Energy Efficient Environment Monitoring Using Minimum Volume Ellipsoid

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***Abstract*—Distributed signal processing is an important area of research in wireless sensor network to make the network durable by using the processing capacity of the individual sensor nodes in the wireless sensor network. Environment monitoring is one brightest application of wireless sensor network. In this paper we have designed a novel way to estimate the state of the environment using minimum volume elisoid method in incremental strategies. The mathematica formulation is done. The mathematica formulation id aso done to calculate the lifetime of the sensor network both for classical technique and proposed technique and it was shown that the lifetime of the sensor increases much more in the proposed technique. The proposed technique is simulated.**

***Index Terms*—convex optimization, distributed signal processing, Minimum volume ellipsoid**

I. Introduction

Wireless sensor network finds extensive application in real life problem[1]. Environment monitoring is one the important application of wireless sensor network. In this case we have to estimate the condition of the environment and then appropriate action is to be taken to aleviate the problem in the environment. There are large number of application which belongs to the environment monitoring like precision agricultre, monitoring hazardious environment like fire in forest, volcanic erruption and for survelliance purpose. In this type of application the sensors are spread across the environment. They start to measure the parameter of the environment in regular interval. For precision agriculture they measure humidity of the field in reguar interval. If in some area the humidity will decrease below a threshhod level then there is scarcity of water, in order to save the crops water should be supply to that area. In case of fire in the forest sensors measure the temperature of the environment. If in some area the temperature is above than the some threshhold level then there is possibiity of fire in that area.

In cassical technique all sensors are sending the temperature value and their position information to the fusion center in regular interval. The fusion center will process the data and will estimate the condition of the environment. When some measured values are above or below some threshhold level then the fusion center will find that there is some abnormal condition has occured and will estimate the area in which it has occured. Then the appropriate action will taken by the control center to alleviate that problem. In this case large number of communication overhead will occur to rout the position and measurement data to the fusion center. Due to large number of communication near the fusion center the sensors near to the fusion center will die down very fast and a time will come when the fusion center will not able to communicate with the other nodes so that the objective of the entire network will no more able to full filled. At that time we can caled the sensor network is dead and large amount of energy of sensors will remain unuse.

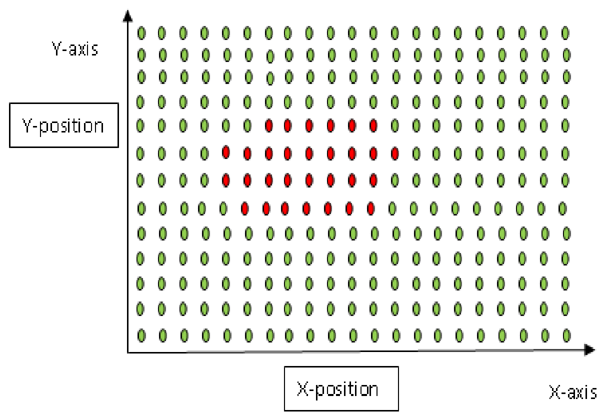

Fig. 1. Sensors are spread in regular manner in th environment

In order to avoid the above drawbacks the processing power of every sensor can be used to increse the lifetime of the network. Incremental and diffusion strategies have been proposed in the literature [2], [3]. In this paper the incremental strategies is used to estimate the area in which the abnormal condition has occured.

As given in fig.1 the sensor are spread in regular rectangular manner to measure the temperature. Suppose the red sensors have sensed a temperature above thethreshhold level then the fusion center will estimate the area where abnormal condition has occured. If we will use the in-network processing power

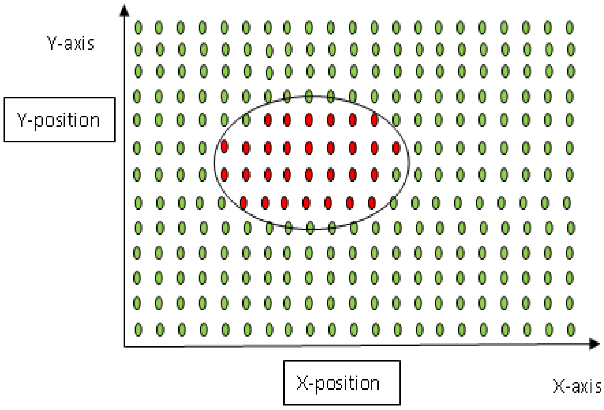

Fig. 2. Sensors in red and blue measure temperature above threshhold and below threshhold respectively

of the sensor to estimate ellipse which is the minimum volume ellipsoid like fig.2 covering the red sensors position then we can increase the life time of the entire network.

