Location Estimation of Sensor Nodes using Harmony Search Algorithm

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Abstract

Wireless sensor networks (WSNs) consists of thousands of sensor nodes that are deployed randomly for various monitoring and sensing applications. Location estimation of sensor nodes is a key factor in WSN as the sensed information can be useful only when its location is known. The locations of the sensor nodes can be estimated using a process of localization. One of the critical issues in localization is the accuracy of the estimated locations. The accuracy of the localization is affected by the environmental or measurement noise which results in localization error. This demands the minimization of localization error. Thus, the localization problem can to be treated as an optimization problem with an objective of estimating accurate locations of sensor in a minimum amount of time. In this paper, location of randomly deployed sensor nodes has been estimated using a few special nodes called as anchor and an optimization algorithm. A population-based meta-heuristic algorithm namely Harmony Search (HS) algorithm has been used to minimize the localization error in the simulated environment of WSN. The results of HS-based localization are compared with results of deterministic trilateration algorithm. The HS algorithm has shown improved location estimation accuracy with the compromise in computing time.

Key Words: Localization, Triangulation, Harmony Search Algorithm, Anchor

1. INTRODUCTION

Wireless sensor networks (WSNs) is composed of several small, low end sensor nodes with minimal memory and processing capability. The primary applications of WSNs include battlefield and traffic surveillance, detection of air and soil pollution, precise agriculture, healthcare, home and office automation etc. [1]. The received information from sensor node can be processed if the location of the sensor node is known. Therefor localization plays a key technology role in WSNs. The most commonly used approach in localization is deployment of Global Positioning System (GPS) in sensor nodes. This approach is not cost effective and feasible as some of the sensors may not be reachable to the satellite due to harsh and unstructured environments. With these problems only a few nodes can be equipped with the GPS and they are referred as anchors. They are aware of their positions and the remaining nodes are termed as unknown nodes. The localization algorithms estimate the location of the unknown nodes with the help of anchors. The unknown nodes measure the distance from the anchors and estimate their location using localization algorithm. The distance measurement can be with the help of the received signal strength, time and direction of the signal [2]. The localization used in this study is range-based technique that uses time difference of arrival (TDoA) for the distance measurement. Also, the localization is distributed in manner and it is performed by each unknown sensor node. Several other approaches of localization include range-free, centralized or anchor-less approaches [3]. The distance measurement in each localization is erroneous due to the environmental noise. The geometric algorithms use the fixed set of equations based on the distance, time or angle of the signal which results in inaccurate location estimation. This drawback can be overcome by the meta-heuristic algorithms that can perform the localization with an objective of reducing the localization error. These algorithms are based on the concepts of Computational Intelligence (CI) and they are adaptive, simple, efficient and with less computation cost. Harmony Search (HS) algorithm is an evolutionary algorithm based on the improvisation process of music by musicians [4].

2. RELATED WORK

Localization has been used in many routing applications and protocols. Many WSN applications associate the location of a sensor to the context sensitive information. Thus, it is important to evaluate the performance metrics in the localization algorithms to select the appropriate algorithm for the given scenario. A metaheuristic algorithm namely Bat Algorithm (BA) is proposed for localization problem in article [5]. The BA has been combined with Doppler Effect for improving the performance. The results indicate the substantial improvement in the accuracy of location estimates with the use of BA. Similarly, four mobile semi-mobile anchors and BA has been used for localization with angle of arrival as a distance measurement technique in article [6]. Another algorithm based on the leadership attacking hierarchy of wolves has been used for WSN localization has been presented in article [7]. The results of localization error and computing time have been compared with other metaheuristic algorithms such as Particle Swarm Optimization (PSO) and modified BA. The Grey Wolf Optimization (GWO) algorithm is better in performance in comparison with the other two algorithms. Various versions of the PSO algorithm have been used in various routing, clustering and energy optimization in WSN.

PROBLEM DEFINITION:

A simulated environment of WSN with N number of nodes is considered with anchors (A) and unknown nodes (U). Each unknown node used the distance (d) from the 3 non-collinear anchors and the localization algorithm to estimate its location as (u_{ix}, u_{iy}). The algorithms are namely trilateration and harmony search algorithm. The trilateration algorithm uses the conventional geometric method and the HS algorithm uses the heuristic approach that substitutes the randomly generated and then refined values in each iteration to minimize the localization error. Finally, the mean square localization error is computed by using the estimated locations and the actual locations.

3. METHODOLOGY

Some of the factors that affect the quality of localization algorithms are: network structure, node density, number of beacons, communication range etc. Localization can be broadly classified as range-free or range-based. This work uses range-based localization with an assumption that the WSN is a combination of unknown nodes and the anchors. The details of trilateration and the HS-based localization are given in this section.

