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REVIEW ON TARGET TRACKING METHODS FOR UNDERWATER ACOUSTIC SENSORS

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Abstract

Acoustic waves are used for communication systems in underwater civilian as well as military applications. Underwater acoustic target tracking is an important component of marine exploration. A large number of target tracking methods are being used based on the nature of the marine environment. In this paper, we survey recent research on underwater tracking technologies. Classification of different under water target tracking algorithms are made based on methods used. The algorithms are analysed to identify the most appropriate one for underwater target tracking. The challenges and issues is also discussed.

Keywords: Target tracking, Acoustic sensors, Underwater communication, Wireless sensor networks.

I. Introduction

Human beings have started exploring underwater resources for minerals, oil, and other developmental activities as these resources overland are getting depleted [XII]. Marine exploration is a challenging task and it has its own problems which are very different from the ones on the land. Recently underwater target tracking has become significant area of research. Target tracking is the process of determining the precise state of the object being tracked. The tracked object could be a single or multiple objects, it could be stationary or moving. It is a process of accurately estimating the position, velocity and acceleration of the object being studied using various sensors. In military applications it becomes a matter of life and death. Accurate determination of the enemy resources will make determine the survival of our men and material and destruction of the enemy. In civilian applications, it may be used for fishing, rescue operations, mineral or oil exploration etc. A review on the existing methods and applications of underwater target tracking would be in order.

Land based target tracking is well studied and a significant research work is available. A variety of sensors are used to detect and track the terrestrial targets [XXVI, IV, XI, XXIX, XX, XIX, XV, XIII]. Electromagnetic waves and optical waves have high attenuation and absorption in water, due to which the devices or sensors which have good performance in land based systems perform poorly in marine environment [X]. Whereas acoustic waves can travel long distance in marine environment, hence acoustic waves are used in underwater target tracking. Here, we classify the target tracking algorithms by methods used. The different methods are instrument-assisted methods, mode-based methods, and tracking optimization methods.

Most review articles on target tracking focus on wireless sensor network (WSN) based target tracking [XXVIII, VII, XVIII, III, XXI]. Few of the articles are focussed on WSN related issues like energy-efficiency, security etc. In an underwater environment there are differences between the underwater target tracking and the traditional WSN based target tracking issues mentioned above. Communication, real time tracking and tracking mode are some of the issues related to underwater wireless sensor networks.

The nature of the water medium makes underwater communication challenging as the water bodies properties can change over space and time [VI]. The most frequent issues are limited bandwidth, high bit error rate and large propagation delay. The speed of sound waves in water is five orders of magnitude lower than electromagnetic waves. It also depends on the temperature, pressure, salinity, depth etc. [XX]. Thus the speed can vary within the same water body. This variation in the speed of the sound waves must be considered when tracking distance of targets in the water. Limited bandwidth is another issue which is of serious concern. Algorithms are developed to use small packets of data. The high bit error rate would lead to high transmission loss. Data fusion techniques are developed to account for the high transmission losses.

Real time tracking is another issue related to underwater sensor systems. The water currents tend to drift the sensors from their deployed position. For tracking applications the accuracy of the sensor position is very crucial. The algorithms used for underwater target tracking needs to consider this issue on a real time basis.

Acoustic sensors consume energy in Watts for transmitting the signal and tens of milliwatt for receiving the signal. This high energy consumption in a remote location requires the sensors to work passively for energy efficiency.

II. Acoustic Target Tracking Instruments

In water electromagnetic waves get heavily attenuated, hence propagation of these waves in water is not feasible. Whereas, acoustic waves can propagate over long distances in water. Hence acoustic waves are the preferred signals for location, tracking of fixed and moving targets as well as navigation. Acoustic sensors, namely speakers and microphones are used for transmission and reception of the signals. As mentioned above underwater acoustic tracking encounter some unique issues related to communications, real-time tracking and tracking mode and hence specific algorithms are needed compared those used for terrestrial wireless sensor networks. These specific issues can also be tackled by designing devices which overcome them. Recent work on acoustic modems is focussed on tackling the challenges of the underwater environment.

A broad survey of underwater acoustic modems is given by Sendra et al. [XXIV]. Underwater sensors are remotely located where power is usually not available from the grid. These devices are given power by a battery based power unit. The sensors also have a communication and processing unit. The acoustic sensors perform two major functions launching of sound waves and receiving of sound waves [XXX]. Most acoustic sensors transmit and receive the sound waves at the same time. Sometimes the sensors are used just to listen to sound signals. The acoustic sensors are used either as active systems or passive systems. The active systems can be single sensor where the sensor acts as both transmitter as well as receiver. Or it can also work in a multi-mode where the sensor performs only one task of transmitting or receiving. The bistatic system has a single source-receiver pair [VIII], [V]. Acoustic sensor sources are usually mounted on the Hull of the ship in an array, and receivers are towed line arrays [XVI]. Here we describe three underwater acoustic target tracking instruments, namely, Acoustic sensor arrays, underwater sensor networks and acoustic imaging sensor.