Estimating the minimum volume ellipsoid covering a finite set is a convex optimization problem[4]. Estimating e minimum volume ellipsoid covering an ellipsoid and a point is also a convex optimization problem. We can take the previous elipse information as constraint and the ellipse can be formed from the previous informantion and new position.

A. notation and paper organization

In this paper the notaion is same as used in [6]. The bold capital letter is for matrix. The bold small letter is for vector. The small letter is for realization of a matrix or a vector. The organization of the paper is as follows. In section II the problem is formulated. The proposed technique is given in section III. Section IV is for life time calculation of the network for classical and proposed technique. In section V simulation result is given and the paper is concluded in section VI.

II. Problem formulation

Suppose there are N number of sensors are spread across the environment. The sensors can be shown by matrix $\mathbf{S}$.

Where

$$\mathbf{S} = \left[\begin{array}{cccc} \mathbf{s}_1 & \mathbf{s}_2 & \cdots & \mathbf{s}_N \end{array} \right] \tag{1}$$

Here $\mathbf{s}_j \in \Re^2$ is the position of the sensor j in x and y coordinate. So the set $\mathbf{S}$ contains the entire sensors position. The sensors are spreaded across the area A. The aim is to estimate the condition of the environment. Suppose the sensors are in regular rectangular manner as shown in Fig-1. Suppose the temperature has increased in the positions of the sensors which is shown in colour red. Let the area is $\mathbf{S}_a$. In order to know the area in which the abnormal condition has occured. In classical technique the sensors sensed the temperature and send their measured data and positins to the fusion center. The fusion center wil estimate the area in which the temperature has increased above the threshhold level.

As it is known that the minimum volume ellipsoid covering the a finite set is a convex optimization problem. If by sharing the information among the sensors we can form a minimum volume ellipsoid and only the parameter of the elipsoid that is the center and spreading matrix to the fusion center. Then the fusion center will also able to estimate the area in which the abnormal condition has occured.

The parameter of a elipsoid is given by one vector $\mathbf{c}$ and one semidefinite matrix $\mathbf{A}$. So the ellipsoid is

$$E = \{\mathbf{c} + \mathbf{A}u \mid \|u\|_2^2 \leq 1\} \tag{2}$$

Where $\mathbf{c} \in \Re^2$ and $A \in \Re^{2\times 2}$. The center of the ellipsoid is $\mathbf{c}$. The spreading matrix of the ellipsoid is $\mathbf{A}$.

Any point $\mathbf{x}_i$ in the ellipsoid must satisfy the following equation.

$$\|\mathbf{A}\mathbf{x}_i + \mathbf{c}\|_2^2 \leq 1 \tag{3}$$

So the objective is

$$\min_{\mathbf{A},\mathbf{c}} \left\{ vol\,(E) \;\middle|\; \begin{array}{l} \mathbf{E} = \mathbf{c} + \mathbf{A}\mathbf{u}, \|\mathbf{u}\|_2^2 \leq 1, \|\mathbf{A}\mathbf{s}_i + \mathbf{c}\|_2^2 \leq 1, \\ i = 1, \cdots, N \end{array} \right\} \tag{4}$$

If the entire positions of all sensors whose temperature have gone above the threshold level can be known then to estimate the above objective will possible. This requires large number of communication overhead. An algorithm is called fully distributed if a sensor only will usees the data from it's neighbourhood sensors only. In order to sove this problem in a fully distributed way a new technique is proposed in this paper.

A. Neighbouhood sensor

By assumption the sensors are in regular manner. Suppose the distance between two nearest sensors in one row or column is d. The neighbouhood sensors to a sensor j is given by

$$S_{n_i} = \left\{ \forall s_j \;\middle|\; \begin{array}{l} \sqrt{\left(s_i\,(1,1) - s_j\,(1,1)\right)^2 + \left(s_i\,(2,1) - s_j\,(2,1)\right)^2} \\ \leq \sqrt{2}d \end{array} \right\} \tag{5}$$

III. proposed techniques

In order to solve the problem in a fully distributed way a sensor should know the perticuar sensor among it's neighbourhood to which it should send it's data. In order to do that a routing technique has been propsed.

