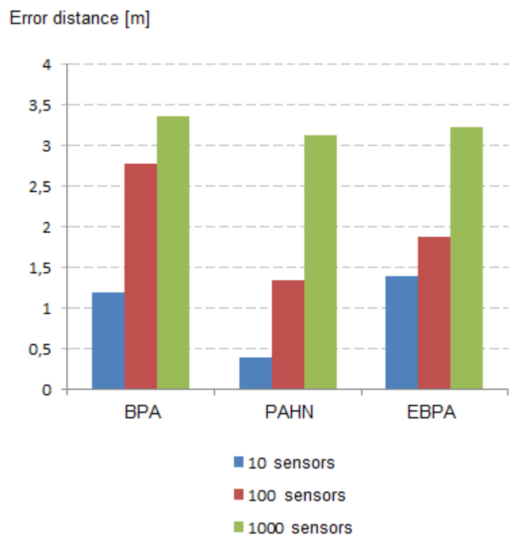

Fig. 6 Change of error distance in function of sensor number

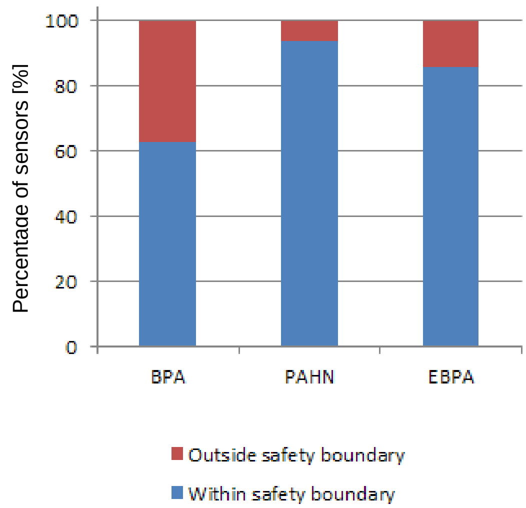

Fig. 7 Sensor dispersion within and outside safety boundary

Using BPA, if sensor number increases, the three supersensors are chosen as parents with lower probability. Therefore, the calculated coordinates will be inaccurate. When the number of sensors is lower, the estimation error of EBPA is higher than the value of BPA. This means we get higher average error if we have less sensors in the network, but it changes if more sensors are used. The reason behind this is the more significant position inaccuracy of the parent sensors that increase the value of average coordinates in wrong direction. In BPA, the probability to choose supersensors as parent is higher. According to our simulation, the best algorithm is the PAHN in this case.

III.4. Sensor dispersion within and outside safety boundary for algorithms

In Fig. 7, we can see how many percent of sensors are within the safety boundary and outside of it. A sensor, which reaches the safety boundary should continue its way within the investigated area by changing their moving direction upon reaching the safety limit. As we can see, there are more sensors within the safety boundary using the PAHN algorithm, since the change of direction does not let all of the sensors to move outside the area if the position estimation is accurate enough. In contrary, significant number of sensors moves outside the safety boundary in case of BPA.

IV. CONCLUSION

Instead of expensive devices, we can use cheap sensors for monitoring the environment. These cheap sensors could be easily placed on remote areas and the measured information will be forwarded via satellite network. In Earth environment, this monitoring system can be applied for detecting, observing and monitoring e.g. oil solution on ocean, measuring local temperature in remote areas, etc. The system could be useful tool in different disaster areas as well.

As for exploration, the sensor based network would be useful for performing different scientific measurements on surface of a distant solar system body, e.g., planet like Mars or an asteroid.

The above described optimization algorithms helps us to locate the elements of a wireless sensor network in an optimal way.

ACKNOWLEDGEMENT

A. Szeile would like to thank the support of Pro Progessio Foundation.

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