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RoboSAR Written Report 1

Abstract

RoboSAR is a robot team composed of a stationary scanning impulse radar and a mobile platform to respond to radar results and “investigate” possible targets. RoboSAR’s base features a Novelda radar system housed and mounted on a two servo pan-tilt system used to steer the radar beam and perform scans. The high range resolution of the Novelda enables RoboSAR to detect and range targets that move on a millimeter scale, and the high bandwidth of the Novelda allows RoboSAR to find moving targets behind permeable obstacles. RoboSAR’s base sends the coordinates of targets over the internet to the mobile platform. RoboSAR’s mobile platform then moves precisely to these coordinates and notifies the base of its location before returning to its initial position.

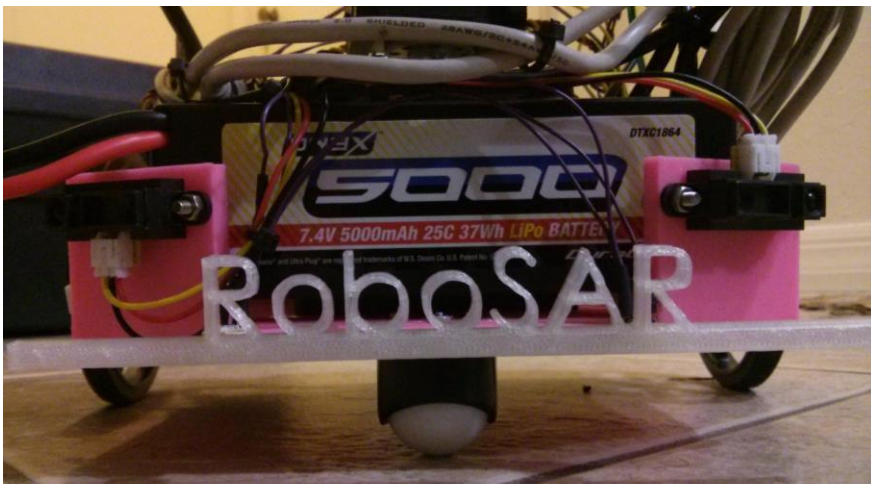

Figure 1: Front view of Mobile Platform with Bump Sensor and IR Range Sensors

Introduction

Through Dr. Jian Li and the Spectral Analysis Lab here at UF, I’ve had the opportunity to experiment with the Novelda Impulse Radar. This unique device bounces nanosecond electromagnetic pulses off targets and samples these reflections at gigahertz speed. This return data is cluttered and not immediately easy to interpret; however the Novelda is well suited for specific applications, such as measuring snow depth, measuring foliage height, and detecting movement in cluttered environments. With little more than a development kit with unwieldy antennas, I was limited to experiments that could only be performed with the Novelda sitting flatly on the desk. My goal with RoboSAR was to develop hardware that would allow me to perform multidimensional imaging experiments. Additionally, I wanted to test the potential of the Novelda to help a robot detect and locate a person.

Due to an unfortunate challenge with the Novelda software libraries, RoboSAR is currently in two parts: the stationary radar and the mobile platform. The radar scans to detect and locate movement. The location of a moving target is then transmitted to the mobile platform, which will go to the target location to scout it out and then return back to the base afterwards.

Integrated Systems

RoboSAR's home base is developed around my laptop running MATLAB, the language that I typically use with the Novelda. MATLAB easily generates plots and images to work with the radar data, and MATLAB's built-in Instrument Control toolbox enabled the use of the USB serial interface to communicate with the Pololu Servo Maestro and the creation of a TCP client to send commands to the mobile platform.

RoboSAR's mobile platform features a Raspberry Pi running Python. This Python program creates a TCP server to which commands can be sent. These commands are parsed and sent to an Arduino Uno using USB serial. All movement and sensing on the mobile platform is handled by the Arduino, controlling two stepper motor drivers, reading analog feedback from two Sharp IR range sensors, and checking the buttons of the bump sensor.

