DYNAMIC POSITIONING CONFERENCE
November 15-16, 2005

Sensors 1

RadaScan: A Local Reference, High Resolution Radar, Dynamic Positioning Sensor

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ABSTRACT:

This paper details the concept and processing principles behind RadaScan, a local reference radar sensor, capable of relaying accurate navigation to dynamic positioning systems. RadaScan represents a next generation in Sensor technology. It is a swept radar system capable of tracking multiple targets and providing relative position and heading feedback at 3Hz to a host system.

An overview of the design principles of the sensor and target system is presented. It considers the technology behind the sensor; a FMCW microwave radar system illuminating a retro-reflective target capable of introducing a unique identification code by modulation of the radar carrier. This design allows the radar to easily detect its targets even within a cluttered offshore working environment, dominated by large installation structures.

A description of the digital signal processing flow that interprets the raw radar return to an accurate position and heading estimate is presented. Consideration is given to the DSP hardware requirements to achieve the data throughput whilst working within cost and space constraints. The use of FPGA technology for front end real-time radar signal processing is demonstrated to be an optimum solution for the DSP needs of the system. Using an FPGA, continuous radar data processing rates of 50MB/s are achieved across 4 input channels. This data throughput allows the system to process incoming targets at a rate of 10Hz.

The paper further considers the algorithms developed for automatic detection of targets using Constant False Alarm Rate (CFAR) principles applied in the frequency domain, and the use of target tracking filters, originally developed for ballistic missile radar trackers, to control hardware feedback loops.

The paper concludes by presenting position data from the sensor, demonstrating the accuracy and overall specification that can be achieved for a local reference position and heading fix using RadaScan.

Introduction

RadaScan represents a next generation in local reference sensor technology. It has been specifically designed to overcome some of the shortcomings of traditional local position reference systems. Being a microwave radar sensor, it is insensitive to the harsh environmental conditions often experienced in an offshore environment, being largely unaffected by heavy rain, fog, or other prevailing sea conditions. RadaScan is a compact ship mounted swept microwave radar system which can interrogate radar retro-reflective targets [1]. It can provide an accurate local position reference to a ship's dynamic positioning system from multiples of these targets located on a nearby structure, such as an offshore installation. The sensor is capable of finding and predicatively tracking targets out to 750m and beyond. The system can be used as a standalone 'black box' sensor, or driven from a graphical user interface identical in appearance and usability to Guidance Navigation's well established CyScan user console. The main sensor is a frequency modulated constant wave [2, 3] (FMCW) mono-pulse [4] radar operating over a 100MHz bandwidth within the maritime radiolocation band centred at 9.25GHz. The targets are totally passive, requiring a battery to drive only the modulation electronics that impart a unique code on the reflected radar return, with no implicit amplification of the microwave signal.

Radar Description

A picture of the complete RadaScan sensor is shown in Figure 1:

