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Research Article

Performance Evaluation of Hop-Based Range-Free Localization Methods in Wireless Sensor Networks

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Knowledge of nodes' locations is an important requirement for many applications in Wireless Sensor Networks. In the hop-based range-free localization methods, anchors broadcast the localization messages including a hop count value to the entire network. Each node receives this message and calculates its own distance with anchor in hops and then approximates its own location. In this paper, we review range-free localization methods and evaluate the performance of two methods: "DV-hop" and "amorphous" by simulation. We consider some parameters like localization accuracy, energy consumption, and network overhead. Recent papers that evaluate localization methods mostly concentrated on localization accuracy. But we have considered a group of evaluation parameters, energy consuming, and network overhead in addition to the location accuracy.

1. Introduction

With the ever increasing applications of Wireless Sensor Networks (WSNs), location discovery of nodes has been an active research area. Applications of localization methods for WSN include clustering, topology control [1], location based routing, node identification, and node coverage [2]. A primary solution for localization is to equip each node with a GPS. But this method may be not the right solution because of the following three problems.

(1) GPSs cannot be used in indoor solutions due to weak satellite signals.

(2) GPSs use a lot of energy and reduced the network lifecycle.

(3) GPSs are expensive and cannot be used in low-price large-scale sensor nodes.

In most of localization methods, a limited number of nodes are location-aware that are named as "Anchors". Anchors could be fixed or mobile. Some methods like mobile beacon, mobile anchor [3], and single mobile beacon [4] use mobile anchors. The advantage of these methods is that a mobile anchor can be used instead of many fixed anchors, and in each location, it can be considered as a fixed anchor.

Other localization methods use "Fixed anchors". In these methods, localization is initiated by anchors. They broadcast their location to the entire network and each node estimates own distance with three anchors and approximates its own location. In these methods, the accuracy of localization is mostly depending on the approximation method. The localization algorithms are generally divided into two categories: range-based and range-free algorithms. Range-based methods use some measurement equipments to calculate distance. Some of these methods are DV-Distance [5], Euclidean [5], N-hop Multilateration [6], and Robust Sensor Localization [7]. Extra hardware and additional energy consumption are important bottleneck for these methods. Another category of localization methods named range-free do not use measurement equipments, so they have lower cost. In hop-based range-free methods, nodes estimate the distance by counting the hops to anchors.

Hop-based range-free methods have no extra hardware and flexible localization precision. They are more practical for implementation in any environment, so we concentrate on this category of localization method. We consider DV-hop [5] and amorphous [8] as typical algorithms of this category and evaluate their performance using simulation.

Recent researches [9, 10] improve the DV-Hop to increase the accuracy of localization method. Here we consider classic DV algorithm.

The rest of this paper is organized as follows. We discuss DV-Hop and amorphous methods in Sections 2 and 3. We evaluate the efficiency of these two methods focusing on their accuracy, network overhead, and energy consumption in Section 4. We conclude the paper in Section 5.

2. DV-Hop Localization Method

Niculescu and Nath [5] introduce a classic DV-Hop method which is similar to the distance vector routing schemes. This method includes three stages: first, anchors distribute their localization message to the entire network. This message may include fields such as Anchor ID, Location, and Hop-count. Hop-Limit is defined as the maximum number of hops that a localization message can be alive. Each node receives this message and stores it in its memory, increases the hop-count by one, and forwards this message to neighbors if the hop-count is less than or equal to the hop-limit; otherwise the message will be killed by the sensor node. If a node receives more than one message from an anchor, the shortest path will be considered; the new message will be ignored and the sensor node forwards the message only. According to the fact that the first message from an anchor includes the shortest hop-length, each node considers only the first message from each anchor and ignores the next messages. When a node receives localization messages from 3 anchors, this step will be terminated.

If any anchor receives a localization message from an anchor, it stores it to calculate the AHL (Average hop Length). For example, in Figure 1, we have 3 anchors ($a1$, $a2$, and $a3$).

