Norris Nicholson
Xiaoli Ma
1961C
Radio-based Two-way Ranging and Distance Measuring Solutions

Introduction

Distance measurement equipment has been an essential part of navigation and communication for decades. On the smaller scale, radio based ranging has been used in warehouses, automated vehicles, and convention centers to track people and materials. Traditionally this technology operates using Two-way Ranging, in which two independent radios use a Time of Flight measurement between the two of them to accurately measure their distance apart [1]. Their applications in mesh networks where individual nodes know the relative position between themselves and all other nodes are numerous.

Two-way Ranging

Except in radar based applications, radio distance measurement uses a transmission node and a receiver node to measure time of flight distances between two points. While several approaches are used in industry, two stand out as the most common [2]. The first utilizes a process known as Time Difference of Arrival (TDoA) and the second is known as Time of Flight (ToF). Each thrives in its own unique setting.

ToF measurements require an interrogator node and a station node. The interrogator sends a signal out to the station which contains some sort of identifying information, as well as a time-referenced pulse or packet. The exact time at which this pulse or packet is sent out is recorded internally. When this signal reaches the station, the message is held in memory for an exact period of time, then sent back out to the interrogator node. When the original interrogator receives a message that matches the original message id, it records the time at which the time-references pulse or packet is received. The distance is then calculated based on the time elapsed between the initial interrogation message and the return message from the station node. Note that the interrogator node must subtract the exact delay period used by the station node in order to establish an accurate measurement [1, 2, 3].

ToF distance measurement has several distinct advantages, as well as a few drawbacks. ToF allows pairs of nodes to measure distances between themselves with relative ease and accuracy. The result can be directly translated into a distance measurement (rather than inferred through situational information), and many devices can use this method at a time, assuming radio signal processing is sufficient to decode overlapping messages [3, 4]. Unfortunately, it requires many measurements to map an entire network.

TDoA distance measurement, on the other hand, relies on synchronized clocks between multiple station nodes. The interrogator node sends out a pulse to all stations in the network. Each station node receives this pulse and records the exact time at which the message was received. They then compile this data to form an accurate position of the interrogator node relative to the positions of the station nodes. When performed several times in quick succession (alternating which of the nodes in the network is the interrogator node), a complete map of the network can be obtained [1, 2, 3].

This form of distance measurement has a definite advantage of being faster and requires fewer distance measurements to completely map the entire network. Unfortunately, it cannot directly measure the distance between two nodes [2]. Instead, the entire network (or at least large portions of it) must be mapped together. This requires more computation than ToF distance measurement, and will likely require more intra-network communication.

It is worth noting that in both cases, nodes can arbitrarily assign themselves to any of the defined positions (interrogator, station, etc…) as needed in software. In a mesh network, nodes will likely communicate and assign roles before performing each distance measurement [2].

Radio Distance Measurement Error

Radio distance measurement is not perfectly accurate, and depends on several physical and environmental factors. One large source of error is the speed of the measurement hardware [4]. Because light travels at such a high speed (e.g, it takes 0.0336 ns for light to travel 1 cm), accurate time recording between message transmission and reception is critical. This is especially true for TDoA systems which require precise time recording among nodes in order to produce an accurate measurement [2].

Current Solutions

The most prevalent commercial option on the market is the DecaWave DW1000 system. The solution adheres to the IEEE802.15.4-2011 standard and complies with all FCC regulations on the subject. It combines distance measurement technology with a fully functional radio transceiver capable of communicating over a range of 300 meters or up to 6.4 Mb/s, depending on channel selection and power settings. The DW1000 is controlled using a standard SPI interface, and can measure distances to within 10cm relative to other DW1000 devices [2, 5]. Several libraries already exist to interface with this device [6].

Sources

[1] S. Lanzisera, D. Zats, and K. S. J. Pister, “Radio Frequency Time-of-Flight Distance Measurement for Low-Cost Wireless Sensor Localization,” *IEEE Sensors Journal*, vol. 11, no. 3, pp. 837–845, 2011.

[2] Decawave Ltd, *DW1000 User Manual: How to Use, Configure and Program the DW1000 UWB Transceiver*, Decawave Ltd, 2017

[3] Digi-Key's North American Editors, “Simplifying Time-of-Flight Distance Measurements,” *Digi-key Article Library*, January 2017. Available: ArticleLibrary, https://www.digikey.com/en/articles/techzone. [Accessed October 20, 2018]

[4] S. Lanzisera, “RF Time of Flight Ranging for Wireless Sensor Network Localization,” *2006 International Workshop on Intelligent Solutions in Embedded Systems*, 2006.

[5] Decawave Ltd, “DW1000 IEEE802.15.4-2011 UWB Transceiver,” DW1000 datasheet, 2015 (Revised 2017)

[6] V. D. Bossche, “DecaDuino,” *irit.fr*, Mar 19, 2016. [Online]. Available: https://www.irit.fr/~Adrien.Van-Den-Bossche/decaduino/. [Accessed October 21, 2018]