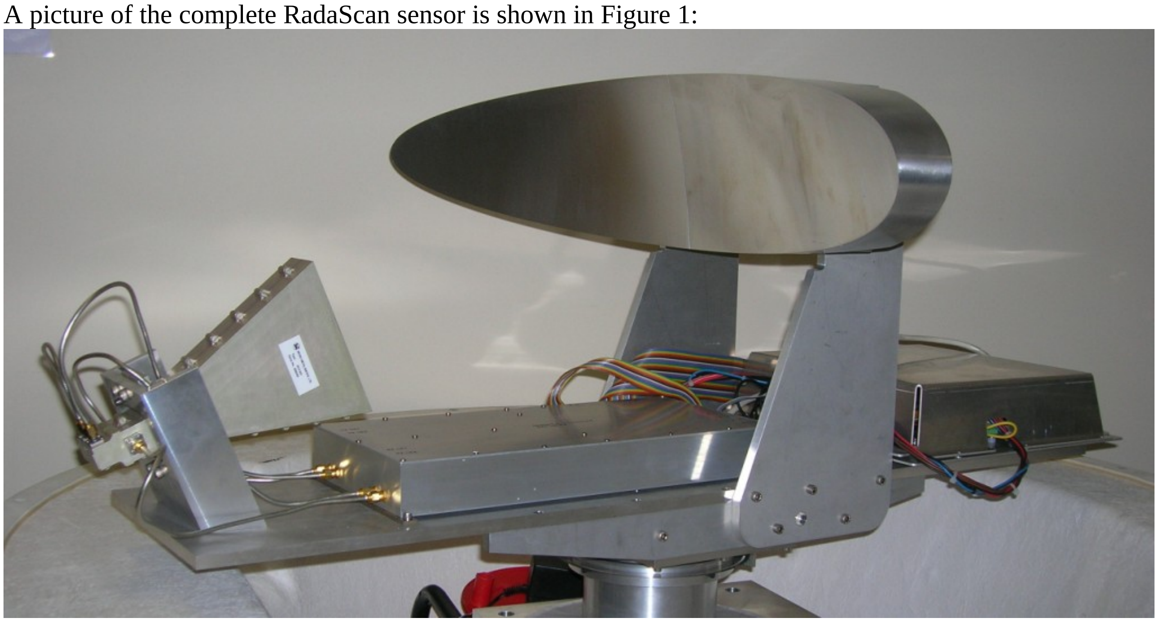

Figure 1: The RadaScan sensor with radome cover removed

The radar front end schematic is shown in Figure 2. The transmitter consists of a ramp generator, the rate of which is driven by the DSP system. This ramp signal is used to frequency modulate the microwave source. The output of the source is passed through an attenuator and then through a power amplifier before being split to feed the two squints of a mono-pulse transmit horn, illuminating a large antenna. The same horn is used to receive the two squints returning from the radar target. To improve the isolation between transmit and receive channels, the target imparts a polarisation change to the incoming radar signal. Using this method, it has been possible to achieve 40dB isolation between receive and transmit chains. The two received squints pass into a hybrid T where they are summed and differenced (the summation = sigma (Σ), the difference = delta (Δ)). Both channels pass through low noise RF amplifiers before being mixed with the transmit signal, to reduce the signal to IF or base band. The signals then pass through target specific filters to remove background clutter before being amplified in preparation for analogue to digital conversion by the processing system.

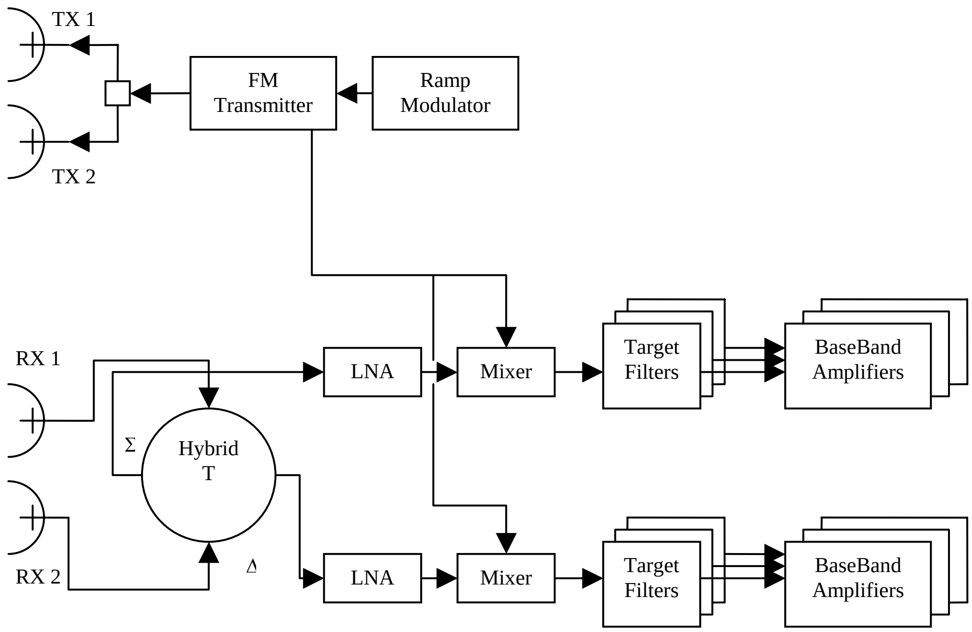

Figure 2: Radar schematic.

Antenna properties.