The distance from $a1$ to $a2$ is 40 m, from $a2$ to $a3$ is 75 m, and from $a1$ to $a3$ is 100 m. The hop-count from $a1$ to $a2$ is 2, from $a2$ to $a3$ is 5, and from $a1$ to $a3$ is 6. Each anchor calculates its own AHL as follows:

$$\mathrm{AHL}(a1) = \frac{100+40}{6+2} = 17.5,$$
$$\mathrm{AHL}(a2) = \frac{40+75}{2+5} = 16.42, \quad (1)$$
$$\mathrm{AH3} = \frac{(75+100)}{5+6} = 16.42.$$

In the second step, each anchor distributes the AHL to the entire network. Each anchor receives this packet and considers that the first AHL receives from the nearest anchor. For example, in Figure 1, for node n, the first AHL received from $a2$ is 16.42, so the distance from anchors for node n is calculated by multiplying the minimum hop number and average distance of each hop:

$$n - a1 = 3 * 16.42 = 49.26,$$
$$n - a2 = 2 * 16.42 = 32.84, \quad (2)$$
$$n - a3 = 3 * 16.42 = 49.26.$$

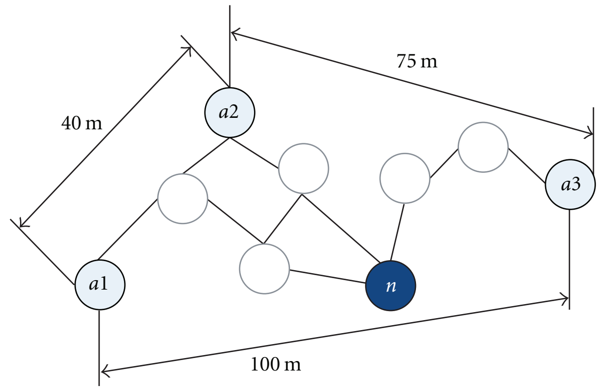

Figure 1: DV-Hop example.

Now, each node is able to estimate the location by Multilateration method. Now let us see how the location could be estimated. Assume that (X_i, Y_i) is the location of ith anchor and r_i is the distance of a node to this anchor. If (X_u, Y_u) is the location of node, then we have from Euclidean distance equation

$$(X_i - X_u)^2 + (Y_i - Y_u)^2 = r_i^2 \quad \text{for } i = 1, 2, 3. \quad (3)$$

We subtract this equation with $i = 3$ from equation with $i = 1$ and $i = 2$ and simplify the equation based on X_u and Y_u, then

$$\begin{aligned}
&(X_1 - X_u)^2 - (X_3 - X_u)^2 + (Y_1 - Y_u)^2 - (Y_3 - Y_u)^2 \\
&\quad = r_1^2 - r_3^2, \\
&2(X_3 - X_1)X_u + 2(Y_3 - Y_1)Y_u \\
&\quad = (r_1^2 + r_3^2) - (X_1^2 - X_3^2) - (Y_1^2 - Y_3^2), \\
&2(X_3 - X_2)X_u + 2(Y_3 - Y_2)Y_u \\
&\quad = (r_2^2 - r_3^2) - (X_2^2 - X_3^2) - (Y_2^2 - Y_3^2).
\end{aligned} \quad (4)$$

By converting of these equations into a matrix, we have

$$\begin{aligned}
&2\begin{bmatrix} X_3 - X_1 & Y_3 - Y_1 \\ X_2 - X_1 & Y_3 - Y_2 \end{bmatrix}\begin{bmatrix} X_u \\ Y_u \end{bmatrix} \\
&\quad = \begin{bmatrix} (r_1^2 - r_3^2) - (X_1^2 - X_3^2) - (Y_1^2 - Y_3^2) \\ (r_2^2 - r_3^2) - (X_2^2 - X_3^2) - (Y_2^2 - Y_3^2) \end{bmatrix}.
\end{aligned} \quad (5)$$

Now X_u and Y_u can be calculated easily.