3.1 Trilateration

Each sensor node measures distance d from 3 or more non-collinear anchors. The deterministic method used in this work is trilateration. The trilateration uses locations of the three anchors. The unknown node measures the distance from itself to three anchors using time of arrival (TDoA) of a signal. In the TDoA measurement, the transmitter sends a signal and waits for the time t_d and produces a pattern of sound. The receiver stores the time of receiving as t_r using the radio signal. When the receiver detects the sound pattern, the time is recorded as t_s. The distance calculation is given in (1).

$$d = \frac{v_r \times v_s}{v_r - v_s} \times (t_s - t_r - t_d) \quad (1)$$

The term v_r and v_s denote the speed of radio and sound waves respectively. The terms $t_d$represents time delay, $t_r$or time radio and t_s represents time sound.

The measured distance is added with Gaussian noise as given in (2).

$$g = r_1 \times \frac{p}{100}(-1)^{r_2} \quad (2)$$

The parameter p denotes the percentage of noise. The percentage of noise increases if there are more uncertainties in the environment. The parameter r_1 is uniformly distributed in the range [0,1]and r_2 is 0 or 1 chosen in a random manner. The unknown node must be within the communication range of each anchor. Each anchor is represented as a circle with communication range as its radius. The intersection of three circles is treated as the estimated location of that unknown node.

3.2 Harmony Search Algorithm

The localization using HS algorithm uses a heuristic approach by taking the three anchor locations and the distance measurement as input. The location estimation error is denoted by the term E. The algorithm searches the locations in such a way that it minimizes the value of E. The HS algorithm is based on the techniques used by musicians and instrument players. The musicians store each musical note by varying the pitch, rhythm, bass etc. related to each instrument. Similarly, in the HS algorithm, the possible solutions for the given problem are stored as harmony (H) in an archive, termed as harmony memory (H_m). The maximum number of iterations used in the algorithm are termed as k_{max}. In each iteration the new value of H is generated and stored in H_m. The value of H is updated using parameters such as the harmony memory consideration rate (H_r) or a random element with a probability of $1 - H_r$ and pitch adjustment rate (P_r). Each component in H_M is deviated by changing the pitch adjustment with in a range called fret width (F_w). The greedy strategy is applied with which the solutions with better fitness are adopted and the ones with inferior quality are discarded. The steps in the HS algorithm for localization are given in Algorithm 1.

Algorithm 1: Harmony Search Algorithm

1: Initialize locations of the unknown node randomly;

2: Initialize the H_R and P_R

2: Evaluate fitness function as given in (3) and store fitness value in HM;

3: k = 1

4: k < k_{max} do

5: Improvise the locations;

6: Improvise the HM and evaluate the fitness;

7: Update the HM parameters and save the new locations;

10: k = k + 1;

11: end while

12: Store the locations with best fitness

The HS algorithm is executed for k_{max} iterations with input parameters as three anchor locations and distance values. Another condition for terminating the algorithm is all the unknown nodes are localized. The fitness function used in HS algorithm is given in (3).

$$e = \frac{1}{3}\sum_{i=1}^{3}\sqrt{\left(U_{jx} - a_{ix}\right)^2 + \left(U_{jy} - a_{iy}\right)^2} \quad (3)$$

The terms i and j represent the j^{th}dumb node measuring distance from i^{th} anchor node. The values of $(U_{jx,}U_{jy})$ are varied based on the HS algorithm k_{max} iterations to get the desired fitness. After completion of the k_{max} iterations or when all the unknown nodes are localized the mean square error (E) is calculated as given in (4).

$$E = \frac{1}{L}\sum_{i=1}^{L}\sqrt{\left(u_{jx} - U_{jx}\right)^2 + \left(u_{jy} - U_{jy}\right)^2}$$

The terms (u_{jx}, u_{jy}) represent the actual locations that were generated randomly at the beginning of the algorithm for j^{th} dumb node. The term $(U_{jx,}U_{jy})$ represent the estimated locations of unknown sensor nodes. The term L denotes the number of localized nodes.

4. SIMULATION RESULTS

The simulation has been performed using the MATLAB 12.0 version. The parameters used in trilateration and the HS-based localization are given in Table 1. Localization process takes place in multiple stages. The L number of sensor nodes get localized and help in localization of remaining unknown nodes. The details of location estimation, error in location estimation and the time required for localization has been recorded for each stage. The details of the parameter setting used in the localization method are given in Table 2. The results for localization using trilateration and HS algorithm is illustrated in Table 3 and Table 4 respectively. The terms S, E and T denote the stage, number of localized nodes, localization error and computing time respectively.

Table 1. HS Parameters

SI. NO	Parameter	Term
1	k_{max},	100
2	H_m , H_n	30,20
3	H_r, P_r	0.8,0.2
4	F_w	$0.2 \times (max - min)$

Table 2. Parameter Setup in Localization

S NO	Parameter	Term
1	(x_{min}, y_{max}) (x_{max}, y_{max})	(0,0) (100,100)
2	P	0.001
3	A	20
4	U	100
5	R	30

The parameter setting is based on the bio-inspired localization in article [11]. In the initial phase the nodes that are not in the vicinity of the anchors are not localized. But in the subsequent phases, localized nodes help their peers and finally all the nodes in the WSN get localized. The initial deployment of 100 unknown nodes and 20 anchors is shown in Fig. 1. The nodes get localized in multiple stages.