The radar antenna and horn arrangement controls the beam shape of the emitted radar wave-front. The antenna also imparts considerable gain to the system. The antenna has been designed specifically to optimise the radar beam shape for its intended application, specifically a wide elevation (or E-plane) pattern to allow the system to cope with the pitch and roll of a vessel, and to sight targets high above the radar at close range. Similarly, a tight azimuth (or H-plane) pattern to ensure good bearing accuracy. The measured results for the reflector patterns are shown in figures 3a & 3b:

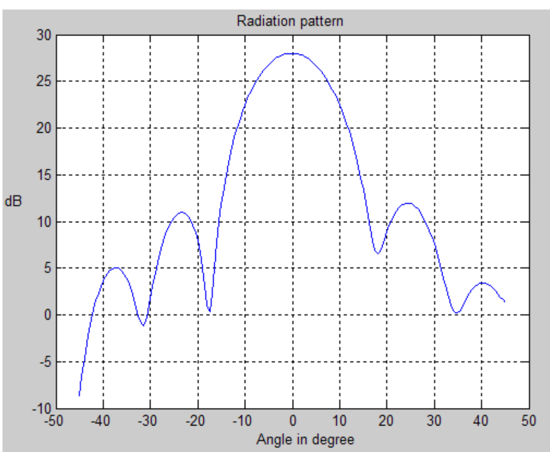

Figure 3a: Reflector elevation gain plot.

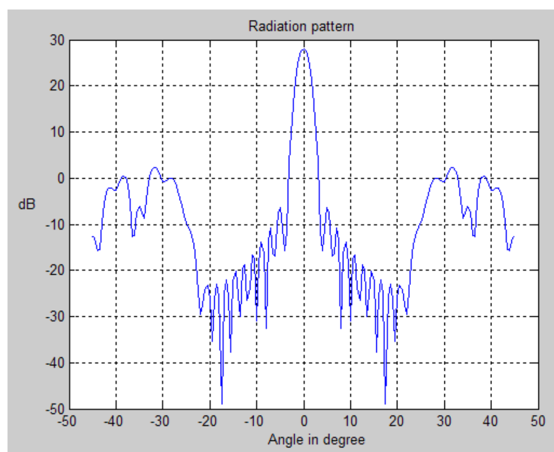

Figure 3b: Reflector azimuth gain plot

The beam shape can be defined in terms of its angle between half power points (-3dB). In elevation, the beam is 15 degrees wide, and in azimuth, 2.4 degrees.

Retro-reflective Target Properties

The target has been uniquely developed in conjunction with the radar sensor to ensure that the system as a whole is easy to use and setup. The targets are true retro-reflectors, i.e., a signal received is reflected back to its point of origin. At the same time, the target flips the polarisation of the reflection by 90 degrees whilst imparting an identifying modulation code. This code is used by the radar processing system to not only identify the target, but to reject the background clutter normally encountered by any marine radar system. This includes the signature of the large installation where the target is placed, and clutter from other sources, such as other vessels.

For ease of installation, two factors have been important in their design:
Firstly, the targets are passive, i.e. they do not amplify the incoming radar signal. They only require an in-built battery to drive the modulation electronics that impart the targets identification code. This battery has a 2 years continuous use lifespan. The passive nature of the target means that no fixed installation or power source is required. Targets can be placed and removed as and when required.
Secondly, the targets have a very wide viewing or acceptance angle. The measured near field response of the target is illustrated in figure 4.

