Analysis of Post-Deployment Sensing Coverage for Video Wireless Sensor Networks

Dan Pescaru, Vasile Gui, Corneliu Toma and Daniela Fuiorea

***Abstract* — A Video Wireless Sensor Networks is composed of hundreds or thousands of autonomous video-sensor nodes having wireless communication facilities. Effectively managing of such as networks is a major challenge. Considering that, a critical issue is the quality of the deployment from the sensing coverage viewpoint. In this paper we analyze the problem from the video-field coverage perspective. As a starting point, we analyze a localization algorithm suitable for this kind of networks. Then we investigate a quality measure that indicates if the deployment provides sufficient coverage, or whether redeployment is required or not.**

***Keywords* — sensing coverage, field of view, redeployment, video wireless sensor network.**

I. INTRODUCTION

Wireless Sensor Networks (WSN) applications have been hardly investigated nowadays in scientific, medical, commercial, and military domains, to perform sensing and monitoring of the physical world. Large-scale wireless sensor networks are composed of hundreds or thousands of autonomous sensor nodes. They operate in the absence of a pre-deployed infrastructure, are self-configurable, low cost, can be rapidly deployed and can work in hostile environments. Their sensors interact with the surroundings monitoring and measuring light, heat, position, movement, chemical presence.

Effectively managing sensor networks is a major challenge starting from deployment phase and during to entire lifetime of the network. Goals during sensor deployment include improving coverage, achieving load balance, and increasing the network lifetime. A large number of sensors can be distributed in mass by scattering them from airplanes, rockets, or missiles [1]. In that case, the initial deployment is difficult to control. However, despite of these hard conditions, good deployment is still necessary. Recent research has focused on methods to improve the initial deployment. One possible method is deploying additional sensors after the initial deployment, called redeployment [2]. Another method is to use mobile sensors [3], thus allowing sensors to relocate. While the first method implies additional post-deployment costs, the main de drawback of the second method is the complexity of moving solution, which reduces drastically the area of applications and increases the initial price.

Many of WSN applications highly depend on the capacity of the networks to determine their nodes' locations. Furthermore, location is assumed known in the realization of many network operations such as routing or security protocols. Indeed, significant research work has focused on developing efficient node localization techniques [4].

Video monitoring for infrastructure surveillance and control is a special case of wireless sensor network applications [5] in which large amounts of data are sensed and processed in real-time, and then communicated over a wireless network. These networks are called Video Wireless Sensor Networks (VWSN). In the rest of the paper we investigate the problems of localization and sensing coverage in this particular context.

II. LOCALIZATION IN WIRELESS SENSOR NETWORK

A. Localization Solutions

Considering the nature of a wireless sensor network, sensor nodes are deployed in an ad hoc manner and there is no a priori knowledge of location in most of the cases. Unfortunately, many of sensor networks applications rely on the correctness of nodes location. Different localization solutions were proposed in the recent publications. They can be classified into fine-grained localization solutions (based on timing or signal strength) and coarse-grained localization methods (based on proximity to a reference point) [6]-[8]. Further, a very next problem is the sensing coverage of supervised area. Sensing coverage highly depends on localization but not entirely. It depends also on various conditions of deployment field [9]. Next sections investigate these problems in particular case of video wireless sensor networks.

B. Localization Algorithm for VWSNs

Node localization problem and post-deployment procedures are even more complex in case of video wireless sensor networks.

In [10] is presented a node localization method together

D. Pescaru is with the Faculty of Automation and Computers, "Politehnica" University of Timisoara, Romania (phone: 40-256-403259; fax: 40-256-403214; e-mail: dan.pescaru@cs.upt.ro).

V. Gui, is with the Faculty of Electronics and Communications, "Politehnica" University of Timisoara, Romania. (e-mail: vasile.gui@etc.upt.ro).

C. Toma is with the Faculty of Electronics and Communications, "Politehnica" University of Timisoara, Romania. (e-mail: toma.corneliu@etc.upt.ro).

D. Fuiorea is with the Faculty of Electronics and Communications, "Politehnica" University of Timisoara, Romania. (e-mail: daniela.fuiorea@etc.upt.ro).

with video-field overlap estimation for surveillance applications, which employs image registration in order to align images quasi-simultaneously acquired from different video sensors. It is based on mean shift estimation [11] for robust parameters like coordinates translation, rotation angle and scaling factor estimation. The mean shift estimator is based on the mean shift algorithm, a fast and robust method to detect local maxima of a multivariate probability density.

