A 3-dimensional Localization Algorithm for Mobile Wireless Multimedia Sensor Networks

Dragoș OFRIM, Dragoș SĂCĂLEANU, Rodica STOIAN, and Vasile LĂZĂRESCU.

Abstract— This article exposes a specific localization algorithm for Wireless Multimedia Sensor Networks. Its hybrid structure is designed for 3-dimensional positioning of the multimedia sensor nodes using in-situ measurements and minimizes the error of localization by proposing an efficient trajectory estimation pattern along with a periodic calibration of the sensor nodes' coordinates. A periodic validation of the coordinates is performed by implementing a classical anchor-based localization algorithm. Providing a decreased error of localization, the suggested algorithm considerably reduces the localization delay, essential to mobile nodes, and offers an insignificant rise in network traffic as well as energy consumption throughout the positioning process. To further reduce the overall energy consumption, an adaptive sampling rate technique is proposed.

Keywords— wireless multimedia sensor network, mobile nodes, 3-D localization, inertial measurements

I. INTRODUCTION

THE term Wireless Multimedia Sensor Network (WMSN) defines a wide range of measuring devices. In essence, all the devices from this category have a local processor, a sensing device (mini-camera and microphone), local memory, are organized in an ad-hoc network and use wireless communication.

Wireless multimedia sensors are high energy consuming devices, as they are active most of the time, acquiring video and sound streams. As they are battery-powered, their energy consumption and complexity becomes a priority when robust and lifelong networks are needed. Low power CMOS cameras are used for video acquisition, as several high-performance video compression algorithms are used for considerably decreasing the amount of network traffic [1].

A very important aspect in the WMSNs is the localization of the nodes, especially if they are mobile and frequently changing their position. Military or environmental applications rely on the well-known position of the multimedia nodes, as the streams reveal important events that take place at a certain location. Most used localization techniques consider static networks and a 2-D map, but certain applications require mobile 3-D localization.

This paper proposes a hybrid scheme (HS3D) to best fit the measurement accuracy needed for 3-D localization in mobile WMSNs, with respect to the energy and traffic constraints specific to this type of network. Several techniques for reducing the error and delay of localization, as well as the overall energy consumption are proposed and tested.

II. RELATED WORKS

Many schemes for localization of sensor nodes have been studied [2], implemented and tested till now, all of them assuming different conditions and scenarios. They can be divided in two big categories: schemes based on nodes using external references to estimate their position and schemes based on nodes performing in-situ measurements to calculate the coordinates.

From the first category, the most used are image based localization algorithms [3] and anchor-based schemes [4]. In anchor-based algorithms a group of nodes that are aware of their location (through GPS, or placed in predetermined positions), serve as anchors for the other nodes in the network, which use distance measurement techniques to calculate their position, referenced to the position of the anchors.

The most popular distance measurement techniques are [5]:

A. Received Signal Strength Indicator (RSSI)

The gap between two sensor nodes is often calculated by measuring the actual signal power at the reception (Received Signal Strength - RSS). This is a technique which offers a really low precision given that the signal strength varies according to environment conditions as well as distance between the transmitter and receiver. When employing RSS solutions it ought to be taken into consideration the particular attenuation of the communication channel, impulse response as well as multiple transmission paths, which require challenging computations. Having the power transmission along with applying standard models to define the environmental communication, the distance between two sensor nodes can be determined.

RSS comes with a significant advantage over the other methods - simplicity. It is contained in radio systems to measure signal quality. In GSM-based networks, acquiring a

Manuscript received August 14, 2011. *The work has been funded by the Sectorial Operational Program Human Resources Development 2007-2013 of the Romanian Ministry of Labor, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/60203.*

Ofrim Dragoș is with the "POLITEHNICA" University of Bucharest, Romania (e-mail: dragosofrim@yahoo.com).

Săcăleanu Dragoș is with the "POLITEHNICA" University of Bucharest, Romania (e-mail: dragos_sacaleanu@yahoo.com).

Stoian Rodica is with the "POLITEHNICA" University of Bucharest, Romania (e-mail: rodicastoian2004@yahoo.com).

Lăzărescu Vasile is with the "POLITEHNICA" University of Bucharest, Romania (e-mail: vl@elia.pub.ro).

strong signal implies a short distance from the base station; therefore the cell phone can decrease transmitting power. RSS could be estimated throughout communications, with no need of further transmissions and it's also a feasible approach regarding systems for which precision is not vital, but energy conservation.

B. Time of Arrival (ToA)

Time of Arrival - TOA requires that all network nodes have synchronized clocks. Thus, at predefined moments of time, nodes that know their position transmit specific signal tones. Non-localized nodes store the moment of time when they receive the signal tone and calculate the distance to the reference nodes.

C. Time Difference of Arrival (TDoA)

Time Difference of Arrival - TDoA does not require that non-localized nodes have synchronized clocks, but only the reference ones. Thus, the reference nodes transmit synchronous signal tones and the non-localized nodes record the time difference in receiving these signal tones.

D. Active Echo.

Active Echo involves measuring the time required for a test signal transmitted by a non-localized node to a reference node to reach back the source node. This technique requires that the reference node to be always active and also instantly send the signal back to the non-localized node. This method improves the measurement precision and also removes the necessity of perfectly synchronized clocks, challenging to accomplish inside sensor networks.