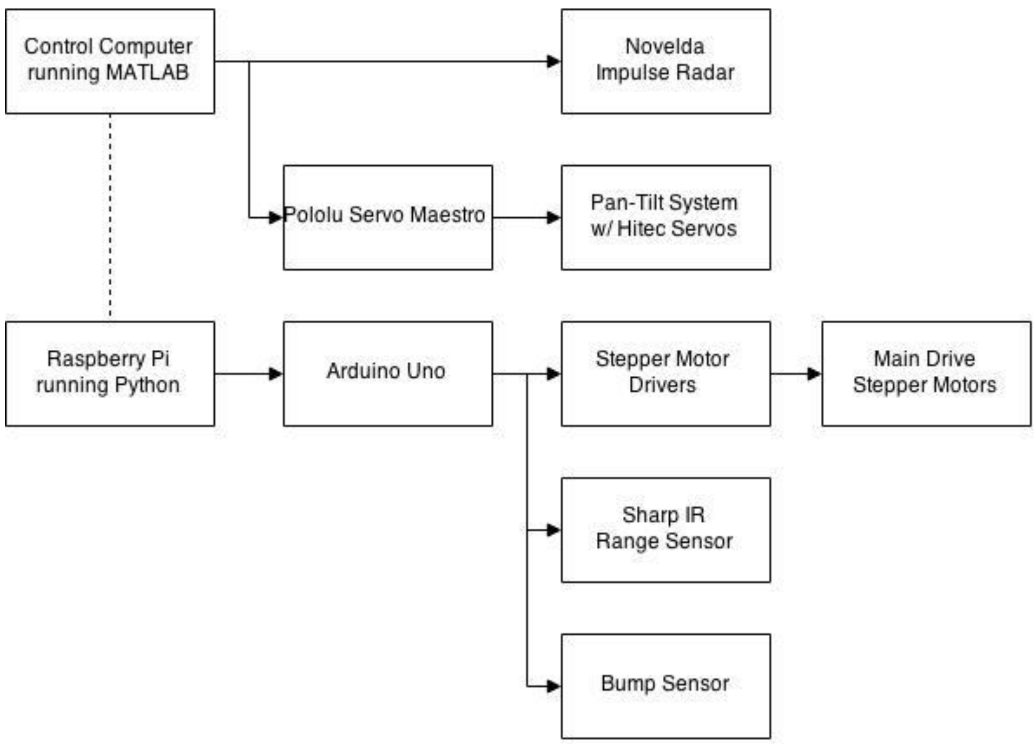

Figure 2: RoboSAR System Diagram

Mobile Platform

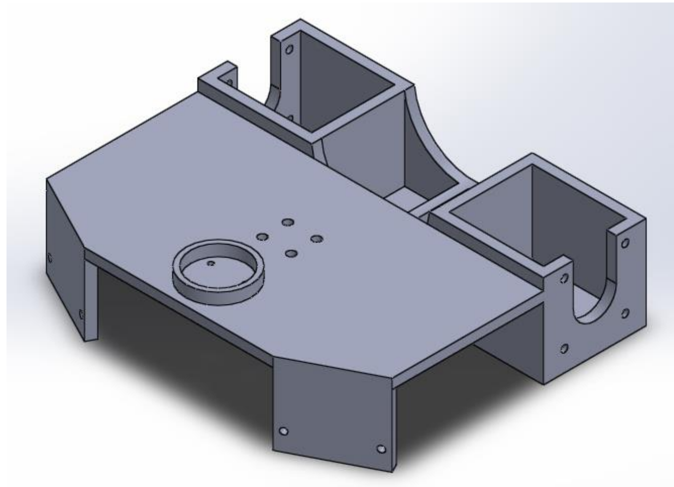

Figure 3: Chassis in Single Piece from SolidWorks

RoboSAR's mobile platform employs two stepper motors for drive and differential steering. 90mm diameter wheels were coupled directly to the stepper motor shafts. For the third wheel, a 1" spherical caster was selected. RoboSAR's chassis was developed in SolidWorks as a single piece. My goals were to eliminate the need for separate stepper motor brackets and to keep the main platform low and level. The following features were included in the design:

- Tight fit slots for stepper motors
- Hole patterns for stepper motors
- Hole pattern for pan-tilt system
- Hole pattern for spherical caster
- Angled IR range sensor mounts

Figure 4: Mobile Platform with Reliefs from back

This chassis was then printed with PLA on a Makerbot Replicator 2. The end product had too little clearance on the stepper motor slots and on a ring around the caster. Reliefs had to be cut in the back of the robot, and the ring on the bottom of the platform was removed with a belt sander. Mounting screws were enough to hold the stepper motors and caster in place. The mobile platform provided high movement resolution and performed well on smooth surfaces. Though the pan-tilt is not mounted on the robot is the current design, the mobile platform is stable while the servos steer the beam of the radar. The holding torque of the stepper motors is employed during scans to prevent the inertia of the servo from rotating the chassis inadvertently.

