INDOOR NAVIGATION USING A SOFTWARE DEFINED RADIO

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ABSTRACT

Time of Arrival (TOA) observations from local beacon signals can be used to augment and provide a back-up navigation source for GPS signals in a Software Defined Radio (SDR). The addition of inertial sensor inputs to the SDR offers the ability to track down to much lower power levels for both the GPS and TOA signals, effectively deal with multipath, and recover more quickly from signal outages. In this paper, multipath mitigation algorithms that leverage combined TOA and inertial measurements are presented to enhance tracking performance in indoor and urban environments.

1. INTRODUCTION

Navigation and communications systems in the tactical environment frequently encounter situations where GPS signal reception is deteriorated, making the position and time information less reliable or unavailable. To address these shortfalls, the Defense Advanced Research Projects Agency (DARPA) is spearheading the Robust Surface Navigation (RSN) program, which seeks to develop technologies to provide the U.S. warfighter with the ability to geolocate and navigate effectively in GPS-degraded and GPS-denied environments. The objective of the RSN program is to exploit alternative ranging signals, including beacons and other "signals of opportunity," including other satellites-based signals, cellular telephone signals, and ever terrestrial television transmissions -- to provide precise location and navigation information to ground troops when GPS signals are not fully available..

Time of Arrival (TOA) observations from local beacon signals can be used to augment and even serve as a back-up navigation source for GPS. Under the RSN effort, NAVSYS has developed multipath mitigation techniques for using beacon signals to navigate in high multipath environments and has prototyped these techniques in a Positioning and Communications (POSCOMM) Software Defined Radio (SDR) device[1]. The two techniques presented in this paper are a Maximum Likelihood Estimator (MLE) for optimal peak detection in the presence of multipath, and a GPS/TOA/Inertial Receiver Autonomous Integrity Monitor (GTI-RAIM).

2. POSCOMM SYSTEM ARCHITECTURE

The POSCOMM SDRs are designed to operate in a networked architecture, as shown in Figure 1, where SDR Master Units are designated as transmitters to provide TOA augmented navigation to SDR Slave units operating as receivers in a GPS-degraded or GPS-denied urban environment. The Master units transmit a TOA message that includes a pseudorandom sequence from which the time of arrival at the Slave unit can be precisely determined. A message is also sent including the precise time of transmission of the TOA message and the precise location of the Master unit based on the GPS observations. The time-of-arrival differenced with the time-of-transmission provides the Slave unit with a pseudorange observation from each of the Master units' locations. This can be used to solve for the position of the Slave either using the TOA updates alone or using a combination of both the GPS and TOA observations.

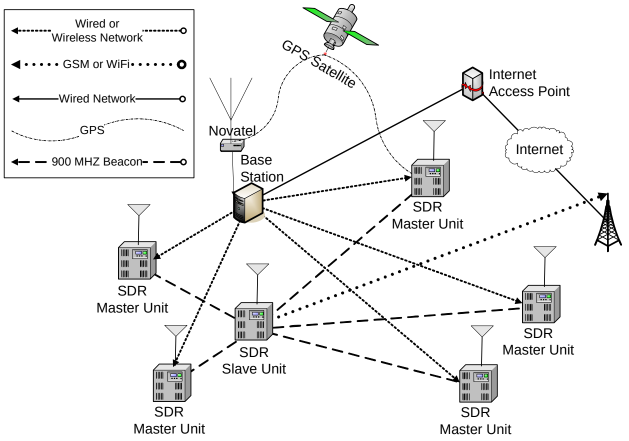

Figure 1 POSCOMM SYSTEM ARCHITECTURE

The POSCOMM SDR developed by NAVSYS includes the capability to operate both as a GPS receiver and also as a 900 MHz transceiver and/or receiver operating within the ISM band. Since both the GPS and communications functions reside within common radio hardware, they can be linked to provide a positioning capability that leverages both the GPS-derived pseudo-range and carrier phase observations and also Time-Of-Arrival observations derived from the communications channel. The integration of an inertial unit and barometric sensor facilitates low power tracking and navigation during signal outages.

3. MLE-AIDED TRACKING

In the indoor environment, beacon signals are likely to suffer from significant power loss due to free space loss and physical obstructions in the signal line of sight. The indoor environment is also typically rich with reflective multipath sources. The factors, combined with local user motion and motion of other objects in the environment, leads to a highly non-stationary and challenging signal environment in which a receiver must operate. By aiding the TOA tracking loops with inertial sensors to ensure proper correlator pre-positioning, additional constraints may be placed on the peak detection algorithms to optimally estimate both the direct and multipath signals and reduce the likelihood of a false peak detection.