C. *The Registration Model*

A widely used 2D geometric transformation in image registration is the similarity transform, consisting of rotation, translation and scaling. The model is defined by the equations:

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} s & 1 \\ 1 & s \end{bmatrix} \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix}, \qquad (1)$$

relating the old pixel coordinates (x,y) to the new ones. As this transform preserves the angles and curvatures, it has been named “shape-preserving mapping”. The four parameters of the transformation can be unambiguously determined from the correspondence of two pairs of points. However, in most of the cases, the number of the points available for estimating the transformation parameters s, φ, tx and ty is higher. By denoting the vector of parameters as

$$x = \begin{bmatrix} s \\ \varphi \\ t_x \\ t_y \end{bmatrix}, \qquad (2)$$

the problem of estimating the geometric transformation can be formulated as the problem of minimizing a measure of the fitting error of the available data points:

$$x = \underbrace{\arg\min}_{x} \sum_i \rho(r_i)\ , \qquad (3)$$

where the residuals r_i represent the matching error between a pair of corresponding features after registration.

D. *Computation of Transformation Parameters*

Following transformation parameters are considered: coordinates translation, rotation angle and scaling factor.

Solution starts from the observation that the angle between two line segments is not changed by translation or rescaling. Therefore, the rotation parameter, φ can be estimated based on such angles prior to estimating the translation or rescaling parameters.

Rescaling parameter estimation can also be performed prior to translation or rotation estimation, based on the distances between known pairs of points.

The translation vector components have to be calculated after the rotation and rescaling parameters have been estimated and compensated.

For rotation angle estimation, the minimal set is defined by two pairs of points (Q_i, Q_j) and (V_i, V_j), and is represented by the corresponding vectors $\mathbf{q}_{ij}$ and $\mathbf{v}_{ij}$. The angle between the two lines, which connect (Q_i, Q_j) and (V_i, V_j), respectively is given by the equation:

$$\cos(\varphi) = \frac{\mathbf{q}_{ij}^T \mathbf{v}_{ij}}{\left\|\mathbf{q}_{ij}^T\right\| \left\|\mathbf{v}_{ij}^T\right\|} \qquad (4)$$

where $\mathbf{x}^T$ denotes transpose of vector **x**.

Considering $\{\varphi_i\}$, $i = 1,2,\ldots,M$ as the set of M angles obtained from pairs of points, the rotation angle is defined as the highest density location obtained by the 1D mean shift algorithm (d=1) applied on all data angle data samples available.

In a similar manner, scale factor estimates can be obtained from the sets of pairs of points using the following equation:

$$s = \|\mathbf{v}_{ij}\| / \|\mathbf{q}_{ij}\|. \qquad (5)$$

After performing the inverse geometrical transform to compensate scale and rotation angle, robust translation vector component estimation is performed by point correspondences. Each pair of points generates pair of translation parameters. The same mean shift algorithm is used to find the best estimates of the translation vector.

This algorithm is still affected by small errors (1 to 5 pixels). To deal with these errors a post-processing step is required. Chamfer-matching post-processing could be considered [12]. First the distance transformation is computed and the distance map is produced starting from the upper right corner. The pattern we are looking for is then moved over the relief defined by the distance map. Under the action of gravity, the pattern slides over the relief until it reaches the lowest possible altitude. If this altitude is zero or close to zero, an optimal matching pattern was found in the image. More formally, the matching criterion is the correlation of the searched pattern with the distance map. The pattern is located where this correlation reaches an absolute minimum.

III. POST-DEPLOYMENT ESTIMATION OF SENSING COVERAGE

A. *Coverage Problem in Sensor Networks*

An important performance consideration for wireless sensor networks is the amount of information collected by all the nodes in the network over the course of network lifetime. This depends hardly on sensing coverage of the supervised region.

However, after an unsupervised deployment, the field coverage could present many gaps. Therefore, it is imperative to verify the functionality of the system at the post-deployment time, thus lowering the risk of early failures and inaccuracies. Moreover, the validation minimizes the expense of revisiting the site in the near future for redeployment, maintenance, or repairs.

In [13] and [14] the authors investigate the problem of modeling and evaluating the infrastructure communication coverage and reliability of a common sensor network. Theirs approach is based on reduced ordered binary decision diagrams. They also incorporate the consideration of common cause failures into the reliability analysis of the wireless sensor network.

In [15] is presented a protocol that dynamically configures the network in order to provide different coverage degrees requested by the application while maintaining connectivity.

Redeployment solutions, i.e. addition of sensor devices during the protocol evolution, were also intense investigated nowadays [16], [17]. Most of the time, redeployment is necessary when there have been some sensor nodes failures in the deployment region. In this context, important issues are how to maximize the source nodes and minimize new deployed nodes. In our analysis, redeployment could play also a role in sensing coverage maximization.

In common wireless sensors networks, the sensor nodes collect simple information about temperature, light, pressure, humidity, etc., around them, from the area determined by the fixed sensing range of the node. Versus them, video sensors could capture images of objects that are not always in the camera vicinity. The objects sensed by the camera can be at arbitrary locations. Also, the information content of images taken by different cameras in a system is unique for each of them as a result of the different relative positions, orientations and perspective of the cameras toward the observed objects.

B. *Coverage Problem in Case of Video Sensors*

In video wireless sensor networks, the sensing range of sensor nodes is replaced with the camera's Field of View. The *Field of View* (*FoV*) is defined as the maximum volume visible from the camera [18]. The camera therefore is able to capture images of distant areas and objects that appear within the camera's depth of field, which is the distance between the nearest and the farthest object that the camera can capture sharply.