Using these distance estimation techniques, sensor nodes are able to compute their coordinates. The most common algorithms for localization implementing distance measurements are: Tri-lateration or Spherical Estimation, Multi-lateration or Hyperbolic Positioning and Least Square Estimation.

Additional to the algorithms that use anchors and distance measurement techniques to compute their coordinates, there are also anchor-free [6] and range-based [7] localization algorithms. Another example is the range-free localization algorithms [8] that use no distance estimation, but connectivity information such as hop count.

In the 2nd category, where in-situ measurements are performed, nodes are equipped with Inertial Measurement Units (IMU) [9], [10], offering information about nodes' direction and speed of movement. IMU's use only accelerometers or both accelerometers and gyroscopes to identify both the translation and rotation of the node, thus being able to calculate the coordinates at each moment.

III. LOCALIZATION MODEL

The proposed HS3D uses both IMU and anchor-based algorithm to perform the localization of the multimedia sensors. A full anchor-based localization scheme is not the best solution when talking about mobile WMSNs, because it considerably increases the delay of localization, the traffic inside the network, leading also to a considerably increase in energy consumption. Moreover, anchors primarily use GPS for localization, which has several drawbacks, being dependent on outdoor measurements and clear sky.

On the other hand, IMU measurements are in-node measurements, performed by low power accelerometers, offering reliable data. IMUs assume both a very small financial cost and energy cost (compared to the energy needed for video and sound processing), are very easy to implement, can perform both outdoor and indoor, independent from the other nodes, and do not increase the network traffic, offering a reduced delay of localization. However, to overcome the localization error from IMU measurements due to the sample rate and quantization of the A/D converter, a periodic back-up from an anchor-based scheme is needed.

A. IMU-based measurements

As discussed in [11], [12], in a 3-D inertial system, an object has 6 degrees of freedom: translation along the X, Y, Z axes and rotation about the X, Y, Z axes. To measure these 6 degrees of freedom, the acceleration on each of these degrees is measured. Systems of six 1-axis accelerometers, three 2-axes accelerometers or two 3-axes accelerometers can be used.

The proposed HS3D implements the version with two 3-axes accelerometers disposed in a cube model (Fig. 1). This model, having the two accelerometers placed in opposite corners of the cube, allows the identification of both the translation and the rotation vectors (Fig. 2), for each axis, by calculations performed over the six measured accelerations.

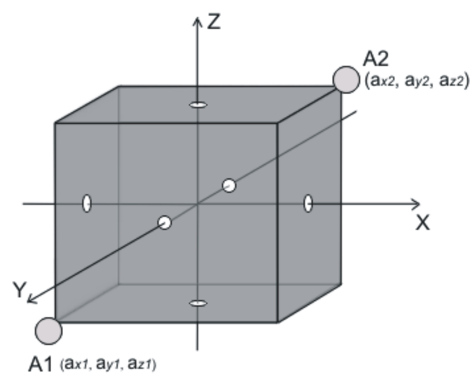

Fig. 1. Cube model for accelerometers' placement

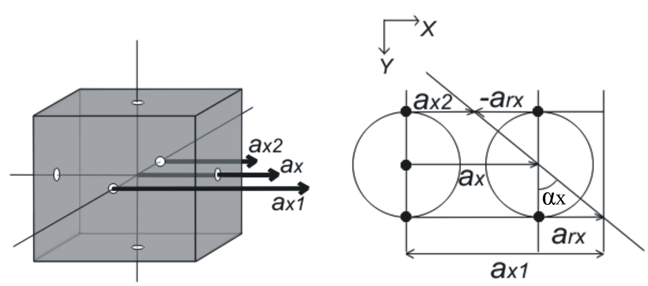

Fig. 2. Translation and rotation acceleration on X-axis

For translation, the acceleration on each axis is the average of the accelerations measured at the center of parallel surfaces of the cube, by both accelerometers, along the respective axis. This is because, in the center point, the rotation cannot be characterized, as only linear translation is detected. Knowing the accelerations and the sampling rate, velocities and distances on each axis are determined:

$$a_x = \frac{a_{x1} + a_{x2}}{2}; a_y = \frac{a_{y1} + a_{y2}}{2}; a_z = \frac{a_{z1} + a_{z2}}{2};$$

$$v_{xyz}(t + \Delta t) = v_{xyz}(t) + \int_t^{t+\Delta t} a_{xyz} dt$$
$$d_{xyz}(t + \Delta t) = d_{xyz}(t) + \int_t^{t+\Delta t} v_{xyz} dt \quad (1)$$

If the object is rotating, then the accelerations due to rotation on each axis are a_{rx}, a_{ry} a_{rz}, and the measured accelerations by the two accelerometers become:

$$a_{x1} = a_x + a_{rx}; \quad a_{x2} = a_x - a_{rx};$$
$$a_{y1} = a_x + a_{ry}; \quad a_{y2} = a_y - a_{ry};$$
$$a_{z1} = a_z + a_{rz}; \quad a_{z2} = a_z - a_{rz}; \quad (2)$$

With these equations, the accelerations on each axis due to rotation can be determined. They are half of the difference between the measured accelerations, on each axis, by the two accelerometers.

$$a_{rx} = \frac{a_{x1} - a_{x2}}{2}; \quad a_{ry} = \frac{a_{y1} - a_{y2}}{2};$$
$$a_{rz} = \frac{a_{z1} - a_{z2}}{2}; \quad (3)$$

At every measurement, the variation of the angle on each axis ($\Delta\varphi_x$, $\Delta\varphi_y$, $\Delta\varphi_z$) can be calculated. Having the accelerations due to rotation, the angular accelerations are determined:

$$\alpha_x = \frac{a_{rx}}{d/2}; \; \alpha_y = \frac{a_{ry}}{d/2}; \; \alpha_z = \frac{a_{rz}}{d/2} \quad (4)$$

where d is the diameter of the circle containing the two accelerometers (Fig. 2) .