3. Amorphous Localization Method

Amorphous method has been introduced in 1999 by Nagpal from MIT University [8]. Amorphous means irregular and unformed. In distributed systems, a set of parallel computer systems are communicating in a large scale. In an amorphous system, all computers are distributed randomly, having no knowledge about topology and physical location. In an

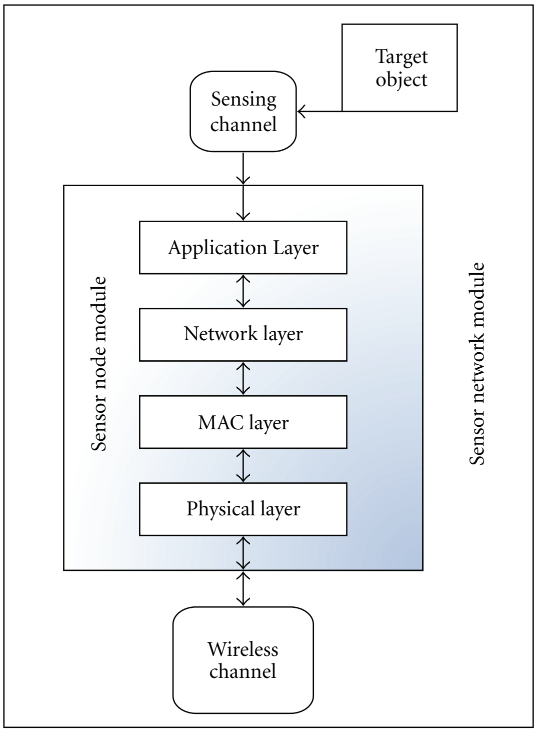

Figure 2: Implemented structure for simulation.

amorphous system, each processor is in communication with the processors that are in a circle with radius r from it. r is very small compared to the network size. Amorphous is a biology-inspired method. Recently, the advanced biology is an important resource in computer science. The DNA-equipped cells use several methods for detecting their own location in relation with other cells. One of the common methods is the chemical gradient. In this method, a chemical material is distributed in environment by cells. The density of this material decreases by going far from cell and shows an approximate distance from this cell.

Amorphous localization method has been customized for estimation of distance from anchors in wireless sensor networks. The localization messages that are distributed by anchors operate as chemical materials and hop-count operates as density.

In fact, the gradient stage is exactly similar to the first step in DV-hop method. The difference between these two methods is in the next stage. In DV-Hop, anchors calculate the AHL and distribute it to the entire network. So, there is a lot of overhead in anchors. But in amorphous, each node calculates the AHL in a smoothing stage. It is assumed that the network density is known. Kleinrock and Silvester [11] formula is used to calculate Hopsize offline

$$\text{Hopsize} = r\left(1 + e^{-n_{\text{local}}} - \int_{-1}^{1} e^{(n_{\text{local}}/\pi)(\text{Arccost}-t\sqrt{1-t^2})}\,dt\right), \tag{6}$$

where n_{local} is the number of neighbor nodes existing in node neighborhood and r is the range of node. This method reduced the overhead of anchor. They should only distribute the localization message. As we will see in the next section, this change would increase the localization speed and also reduce the traffic overhead of the network. To calculate the number of neighbors, each node that forwards the localization message in gradient appends own ID to the message. Each node receives this message and stores the sender ID in a table and finally; it can find out the number of neighbors. The location estimation can be performed by Multilateration method, explained in previous Section.

4. Simulation Results

We have used OMNET++ 3.2 to simulate these methods. OMNET is an object oriented and event-driven software based on C++. Implemented model is formed by hierarchical modules communicating by messages. Figure 2 shows the implemented structure for simulation.