In general, a three-dimensional coverage of space is required. This problem is extremely hard to analyze. Some preliminary work has been done in this direction [19]. To simplify this problem, we consider monitoring of a scene in one projection plane. In this case, all camera nodes are mounted in one plane and they shoot the images of the scene from a parallel plane.

Considering that, the main advantage of localization algorithm presented in section II is the possibility of video-field overlap estimation between each pair of camera-nodes in addition to spatial localization, as presented in Fig. 1.

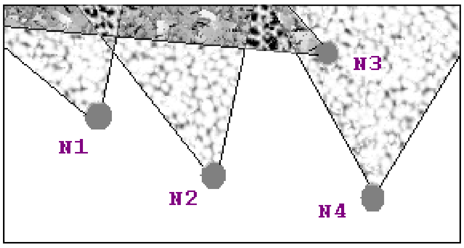

Figure 1. Fields of view overlap estimation.

IV. COVERAGE QUALITY ESTIMATION

Despite of the fact that object sensed by the camera can be at arbitrary locations, information quality hardly depends on camera's resolution, size of the object and distance between camera and object. Depending on particular application and on the size of smallest interesting object, we can determine experimentally the medium distance D_q which provide enough quality. The *Node Area* (*NA*) is defined as a circle centered in the node and with a radius D_q. The *Relevant Camera's Sensing Area* (*RCSA*) could be defined as a sector resulting from intersection of field o view and the monitored area *MNA*. Considering that, we define the *Network Coverage Area* (*NCA*) as union of all node areas and *Network Relevant Sensing Area* for whole VWSN (*NRSA*) as a cumulative area obtained from all individual cameras sensing areas as depicted by Fig. 2.

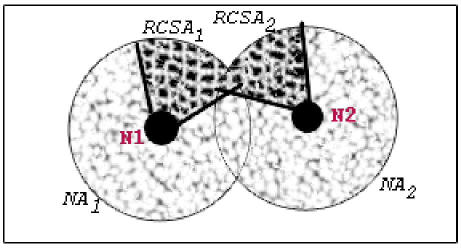

Figure 2. Network relevant sensing area (NRSA)

For a *N*-size network relations could be expressed as:

$$NCA = \bigcup_{i=1}^{N} NA_i \tag{6}$$

$$NRSA = \bigcup_{i=1}^{N} RCSA_i \tag{7}$$

An important deployment quality parameter is denoted by the ratio between *NRSA* and *NCA*. We name it *Deployment Coverage Quality* (*DCQ*).

$$DCQ = \frac{NRSA}{NCA} \tag{8}$$

V. EXPERIMENTAL RESULTS

We design a simple graphical deployment simulator in order to estimate *Deployment Coverage Quality* on various deployment conditions. To run these simulations we consider 10 different network sizes between 2 and 20 (2x*i* *i*=1..10) nodes deployed in a 2-D obstacle-less environment. Network topology uses a uniform random network model. A uniform random network is one in which the nodes are distributed randomly and with a uniform density. For such networks, the probability of finding *i* nodes in a specified domain depends only on the area of the domain and not on its shape or location. Given any area *S*, the probability that it will contain exactly *i* nodes is given by equation:

$$P(i) = \frac{(\rho S)^i}{i!} e^{-\rho S}, \qquad (8)$$

where ρ is the density of node deployment [20].

Also, we consider in our experiments only cohesive networks deployed in a fixed area with a radius of 6xD_q. That is, for each network node at least one distance between it and other node is less than 2xD_q. Also, all video cameras have identical parameters. We consider here a view angle of 60° and same resolution implying same D_q. Twenty topologies was generated for each network size and mean values was considered. Fig. 3 presents simulations results. The deployment coverage quality increases meaningful when network size exceeds six nodes. This is because in that point the worst case DQC start to rise from value of 0.16 and the best case achieve 1 when at least six nodes have same location and non-overlapping video fields.

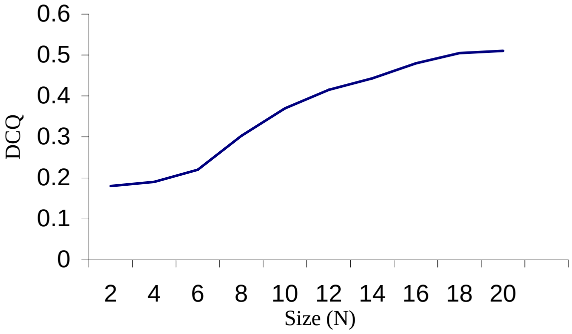

Figure 3. Deployment coverage quality (DCQ) variation

As a future work we plan to do investigation on relationship between the network size and the deployment area and shape.

VI. CONCLUSION

Localization solution and coverage analyses in video wireless sensor networks were presented. A deployment coverage quality parameter was proposed for coverage estimation. Experimental results on various deployment simulations were presented.

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