A. Finding the routing path

There are three types of interaction strategies among sensors is shown in literature[2].

(1) Incremental strategies.
(2) Diffusion strategies.
(3) Probabilistic diffusion strategies.

Here the incremental strategies is taken into account which is very simple. So it is easy to formulate the routing path using this strategies. The figure of the incremental strategies is given in Fig-3. Finding the incremental path so that the sensors will collaborate to their neighbour sensor is given below.

The proposed technique is like below. There are two types of strategies one is like (a), another one is like (b). There are three direction $g1, g2, g3$. Sensor will take the following way to decide to which sensor they should communicate.

(1) The sensor should send the data to $g1$ direction sensor, if not able then $g2$ direction sensor, if not then to $g3$ direction sensor. So they should choose a direction in order $g1, g2, g3$.

(2) The sensor should not send the data to the sensor from which it has just received the data.

B. Proposed technique to find the required ellipse

The sensor should communicate like the above way. If the sensor will find that the sensed tempreture is above than the threshhold level then it will take the previous information as constraint and then it find a new ellipse using it's own position and previous infomation. If the sensor measure the temp that is not above the threshhold level then it will send the infomation to the next sensor without any change in it. By this way this will conitnue from the sensor 1 to sensor N.

The algorithm start from the value of the center $\mathbf{c} = zeros(2, 1)$ and the spreading matrix $\mathbf{A} = zeros(2, 2)$. The processing starts from node 1 and it will go incremental manner and path obtain according to the strategies in subsecion III.A to node N. When it will encounter the first sensor whose temperature has gone up, it will make the first ellipse, but for one node it will be the circle so it's center will be the position of the sensor and the spreading matrix is a very smal value that will be the radious of the circle. So

$$\begin{aligned} \mathbf{c}_k &= \mathbf{s}_k \\ \mathbf{A}_k &= k \times diag\left(I\left(1,2\right)\right) \end{aligned} \tag{6}$$

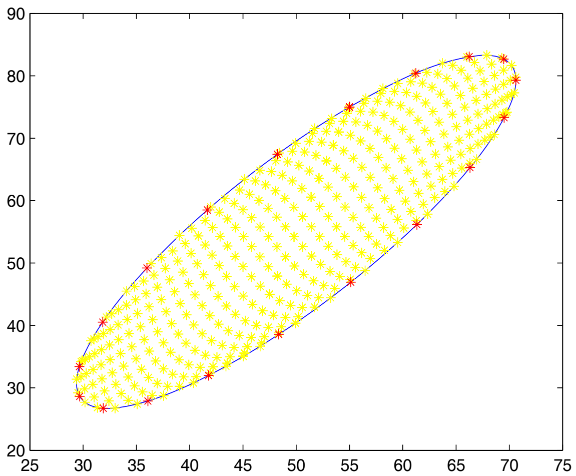

Fig. 3. Ellipsoid and ellipse

Then when it will encounter the second sensor whose temperature has gone up it will update the new ellipse taking the preveious ellipse as the constraint. As shown in the fig-4 the yellow area is the ellipsoid which can be get by the equation2. If the points only on the border area of the ellipsoid will be consider to be subset of the new ellipsoid then the entire ellipsoid will be also subset of the new ellipsoid. x

The outer ellipse can given by the equation

$$\mathbf{E} = \left\{ \mathbf{c} + \mathbf{A}\mathbf{u} \,\middle|\, \|\mathbf{u}\|_2^2 = 1 \right\} \tag{7}$$

In order to choose 20 points in regular interval. This can be done by the follwing method

$angle = linspace(0, 2*pi, 20)$
$for \quad i = 1:20$
$x\_position(i) = c(1,1) + A(1,1) \times \cos\left(angle\left(i\right)\right) + A\left(1,2\right) \times \sin(angle(i))$
$y\_position(i) = c(2,1) + A(1,1) \times \cos\left(angle\left(i\right)\right) + A\left(1,2\right) \times \sin(angle(i))$
end

So the new minimum volume elipsoid to be fomred which will include the 20 points of the previous ellipse and the new position. So the total points is 21. Now the problem is to estimate the new minimum volume ellipsoid covering the 21 points.