Knowing the angular acceleration, the angular velocity is calculated and then, the angles of orientation on each axis:

$$\omega_{xyz}(t + \Delta t) = \omega_{xyz}(t) + \int_t^{t+\Delta t} \alpha_{xyz}\, dt \,;$$
$$\varphi_{xyz}(t + \Delta t) = \varphi_{xyz}(t) + \int_t^{t+\Delta t} \omega_{xyz}\, dt \,; \; (5)$$

B. Anchor-based measurements

The proposed HS3D uses a low complexity Min-Max algorithm [13], for anchor-based localization. In anchor-based localization techniques, nodes compute their location by referencing to other nodes (named *anchors*), which are GPS-enabled, thus able to determine their position.

The basis of this localization scheme is that first, nodes measure their distance to at least 3 anchors using RSSI. The concept is to consider a bounding box all around every anchor together with defining the actual junction of them. The approximated placement of the node to be localized is the particular centre of the resulting intersection box (Fig. 3).

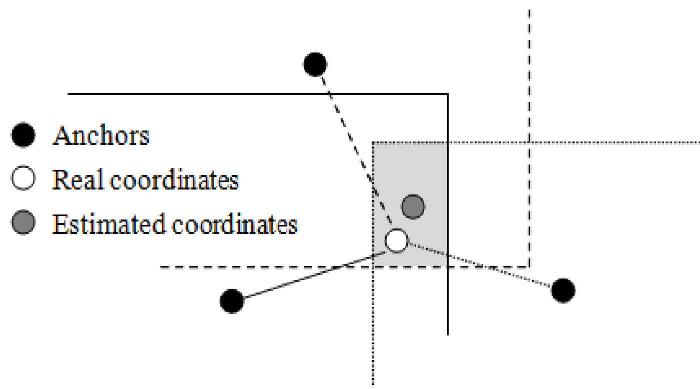

Fig. 3 Min-Max localization algorithm

The bounding box of each anchor is determined by adding and subtracting the distance (D_{ni}) towards the node to be localized from the anchors' coordinates. Therefore, the upper-right corner ($C_{ur}(n)$) and the down-left corner ($C_{dl}(n)$) of the bounding box corresponding to anchor n will have the following coordinates:

$$C_{dl}(n)\!: \; [x_n - D_{ni};\; y_n - D_{ni}]$$
$$C_{ur}(n)\!: \; [x_n + D_{ni};\; y_n + D_{ni}] \quad (6)$$

These corners can be calculated for every anchor nodes. To determine the coordinates associated with the intersection box, it is needed to identify the maximum of the minimum coordinates as well as the minimum of the maximum coordinates. The coordinates associated with the down left corner are the maximum among the minima on the Ox axis and also the maximum among the minima on the Oy axis. The coordinates associated with the upper right corner are the minimum among the maxima on the Ox axis as well as the minimum among the maxima on the Oy axis.

$$C_{dl}\!: \; [\max(x_n - D_{ni});\; \max(y_n - D_{ni})]$$
$$C_{ul}\!: \; [\min(x_n + D_{ni});\; \min(y_n + D_{ni})] \quad (7)$$

The final coordinates of the node to be localized are considered to be the center of the intersection box:

$$x_i = \frac{\max(x_n - D_{ni}) + \min(x_n + D_{ni})}{2}$$
$$y_i = \frac{\max(y_n - D_{ni}) + \min(y_n + D_{ni})}{2} \quad (8)$$

C. Network model

HS3D proposes the use of two types of mobile wireless multimedia sensors: sensors only equipped with IMUs and sensors equipped both with IMUs and GPS. The normal state of the GPS units is *off*, periodically turning on to perform a location correction, if errors have been encountered during the IMU measurements. This behavior strongly reduces the energy consumption, thus maintaining an increased grade of confidence.

Before randomly deployed in a certain area, the sensor nodes are calibrated. Considering the system of coordinates from Fig. 4 as the reference, all nodes are put in the origin and their coordinates and angles of orientation are initialized with the values from origin. After that, they are randomly deployed, always performing calculation of position and angle with respect to the initial values.

