Geo-Location in Harsh Environments

Localization of radio devices operating in indoor channels is a daunting task due to the presence of severe multipath and low probability of a line-of-sight (LOS) signal between the transmitter and receiver. This harsh propagation environment for radio signals results from the shadowing and reflections from walls and objects in such channels.

We have built a set of high-accuracy indoor ranging devices using ultra-wideband (UWB) RF signals. UWB radios are particularly suited to ranging because of their short-duration (high-bandwidth) pulses. Our ranging and positioning techniques directly address some known challenges in UWB localization. A single distance measurement is gathered from repeated range measurements across a channel, and distance measurements from many locations surrounding the target are combined in a way that minimizes the range biases associated with indirect flight paths and through-wall propagation delays.

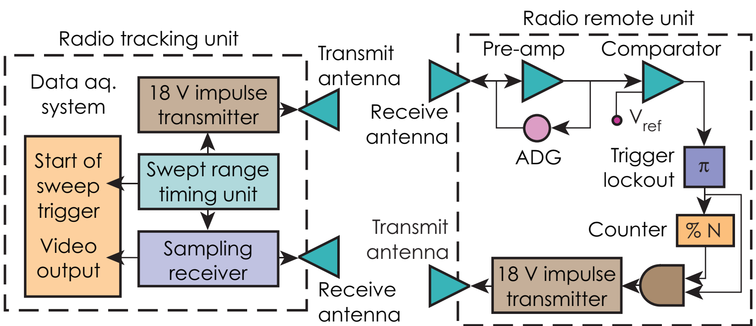

Figure 1. Block diagram of the round-trip TOF ranging pair, consisting of two units. The radio tracking unit sends a pulse to the remote unit, which replies with its own pulse. The main unit records the total round-trip TOF to extract the distance between the units.

Project Goals

Our goals are to build UWB radios to collect range measurements suited for positioning; implement the signal processing necessary to recover pulses in highly reverberant environments; and execute an experimental plan to document the signal-to-noise ratio (SNR), resolution, and accuracy of the system.

Figures 1 and 2 show the hardware and the ranging routine of our system. The remote unit receives the request stream and responds with its own uniquely encoded reply pulse stream. The tracking unit receives and time-stamps the reply to find elapsed round-trip travel time, and thus distance.

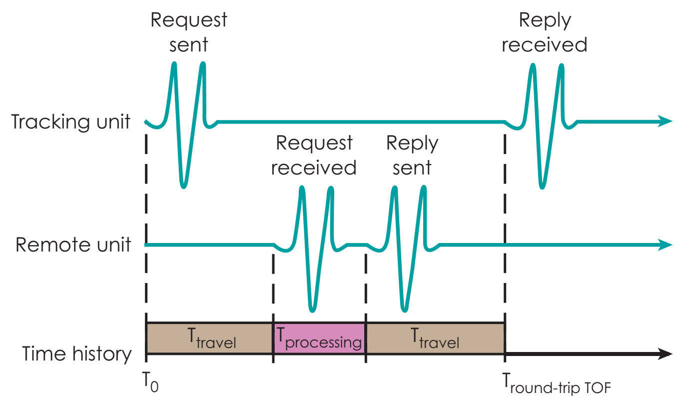

Figure 2. The round-trip TOF, consisting of travel time to and from the remote unit (approximately equal) and time spent in processing at the remote location (a known value we can subtract out). Distance between the tracking and remote units can then be calculated.

For more information contact
Claudia Kent Hertzog
(925) 424-3043
hertzog3@llnl.gov

Relevance to LLNL Mission

Several LLNL programs have an interest in the high strategic potential of urban tracking. Applications for a high-accuracy system for use in complex, urban environments is growing, and LLNL's established technology in MIR UWB radios allows us to be at the cutting edge of this technology.

FY2005 Accomplishments and Results

We set up several scenarios to test the performance of the time-of-flight (TOF) ranging radios in three areas: SNR gain using beam-formed signals across a channel; resolution of the beam-formed measurement; and absolute accuracy of a measurement obstructed by several types of walls. To date, we have built, tested, and documented performance of the ranging radios meeting all of our expected goals. We tested the ranging performance in several harsh environments.

Ranging accuracy depends heavily on being able to resolve the exact arrival time of the incoming signals. In harsh ranging environments, signals are forced to travel though walls or around corners along a non-line-of-sight (NLOS) transmission channel. Our approach is to combine multiple repetitions of the transmission into a single beam-formed signal. Figure 3 compares a single NLOS range measurement in a volcanic rock cave with a beam-formed range collection under the same conditions. Combining 100 copies of the same range measurement gives back 17 dB of the lost SNR.

With the radios in LOS as well NLOS environments, repeated measurements fall within a standard deviation of less than 0.5 in. by thresholding a ratio of short- to long-term amplitude to find the peak arrival time.

UWB range measurement residual errors from several distances in a clear LOS show our ability to measure range distance within 1.5 in. of the actual value. Through a sheet-rock wall we can measure range distance within several inches of the actual value, and behind a concrete wall we can measure range distance within a foot.

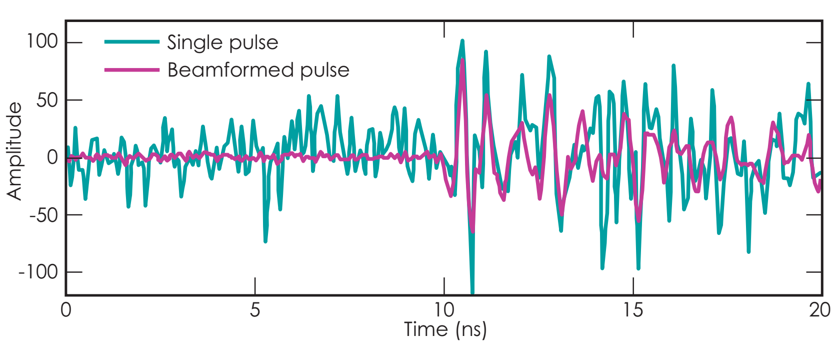

Figure 3. UWB pulse received inside a volcanic rock cave with NLOS between tracking and remote radios. Only a slightly discernable pulse is seen with a single signal, but by beam-forming 100 frames we decrease the noise to clearly identify the pulse.

Related References

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2. Young, D., *et al.*, "Ultra-wideband (UWB) Transmitter Location Using Time Difference of Arrival (TDOA) Techniques," *Conference Record of the Thirty-Seventh Asilomar Conference on Signals, Systems and Computers,* 2003.
3. Jourdan, D., *et al.*, "Monte Carlo Localization in Dense Multipath Environments Using UWB Ranging," *Proceedings of the IEEE Conference on UWB,* Zurich, Switzerland, 2005.
4. Lee, J., and A. Scholtz, "Ranging in a Dense Multipath Environment Using an UWB Radio Link," *IEEE Journal on Selected Areas in Communications,* **20**, 9, pp. 1677-1683, 2002.
5. Smith, J., and J. Abel, "Closed-Form Least-Squares Source Location Estimation from Range-Difference Measurement," *IEEE Transactions of Acoustics, Speech, and Signal Processing,* **ASSP-35**, 12, 1987.

FY2006 Proposed Work

For FY2006 we have proposed The Urban Tracking and Positioning System to be a high-resolution (~1-ft accuracy) urban tracking demonstration system, similar to GPS but suitable for indoor use in urban combat scenarios: buildings, city streets, and caves. Together with proven technologies from past years, this system can provide a packaged, real-time, high-resolution, urban tracking demonstration system.