Mathematically the problem is

$$\begin{aligned} &\min \quad \log\det\, A_{k+1}^{-1} \\ &s.t. \quad \|A_{k+1}x_i + c_{k+1}\|_2^2 \leq 1, \, \forall x_i \in O_k \end{aligned} \tag{8}$$

This can be solved by gradient based method using interior point method

IV. Sensor Network Lifetime

The sensor network life time is defined by the duration from the deploy of sensor network to the time when it will not able to solve the objective for which it was deployed. This time can be calulated by the state space approach. Suppose the energy of i^{th} sensor is ϵ_i and transmitting energy loss in one transmission is e_i. Let the intitial energy and transmission energy is same for all the sensor nodes.

The lifetime of a sensor network depends upon three factors

(1) The architerture of the network. Here we have taken the flat and fixed architerture with rout path is to the fusion center in clssical technique and rout path for proposed technique is defined in the section III-A.

(2) data colection intiation of the sensor network. There are several type of data collcetion mode. In this paper the sensors are measuring the environment data at regular interval.

(3) The energy consumption model of the sensor network. There are two types energy consumption in wireess sensor network. One is continuous energy consumption and another one is reporting energy consumption. Let the continuous energy consumption is same for every sensor and it is ϵ_c. Suppose the sensing energy is negleted.

So minimum e is the amount of energy is required for the transmission of one bit data in one time. So if the energy of one sensor decreases less than e then it will not able to send it's data. Then we can called the sensor is dead. Energy state of the sensor network can be defined by the vector

$$\varepsilon = \left[\begin{array}{cccc} \varepsilon_1 & \varepsilon_2 & \cdots & \varepsilon_N \end{array} \right] \tag{9}$$

Energy of the sensor will decrease by reporting energy and continuous energy. Let the reporting interval is λ. So after n reporting time the energy of the sensor will be

$$\varepsilon_i^k = \varepsilon - \lambda k \varepsilon_c - kbe \tag{10}$$

So the energy of any sensor will be one of the any value belong to the set.

$$\epsilon_{p,i} = \left[\begin{array}{cccccc} \epsilon_i & \epsilon_i - 1 \times e_i & \epsilon_i - 2 \times e_i & \cdots & \epsilon_i - (L-1) \times e_i & \epsilon_r \end{array} \right] \tag{11}$$

So the entire space is a discrete space points are in N dimensions with points corresponds to the energy state of the network which says condition of the sensor. The state moves from one state to the other state with time interval. There are some area in which if the state will fall then the network will be of no use. But some resudual energy will remain which will not able to use. Then we called the network is in dead state. If the reward wil give for every change of the state until it will fall in the dead state then the total reward times the interval time between two reporting time will be the life time of the entire network. Suppose if N_0 sensors will be dead then the entire network is dead. So the ife time can be defined by the time from the deploy of the sensor network until N_0 numbers of sensors will become dead.

A. *In classical technique*

In classical case since sensor are sending their data and position to the fusion center so the sensors responsible to send their data in one hop to the fusion center will face large number of energy reduction. So the probality of becoming first dead for neighbourhood sensor to the fusion center is one. So for classical technique the sensor network life time can be defined by the time from the deploy of the sensor nodes to the time when the all the neighbourhood sensor of the fusion center will become dead. For classical technique the state vector can be rearranged like below

$$\varepsilon_{cl} = \left[\begin{array}{cc} \varepsilon_{fn} & \varepsilon_{nfn} \end{array} \right] \tag{12}$$

So if we will take

$$\mathbf{E}_{fne} = \left\{ \sum \mathbf{E}_i \, | i \in S_{fn} \right\} \tag{13}$$

and

$$\mathbf{E}_{nfne} = \left\{ \sum \mathbf{E}_i \, | i \in (\mathbf{E} \backslash \mathbf{E}_{fne}) \right\} \tag{14}$$

Now we can write a new state vector of two dimension

$$E = \left[\begin{array}{cc} E_{fne} & E_{fne} \end{array} \right] \tag{15}$$

So the transition of the state vector 15 to a state vector

$$P\left(\left[\begin{array}{cc} E_{fne}^k & E_{nfne} \end{array} \right] \middle| \left[\begin{array}{cc} E_{fne}^1 & E_{nfne}^1 \end{array} \right] \right) = 1 \tag{16}$$

mathematical calculation

$$L_T = \frac{E^{nf}}{E_c^{nf} + \lambda E_r^{nf}} \tag{17}$$

Suppose to send the data one sensor using b number of bits. In one time frame the number of data will send is $3Nb$ to the fusion center. So the number of communication will occur for the senor spreading neighbourhood to the fusion center is $3nb$. So energyloss per unit time is continuous energy loss which is ϵ_c^{nf} and reporting energy loss is $3Nbe/L$.