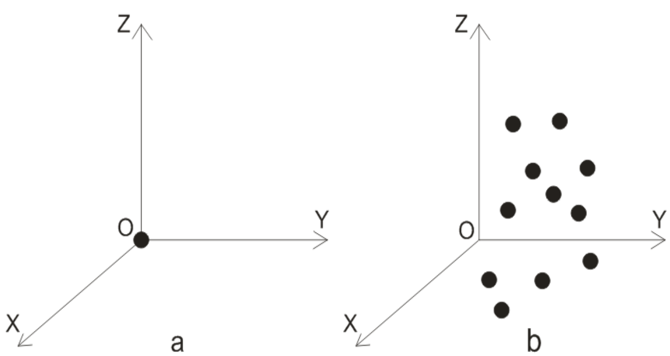

Fig. 4. Network model: a) Sensor nodes are calibrated in the origin of the reference system of coordinates;
b) Sensor nodes are randomly deployed

The direction in which the nodes are moving can always be determined with (5), and the distance that they are covering is calculated with (1).

D. Energy consumption model

One of the main challenges and goals of a multimedia sensor network is to increase its lifetime as much as possible, without affecting the performances and accuracy of the measurements. In order to do that, a rigorous analysis of the energy consumption needs to be done in order to identify efficient solutions to optimize it.

As mentioned in [14], [15], to evaluate the energy consumption of a sensor node, it has to be taken into consideration the amount of energy consumed by all the components of a sensor node in each of its possible states, along with the energy consumption attributed to the change from one state to another. A wireless multimedia sensor node has the following possible components:

Transceiver. The transceiver could be in one of the following four possible states: *off*, *sleep*, *transmit* and *receive*. The last two states consume the largest amount of energy, as transferring data through the wireless channel is much more energy demanding than the processing of the raw data obtained from the transducer. Therefore, the aim is to reduce the length of the data packets involved in the communication between nodes and the base station.

Microprocessor. The microprocessor is in charge with the acquisition and digital conversion of the signal, along with the processing of raw data and management of the entire sensor node behavior and data transfer within the network. The possible states of a microcontroller are: *sleep*, *off*, *idle* and *active*. In order to provide shorter data packets to the transceiver, the algorithms running on a microcontroller must compress the data and eliminate the redundancy. The increase in the energy consumption due to the increase in the processing demand is insignificant compared to the energy saving from the transceiver. Therefore, the microcontrollers installed on the multimedia sensor nodes must have sufficient processing capabilities in order to sustain such algorithms.

Multimedia sensors. Each multimedia sensor is equipped with a mini-camera and microphone in order to acquire video and audio streams. These sensors can be either in *off* state, or in *active* state. The amount of energy consumed by this type of sensors depends on their hardware technology. The implementation of CMOS cameras will effectively lower the overall energy consumption of a multimedia sensor node.

To calculate the total energy consumed by a sensor node within a specified period of time, the following mathematical model can be used:

$$E_{\text{consumed}} = \sum_{j=1}^{k}(n_j \times P_j) + \sum_{i,j=1, i\neq j}^{k}(st_{ij} \times E_{ij}) \quad (9)$$

The left term of the sum represents the energy consumed by a node in all states, where P_j is the power consumed in state j for n_j amount of time. In the right term of the sum the total energy consumed to switch between states is expressed, where E_{ij} represents the necessary energy to switch between states i and j, while st_{ij} is the number of switches between states i and j.

IV. Implemetation Of HS3D

In this chapter, proposed solutions for minimizing the localization error are discussed. HS3D uses several techniques to provide accurate localization calculations. In addition, techniques for reducing the overall energy consumption of the multimedia sensors are proposed.

A. Trajectory estimation pattern

The acceleration is measured at a certain sample rate. Between two consecutive measurements, the actual trajectories of the sensor nodes are not exactly known and they need to be estimated. This is an important source of error regarding the localization process, as from sample to sample the localization error could become significant.

HS3D implements an efficient scheme for estimating the trajectory of the nodes. If from the actual measured point to the next measured point, no rotation is encountered, this means that the node suffered only a translation and its trajectory is considered linear.

On the other hand, if both translation and rotation are detected between the measurements of the two consecutive points, the trajectory is approximated with an arch (Fig. 5). P_0 is the initial point of the node, at moment t_0.

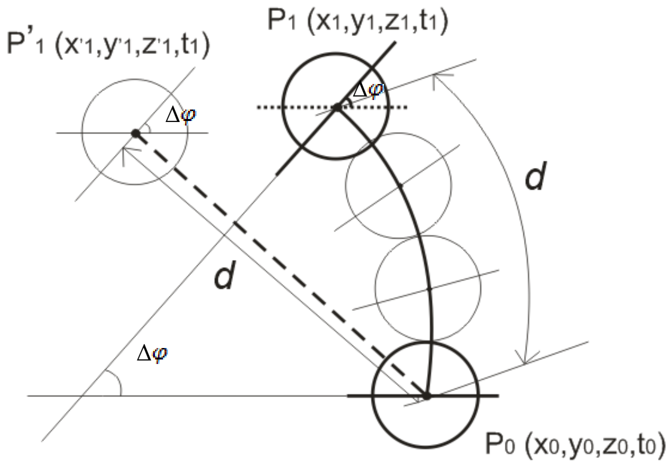

Fig. 5. Trajectory estimation when both rotation and translation.

At t_1, it could be observed both a translation (d - measured distance) and a rotation ($\Delta\varphi$ – measured change of the angle). The problem now is to estimate the new position of the node. Because the interval between the two consecutive measurements is about several milliseconds, it would be wrong to consider that translation and rotation occurred separately, thus leading the node to point P'_1. The most suitable hypothesis is that rotation and translation happened at the same time, leading the node to point P_1. This means that the trajectory of the node is estimated with an arch, with the angle at center being $\Delta\varphi$. The difference between the two points is considerable, leading to a multiplied error of localization in case the proposed arch pattern is not used.