The MLE algorithm starts with the previous navigation solution and propagates it forward based on current inertial measurements to determine a best estimate of user position at the time of PR measurements. With this estimate of user position and velocity, the correlators may be prepositioned in both the τ and *f* dimensions, and a priori estimates of pseudorange may be formed. A cost function is defined that estimates the combined direct and multipath signals through minimization of the cost function. As shown in Figure 2, this allows detection of both a direct path signal and also close-in multipath from the correlation curves generated using the prepositioned data.

The first plot in Figure 2 shows the TOA correlation peak with a direct line of sight between the TOA beacon and the SDR receiver. The second plot in Figure 2 shows the TOA correlation peak with a strong multipath signal. The MLE algorithm correctly detected the direct path and also identifies the presence of the multipath signal. The third plot shows the correlation peak once the operator moves past the obstruction and is no longer receiving a strong multipath reflection. The MLE-aided tracking algorithm allows the operator to continue to track the beacon signals under low power and high multipath conditions. In the event of a total signal dropout, it will allow rapid re-acquisition of the beacon signal once it is present again.

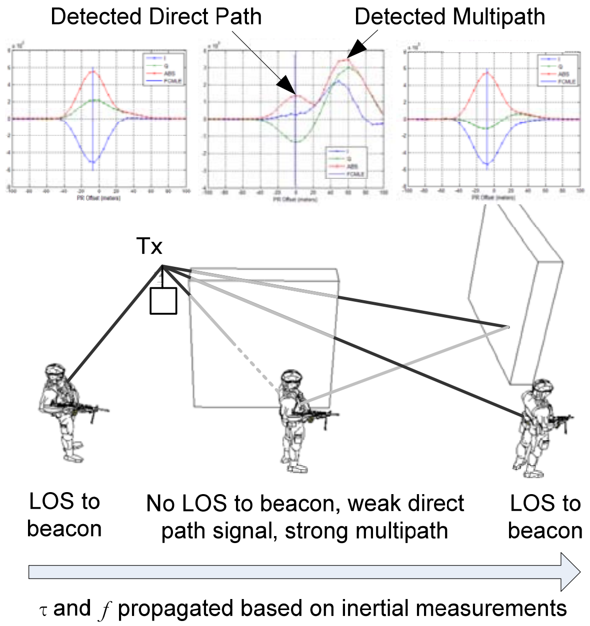

Figure 2 MLE-Aided Tracking with Signal Blockage and Strong Multipath

Example tracking results from live data are shown in Figure 3. In-phase, quadrature, and absolute value data are plotted for a received signal. The absolute value shows that no peak is visible for the direct path signal (at a PR offset 0m) and that there are two multipath reflections occurring at PR offsets of 20m and 70m. By looking at both the in-phase and quadrature components of the correlation peak the MLE-Aided tracking algorithm is able to pick out the low power direct path signal in the presence of much stronger multipath reflections.

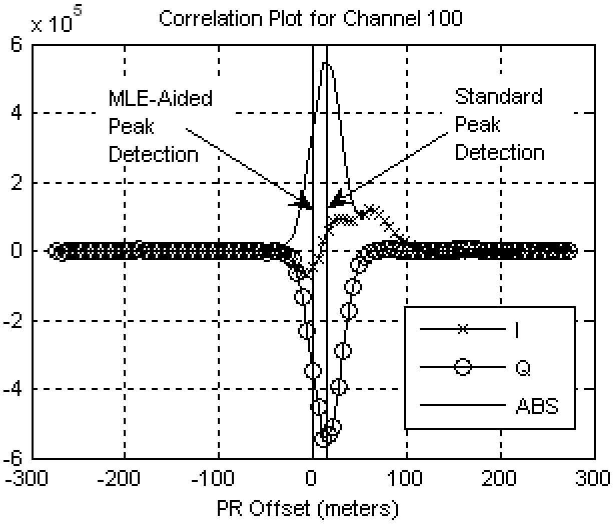

Figure 3 MLE-Aided Results with Signal Blockage and Strong Multipath

4. GTI-RAIM

In deep signal fades or in the presence of very high levels of multipath, the peak detection algorithms may fail to detect the direct path signal and may provide the navigation filter with erroneous range measurements based on spurious noise or multipath reflections. The purpose of the GPS/TOA/Inertial Receiver Autonomous Integrity Monitor (GTI-RAIM) is to detect any out of tolerance GPS or TOA ranges in order to prevent them from being used in the GPS/Inertial Kalman filter solution. Unless the GPS and TOA range observations pass this high integrity test, they are not applied as measurement updates thus maintaining the integrity of the blended solution.

