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Empirical Tests No. 2

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I. Overview

At this point in time, the system is experiencing the same phase difference instability issue as before. This is currently the central issue to the inaccuracy of measured angles of arrival (AoAs) because the measured phase differences directly correspond to the computed AoA (via 2-element phase interferometry, MUSIC, or root MUSIC). If the phase differences are all zero (irrespective of tag positioning), the measured angle of arrival will be 90 degrees. This document will briefly discuss the observed central issue and steps moving forward.

II. Observations of the Technical Issue

In the last document, I proposed solutions to the phase difference instability issue. One solution was to implement forward spatial smoothing. A new module called “spatial\_smoothing.” was added to the vanilla ETTUS-doa library with the gr-modtool. This module contained the header files, source file, and GRC xml code (the xml code provides the framework for the GNU Radio block in the graphical user interface) to implement spatial smoothing in GNU Radio. The autocorrelation program was used as a basepoint for writing [this code](https://github.com/jakapoor/AMRUPT/blob/master/Firmware/Ground_nodes/Pi_DOA/Summer%202018/GNU%20Radio/forward_spatial_smoothing.cc) (the most recent version currently on the Pi, and backed up on my computer, will be uploaded soon to GitHub soon). This new block is meant to replace the autocorrelation block and includes an option for no spatial smoothing, forward spatial smoothing, and forward-backwards spatial smoothing. The block retains the original smoothing option as well (forward and forward-backwards smoothing in time/samples).

When no spatial smoothing was used, the MUSIC pseudospectrum was observed to be almost flat (between 0 and -10 dB) with an occasional smooth hill or two. This is likely due multipath signals impinging on the antenna array omnidirectionally. When forward spatial smoothing was used, a sharp peak was observed (20-30 dB in height) corresponding to a measured angle of arrival of the transmitter. Very occasionally, a second shorter peak or same-height peak would be observed. Even though this first observation for forward smoothing was promising, the peak would experience instability, bouncing between +/- 5 degrees. This problem is not system-breaking; however, as a moving average can be used for stabilization. The major issue observed with this peak is that it was often located at an unequivocally incorrect angle related to the tag. This angle was also discontinuous as the tag moved angularly around the array. For example, the measured angle could increase by 40 degrees when the tag moved 5 degrees. Please note that this measured discontinuity differed unexpectedly in that the measured peak could move anywhere by 10-40 degrees when the tag moved ~5 degrees irrespective of position.

There is a clear issue in the forward-backward smoothing option because the angle is only at 0 or 90 degrees irrespective of tag position. This is likely due to the forward averaging completely canceling out the backwards averaging. More time can be put into debugging and creating a forward-backward spatial smoothing routine based on [1, 2] which may yield better results in a dense multipath environment. The forward spatial smoothing code simply averages the autocorrelation operations performed on rows 1-2, 2-3, and 3-4 of the observed steering vector. The forward-backwards spatial smoothing code averages the forward spatial smoothing output with the backwards smoothing output. The backwards smoothing output is performed by reversing rows 1-2, 2-3, and 3-4 of the observed steering vector before performing autocorrelation operations and averaging. A different implementation may be necessary for the backwards smoothing output as discussed in page 170 of [1] and page 232 of [2].

All the experimentation was performed with a JSC to SMA connection from the CC1310 to a whip antenna (the same antenna as the ones placed on the testing rig). The whip antenna was held vertically throughout testing to mimic the antenna polarization of the receiving antennas. Close range distances (5-20 meters) to the antenna array were primarily used in testing. To make sure the phase difference issue was not caused by the transmitter, the RF signal generator was used as a transmitter with a long sma cable to a whip antenna on the top of a long pole. Even after this testing configuration, with no observed signal leakage from the signal generator (no signal is recorded on the receivers if the transmitter antenna is not attached), the antenna placed away from the near field of my body, and the antenna placed at the same height as the receiving antennas, no changes were observed in the issues stated above.

It is important to state in the observations section that ~90% of forward averaging tests could determine whether the tag was left of 90 degrees, near 90 degrees, or right of 90 degrees. This was observed to be the case if the tag was within 30 to 150 degree of the antenna array reference line (0 degrees). Put more simply, the system was able to tell whether the tag moved left or right of the 90-degree line inaccurately (+/- 10-20 degrees).

III. Steps Moving Forward

First, it would be a good idea to test the system outdoors in an open-field environment to see if it performs better with low multipath interference. Second, it seems better results have been obtained by Igor Sedov, Sam Whiting, and Travis Collins. I think it would be a good time to record the system’s performance in video and contact these experts on the central phase instability issue when a transmitter is used. Third, frequency-hopping can be implemented to find common angles of arrival among multiple frequencies and forward-backwards smoothing can be used to more fully mitigate the effects of multipath interference. Finally, we could move to single ground node TDOA or PDOA low-range tracking as most of the system infrastructure (hardware/extraction firmware) required for this system has been implemented. We should discuss if PRN codes are necessary for single ground node TDOA or PDOA low-range tracking (as they are necessary to accurately align the received signals between distributed ground-nodes).

IV. References

[1] https://github.com/jakapoor/AMRUPT/blob/master/Literature/General\_radio\_direction\_finding/Angle%20of%20Arrival%20Methods/Sensor%20Array%20Processing%20for%20High%20Resolution%20of%20DOA%20Estimation%20of%20Spatial%20Subspace%20using%20Smoothing%20Technique%20of%20Beamspace%20MUSIC%20in%20Coherent%20Channels.pdf

[2] <https://github.com/jakapoor/AMRUPT/blob/master/Literature/General_radio_direction_finding/Angle%20of%20Arrival%20Methods/Direction%20of%20Arrival%20Estimation%20in%20a%20Multipath%20Environment%20an%20Overview%20and%20a%20New%20Contribution.pdf>