Ultrawideband Radar Processing Using Channel Information from Communication Hardware

Literature Review

by

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Abstract

Channel information provided by impulse-radio ultrawideband communications is used in radar applications requiring information on the surrounding physical environment. Many algorithms used by sonar are applied to this problem due to the similarities of the technology. Echolocation and map-building algorithms are particularly relevant, but the problem is significantly different since directionality information is not available. The use of other communications devices as distributed sources provides opportunities for unique algorithms.

I. INTRODUCTION

Emerging ultrawideband technology potentially offers hundred-megabit-per-second data rates and sub-centimeter radar resolution [1]. The baseband filtering and receiver designs are the same, and both applications use information on the arrival times of all incoming pulses. Radar applications use the arrival time of each pulse to determine distances to reflecting objects, whereas communications use the arrival times to set up correlators to collect signal energy. Since the majority of work is already being performed by the communication hardware, this literature survey evaluates the applications of radar signal processing algorithms to channel information from that hardware in order to obtain useful information about the surrounding physical environment.

Location-based services, such as emergency-911, are already proving popular in the cellular industry [2]. GPS is limited by accuracy and does not work well indoors, and would benefit from complementary location algorithms [3]. Location-based security is a great potential application to prevent wireless networks from being accessed outside of a building [4]. These applications and others could be implemented, and provide useful location-based services to complement ubiquitous data connectivity.

II. BACKGROUND

A. *Implementation Issues*

While one could easily add extra hardware and antennas to accomplish these tasks, the point of this survey is to only use communication hardware available, which saves the cost, space and power of extra hardware. The only required modification is to make information from channel estimation available for signal processing. Rake receivers are common with CDMA and impulse-radio ultrawideband technology [1], and could be a great source of this timing information. Successive interference cancellation (SIC) is one of the few practical multiuser detection technologies [5]. This technology has potential for future ad-hoc network design, which is itself a natural option for range-limited ultrawideband (UWB) communication hardware, and is also a great source since multipath of all nearest users is decoded as well to increase capacity [6]. The spatial diversity provided by Multi-Input Multi-Output (MIMO) approaches effectively acts as an antenna array for more accurate radar processing.

Fortunately, the IEEE 802.15 TG4a Wireless Personal Area Network Task Group is working on many of the practical issues involved with using ultrawideband communication hardware for radar applications, including the synchronization and hardware modifications required [7]. This work is based on the Multi-Band Orthogonal Frequency Division Multiplexing Alliance (MBOA) ultrawideband implementation, but much of the work could be adapted to the impulse-radio implementation. The goal of this working group is to make radar processing possible from the communication hardware, allowing future applications to be entirely software issues [8].

B. Related Technology

Due to the similar resolution and baseband processing of ultrawideband radar and sonar, much of the work done in sonar signal processing can be applied to this technology. The technologies are so similar that one ultrasonic positioning system by Kazys [9] proposed the use of orthogonal CDMA signals with cyclic deconvolution to process all reflections by all transmitters, which is essentially identical to SIC for impulse radio ultrawideband communications.

Many algorithms rely on specular propagation, which occurs in both electromagnetic and acoustic signals when the wavelength is much less than the dimensions of the major features of the environment. In specular propagation walls have mirror-like reflection, right-angle corners reflect back to all directions and edges will diffract back to all directions.

Echolocation is a particularly useful area of research, commonly used in robot navigation, where geometric information about the local environment is obtained by measuring the time of flight of ultrasonic pulses [10] and dates back to the analysis of biological echolocation used by bats [11]. While most applications use sensor arrays to calculate the direction of a range measurement, those based on position information alone are more applicable to the single-antenna ultrawideband radar case, since direction of arrival cannot be measured. The impulse response of a wireless channel determines the arrival time of all multipath (similar to acoustic echoes), which must then be processed to obtain useful information about the environment.

III. RELOCATION ALGORITHMS

The task of relocation involves fitting the current data to a position on a known map of an environment. The first approach by Lim and Leonard [12] uses range information alone provided by time-of-flight calculations, and is most relevant to the current situation as no information is available on the direction of the range measurements.

In this algorithm the pair-wise interpretation algorithm of Grimson and Lozano-Perez [13] is applied to every combination of a pair of objects and a pair of range measurements. This will produce one, two or zero possible positions for each pair. One solution corresponds to the intersection of two lines drawn normal to two planar objects, two solutions corresponds to one or both of the objects being a diffracting edge or corner, and no solution corresponds to objects that cannot match a measurement. Multiple solutions will be found for the correct position, but due to errors in measurement and non-ideal environmental objects a cluster of solutions will be found for the correct position. Within a threshold, the location with the most "hits" will be determined as the best position and the minimum mean-squared error estimate of the actual location will be determined. This is based on the work of Drumheller [14], which implements the interpretation algorithm on range data with known directionality.