The GTI-RAIM integrity algorithm is based on developing a set of conditional probabilities to assure detection of a satellite or beacon failure. A failure is defined as having a pseudorange measurement error that defines some threshold. This algorithm uses the “Bounded Probability of Missed Detection” (BPOD) approach developed by NAVSYS[2,3]. The steps for the GTI-RAIM algorithm are shown in Figure 4, and the principle of operation of the BPOD algorithm is illustrated in Figure 5. When a satellite or beacon failure occurs, the position and velocity error distribution has a mean offset with the locus of position or velocity errors distributed around this mean in an ellipse. The magnitude of the ellipse is determined by the satellite/beacon geometry and the noise on the solution.

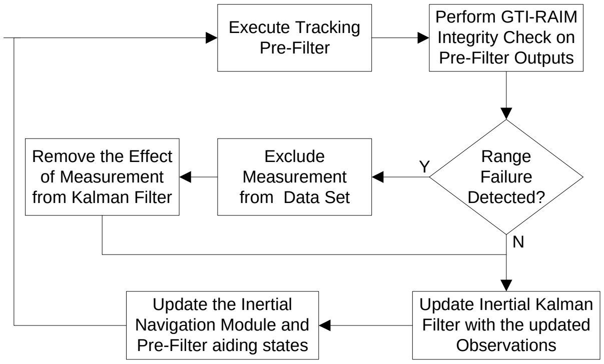

Figure 4 GTI-RAIM Algorithm Steps

The BPOD algorithm uses the pseudo-range measurements to determine whether or not a bias has occurred. If a bias is detected, the algorithm determines the channels on which the failure is most likely. This information is then used to estimate the bias (B), and the mean radial position error (RPE). Thus RPE is the radial error that would result from a bias B. However because of noise, the actual radial position error will have a statistical distribution about RPE. The algorithm calculates this distribution and computes another radial position error value, RPE(PMD), which is the radius of a circle centered at the true position that encompasses (1-PMDmax) of the errors. The probability of a navigation error being greater than RPE(PMD) is thus PMDmax.

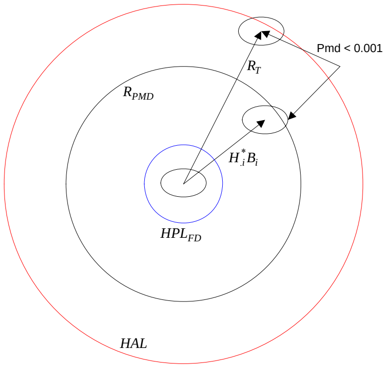

Figure 5 BPOD Principle of Operation

The algorithm compares RPE(PMD) to a user-specified maximum allowable radial position error (RPEmax) or, equivalently, compares RPE to a threshold RPET. If RPE(PMD) is less than RPEmax, then RPE will be less than RPET and the actual error is declared to be within the allowable limits. The probability of missed detection (PMD) will be less than PMDmax. If RPE(PMD) is greater than RPEmax, then RPE will exceed RPET and an alarm (red) or warning (yellow) is given.

The choice between a red or yellow alarm is made by calculating the probability of false alarm (PFA) as a function of RPET, geometry, and noise. If the probability of false alarm exceeds a user-defined maximum (PFAmax), a yellow alarm is raised, warning the user that a potentially unsafe condition has occurred. If the probability of false alarm is low (<PFAmax), then a red alarm is raised to alert the user that a failure has been reliably detected.

Even though a bias is not detected, there may still be reason to raise an alarm. If B = 0, then the mean radial error, RPE, will equal zero. There will still be a statistical distribution of the actual error about zero, and RPE(PMD) will be non-zero. In the case of large HDOP, RPE(PMD) may exceed RPEmax and a red alarm will be raised. This is an HDOP alarm. A red alarm raised after the detection of a bias will be called a BIAS alarm. Table 1 shows how the BPOD algorithm sets integrity alarms based on these parameters.

