A Survey of Underwater Wireless Sensor Networks—localization system design

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Abstract
Wireless Sensor Networks (WSN) have recently commanded the attention of many researchers. However, when compared to terrestrial WSN, Underwater Wireless Sensor Networks (UWSN) present a novel underlying paradigm. The deployment of UWSN is not straightforward, basic challenges need to be addressed due to the type of environment found underwater. This paper discusses major challenges on localization aspects of UWSN. A novel localization algorithm design based on SemiDefinite Programming approach has been discussed.

1. Introduction
More than 70% of the earth's surface is covered with water. As more research is being done on underwater systems, data collection and environment monitoring become major components. This raises the need for an effective way to collect and deliver the environment. Underwater wireless sensor networking offers an unmatched option. The characteristics of the underwater environment present researchers with many challenges, especially effective communication and sensor localization techniques. The significant difference between Terrestrial WSN and UWSN

* Terrestrial WSN (TWSN) : Radio Frequency (RF) to communicate
  - GPS works

* Underwater WSN (UWSN) : Acoustic Signal to communicate
  - GPS doesn’t work

Therefore, GPS-free localization schemes are needed in this certain situation. In most underwater localization schemes, it is extremely challenging to calculate the distance accuracy between two sensor nodes. This is due to the weak acoustic signal. The SemiDefinite Programming approach has proved to give better results even in this very noisy background.

1.1 Mathematical model of the localization problem
There are n distinct sensor points in 2d whose locations are to be determined, and each d points form a plan (the anchor points) whose locations are known. Four distinct sensor points are shown in Figure 1.

- Each distinct sensor point is known as a reference point.
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Usually,

\[ N_i = (x_i, y_i) \quad \text{where} \quad x_i, y_i \in \mathbb{R} \]

And the sensor network localization problem is to find vector [x, y] T for all \( x, y \in \mathbb{R} \), such that

\[ |x_i - x| + |y_i - y| = d_i \quad \text{for all} \quad i = 1, 2, \ldots, n \]

Then, this problem's relaxation model can be represented by a standard SDP model. In [10], two future solutions of the SDP have been proposed and tested. From their result, the more efficient way to solve the optimal problem is an approach called the smaller SDP (SSDP) approach. The performance of SSDP approach is compared to the original SDP approach in [10][11]. Further details and conclusive observation on SSDP can be found in [10][11].

1.2 Related work
In essence, the major challenges of underwater localization schemes are due to the physical environment. Therefore, it is still a challenge to study challenges associated with the use of acoustic signals at the communication medium.

1.3 Challenges of acoustic signals
The following shows major factors that may affect the localization system.

1.3.1 Bandwidth
The bandwidth of a WSN sensor is limited by the amount of data it can transmit within a given amount of time. This limits the overall performance of the system. The bandwidth of an underwater sensor is usually limited by the amount of power it can consume, and the amount of power it can harvest. This is due to the fact that underwater sensors are typically deployed in remote areas and have limited access to power.

1.3.2 Propagation delay
Underwater propagation delay is five orders of magnitude higher than in RF. It greatly affects the real-time evaluation of underwater Wireless Sensor Networks (UWSN).

1.3.3 Acoustic noise:
This is due to the high bit error rate and temporary losses of connectivity due to the extreme characteristics of the underwater channel.

\[ (C_{\text{UW}}) (C_{\text{RF}}) + (C_{\text{RF}}) (C_{\text{UW}}) \times (C_{\text{US}}) = (C_{\text{US}}) (C_{\text{US}}) + (C_{\text{US}}) (C_{\text{US}}) \]

Where,
\[ C_{\text{US}} \quad \text{speed of sound (m/s)} \]
\[ C_{\text{RF}} \quad \text{radiolocation} \]
\[ C_{\text{US}} \quad \text{acoustic signal (m/s)} \]
\[ C_{\text{US}} \quad \text{propagation (m/s)} \]
\[ C_{\text{US}} \quad \text{depth (m)} \]

1.4 Energy
Battery power is limited because underwater batteries are extremely difficult to recharge. Unlike terrestrial WSN, UWSN cannot use solar energy to regenerate the power of the battery.

1.5 Failure
Underwater sensors are prone to failure because of fouling and corrosion.

1.6 Attenuation
Attenuation is the reduction in amplitude and intensity of a signal. Attenuation at distance u is given as (4)

\[ A(u) = e^{-\beta u} \]

where, \( \beta \) is the normal attenuation rate, \( u \) is frequency dependent term obtained as a + 2e - 2f.

The formula illustrates attenuation is dependent on frequency as well as distance.

1.4.2 Related GPS-free localization schemes
Normally, localization schemes can be classified into two categories:

1.4.2.1 Range-based
Range-based schemes use Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) or Received Signal Strength Indication (RSSI) to estimate the distances to the anchor nodes.

Disadvantages used in UWSN:

- These schemes are vulnerable to the speed of acoustic signal, which depends on temperature, pressure, and salinity, as shown in formula (6).
- For TOA and TDOA is the synchronization between nodes caused by long propagation delays and temporary connection loss.

1.4.2.2 Range-free
Range-free schemes do not provide the accurate distance to those reference nodes. Therefore, they only fit applications that do not require accurate positions of target sensors.

These schemes estimate the location of sensor nodes either by exploiting the radio communication information among neighboring nodes, or by exploiting the sensing capabilities that each node possesses. For example, if one node is equipped with an optical sensor, information is used to estimate distances, and if many nodes in the network are equipped with optical sensors, they contribute to the localization.

Advantages used in UWSN:

- Compared to range-based scheme, the cost of equipment is cheaper and the physical factors give less impact on these algorithms.
- Even some terrestrial range-free algorithms can be used directly.

Disadvantages used in UWSN:

- The crude result may not be the desired position information.

3. Communication architecture design
3.1 How to use SDP approach
To use SDP approach, researchers need to collect two kind of data:

- anchor*position coordinates
- partial pair-wise distance measurements between some of the nodes. (including the distances between sensors, and distances between anchors and sensors, and distances between anchors.)

According to [10], three factors impact accurate results from the SDP approach:
- number of anchors
- number of sensors in sensor acoustic signal range
- number of outliers noise

More anchors, large connectivity and less noise will generate more accurate position results. Among these three factors, it is possible to improve the first two, but it is hard to control the noise factor. However, increasing the number of anchors and connectivity increases the deployment cost of the whole system. Therefore, the balance between the result and cost needs to be weighted carefully.

3.2 Two key problems in the design
Communication architecture design of a UWSN system needs to address two key problems to satisfy the requirements of SDP:

- how to get the distance between sensor nodes?
- how to get the distance between sensor nodes?

Solutions: Round trip propagation of data packet transmission is used to measure the distance between two sensor nodes. Figure 2 illustrates how round trip propagation works.

3.3 Flop-position-transmitter
The main idea is to use fix-position-transmitter to improve connectivity of the whole system. Compared to target sensor, fix-position-transmitter does not move with the target.

This design leads to a reduction in power consumption for all the sensor nodes. That is because connectivity must be above a certain value to guarantee the accuracy of position results. If the system does not have those transmitters, it should increase the power of acoustic signal to improve node range.

Figure 1. Round trip propagation

Distance = speed of sound * Round-Trip Time / 2

Figure 2. Communication architecture

6. References