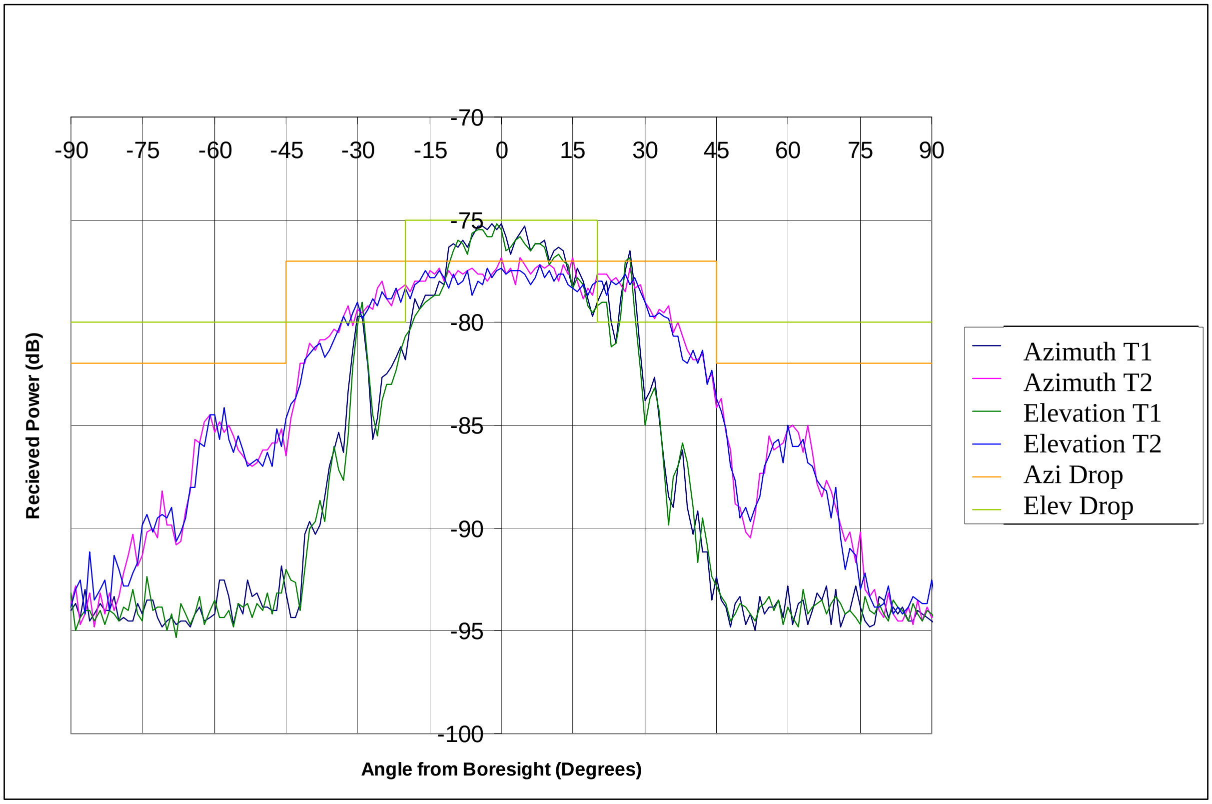

Figure 4: Near field target reflection response, T1 = target id 1, T2 = target id 2, Azi Drop = azimuth half power points, Elev Drop = elevation half power points (3dB down).

The acceptance or viewing angle of the target can be defined using the angle between the half power response points either side of boresight (in the same way as defined for the antenna beam shape). In elevation the target acceptance angle is 47 degrees, whilst in azimuth, 90 degrees. The view angle however depends on the range. For instance at close range, the viewing angle is much greater since the system has considerable spare receiver gain, and the antenna has a wide elevation pattern. In trials, at 50m range, the radar was able to view up to 85 degrees from boresight in azimuth (170 degrees total viewing angle). At 25m range, the radar was able to view the target at 35 degrees from boresight in elevation (70 degrees total viewing angle). For instance, in a typical DP working environment, this would allow a vessel to ‘look up’ at targets on an installation, some 17.5m above the position of the radar on the vessel.

Radar Digital Signal Processing Hardware

A single platform provides all the radar processing hardware requirements, as well as the client server interface. The system is diagrammatically described in figure 5.