Simulation parameters are

(i) network size (the number of sensor nodes),

(ii) the number of anchors,

(iii) distribution model of sensor nodes,

(iv) distribution model of anchors,

(v) hop limit,

(vi) range of sensor nodes,

(vii) range of anchors.

The evaluation parameters are as follows.

(i) *Localization Error.* The localization error is the Euclidean distance between estimated location (X_e, Y_e) and actual location (X_r, Y_r) in relation to the radio range of sensor nodes (R).

$$\text{Localization error} = \frac{\sqrt{(X_r - X_e)^2 + (Y_r - Y_e)^2}}{R}. \tag{7}$$

(ii) *The Consumed Energy.* There are several ways to estimate the consumed energy, but we consider the number of packets that have been sent or received by each node.

(iii) *The Localization Overhead.* It is the traffic that produced for localization, which means the total number of packets generated by anchors.

We assume, the radio range of sensor node is 100 m. Now, we see the result of simulation based on these three criteria.

4.1. Evaluating of the Localization Error. First, we studied the influence of distribution model of nodes. We concentrated on two famous models: uniform and normal distribution. Figure 3 shows the localization error for the uniform model and Figure 4 shows it for the normal model. As can be seen, the accuracy of both methods in uniform distribution is the same. But in the normal distribution, amorphous has higher localization accuracy than DV-hop. In both methods, by increasing the dispersal of network, accuracy is decreased.

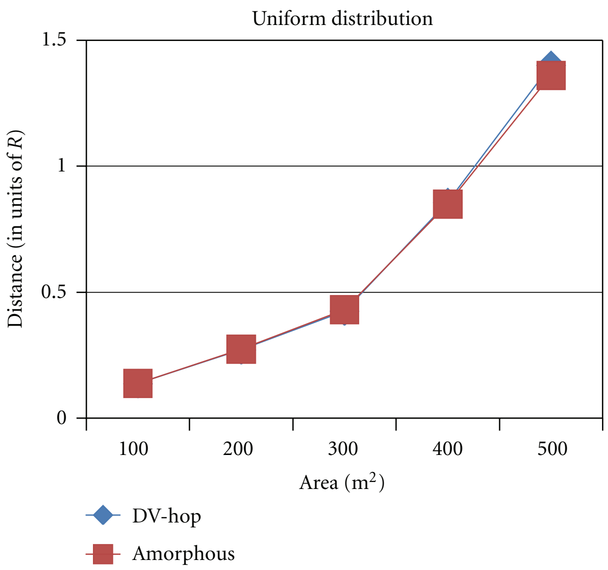

Figure 3: Localization error in uniform distribution.

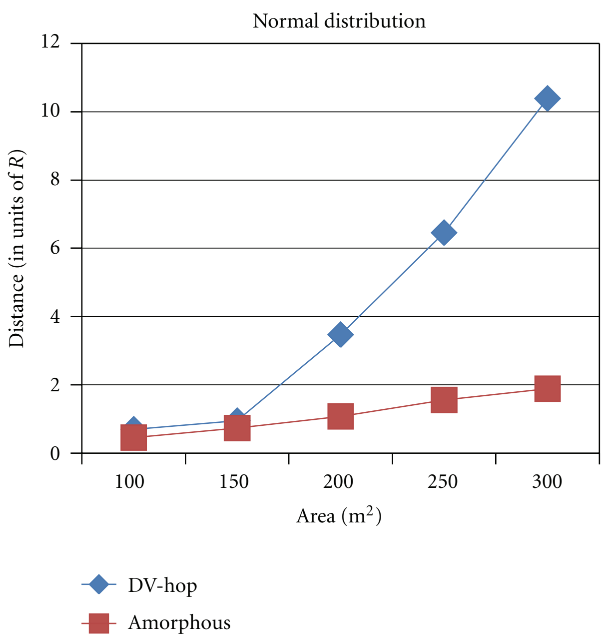

Figure 4: Localization error in normal distribution.