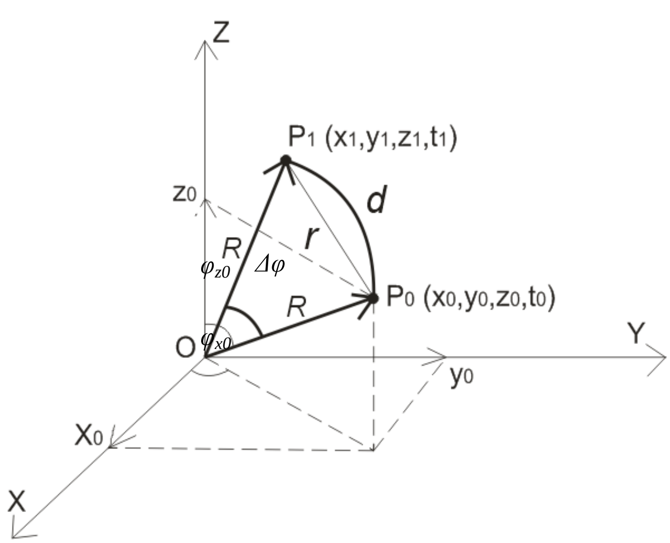

Fig. 6. Translation and rotation of node in 3-D representation

With the trajectory being identified, the new coordinates have to be calculated. The case with both translation and rotation will be used for calculations, this being the most challenging. Fig. 6 is the 3-D version of Fig. 5, calculations along the X, Y, Z axes being performed. The origin of the reference system of coordinates, described in the network model, is translated in the center of the circle containing arch d, so the coordinates in Fig. 6 are normalized.

The arch of length d (measured distance) is a fraction of a circle with radius R. With accelerations due to translation being known, d is calculated using (1). To simplify the calculations, polar coordinates are used:

$$\begin{aligned} x_1 &= R sin\varphi_{z1} cos\varphi_{x1}\,; & x_0 &= R sin\varphi_{z0} cos\varphi_{x0}\,; \\ y_1 &= R sin\varphi_{z1} sin\varphi_{x1}\,; & y_0 &= R sin\varphi_{z0} sin\varphi_{x0}\,; \\ z_1 &= R cos\varphi_{z1}\,; & z_0 &= R cos\varphi_{z0}\,; \end{aligned} \qquad (10)$$

All the φ_{xyz} angles are known from (5), and R needs to be calculated in order to determine the new coordinates of the node. R is the radius of the circle containing the arch d under the angle $\Delta\varphi$.

$$d = \frac{\pi \cdot R \cdot \Delta\varphi^o}{180^o} \Rightarrow R = \frac{180^o}{\Delta\varphi^o} \cdot \frac{d}{\pi}\,; \qquad (11)$$

To solve (7) $\Delta\varphi$ has to be determined. The *Cosines Theorem* is applied in the triangle OP_1P_0:

$$r = R\sqrt{2(1 - cos\Delta\varphi)} \qquad (12)$$

There is another way to calculate r, using the *Euclidian distance* between P_1 and P_0.

$$r = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2}$$
$$\overset{(6)}{\Rightarrow} r = R \cdot \beta \qquad (13)$$

where β is calculable from all the φ_{xyz} angles, known.

From (12) and (13) $\Delta\varphi$ is determined. Knowing $\Delta\varphi$, R is calculated from (11), and then all the coordinates from (10).

B. Periodic recalibration

Although considerably reduced, the error of localization induced by the sample rate and trajectory estimation could still rise in time to significant values, due to undetected translations or rotations. In order to overcome this issue, sensor nodes perform periodic recalibrations of their coordinates (x, y, z) and orientation ($\varphi_x, \varphi_y, \varphi_z$).

The recalibration of the angles is performed while nodes are static. In this state, only the gravitational acceleration is measured, that should be 1g on the Z axis, and 0 on the X, Y axes. If not, this means that the node is rotated and the projection of the gravitational acceleration is measured on each axis, leading to the calculation of the angles φ_x, φ_y, φ_z.

To recalibrate the coordinates, the proposed HS3D uses the Min-Max algorithm to perform the localization of the nodes. This is done periodically, at a predefined rate. The nodes predefined as anchors turn on their GPS module and verify their position. If the difference between the GPS-obtained position and the actual registered position is less than the known error of localization of the GPS, the actual position is kept. Otherwise, the GPS-obtained position is saved.

After this initialization procedure, the other nodes calculate their position with reference to these anchors. If the difference between the anchor-based determined position and the IMU-based determined position is less than a predefined threshold, the IMU-based determined position is kept. Otherwise, the position is corrected.

C. Adaptive sampling rate

The overall energy consumption of the multimedia sensor nodes must be optimized in order to increase the lifetime of the network. Considering the HS3D algorithm, the most energy-consuming task of the sensor nodes are the signal acquiring from the accelerometers along with the computation of the position. This is done classically at a predefined sampling rate.

Setting up the sampling rate raises several issues. First, if it is too low, some fluctuations in the translation or the rotation accelerations might not be detected, leading to an increase in the error of localization.

