POSITIONING ISSUES IN UNDERWATER ACOUSTIC SENSOR NETWORKS

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ABSTRACT

In this paper we discuss challenging issues related to positioning in underwater acoustic networks focussing in the major goal of establishing a common coordinate system which should allow applications to perform collaborative sensing tasks such as identification, detection, and/or tracking of sea targets.

A general description of the most important positioning methods and algorithms which have been proposed, developed and employed in the underwater environment is provided along with their major advantages and requirements. Also the applicability to the underwater acoustic scenario is discussed.

Finally we argue the need of a new ad-hoc positioning scheme adapted to the underwater acoustic environment and an outlook of our future work is given.

1. INTRODUCTION

The main objective of this work is to develop a distributed, scalable, cooperative ad-hoc positioning methodology for underwater acoustic sensor networks. The positioning functionality will be integrated in the communication process because of the need to economize the limited available resources in the underwtaer environment.

The rest of the paper is organized as follows. In Section 2 a list of the desired requirements of a positioning algorithm for underwater acoustic sensor networks is provided. An overview of positionig principles is given in Section 3. Next Section 4 summarizes the most important positioning methods being employed in the underwater environment. We will discuss the need of an ad-hoc positioning algorithm for acoustic sensor networks in Section 5, and in Section 6 we will describe our proposed integrated scheme, along with the description of the major goals and our future work. Finally we conclude with a summary in Section 7.

2. GENERAL POSITIONING REQUIREMENTS

Any requirement on the positioning functionality of a network is very dependent on the scenario of applicability. In order to understand and differentiate the positioning methods and algorithms described in this document, firstly we propose the following general requirements to be used as parameter criteria for the evaluation of the different approaches.

- Dimension of the network: our defined scenario includes coastal regions with depths of up to 1000 meters and with maximal distance between sensor nodes of 1000 meters.
- Accuracy: depending on the application, the requirements on the accuracy can vary from a few meter to some centimeters.
- Robustness and relialability: the positioning availability of the sensors in a network should be full-time available and highly reliable.

- Update rate of the position information: the required update rate will have strong influences on the changes of the topology as well as in the estimation of a detected sea target moving at a given velocity. Depending on the application the update rate could be performed many times in a second.

Additionally we identify additional requierements which are not high restrictive but which could improve the optimal positioning solution. Among them we identify the following ones:

- Generally an underwater positioning method for an ad-hoc scenario should work independently of the installation and calibration conditions in which the network is deployed.
- The positioning functionality should require and use as few communication resources as possible due to the limited reosorces availability in the underwater acoustic environment. This effect is strongly affects to the scalability of the developed algorithm.
- Finally the positioning algorithm should be easy to deploy and cost effective.

After the most relevant positioning requirements have been described we discuss some positioning principles in the next section.

3. POSITIONING PRINCIPLES

The basic elements needed to perform a succesful positioning are references (also known as reference points). There are basically two main methodologies: positioning based on wave propagation and positioning with assistance of inertial sensors [1],[2]. Both methodologies measure a physical magnitude or quantity by which a distance can be estimated. Distances or angles to one or more reference points result in the required position by using geometrical methods. These geometrical methods result in different geometries depending on the different types of measurements such as: absolute distances to the references, differences on the distances, or angle difference to two or more references.

The positioning systems which use wave propagation to estimate the position are very common in the literature and have been intensively studied. Electromagnetical waves are used by optical positioning methods and by radio systems. However electromagnetical waves suffer from a very strong attenuation in the underwater environment. This effect leads to high propagation losses, and therefore to relatively low ranges [3]. Due to these limitations the utilisation of electromagnetical waves is excluded. For the same reason the utilisation of the GPS System (Global Positioning System) can be used only over the sea surface.

Due to the properties of propagation underwater we have the possibility to transmit acoustic waves [4],[5]. Its utilitsation is therefore the most adequate for our purposes of an underwater positioning system. There is relatively few literature on positioning by means of acoustic waves. Whereas many models and scenarios based on electromagnetical waves in the field of terrestrial radio positioning systems are known, their principles could be adapted to the underwater medium. Therefore we refer to this kind of systems in our work although we will not use them.