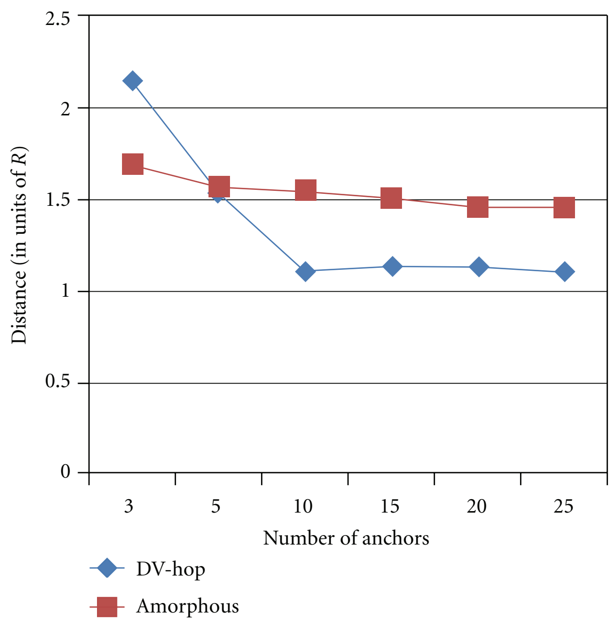

Figure 5: Localization error versus number of anchors.

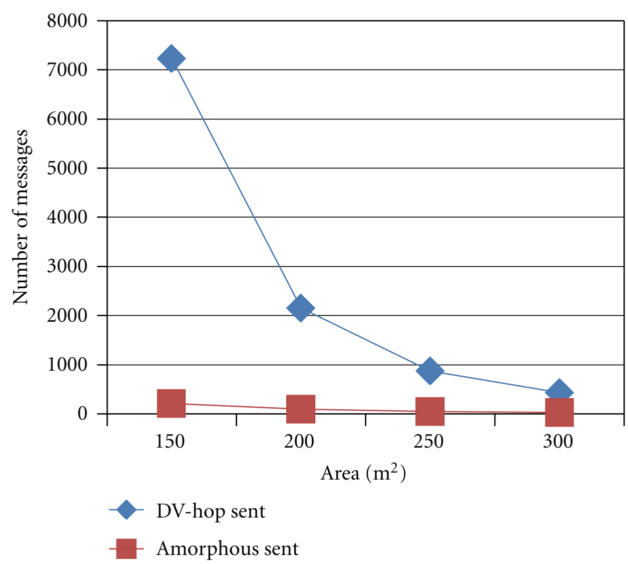

Figure 6: Consumed energy versus network area.

Then, we studied the relationship between the localization error and the number of anchors. As shown in Figure 5, localization error in amorphous method is almost independent from the number of anchors. But in DV-Hop, error is reduced until an optimum point is reached. After this, we do not see any improvement by increasing the number of anchors. In this case, the optimum point is 10.

4.2. Evaluation of Consumed Energy. In this Section, we study the consumed energy in the sensor nodes. This criterion can be divided into 2 items: processing power and transmission power. Processing power is very low in comparison with the transmission energy so we can ignore it.

For transmission energy, we consider the number of outgoing messages including both of generated messages and forwarded messages.

Figure 6 shows the consumed energy in relation to the network area. We see two important points in this figure. First is that the DV-Hop energy is more than amorphous by a significant difference especially in aggregate network. We can analyze the reason as follows. In the DV-Hop method, anchors propagate both of localization messages and AHL messages and each sensor node should forward