On the other hand, if the sampling rate is too high, than the volume of data will increase, and in case the multimedia nodes are moving very slowly or not at all, it will be inefficient from the energy consumption point of view. Therefore, a solution should be found in order to outcome these two drawbacks.

The solution proposed for this matter implements an adaptive sampling rate of the multimedia sensor nodes. In case low change in movement is detected, the sensors will use a lower sampling rate, which will increase accordingly if the sensors start moving faster.

After each measurement, the changes in the measured accelerations are evaluated. After this evaluation period, the next sampling moment of time is decided. In (14) the relation between the sampling period and the change in acceleration is presented:

$$t_s = \alpha \times \frac{1}{a_{RMS}} \qquad (14)$$

Where a_{RMS} represents the Quadratic Mean of the changes in rotation and translation accelerations over the three axes (Δa_t – change in translation acceleration; Δa_r – change in rotation acceleration):

$$a_{RMS} = \sqrt{\frac{1}{3}\sum_{i=1}^{3}(\Delta a_{ti}^2 + \Delta a_{ri}^2)} \qquad (15)$$

And α represents the *adaptive coefficient* which decides the ratio to which the sampling period changes in accordance to the change in the quadratic mean of the accelerations. It can be observed that as the changes in the accelerations increase, the sample period of the multimedia nodes decreases; therefore the movement of the nodes is characterized more accurately.

V. Simulation Results

To evaluate the performance of the proposed HS3D, several simulations were performed on an OMNet++ platform. Initial conditions of the simulations were: sample rate - 100 samples/s, diameter of the circle containing the two accelerometers - 5 cm, number of anchors - 10, maximum distance of communication between nodes - 500m, GPS localization error - maximum 5 m, A/D conversion time - 50μs, data rate of the RF transceiver – 250kbps, frequency of the RF transceiver – 2.4GHz.

The first objective of the simulation was to study the evolution in time of the localization error. The number of nodes in the network was 50. Three algorithms were tested and compared: the proposed HS3D, a full IMU-based scheme with no trajectory estimation and periodic calibration (IMU-L) and the Min-Max algorithm (MM). The results are presented in Fig. 7.

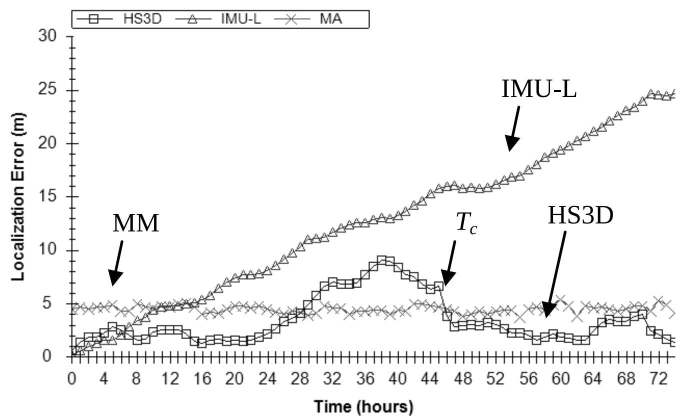

Fig. 7. Localization Error of HS3D, IMU-L and MM algorithms

For IMU-L it can be observed that the localization error accumulates over time, because no techniques are used to minimize that error. For MM, the localization error is strongly connected to the localization error of the GPS and the distance measurement error of the RSSI technique, leading to a rather constant value. In the case of HS3D, as the value of the localization error increases over time, it is still considerably lower than in the case of IMU-L, due to the trajectory estimation pattern. Moreover, periodic recalibration of the coordinates and angles of orientation are done (as it can be seen at moment T_c, Fig.7), keeping the localization error lower than in the MM case.

The second objective of the simulation was to study the evolution of the localization delay (time period until all nodes in the network are localized) related to the number of multimedia nodes in the network. The number of nodes was varied from 50 to 150 in steps of 5. Two algorithms were tested and compared: the proposed HS3D and the MM. The results are shown in Fig. 8.

It can be observed that for the proposed HS3D, the localization delay is approximately constant due to the fact that it generally depends on the A/D conversion and computational speeds of the nodes. For MM, the localization delay grows by the number of nodes in the network, because more rounds of localization are needed. In the first round of localization, nodes that are close to at least 3 anchors are able to determine their position, becoming themselves anchors. In the next round of localization new nodes are able compute their position, because the number of anchors increased. This is done until all the nodes determined their position. Because of this localization scheme, MM has an increased localization delay (compared to HS3D), dependent on the anchors-nodes ratio.

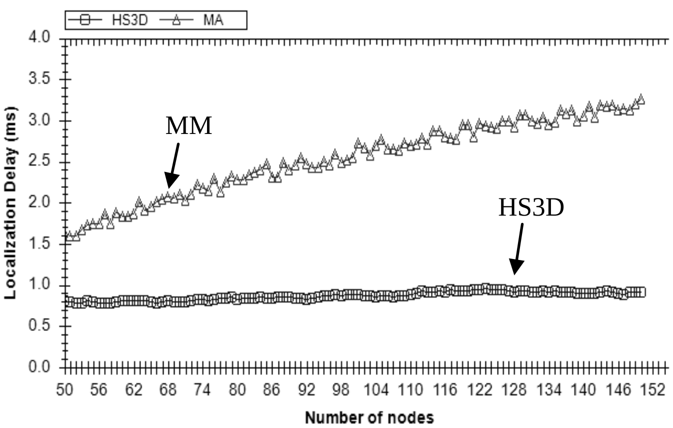

Fig. 8. Localization delay of HS3D and MM algorithms

Moreover, the repeatedly transmitted beacons from the anchors to nodes increase the network traffic and the energy consumption. To lower the localization delay, MM would need to enlarge the anchors-nodes ratio, but with energy cost due to the increased energy consumption of the GPS units.

