"Radar-A-Thon" Concept Paper: PRINCESS Radar System

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Competition Category: Maximum Value - Bill of Materials (BOM) < $750

Background

The radar system that is being entered for the IEEE Radar Conference 2020 "Radar-A-Thon" is a single node of a high-resolution, fully polarimetric, Multiple Input Multiple Output (MIMO) multistatic radar system. This multistatic radar system is being developed as a data collection tool which will support investigation into the limitations of, and the solutions to, sparsely populated apertures for remote imaging of building interiors. This experimental radar system has been named **P**ersistent **R**adar **I**maging using **N**etworked **C**oherent **E**mitting **S**ensor**S**, (PRINCESS). This system is a networked multistatic wideband stepped frequency solution.

The persistent part of the PRINCESS radar is a key driver for its development, and is obtained by utilising multiple static transceivers in a multistatic approach, rather than being reliant on a moving radar platform. Persistent imaging using static, highly coherent sensors opens up the possibility to:

- Take advantage of high coherent processing gain over long dwells, increasing sensitivity and overcoming short falls in compact wideband antennas.
- Maintain high coherency between collections to enable Coherent Change Detection (CCD), increasing sensitivity to sub wavelength physical changes in a scene.
- Obtain high frequency resolution doppler information for oscillating / rotating targets, enhancing target classification capability.

The majority of prior open literature on building imaging radar solutions rely on Synthetic Aperture Radar (SAR) techniques [1], where a radar platform has to move through the length of an aperture to obtain the cross-range resolution required for imaging. If continuous imaging is required then the aperture must be swept continuously. Although this allows for a fully populated aperture to be generated in at least one dimension, the required motion removes the element of persistence, where a radar platform may need to refuel / recharge or operators may need to take a break.

A single node from the PRINCESS radar on its own is still a very capable short-range radar, offering better than 10 cm range resolution, and high doppler resolution (depending on dwell time). A single transceiver node of PRINCESS does however lack the ability to image a scene on its own, without a synthetic aperture being swept out. Therefore, the Radar-A-Thon demonstration of PRINCESS will be focussed on:

1. Separation of targets in range using the high-resolution capabilities of the radar
2. Classification of targets through High Range Resolution Profiling (HRRP) where target extents are multiple range bins in depth.
3. Classification of targets through polarimetric measurements and processing.
4. Classification of oscillating, rotating, or moving targets through high doppler resolution.
5. Tracking of targets through the scene.

Some of the above capabilities may be demonstrated using a single radar mode, however others will require the radar to be operating in different modes. Each mode will require additional collections of the scene (with the scene reset for each collection, if there is a target moving through it).

If it is deemed beneficial to obtain images of the scene whilst at the conference, time and space permitting, a synthetic aperture will be collected by manually stepping the radar in azimuth.

Radar Design

The radar uses a wideband stepped frequency waveform to obtain a high range resolution. In doing this the radar can be instantaneously very narrow band, allowing for low cost digitisers to be used.

Figure 1 shows a block diagram for a single radar node; detailing the Radio Frequency (RF) circuitry, control and overall architecture for the radar.

