Section A: Overview of the Research Project Proposal

1. Title of the research project: Implementation and Analysis of Wideband Direction-of-Arrival MUSIC Algorithms using a Red-Pitaya
2. Broad field of research: Engineering
3. Academic level of research project: Masters
4. Abstract of research project

A very important tool in localising Radio Frequency Interferers (RFI) is Direction of Arrival (DOA) estimation (also known as direction finding). The objective of a DOA estimation system is to acquire and track the angle of arrival of signals incident on a phased array, using array signal processing algorithms [1]. One of the most well known techniques for DOA estimation is the MUSIC algorithm. However, the MUSIC algorithm is inherently a narrowband technique, while practical RFI systems emit wideband signals. This project has two main objectives: 1. Investigate wideband adaptations of the MUSIC algorithm. 2. Implement these wideband MUSIC implementations on a Red-Pitaya, using the CASPER toolflow, in order to compare and analayse real-time performance.

5.a. Supervisor: Daniel, J, J, Versfeld (Jaco)
5.b. djjversfeld@sun.ac.za
5.c. University: Stellenbosch University

Section B: Details of Research Project

1. Scientific/Engineering merit:

A very important tool in localising Radio Frequency Interferers (RFI) is Direction of Arrival (DOA) estimation (also known as direction finding). The objective of a DOA estimation system is to acquire and track the angle of arrival of signals incident on a phased array, using array signal processing algorithms [1].

Several DOA estimation algorithms exist in literature. These algorithms can be widely classified into four different categories namely, conventional, subspace-based, maximum likelihood and integrated algorithms [2]. Well-known algorithms include the MUSIC algorithm [3] and adaptations (see for instance [4]), ESPRIT [5] as well as Bartlett and Capon's minimum variance [6].

The MUSIC algorithm is a very popular algorithm as it yields high-resolution and stability [7,8]. However, in order to implement the MUSIC algorithm on a real-time system, several challenges needs to be overcome. According to [9], these challenges include computational complexity and cost, model mismatch, robustness to system errors and higher resolution Signal-to-Noise Ratio (SNR) threshold. Another major challenge is that the MUSIC algorithm assumes narrowband sources. With RFI, we are not always guaranteed that the sources can be modelled as narrowband sources.

Several adaptations to the MUSIC algorithm have been proposed in order to be able to handle wideband signals [10],[11] and [12]. The main research problem to be addressed with this project is to compare different Wideband MUSIC algorithms, in terms of complexity and accuracy. A major objective of this project is to investigate which parts of these Wideband MUSIC algorithms can be parallelised in FPGA implementations, in order to speed up calculations and enable realtime operation. These algorithms will be implemented on a Red-Pitaya, and the CASPER Toolflow will be used to program the FPGA logic.

2. Feasibility

This project consists of a combination of theory, mathematical analysis, computer simulation and implementation and verification of the algorithms on an actual hardware platform. One of the main objectives of this project is to implement and test a real-time system using a Red-Pitaya, using the CASPER framework. The Red-Pitaya is a low-cost FPGA device, with two high-speed Analog-to-Digital and two high-speed Digital-to-Analog converters. The CASPER toolflow is an opensource toolflow, widely used by the Astronomy fraternity. Two Red-Pitaya FPGA systems are readily available for this project. All the necessary research facilities and resources required to successfully fulfil this project is available.

Project milestones:

Literature Survey (6 Months): The first six months will be devoted to the theory and analysis of direction-of-arrival systems. Specific attention will be given to the MUSIC algorithm, and then adaptations of the MUSIC algorithm for wideband signals.

High-Level Algorithm design and evaluation using MATLAB (6 Months): After the mathematics and theory has been studied, the study will progress to implement and compare the various identified algorithms using a high-level simulation such as Matlab.

Prototyping and verification of algorithms on Red-Pitaya (6 Months): The various algorithms will then be implemented on a FPGA system such as the Red-Pitaya. Research activities here include the efficient parallelisation of the candidate algorithms.

Write-up of dissertation (6 Months): The last 6 months will be spend on verifying results and write-up of a thesis.

3. Priority areas addressed

This project addresses Engineering areas 2 and 3, namely Real-time digital signal processing instrumentation for radio astronomy (FPGA) as well as Hardware and data analysis systems for detecting, monitoring and locating source of Radio Frequency interference.

4. Special requirements

None.

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