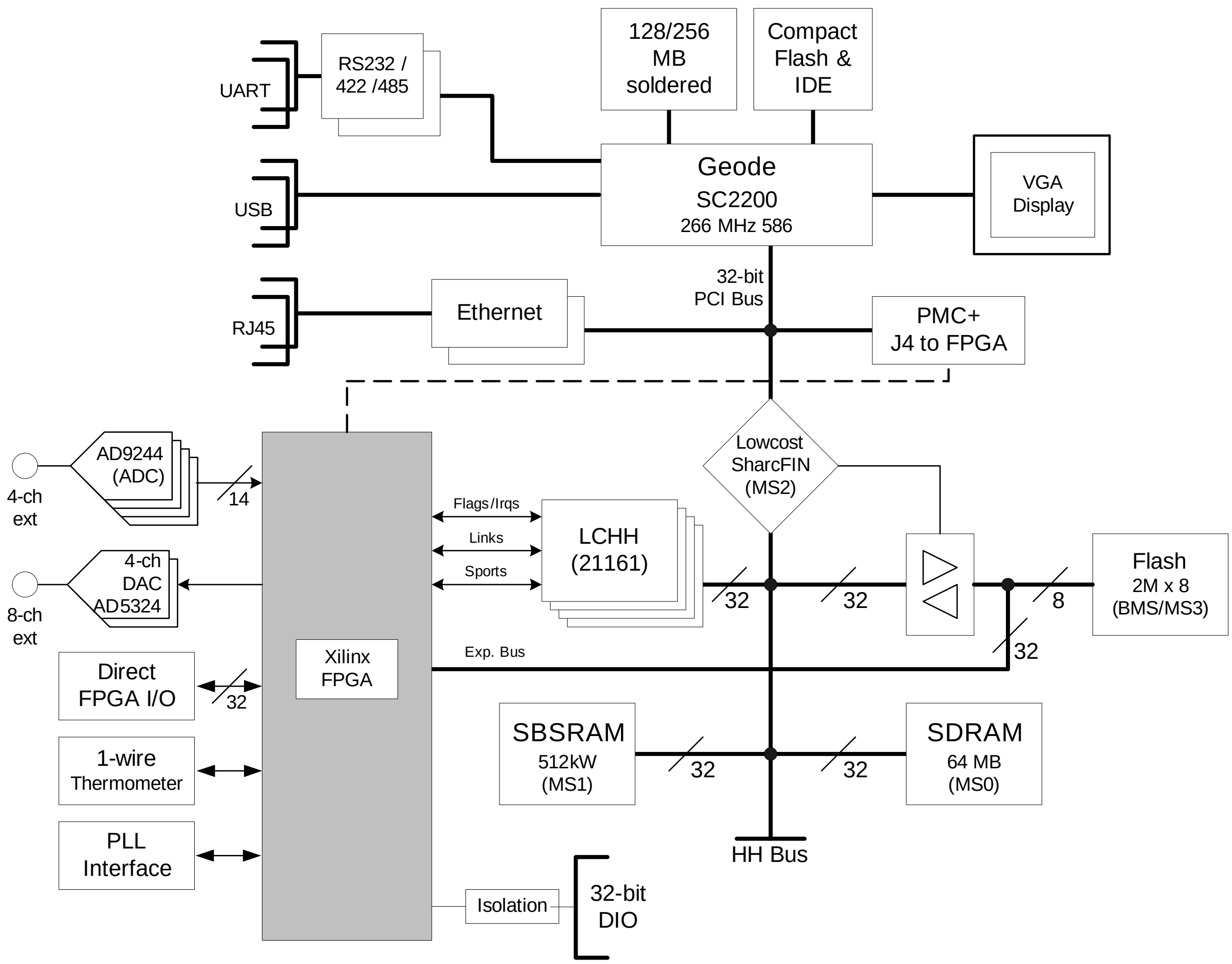

Figure 5: RadaScan processing hardware schematic

The board is split in half:
In the 'DSP' section, the board provides four analogue to digital converters, sampling incoming radar signals with 14-bit resolution at 65 MWords/s, controlled by, and linked directly to a Xilinx Spartan 3 FPGA. The FPGA provides a platform for control of external radar hardware via isolated 32-bit digital I/O and an 8 channel DAC. The FPGA also interfaces directly to four Analog Devices 21161 DSP processors via high speed link ports. The DSP processor cluster shares access to a large block of fast access SBSRAM and a further block of SDRAM. A block of Flash memory is provided storing the runtime image of the FPGA and DSP executables.
The 'Embedded PC' section comprises a Geode 'thin client' processor, a compact flash hard drive providing windows XP embedded, 256MB memory, dual serial and Ethernet ports. The geode has access to the DSP processors internal memory, flash, SBSRAM, FPGA registers and SDRAM via its PCI interface. The embedded PC hosts the RadaScan network server allowing multiple users to connect to the unit simultaneously. The DSP cluster alone provides 1.2GFLOPS of processing power at 32bit resolution. All this hardware is provided in a small area board, compliant with the microATX standard.

Radar Processing Flow

The front end digital signal processing executed by the FPGA is shown in Figure 6. The FPGA architecture and parallel processing capability lends itself very well to high speed, large volume data processing. The FPGA performs target filtering and digital down conversion duties. It can process up to 50 Mbytes /second in real time, allowing the RadaScan system to interpret targets at rates greater than 10Hz. This system redundancy means the sensor can easily maintain a 3Hz rotation speed, and target refresh rate, processing multiple targets per revolution.