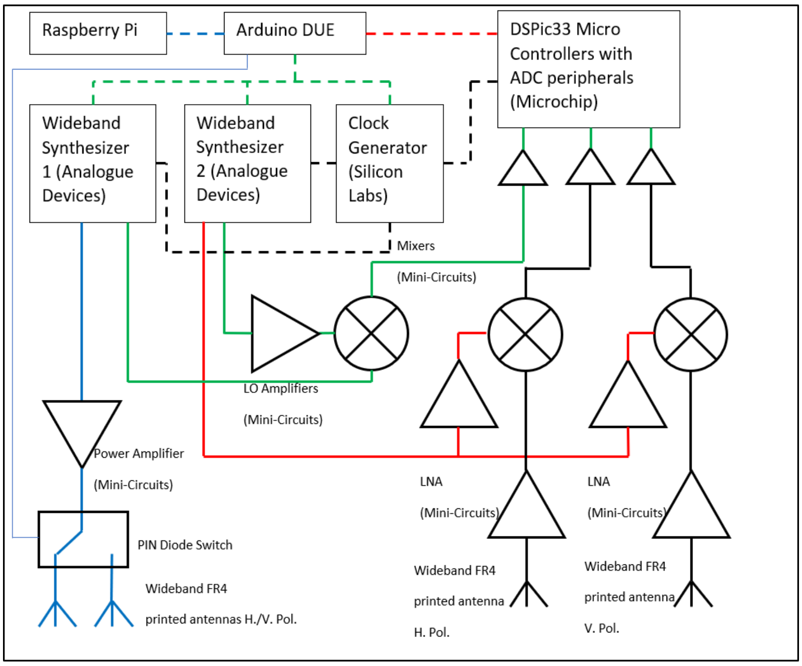

Figure 1 – System Block/Circuit Diagram

Data analysis and user control interface is provided by the Raspberry Pi, which is connected to the radar controller (Arduino DUE) via USB. The Arduino DUE provides real time control, data handling and some of the signal processing for the radar in the following way:

1. A control message is sent to the clock generator telling it what clock frequency to output to each of the modules. This control message is sent via an Inter Integrated Circuit (I2C) bus indicated by the green dotted line. The clock generator ensures that both frequency synthesizers and the Analogue to Digital Converters (ADC) are coherent with one another.
2. A control message is sent to the wideband synthesizers telling them what mode to operate in and what frequency to output. This control message is sent via a serial interface indicated again by the green dotted line. The wideband synthesizers are identical to one another, each outputting a Continuous Wave (CW) tone at Radio Frequency (RF), which are offset from each other by a frequency equal to the Intermediate Frequency (IF), which the ADC sees.
3. In order to obtain range resolution a waveform with a bandwidth must be transmitted; this is done by commanding the wideband synthesisers to step through a predefined set of CW tones (in accordance with local frequency regulations).
4. At each transmitted CW tone, three ADC channels on the microcontroller digitise the following:

a. An internal reference, that is used to apply phase corrections to the reflected channels. This is required because the digitisation of the reflected energy does not start at a set phase for each transmitted CW tone. Obtaining phase coherency in this way reduces the required complexity of the wideband synthesizers, reducing system cost, despite the need for an additional ADC channel and mixing stage.
b. A reflected path channel taken from a horizontally polarised antenna.
c. A reflected path channel taken from a vertically polarised antenna.

A basic RF front end is included that allows for power amplification of the transmitted waveform, and down conversion to an IF that is within the bandwidth of the ADC. The solid blue line indicates the transmit path, where the output RF waveform is directly synthesised by Wideband synthesizer 1. The transmitted power can be switched between a horizontally polarized toothed log periodic antenna or a vertically polarised toothed log periodic antenna.

Two receive antennas (one horizontal and one vertically polarised toothed log periodic antenna) are provided which are amplified and mixed down (solid black line in Figure 1) with the output of Wideband Synthesizer 2 (solid red line in Figure 1) to generate the IF frequency that is digitised by the ADCs. The receive channels are mixed down along side an internal reference path (solid green line in Figure 1) which is used for phase corrections over the stepped frequency waveform.

All three channels are digitised and a "fast time" Fast Fourier Transform (FFT) applied by the DSPic33 microcontroller. The FFT data is then passed to the Arduino DUE over a Serial Peripheral Interface (SPI) bus at the end of each CW tone. The Arduino then passes the data on to the Raspberry Pi to carry out the slow time FFT (producing a range profile), and store the data.

Radar Specification and Capabilities

Table 1 shows the operating envelope and capabilities of the radar in unconstrained conditions, and the parameters that will be used for the Radar-A-Thon.