So lifetime of the sensor network is

Which is

$$L_T = \frac{\epsilon^{nf}}{\epsilon_c^{nf} + 3Nbe/L} \tag{18}$$

B. *In proposed technique*

In the distributed case the sensor are sending the data to it's next sensor not to the fusion center. So the sensor near to the fusion center not will do large number of routing. If one of the sensor fails then some part of the environment will not able to work properly. So we can take life time of the sensor until one sensor will become dead. in order to take worst case condition we are considering sensor near to the last sensor then in every iteration they are processing some data and sending the updated data to the next sensor. So in one interval the sensor sending the data is $6b$.

So the life time of the sensor network can be defined by

$$L_T = \frac{\varepsilon_i}{\varepsilon_c^i + \lambda \varepsilon_r^i} \tag{19}$$

Which is changed to

$$L_T = \frac{\varepsilon_i}{\varepsilon_c^i + 6be/L} \tag{20}$$

V. Simulation Result

Here 121 sensor have taken into account. The left bottom is the first sensor and right top is the Nth sensor. The routing path is taken like (A) of fig:3. In this case $40, 41, 48, 49, 50, 51, 59, 60, 61, 62, 74, 75$ sensors sensed the tempreature in that case temperature has gone above the threshhold evel. In the first figure the ellipse has formed by $48th$ sensor taking previously formed ellipse by sensor 40 and 41. The second figure is the final ellipse formed after the process. Now the last ellipse parameter is center and spreading matrix. Center is

VI. Conclusion

The technique shown is very good for the environment where the environment change sets is very near to the convex sets. It increases the lifetime of the sensor network with large scale. The lifetime of the both the case is shown in which it is shown that the life time for the proposed technique increases very rapidly.

When the environment changes is not near to the convex sets then the problem and formulation becomes very interesting.

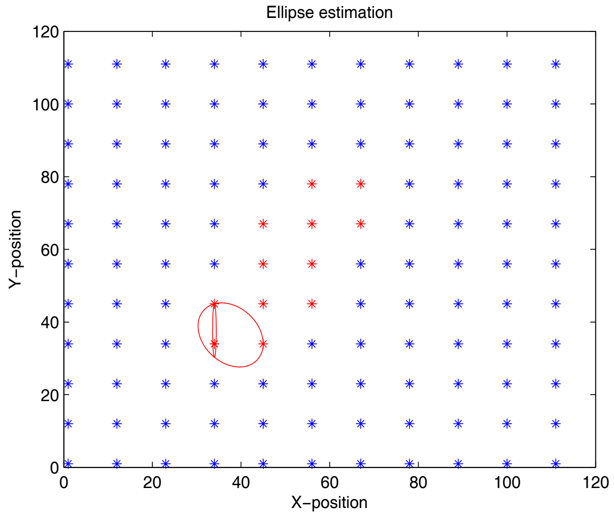

Fig. 4. Ellipse formed by three sensors position

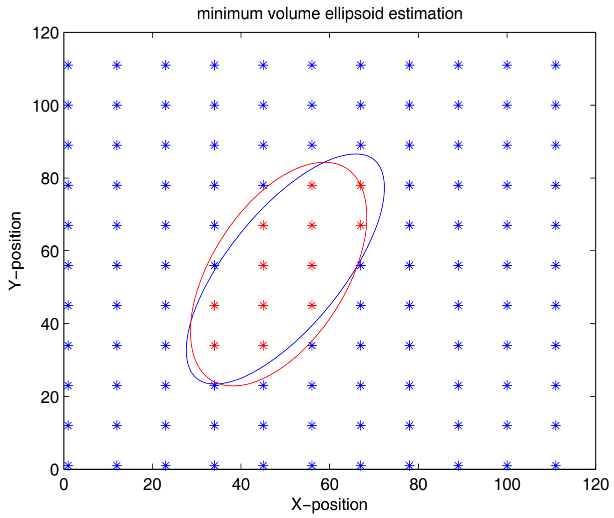

Fig. 5. Ellipse formed by all the sensor

Designing the new energy efficient protocol to increase the lifetime of the sensornetwork. Which can regard as the furure work of this.

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