Table 1 BPOD Integrity Alarms

Alarm	Explanation
Red (HDOP alarm)	RPE > RPEmax with probability > PMDmax and PFA < PFAmax and B = 0
Purple (BIAS alarm)	RPE > RPEmax with probability > PMDmax and PFA < PFAmax and B≠ 0
Yellow	RPE > RPEmax with probability > PMDmax and PFA > PFAmax
Green	RPE < RPEmax and PMD < PMDmax

5. FIELD TEST RESULTS

A series of field tests were conducted where the ability of the MLE-Aided filtering and GTI-RAIM algorithms were tested to characterize the potential performance improvements that may be realized. Results using baseline algorithms and the algorithms discussed in this paper are shown in Figure 6 and Figure 7, respectively. The absence of outliers in Figure 7 is due to application of GTI-RAIM processing, which excludes range measurements with large multipath errors, and tighter distribution of solutions in is due to MLE-aided peak detection algorithm, which reduces small multipath-induced range errors.

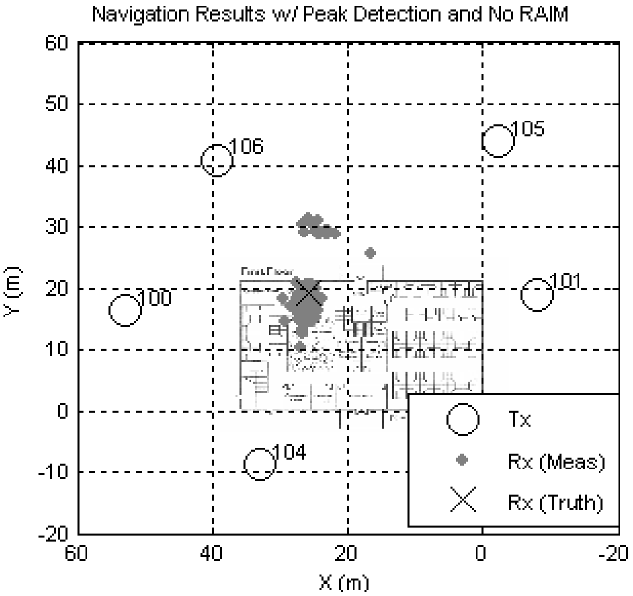

Figure 6 Navigation Results with Baseline Techniques

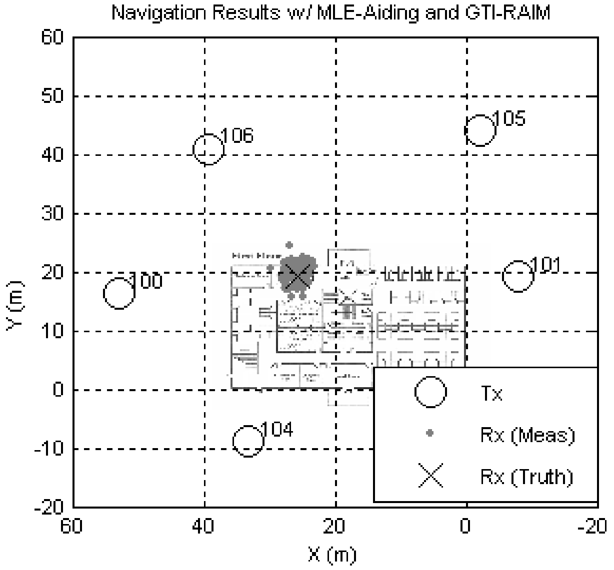

Figure 7 Navigation Results with Proposed Techniques

6. CONCLUSIONS

In this paper we have presented and demonstrated the performance of a MLE-Aided peak detection algorithm and a GTI-RAIM algorithm. The MLE-Aided peak detection algorithm uses inertial aiding to pre-position tracking loops to reduce processing overhead and increase the noise and interference thresholds to which tracking may be maintained. This algorithm also provides a framework for weighting detected peaks and energy, reducing the likelihood that a strong multipath source will overpower a weak direct path signal. In the event of a failure of the peak detection algorithms, the GTI-RAIM algorithm provides the ability to use an overdetermined solution to detect and exclude erroneous measurements before they are used in the integrated filter.

Future urban and indoor navigation systems will need techniques such as the ones presented in this paper to provide users with GPS-like quality of service both outside and inside buildings and urban environments. The POSCOMM SDR units developed under this can provide a robust urban navigation solution that can provide precise positioning inside buildings where the GPS signals cannot be received. Military applications for this technology include improved military operations in urban terrain (

7. ACKNOWLEDGMENTS

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8. REFERENCES

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