The third objective was to test the energy efficiency of the proposed HS3D algorithm in comparison with the MM technique. For this, the lifetime of the multimedia sensor network was measured. It was considered that a network fails when 30% of its nodes run out of energy.

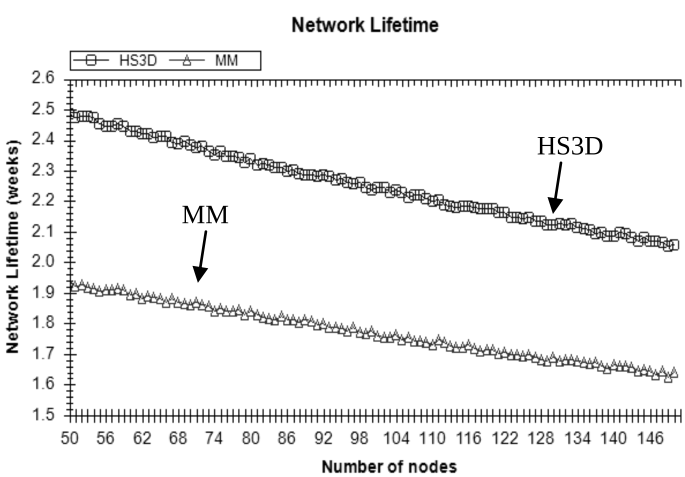

Fig. 9. Network lifetime of HS3D and MM algorithms

The number of nodes was varied from 50 to 150 in steps of 5. The maximum area of deployment was set 40.000 m^2. Each sensor node is powered up by a 3V lithium-ion battery having 750mAh. The radio transceiver of each multimedia node consumes 60mA in *active* state and 10µA in *sleep* mode. The microcontroller is an 8 bit Atmel ATmega 1281, consuming 18mA in *active* mode. For the transition between states, we considered an average of 10µAs consumption and a switch interval of 0.4ms.

In Fig. 9 the results of this simulation are presented. It can be observed that the lifetime of the network, when employed the HS3D algorithm, is essentially higher than in the case of a network using the MM techniques. This is due to the fact that in the MM case there are many data packets that are exchanged between multimedia nodes, loading the traffic inside the network. In the case of HS3D, the localization is performed locally, thus no increase in network traffic is generated, except the time moments when the calibration of the coordinates is executed.

The fourth objective was to verify the improvements in the network lifetime brought by the implementation of the adaptive sampling rate. The HS3D version with no adaptive rate was compared to the HS3D version implementing the adaptive sampling rate. The number of nodes was varied from 50 to 150 in steps of 5. The adaptive coefficient was chosen: $\alpha = 0.01\,{}^{m}/_{s}$. In order to preserve the energy a maximum sampling rate of 100 samples/s was established (like in initial conditions). The results are present in Fig. 10.

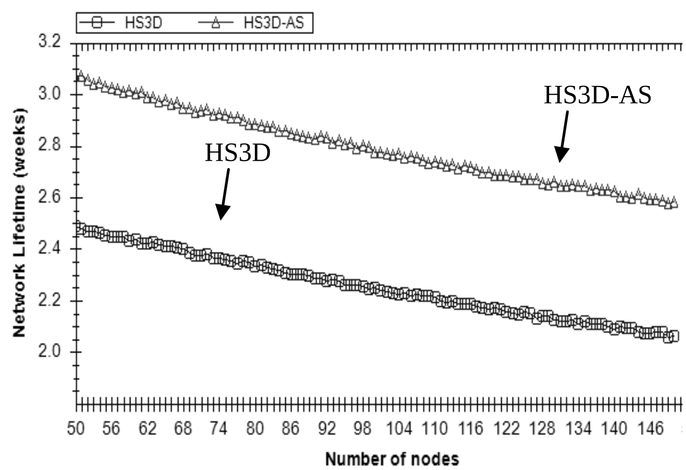

Fig. 10. Network lifetime of HS3D and HS3D-AS algorithms

It can be observed a significant improvement in the network lifetime when using the adaptive sampling rate technique (HS3D-AS), thanks to a lower sampling rate when the multimedia nodes do not encounter consistent changes in their movement. When detected, an increase in the movement is characterized by a higher sampling rate, thus preventing an unwanted increase in the error of localization

The fifth objective of the simulations was to evaluate the evolution of the error of localization when applied the adaptive sampling rate technique throughout the localization process.

The HS3D implementing the adaptive sampling rate was compared with the HS3D using the maximum sampling rate (100 samples/s). The number of nodes was 50. The results are presented in Fig. 11.

As concluded, the error of localization is slightly increased when using the adaptive sampling rate (HS3D-AS). This happens because of possible undetected quick changes in the nodes' movement in case of a lowered sampling rate. On the other hand, this is a small price to pay considering the decrease in the energy consumption of the multimedia sensor network, allowing for a considerably increase in network lifetime.