A second relevant relocation method by Dijk [15] uses the signal received from a base station to predict the best position. At the receiver the time-of-flight of the line-of-sight path of the pulse determines the distance from the base station, the actual position lies on the surface of a sphere with that radius. Once the radius is determined, the expected response to this pulse, or signature, at the receiver is calculated for uniformly-spaced samples of the surface of the sphere assuming specular propagation. The calculated signature that most closely matches the measured data is determined to correspond to the actual position. This algorithm is sensitive to blockage of line-of-sight and degenerates into simple trilateration when multiple base stations are used simultaneously, however a distributed system would provide a lower probability of line-of-sight blockage.

IV. Map-Building Algorithms

Unlike relocation algorithms, map-building algorithms are provided no *a priori* information on the geometry of the environment. All algorithms found use information on the direction of all range measurements.

Kuc and Seigel [16] proposed one of the first map building algorithms. The algorithm relies on specular propagation which locates walls, corners and edges, then fits a map based on the corner, edge and wall transducer (CEWT) model. A rotating sensor samples the azimuthal plane and records range and direction measurements. Corners behave like walls, which have mirror-like reflection, and edges also diffract to all directions by Huygen's principle. This algorithm tracks shadow regions after all elements are calculated, where the limits of these areas are defined by edges, then a line is projected to calculate the edge of visibility on a partially shadowed wall. Known shadow regions allow relocation algorithms for data that would otherwise not fit the given model. In this paper edges and models are determined by unique properties of sonar to distinguish edges from corners, but the later proposed methods would allow this calculation in ultrawideband.

More accurate methods use map building in conjunction with localization, which estimates motion for navigation, and is known as simultaneous localization and map building (SLAM). The algorithm by Guivant [17] uses an extended Kalman filter to estimate and update the current estimate of position, while simultaneously building and maintaining a map of the local environment. A Kalman filter is an iterative method designed to create an estimate of a process that minimizes the mean-squared error. The discrete Kalman filter operates with two cycles: first the propagation cycle predicts the next state based on past estimates and the noise statistics, and second the update cycle incorporates new data to improve the prediction.

Over time, major features of the environment become stable and are implemented into the state vector. An optimization is suggested to allow the algorithm to run in real-time, where the covariance matrix is only updated for states that provide the most information about the environment according to current measurements.

V. DISTRIBUTED ALGORITHMS

Distributed algorithms are typically based on the localization problem for groups of robots which require accurate estimation of position when in motion. The work by Roumeliotis and Bekey [18] decentralizes a Kalman filter to allow measurements to take place independently, and information is only exchanged when a pair of robots each measure the range of the other. Individual filters can operate independently, as long as the covariance matrix of all filters is maintained by all filters. During an update, the cross correlation terms are updated, and information is spread across the group. This distributed approach may be applied to Kalman filter-based SLAM methods; however, no algorithm found assumes distributed transmitters and is based on range information alone.

A third paper by Kuc [19] shows that it is an ill-formed problem to perform localization using signals from other sonars when the relative transmitter locations are not known, since an infinite number of solutions exist. However, if the difference between the line-of-sight and reflected pulse is measured, the minimum distance to the object or source can be determined. It is also shown that a distributed echolocation system can be implemented provided the relative position of all transmitters is known, and the IEEE 802.15 task group will provide this information with simple trilateration algorithms.

VI. COMPARISON OF METHODS

Echolocation algorithms are applied to many very different scenarios, with a variety of sensors. The fundamental goals of these algorithms are compared in Table I, along with the unique properties of these algorithms.

Algorithm Goals	Properties
1. Relocation algorithm 2. Map-building algorithm 3. Localization algorithm	4. Uses range info only 5. Distributed 6. Iterative or adaptive 7. Signature based

	1	2	3	4	5	6	7
Lim and Leonard [12]	x			x			
Dijk [15]	x			x			x
kuc and seigel [16]		x					
Guivant [17]		x	x			x	
Roumeliotis and Bekey [18]			x		x	x	

TABLE I
COMPARISON OF PREVIOUS METHODS FOR ECHOLOCATION

VII. PROPOSED METHODS

I propose to extend the first relocation algorithm to use distributed sources, assuming relative positioning is available; all ranges will extend to ellipses in this scenario. I also propose to explore new methods that assume distributed sources rather than adapting to the scenario. One possible solution would be to extract all possible tangents to all combinations of range measurements, using the simple algorithm proposed by McKerrow [20], then keep only coplanar solutions. Also, since no related work uses the timing of secondary echoes, I propose to explore this approach assuming only two sources, or a single source with multiple antennas.

VIII. CONCLUSION

Echolocation, relocation, localization and map-building are rich areas of sonar research, providing many solutions to many types of problems. The similar propagation of sonar allows these methods to be used in ultrawideband, but the problem is fundamentally different as directionality information is not available. However, the potential ubiquity of wireless devices can provide a distributed set of sources providing unique information to allow for novel algorithms based on range information alone. These algorithms combined with basic synchronization and trilateration of sources allows for robust solutions based on existing communications hardware, only requiring that channel estimation information be provided from the hardware.

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