Acoustic Sensor Arrays:

Underwater target tracking are usually performed using sensor arrays like hull mounted and towed arrays [XXVII, XXIII, II]. These array systems are installed on a ship in a spherical or cylindrical array. It is an active system which transmits certain frequency of sound waves in a row and tracks the objects from the reflection of the echoes of the sound waves. Towed array is a linear array which is dropped in the sea and towed by the submarine. This is a passive listening sensor which monitors radiated sound from the target.

In certain critical situations these tracking systems which are mounted or towed by a ship or a submarine have flaws [IX]. The tracking method depends on the patrolling of seas and it is practically impossible to patrol the seas 24x7 using ships or submarines. As the ships and submarines are moving the intruders can easily move away from the path of these ships and avoid being detected. The tracking in these systems is possible only along the path of the ships. In case of an attack or failure this will affect the whole system.

UWSNs:

The above problems of underwater target tracking can be tackled using the underwater wireless sensor networks. UWSNs are low cost, can be deployed rapidly, is able to self-organize and fault tolerant compared to the acoustic sensor array [I]. UWSNs consist of sensor nodes, sink nodes and acoustic modems. The sensor nodes have limited data processing capacity and it communicates via acoustic modems [XVII]. The target tracking in UWSNs is achieved by randomly deploying the sensors across the area which is to be monitored [XXV]. This system can be used to detect single or multiple targets. When the target is detected, the data from the sensors can be used to estimate the position of the target. This data is transmitted to the sink node which has a bigger processing capability and is also the gateway between the network and the end user. The sink node uses the data collected from the sensor nodes to compute the accurate position and determine the trajectory of the tracked object [XXXI]. In certain applications the algorithms can predict the target trajectory. This will help in reduction of energy consumption as it can predict the target trajectory and allow in activating those sensors where tracking is required [XIV]. Sensor nodes are remotely located hence they have to limit the energy consumption. Conservation of energy is a major factor for a UWSN based target tracking system. Certain key parameters related underwater target tracking is identified as node localization, node cooperation, position computation, position prediction, and energy management.

Global positioning systems cannot be used for determining the position of underwater sensor nodes. The node localization algorithm is used to estimate the accurate position of the nodes and this determines the accuracy of the tracking performance. Node cooperation is used to communicate between the nodes. Underwater environment is very noisy and it is quite challenging to get the accurate data which are required for computing the position of the target. In some cases it is important to predict the trajectory of the target, in such cases algorithms to predict the future position of target can be very useful. As the sensor network is remotely located power for the system will not be available locally, hence most network systems use battery based power schemes. In such cases efficient energy consumption will determine the lifetime of the network.

Acoustic Imaging Sensor:

Recent development of image processing technology gives a new way to tackle the problem of underwater target tracking. Acoustic imaging and video processing technology has made it possible to track targets using acoustic imaging sensor. A forward looking sonar located on the front of most ships, submarines or automatic underwater vehicles can be used as the imaging sensor. The sensor transmits acoustic signals to underwater terrain which is to be scanned and processes the scattered echoes reflected from the surrounding objects. By continuously scanning the underwater environment any change in the same can be instantly identified and can also be tracked efficiently.

Different underwater acoustic target tracking methods have been studied. The systems which use acoustic tracking devices like acoustic imaging sensor, acoustic sensor arrays or underwater wireless sensor networks are called as instrument assisted methods. The mode based method is the active or passive mode sensor systems. This mode focusses on achieving better tracking results. The tracking optimization mode method is used to improve the accuracy of the tracking.

III. Discussion

A large number of research work has been reported for underwater target tracking for both the civilian and military applications. The marine environment is not conducive for the electromagnetic waves. Acoustic waves are the only signals that can propagate through water without any losses or attenuation. Hence acoustic waves are used for underwater target tracking. Different instruments and algorithms have been developed for acoustic target tracking. Each of these methods have their own advantages and disadvantages. The different methods used for target tracking are instrument based method, mode based method and tracking optimization method.

The challenges of communication in a difficult marine environment create many problems for target tracking. The low contrast and visibility in deep underwater makes it very difficult for the imaging sensors to detect the target even from a close range. Acoustic echo based tracking also face the problem of attenuation of acoustic waves at a large distance. Many tracking methods and algorithms assume that the acoustic waves travel at a constant speed in the complex marine environment. In reality the speed of acoustic waves are highly dependent on the properties of the water like temperature, pressure, salinity at the given location. Hence the measurements based on this assumption leads to errors. For UWSNs based tracking conservation of energy is a crucial factor. This sometimes leads to reduction in tracking accuracy. It is challenging to design the system where the energy consumption is minimised and the tracking accuracy is also maintained.

IV. Conclusion

As the terrestrial resources are depleting, human beings are moving towards exploring the marine resources. In a marine environment different type of challenges are encountered. Acoustic waves are the preferred mode of communication in a marine environment. Target tracking systems also use acoustic waves for underwater exploration and tracking. Many research work is reported on underwater target tracking. Here we carried out a survey of underwater target tracking instruments and algorithms. Some of the future challenges of target tracking are the tracking of multiple targets, enhancing measurement accuracy, data fusion etc.

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