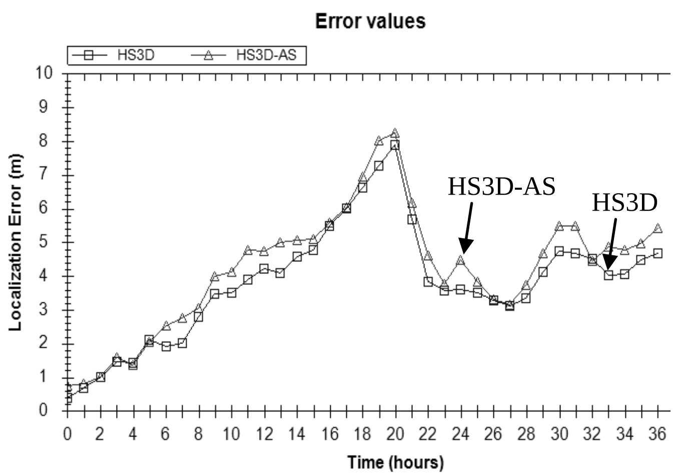

Fig.11 Localization error of HS3D and HS3D-AS algorithms

VI. Conclusions And Future Work

As tests revealed, the proposed HS3D represents an accurate solution for solving the localization problem in mobile Wireless Multimedia Sensor Networks. It can be implemented both indoor and outdoor and offers the advantages of low localization error and reduced localization delay.

Moreover, the energy consumption is considerably lower compared with the classical localization schemes. In addition, by implementing the adaptive sampling rate technique, the energy consumption is reduced even more, thus leading to an increase in the lifetime of the wireless multimedia sensor network. However, a compromise needs to be done with respect to an increase in the error of localization.

As future work, one possible topic would be the study of how the quality of the synchronization between nodes and the clock resolution affects the localization process. This topic is very important, as the lack in the perfect synchronization between the multimedia nodes could lead to a significant increase in the error of localization.

References

[1] Zhuo Xue, K.K. Loo, J. Cosmas, Wireless Multimedia Sensor Network with an Efficient Distributed Video Coding for Multimedia Broadcasting, *In 8th WSEAS Int. Conf. on MULTIMEDIA SYSTEMS and SIGNAL PROCESSING*, Hangzhou, China, April 2008

[2] Amitangshu, P. Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges, *Network Protocols and Algorithms*, 2010, Vol. 2, No. 1

[3] Bhanu, B., Ravishankar, C., Roy-Chowdhury, A., Distributed video sensors, pg.289-303 *In Springer-Verlag London Limited*, 2011.

[4] Bao, H., Zhang, B., Li, C., Yao, Z. Mobile anchor assisted particle swarm optimization (PSO) based localization algorithms for wireless sensor networks. In *Wireless Communications and Mobile Computing*, 2011

[5] Gao, J. Localization in Sensor Networks. In *Stony Brook, State University of New York* 2006

[6] Pei, Z., Deng, Z., Xu, S., Xu, X. Anchor-free Localization Method for Mobile Targets in Coal Mine Wireless Sensor Networks. In *Sensors*, 2009

[7] Hemat, K, Maheshwari, A, Kemp, H., Zeng, Q., Range based real time localization in Wireless Sensor Networks. In *Wireless Networks, Information Processing and Systems*, Volume 20, 2009

[8] Kumar, A., Vinay, K., Range-free schemes for Wireless Sensor Networks. In *WSEAS Recent Researches in Software Engineering, Parallel and Distributed Systems, Cambridge*, 2011

[9] Kuzmanic A., Vlak T., Stancic I., Inertial Sensor Measurement of Head-Cervical Range of Motion in Transverse Plane, In *3rd WSEAS International Conference on Remote Sensing*, Venice, Italy, November 21-23, 2007

[10] Ofrim D., Săcăleanu D., Stoian R., Lăzărescu V., Hybrid Scheme for 3-D localization in mobile Wireless Multimedia Sensor Networks, In *Proceedings of the 15th WSEAS international conference on Communications*, Corfu, Greece, 2011

[11] Warren S. Flenniken, Modeling Inertial Measurement units and analyzing the effect of their errors in navigation applications, *Thesis Submitted to the Graduate Faculty of Auburn University*, 2005

[12] Yi-Lung, T., Ting-Ting, T., Hyeoungho, B., Modelling ECOIMU: A dual triaxial-Accelerometer Inertial Measurement Unit for Wearable Applications. In *Proceedings of the 2010 International Conference on Body Sensor Networks*, IEEE Computer Society Washington

[13] Håkon K. Olafsen., Wireless Sensor Networks Localization Strategies. In *Master Thesis, University of Oslo*, 2007

[14] Ofrim D., Săcăleanu D., Increasing Lifetime of Wireless Sensor Networks using Adaptive Scheduling Technique, In *Proceedings of the 3rd WSEAS International Conf. on Advances in sensors, signals and materials*, Faro, Portugal, 2010

[15] Ofrim D., Săcăleanu D., Ofrim B., Stoian R., Implementation of an Adaptive Synchronizing Protocol for Energy Saving in Wireless Sensor Networks, In *NAUN International Journal Of Communications*, Issue 4, Volume 4, 2010