Another principle is inertial positioning. This principle is based on acceleration measurements in space where the left path can be reproduced and measured. Opposite to waves propagation, inertial positioning works independently of any external infrastructure outside of the referred objects. In order to reach to the destination point a succesive integration from an initial point is required (e.g. the Dead-Reackoning principle [1],[6]). The inertial positioning system works independently of the medium in which the movement takes place.

4. UNDERWATER POSITIONING SYSTEMS

In the last tenths years different positioning methods and algorithms have been proposed. Most of them are based on acoustic and electromagnetical waves as well as on inertial systems for underwater unmanded vehicles (UUV's) [3],[4],[7]. Next we present some of them.

4.1. Acoustic Systems

Acoustic beacon systems are the most common systems. They provide a good positioning accuracy (from some centimeters up to 50 meters) over ranges of up to few kilometers. Tipically these systems are classified according to the distance between beacons or reference points (i.e. known as baseline) as shown in Table 1. A baseline with a length of 10 cm means that three acoustic wave senders form an isosceles triangle with side length of 10 cm attached to a fixed mast under the sea surface. The frequency typically increases with the baseline length which at the same time defines the achieved range and accuracy as shown Figure 2. We appreciate that the accuracy increases with the frequency and the the range decreases.

Acoustic beacon systems typically need a lot of resources for installation and calibration purposes therefore limiting its applicability and bringing additional difficulites. But the main disadvantage is the consumption of resources which can not be used by the communication process such as bandwidth and frequency.

Table 1: Classification of the underwater acoustic positioning systems vs. distance between beacons.

DEFINITION OF THE ACOUSTIC POSITIONING SYSTEM	BASELINE-LENGTH
USBL (Ultra Short Baseline)	< 10 cm
SBL (Short Baseline)	20m to 50m
LBL (Long Baseline)	100m to 6000m

Table 2: Accuracy and range of the underwater acoustic positioning systems according vs. frequency.

DESCRIPTION	FREQUENCY RANGE	ACCURACY	RANGE
Low Frequency (LF)	6 kHz – 16 kHz	2m – 5m	> 10 km
Medium Frequency (MF)	18 kHz – 36 kHz	0,25m – 1m	2 km – 3 km
High frequency (HF)	30 kHz – 60 kHz	0,15m – 0,25m	1500m
Extra High Frequency (EHF)	50 kHz – 110 kHz	< 0,05m	< 1000m
Very High Frequency (VHF)	200 kHz – 300 kHz	< 0,01m	< 100m

4.2. Sonar Systems

In sonar (i.e. Sound Navigation and Ranging) systems a transmitter sends an acoustic impuls and after receiving the reflected signal (i.e. echo) it is able to compute the distance to the object which has reflected the impuls. The principle is similar radar systems [8].

An important application of underwater positioning and navigation is the sonar scanning of the sea floor (i.e. underwater terrain matching). The result of this scanning is a chart of the sea flor which can be compared with known charts and used for positioning and navigation of UUV's [9],[10].

For absolute positioning a complete floor chart is required. This implies that some previous work is needed therefore strongly limiting the flexibility and applicability of this approach. Additionally when the number of elements in the network increases more impulses are required which again consumes the limited communication resources. The positioning sonar based system presents relatively low scalability.

4.3. Optical Systems

Optical systems use tipically a laser beam as reference signal to perform distance measurements. The propoerties of this beam (e.g. delay, interferences) are used in the optical system which comprises optical lenses and reflectors which are used to estimate the distances. This laser beam is very directional. Therefore the sender and the receiver must be pointed to each other. Additionally the elements need to be very stable and not vary its position with time in order to receive the optical beam [7]. Moreover intervisibility between the sender and receiver is required and this can be obstructed by obstacles. Even small particles or movement of the water can affect to the pointing of sender and receiver and making the positioning functionality unavailable.

The strong requirements and difficulties of such an approach limit strongly the applicability range and reliability of the system.

4.4. Inertial Systems

Atounomous inertial systems generally use gyroscopes and acceleration measurements as principles for positioning. This devices are installed in the element to be positioned. These systems are based on the principle by which the velocity and the changes in the direction can be computed. The actual position is inferred by integrating the initial position.

A major weakness of inertial systems is that the error during integration is accumulated [6],[11]. This disadvantage make that are inertial systems are rarely used although they are combined with other systems to provide enhanced absolute position information [12].