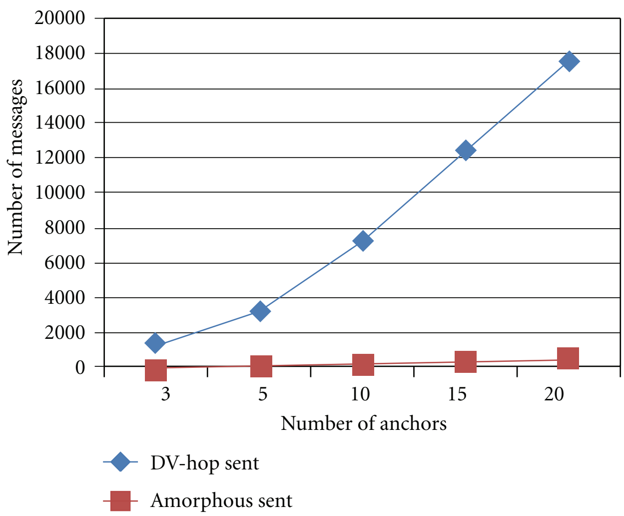

Figure 7: Consumed energy versus number of anchors.

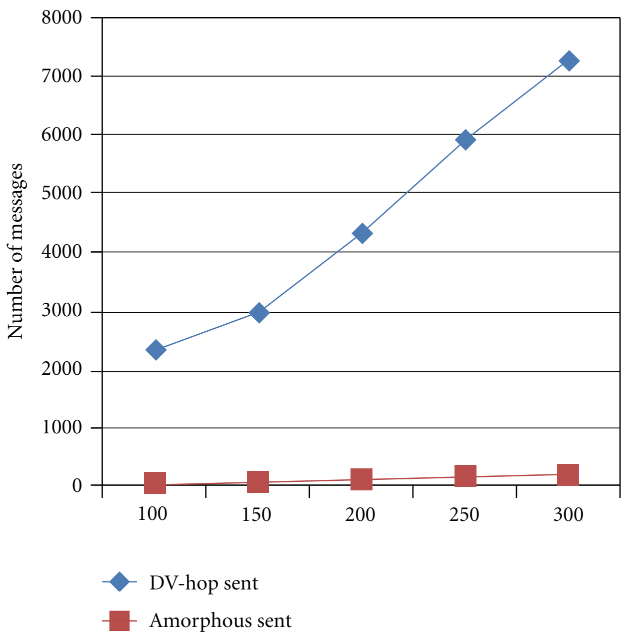

Figure 8: Consumed energy versus range of anchors.

these messages. But in amorphous, they propagate only localization message, and AHL is estimated locally by each sensor node. So the number of propagated messages in DV-Hop is more than amorphous and it means that it consumes more energy.

The second important point in this figure is that DV-Hop energy has a significant energy consumption reduction by increasing the area. In fact, when we have an aggregate network, each node covers a lot of nodes and so, the time that each node cooperates in localization message forwarding is more than a low-density network.

In DV-Hop, the localization overhead is on the anchors; therefore by increasing the number of anchors, the consumed energy has a significant increase compared to the amorphous. This point is shown in Figure 7. Also increasing the range of anchors will increase the consumed energy because of the same reason as shown in Figure 8.

4.3. The Localization Overhead. The localization overhead is the number of sent packets by total nodes, so the results are the same with previous section because this parameter is a coefficient of sent packets. Also the analysis is the same.

5. Conclusions

Localization is an important challenge in the wireless sensor networks. In this paper, we evaluate performance of two hop-based range-free methods that are more practical in WSN.

In both methods, the localization error is reversely proportional with consumed energy. It means that for improving the accuracy, we should send more localization messages and consume more energy.

The localization accuracy in uniform distribution is higher than nonuniform in both methods, but this difference in DV-hop is more than amorphous. It means that amorphous is more accurate than DV-hop in nonuniform and high-diffusion networks.

This prominence also was shown in consumed energy especially in congested networks. In fact in amorphous, AHL is calculated locally and we need no extra messages.

Another point is that amorphous is less-sensitive to the number of anchors than DV-hop. But for the same localization error, increasing the number of anchors improves the accuracy in DV-hop more than amorphous. In this paper, we evaluated the performance of two hop-based range-free localization methods in WSN using simulation. Other localization methods like area-based or range-based methods can be evaluated in the future. There are also other evaluation parameters that could be considered such as scalability and fault-tolerance.