Table 3. Localization using Trilateration

#	S	L	M	T
1	1	42	0.75	4.21
	2	78	0.81	5.34
	3	100	1.54	8.41
2	1	66	0.42	2.14
	2	82	1.62	3.41
	3	100	0.51	4.43
3	1	54	1.13	3.03
	2	100	1.31	5.21
4	1	53	0.15	2.41
	2	80	0.22	5.31
	3	100	0.31	6.34

Table 4. Localization using HS Algorithm

#	S	L	M	T
1	1	52	1.45	1.36
	2	88	2.53	2.74
	3	100	4.54	3.62
2	1	56	1.36	1.24
	2	91	2.46	2.12
	3	100	2.68	3.33
3	1	74	1.13	1.53
	2	100	0.25	1.13
4	1	33	0.93	1.11
	2	76	0.98	5.21
	3	100	1.31	6.12

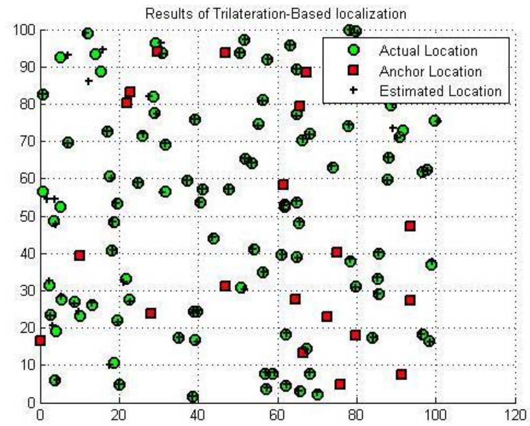

Fig. 1 Initial Scenario of WSN

The final stages of both trilateration and HS-based localization are presented in Fig. 2 and Fig. 3 respectively.

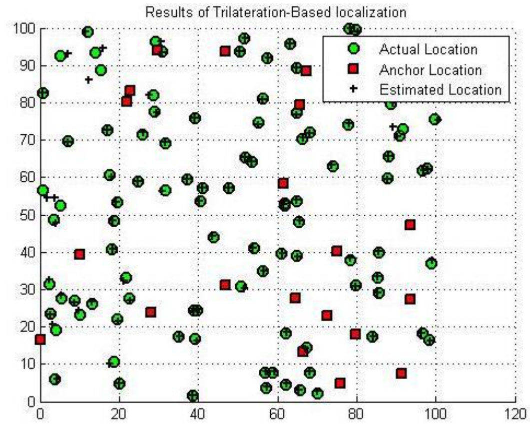

Fig. 2 Results of Trilateration-based localization

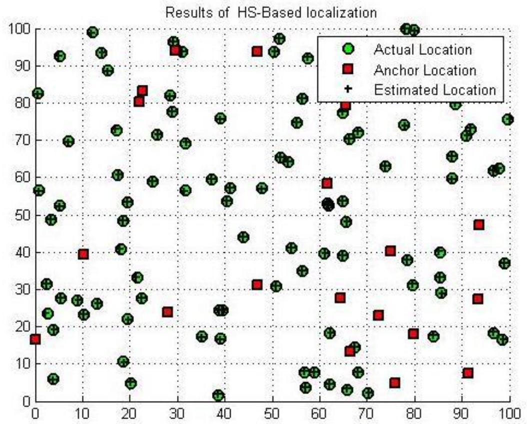

Fig. 3 Results of HS-based localization

From Fig. 2 and 3, it is visible that the accuracy in the trilateration-based approach is inferior to HS-based localization. This is because the distance measurement is affected by the noise in the environment and this does affect the localization result. In some of the cases, location estimation is exceeding the maximum value and it has been clipped to suit within the limits. This makes it more inaccurate. However, the computing time required by the HS algorithm is more than the trilateration. This makes it unsuitable for the applications where a quick response is essential.

5. CONCLUSION

In this paper, localization of unknown sensor nodes has been performed using trilateration and a heuristic HS algorithm. Each unknown sensor node performs self-localization using locations of three anchor nodes in a distributed manner. The trilateration and the HS algorithms have been discussed in brief. The results of both the algorithm are compared in terms of accuracy, computing time and the complexity. The HS algorithm optimizes the localization error to the maximum possible extent and the results show that HS-based localization is more accurate than the conventional trilateration method. The computing cost of both the algorithms is $O(n^2)$. The fitness function in HS-based localization minimizes the localization error and results in more accuracy than trilateration-based localization. Due to random parameters and a greater number of iterations than trilateration, the location estimation using HS-based localization takes more computing time than the trilateration. This makes HS algorithm suitable for the applications which are not time-sensitive.
This study can be further extended for application of heuristic algorithms to address various challenges in wireless sensor networks such as reducing number of beacons, security of the sensor nodes, energy consumption optimization and improvement of the lifetime of sensor nodes, localization with dynamic topology in WSN etc.

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