5. INTEGRATION IN THE COMMUNICATION PROCESS

5.1. Positioning and Communication in Underwater Systems

In the underwater environment there is additionally the possibility to use acoustic beacon systems for positioning purposes. The beacons are also used as base stations which further can be used to forward the collected information to a central station. The positioning is computed generally by measuring the time-of-flight of the acoustic signals and by multilateration. The advantage of this approach is that requires few communication resources.

However the main problem of this approach is that first tries to optimize the positioning functionality and second the communication process. A disadvantage is that both the scalability and the accuracy which can be achieved in long distances are relatively low.

We argue that the integration of the positioning functionality and the communication process in a common scheme is an important issue to be integrated within the framework of providing positioning facilities to underwater acoustic sensor networks. This consideration should lead to a more efficient and scalable developed system.

5.2. Ad-hoc Positioning

Ad-hoc positioning is a positioning system where the positioning of the elements or nodes can is made in a distributed policy. Each node measuremes time-of-flight signals, signal strength, and/or angle of arrival [13] which allow the estimation of the distances to neighbour elements.

The estimated measurements are shared among the neighbour nodes in order to compute a local positioning map generally by multilateration methods. Again by sharing the position information and disseminating this information within the network the nodes can create a complete positioning map of the network. Finally this computed map is distributed among all nodes of the network in order to create a common network topology. In order to estimate the absolute position of a given node we suppose that some of the nodes which form the network are aware of its absolute position information.

Additionally to the creation and distribution of the network positioning map we develop methodologies to define the update rate of positioning information. We specially consider the distribution of the estimated distances among the nodes of the network which is a majo challenge in multi-hop networks [14].

The ad-hoc positioning approach is of major importance in our work because it allows the integration of the positioning functionality in the communication process therefore consuming few communication resources. The applicability of this approach is almost unrestricted and depends more from the density of the nodes than from the extension of the network. It is also a flexible solution and can be deployed without additional work.

However our underwater ad-hoc positioning approach is based on the terrestrial transmission of radio waves systems, although this systems have not been tested on the underwater environment.

5.3. Channel Estimation

The channel estimation provides valuable information about the received signal which suffer from modifications during its propagation due to attenuation, scattering, reflexion, or multi-path effects. Additionally a non line-of-sigth (NLOS) situation can occur e.g. when the transmitter and the receiver do not have a direct communication path and the signal is received by multipath. This would result in time-of-flight measurements which would result in errors in the estimation of the distance between the transmitter and receiver. Here the estimation of the communication channel can evalueate this effects which are even more important in the underwater acoustic environment [15].

The integration of the channel estimation in the positioning functionality has a big potential to enhance the underwater positioning performance. Our future investigations include the research and development of a positioning scheme which includes channel estimation and measurements.

6. AD-HOC POSITIONING IN UNDERWATER ACOUSTIC NETWORKS

Our work addresses the investigation of an ad-hoc positioning scheme adapted to the underwater acoustic environment for the ocean sensor network scenario. Our scenario defines initially some beacons deployed at sea surface which are aware of their position information.

During estimation of the position in the sensor nodes the properties of the communicaiton channel are taken into consideration (e.g. temperature, salitinity, and depth), which strongly influence the propagation properties of the acoustic signal.

The major investigations will focus on the performance achieved by the positioning functionality in the underwater acoustic environment specially regarding to accuracy, scalability and robustness metrics.

The proposed ad-hoc positioning approach will result in the following outcomings:

- A model of ad-hoc positioning information for underwater acoustic sensor networks,
- A methodology to estimate the distance between nodes (e.g. time-of-fligth),
- A methodology to calculate the positioning information,
- A methodology to update the positioning information when needed,
- A methodology to calculate the accuracy and robustness of the approach,
- Investigation of the consumption of the most important resources (e.g. hardware, software).

To the best of our knowledge an ad-hoc positioning scheme adapted to the underwater acoustic environment has not been adapted yet.

7. SUMMARY

The main objective of this work is to propose a new ad-hoc positioning scheme for underwater acoustic sensor networks and its integration in the communication process.

Expected results include the specification of the interfaces between the different communication layers and system services (specially control and navigation), the development of an optimal ad-hoc positioning algorithm, the development of methodologies to calculate and adapt the calculated coordinates within a common coordinate system, evaluation of the performance achieved by our system as well as analysis in terms of accuracy and robustness.

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