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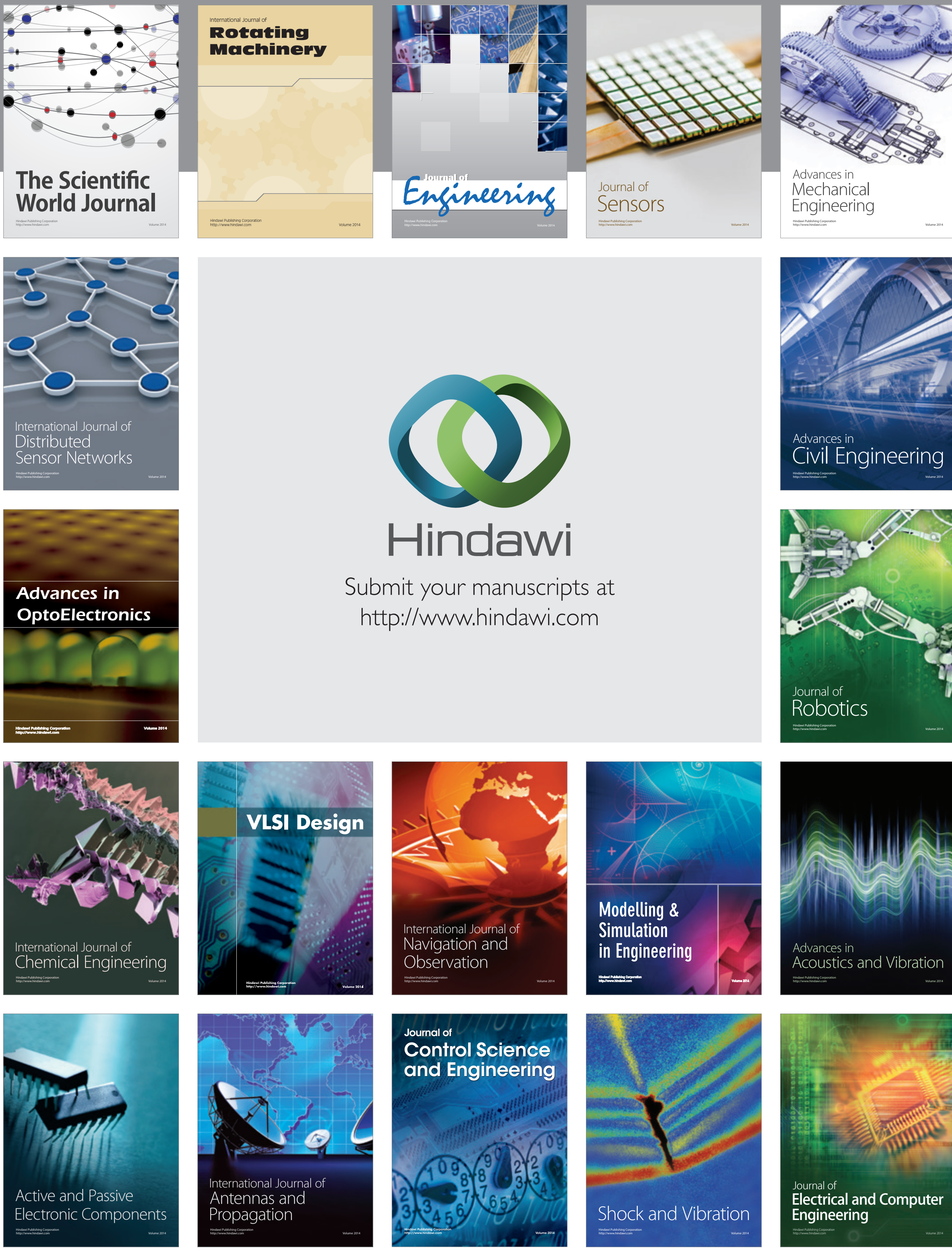
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