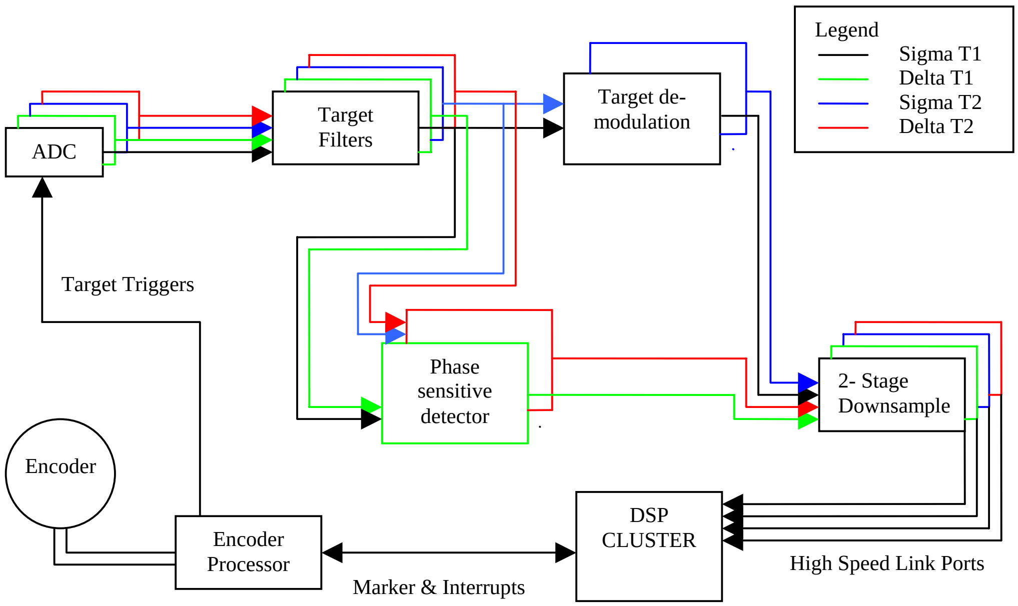

Figure 6: FPGA DSP schematic for front end radar processing.

Data delivered to the DSP cluster is used to determine the range and bearing to the target, and to control radar hardware using feedback from the target range and bearing trackers.
The range is determined in the frequency domain using an adaptive threshold CFAR [5] (Constant False Alarm Rate) algorithm to identify the target signal in the spectrum above a certain signal to noise ratio threshold. An 8192 pt FFT divides the spectrum in to a series of range bins which are tested sequentially for a target 'hit'. Once a target is detected, the CFAR window is narrowed to maximise the signal to noise ratio, and is continuously manoeuvred by the target range tracker, following the targets range signature. The range tracker also controls the source ramp rate to ensure that the target range always falls within the radars optimum detection window or range bin.
The bearing is determined by a process model fit to the measured target sigma envelope. This method provides accuracy far exceeding a traditional radar system.

Target Tracking

Both range and bearing are tracked using fading memory polynomial (FMP) trackers [6]. These are one step predictors providing feedback to control the radar hardware. The trackers are optimally parameterised to track targets in an environment with the velocity and acceleration characteristics of a typical offshore DP equipped vessel. The range tracker controls the source ramp rate and CFAR detection window, whilst the bearing tracker controls the radar's data acquisition window for that target.
Figures 7a & b display range and bearing plots for a target at ~187m.

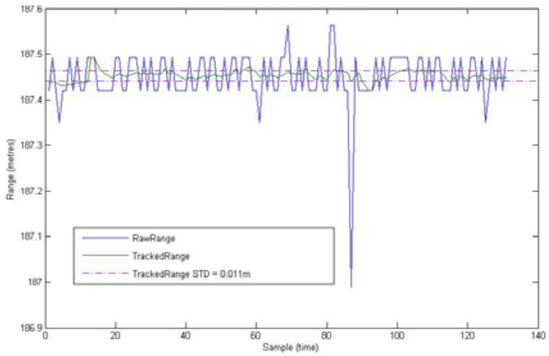

Figure 7a: Range Plot

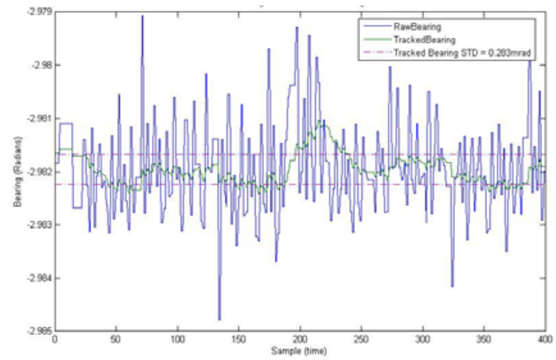

Figure 7b: Bearing Plot

Sensor Accuracy & System Specification

The results from extensive trials have been used to define the following system specification:

Range Accuracy:		better than 0.1% of range.
Operating Range:		10 to 750m
Angular repeatability:		STD 0.3 mrads @ 200, 1.0 mrads @ 500m
Beam Shape:	elevation:	± 7.5 degrees @ -3dB gain
	azimuth:	± 1.2 degrees @ -3dB gain
Max Elevation at Close Range:		+35 degrees @ 25m.

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