GNU Radio development for DOA-based projectile tracking

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Nowadays projectile tracking is usually performed with active radar systems. This paper intends to present our work on a passive projectile tracking ground-station using Software-Defined Radios (SDR) to steer an antenna array. Simulation results are presented and real measurements will be carried out before the oral presentation.

Keywords: tracking, USRP, GNU Radio, DOA, beam steering, simulation, projectile

1 Introduction

Projectile tracking is usually performed using dedicated active radar systems, but the recent breakthroughs in SDR technology could allow for the use of commercial SDR, saving time in development and money in equipment purchase. As we wanted to develop a system able to perform passive projectile tracking over a large frequency range for the cheapest price possible, we used Universal Software Radio Peripherals (USRP) X310 [?] and UBX-160 daughterboards and implemented the needed signal processing functions in GNU Radio. As UBX-160 daughterboards do not provide built-in phase synchronization between their channels, which is a prerequisite for the DOA applications we are interested in, we propose a simple solution to solve the latter issue. The rest of the abstract is organized as follows: part 2 details how we perform projectile tracking with USRP. Part 3 introduces one of the simulations we have run to assess our program capabilities. We finish by presenting our conclusions and ongoing work.

2 Proposed solution

The system we propose consists in a receiving ground-station made of a 4 element Uniform Linear Array (ULA) antenna steered by two USRP, each equipped with two UBX-160 and synchronized using an Octoclock fed with a GPS signal. To track high-speed projectiles, electronic beam steering is preferred over mechanical steering. The array then remains steady while its main lobe is electronically steered toward the transmitting projectile direction using our GNU Radio implemented DOA estimation and beam steering blocks. The main lobe steering is computed using ULA phase increment [?] and the used DOA algorithm is the conventional beamformer [?], since our setup introduces only one transmitter in open-space. The setup is exposed in Figure 1.

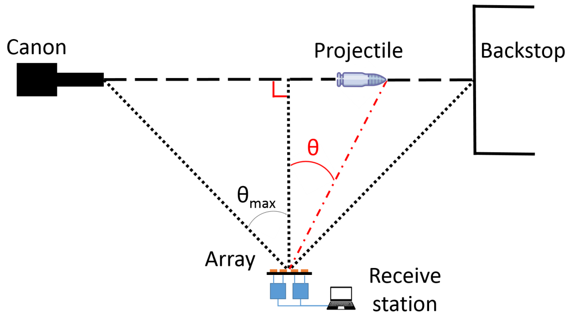

Figure 1: Proposed setup to electronically track a fired transmitting projectile with a passive ground-station steered by USRP

The array is placed at the middle of the projectile trajectory. As we mentioned, phase synchronization is not ensured by the UBX-160. The frequency and sampling-time alignment synchronization provided by the Octoclock ensures the phase-shifts between channels, although random at each program start, remain constant over a large period of time during a program run. We therefore defined a phase initialization position for which the phase-shifts between channels are computed and compensated before the measurement starts through an initialization block we implemented. That position consists in the transmitting projectile being aligned with the perpendicular to the array broadside axis (no phase-shift is then induced by the signal angle of arrival) and is referred in our figures and measurements as the $\theta = 0°$ position. The measurement is performed so that: $\theta_{max} = 50°$.

3 Simulation in GNU Radio

A simulation version of our tracking GNU Radio program is presented in Figure 2.

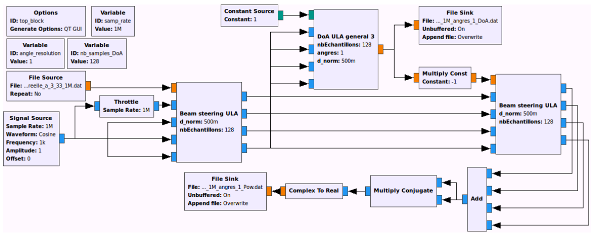

Figure 2: GNU Radio Companion flowgraph to simulate tracking of a fired projectile.

Simulations are carried out using values for θ from a previous measurement with a real fired projectile. A speed coefficient has been applied to simulate a projectile flying three-times faster, raising the maximal angle variation speed from $610°/s$ to $1830°/s$, which is coherent with projectiles we are willing to follow. These θ values then feed a beam steering block that uses ULA phase law to adequately phase-shift the incoming signals to simulate the signals received by the array with the associated angle of arrival. The estimated DOA is used by the second beam steering block to compensate the natural phase-shifts between channel signals. When the signals are correctly phase-realigned, they add constructively and result in maximum received power: the array main lobe is steered toward the transmitter. Figures 3 and 4 respectively show the simulated DOA and power for a projectile flying for 0.3s when the sample rate is fixed to 1MS/s, the angular resolution of the DOA search is 1° and estimations are processed every 128 samples.

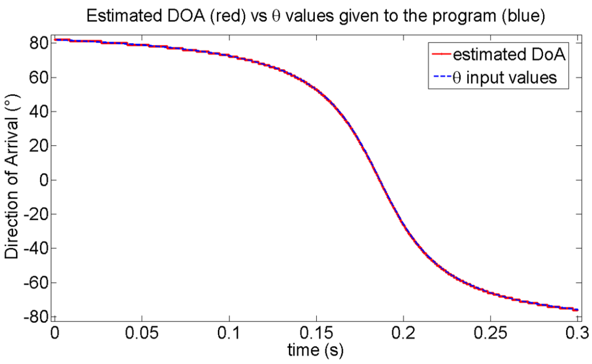

Figure 3: Estimated DOA (red) vs theta values fed to the program (blue) for the simulated trajectory.

The DOA simulation shows a good match between the processed estimation and the θ value given to the program. Although this is not surprising since the original phase-shifts are created using our own beam steering block, this simulation indicates the specified settings allow for an accurate tracking of a fired projectile with that speed.

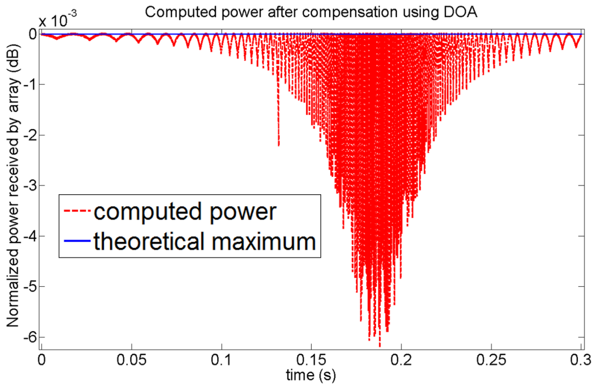

Figure 4: Computed power over the simulated trajectory.

The last simulation shows received power variations within $6 \times 10^{-3} dB$ over the projectile trajectory, confirming the antenna array main lobe is accurately steered in the projectile direction for the specified sampling rate, angular resolution and number of samples per DOA estimation.

4 Conclusion

A passive projectile tracking application based on DOA estimation and beam steering has been developed using GNU Radio and USRP. The signal processing functions have been implemented in GNU Radio to match our requirements and our UBX-160 daughterboards, and a simple solution to solve the phase synchronization issue has been proposed. Simulations have been run in GNU Radio and have shown good results using angle values from a real fired projectile measurement, showing the program capability to steer the array main lobe in the wanted direction and giving insights on the system performance capabilities with regards to the projectile speed and trajectory. Real measurements will be carried out in June with fired projectiles, to confirm the performance on real data.