Parameter	Units	Min	For Radar-A-Thon	Max	Notes
Frequency	MHz	300	300-2690	4400	Synthesizer capable down to 137.5 MHz, antenna limited to 300 MHz
Transmit Power	dBm	0	Dependant on band	20	Additional attenuation can be manually added if required
Frequency Step	Hz	10e3	2.5e6		Determines unambiguous range
Unambiguous Range	m		60	15,000	
Range Resolution	m		0.063	0.0365	Theoretical based on C/(2*BW)

Table 1- System Capabilities

Radar Signal Processing

All signal processing is planned to be carried out post data collection for the challenge scene, it is unlikely that real time processing will be at a level of maturity for demonstration at the radar conference. The primary processing that will be applied to the data will be:

- Collection Decompression – A sparse data collection will be conducted in frequency due to FCC restrictions, the scene will be assumed to be sparse, therefore compressive sensing reconstruction techniques will be applied.
- Wideband Stepped Frequency High Resolution Range Profile Formation – Phase corrections based on the internal reference channel will be applied to the collected data, and range profiles will be formed. The particular phase correction technique has been successfully demonstrated in a early demonstrator of the PRINCESS radar system, as well as work conducted by Gunma

University (Japan), which investigated using a low cost Blade RF for Ultra Wide Band (UWB) Radar [2].

- Doppler corrections will also be applied across the wideband waveform to support doppler analysis of moving targets.

Bill of Materials

Item	Upper estimate of cost including PCB manufacturing
Raspberry Pi	$50
Arduino Due	$40
Digitiser boards	$100
RF Front End (Including Synthesisers and clock)	$200
Antennas	$300
Total	$690

Table 2 - Bill of Materials

FCC Part 15 Compliance

The PRINCESS radar will be operated in a way that is compliant with FCC Part 15 Subpart C, specifically:

15.205 – Restricted Bands of operation – The following bands have been identified that are outside of the restricted frequencies, and any specific uses, the intention is to only transmit CW tones in these bands. Only spurious emissions will exist in the restricted bands, these will be limited as much as possible.

Band Id	Frequency Lower Limit (MHz)	Frequency Upper Limit (MHz)	Band Id	Frequency Lower Limit (MHz)	Frequency Upper Limit (MHz)
1	300	322	9	1626.5	1645.5
2	335.4	399.9	10	1646.5	1660
3	410	433.5	11	1710	1718.8
4	433.5	470	12	1722.2	2200
5	668	890	13	2300	2310
6	890	940	14	2390	2483.5
7	1240	1300	15	2500	2690
8	1427	1435			

Table 3 - FCC Part 15 allowed transmit bands

15.243 – "material property measurement" – transmissions in band 6 (indicated in red in Table 3) must not exceed 500 uV/m at 30 m in accordance with this section. [3]

System Maturity

A version one of the hardware has been built, and tested in an anechoic chamber at University College London (UCL). The V1 hardware consisted of similar hardware shown in Figure 1, however digitisation was carried out by two RTL-SDR V3 dongles (one for the internal reference channel, and one for a reflected co-polarised channel). Range profiles with range resolution less than 10 cm were successfully generated using the chamber data. The total cost for the V1 hardware (without wideband antennas) is less than $200. V2 of the hardware with the full capabilities listed above is currently in development, and is expected to be ready and tested in an anechoic chamber prior to the IEEE 2020 Radar Conference.

References

[1] Wenji Zhang, Ahmad Hoorfar, Christopher Thajudeen, "Building layout and interior target imaging with SAR using an efficient beamformer", 2011 IEEE International Symposium on Antennas and Propagation (APSURSI)
[2] Kazunori Takahashi, Takashi Miwa, "Near-Range SFCW UWB Radar Based on Low-Cost Software Defined Radio", 2019 IEEE Radar Conference (RadarConf)
[3] FCC website, "Electronic Code of Federal Regulations", https://www.ecfr.gov, Last accessed 29/01/2020.