Ultra-Wide Band Two-Cluster Angle of Arrival Tracking System Design

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This report describes a design effort for a prototype ultra-wide band (UWB) tracking system that is currently under development at Johnson Space Center (JSC). The system is being studied for use in tracking of lunar/Mars rovers during early exploration missions when satellite navigation systems, such as Global Positioning System (GPS), are not available. The Science Crew Operations Utility Testbed (SCOUT) vehicle, under development at JSC, provides a testbed for the use of the UWB tracking system in such an environment.

UWB technology is exploited to implement the tracking system due to its fine time resolution, which is on the order of picoseconds, its low-power spectral density, which allows the system to coexist with other communication systems, and its resistance to multipath interference. A two-cluster Angle of Arrival (AOA) tracking method using Time Difference of Arrival (TDOA) information is used for implementation of the tracking system, not only to exploit the achievable fine time resolution of UWB signals, but also to eliminate the need for synchronization between the transmitter and the receiver. The UWB radio at each cluster is used to obtain the TDOA estimates from the UWB signal sent from the target.

Tracking Methodology

Many different approaches can be applied to estimate the location of a radio source including AOA, Time of Arrival, TDOA, relative signal strength, and various hybrids of these. For close-in applications, the TDOA approach was chosen as the tracking method since it does not require synchronization between the transmitter and receiver but can still exploit the fine time resolution available with UWB signals. For long-range applications, the AOA approach can be applied to estimate the location of a target since the approximation error under the long-range assumption is relatively small. The AOA technique is discussed briefly below.

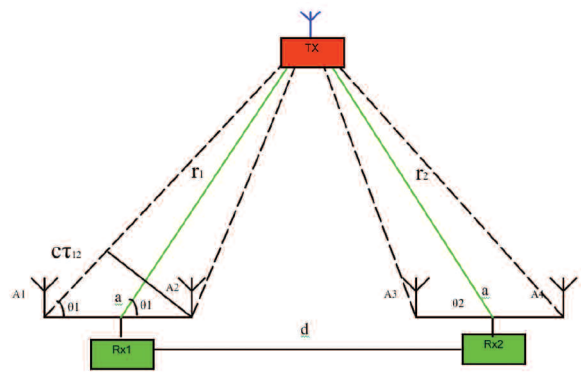

Fig. 1. *AOA localization in two-dimensional space.*

A two-dimensional AOA tracking case is illustrated in figure 1. Two receivers are used to locate the transmitter in this two-dimensional space by a simple triangulation. Two receivers' positions (Rx1(0,0), Rx2(d,0)) are assumed known. If the AOA from the target to each receiver (i.e., θ1 and θ2) can be estimated, the transmitter's position can be computed using the Law of Sine as follows:

$$\left[\frac{d\cos\theta_1\sin\theta_2}{\sin(180^0-(\theta_1+\theta_2))},\ \frac{d\sin\theta_1\sin\theta_2}{\sin(180^0-(\theta_1+\theta_2))}\right]$$

To find the AOA information (θ1 and θ2), two antennas spaced by distance *a* are connected with each receiver. Since the UWB signal has fine time resolution, the TDOA information (τ12 and τ43) was measured and carefully converted to the AOA information as follows.

Since electromagnetic waves travel with constant velocity *c* in free space, the distance between the transmitter and the receiver's antenna is directly proportional to the propagation time of the signal. Under the long-range assumption (**r1**, **r2** >> *a*),

$\theta 1 \approx \arccos(c\tau 12/a)$;
$\theta 2 \approx \arccos(c\tau 43/a)$.

The advanced signal processing techniques are developed to estimate the TDOA information (τ12 and τ43) from the pulses transmitted from the target UWB radio. The TDOA estimates are then fed into the above AOA algorithm to locate the target.

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continued

Field Tests

In September 2005, a joint tracking test was conducted with the SCOUT vehicle at the Meteor Crater in Arizona. The two-cluster UWB AOA tracking system baseline has the following setup (figure 2): two receivers are 50 meters apart and two horn antennas at each receiver are 15 meters apart. One UWB radio was integrated with the SCOUT vehicle as the transmitter (figure 3).

The objective of the test was to:

1. Test the real-time tracking of a moving target.
2. Test the interference with other communication systems on vehicle.

The SCOUT vehicle was running at normal speed (7 miles/hour) in the tracking area. It shows the tracking accuracy compared to the differential GPS, with less than 1% error at ranges up to 610 meters (2,000 feet). A recorded SCOUT running trajectory demonstrates the real-time tracking capability of the system. The tracking update rate for the trajectory was approximately 5 Hz. No radio frequency (RF) interference was observed between the UWB tracking system and other on-board SCOUT systems (such as GPS at 1.6 GHz, video at 5.8 GHz, voice at 140 MHz, and telemetry at 2.4 GHz).

Conclusion

A prototype UWB two-cluster AOA tracking system has been designed and implemented. Field tests were conducted jointly with the SCOUT vehicle at the Meteor Crater in Arizona to test the tracking capability for a moving target. These tests demonstrated that the UWB tracking system can coexist with other RF communication systems on board SCOUT, and that a tracking resolution less than 1% of the range (range up to 2,000 feet) can be achieved.

Fig. 2. Tracking system baseline setup.

Fig. 3. Tracking target – SCOUT vehicle.