Constructing a housing for the Novelda was also a significant challenge. My initial radar housing was 3D printed with the antennas upright and separated by a centimeter; the goal was to reduce the size of the beam and the size of the housing by bringing the antennas closer together. Patch cables were used to connect the antennas to the radar board, and the board was mounted on the side. This housing rendered the radar ineffective, and none of the experiments performed with the Novelda on the desk could be recreated. My second radar housing was created out of balsa using the T Tek. This housing avoids contact with the antenna leads and holds the antennas in their original flat position. With no noticeable interference to the radar, the wooden housing was used in the final design. When mounted on the mobile platform, this housing proved unwieldy, and more bump sensors would be necessary to safeguard the radar.

Actuation

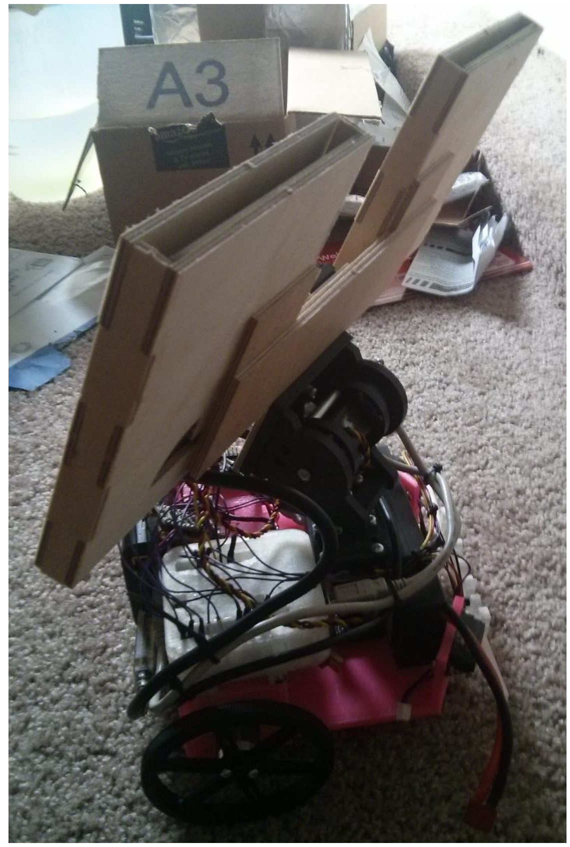

Figure 5: Pan-Tilt System with Radar on Mobile Platform

The radar system at RoboSAR's home base is actuated by a pair of Hitec HS-645MG servos. The wooden radar housing was fastened to the top platform of an SPT200H pan-tilt system from ServoCity. This pan-tilt system steers the antennas to direct the beam of the radar in two angular dimensions. The selected Hitec servos provide enough torque to support the housing and provide the radar a 180° field of view. Although servos offer high angular resolution, few angles can be can scanned to keep scan times reasonable. Small amounts of movement from the servos interfere with my motion detection algorithm, requiring a short delay between moving and firing the radar. Initially the goal was to fasten the bottom of the pan-tilt to the chassis of the mobile platform, but a separate base had to be made of balsawood when the Novelda libraries could not be implemented on the Raspberry Pi.

The main drive of the mobile platform is provided by a pair of NEMA 17 bipolar stepper motors. High torque was not a priority for RoboSAR, as the mobile platform is only intended to drive on smooth surfaces. Stepper motors were chosen for high movement resolution, allowing RoboSAR to make small, precise movements. Though these movements can be effectively estimated from the angular movement from a single step, slippage causes the mobile platform to turn or move slightly less than expected. Initially, an advantage of stepper motors was the holding torque on the wheels to prevent RoboSAR from inadvertently moving during radar scans; ultimately this holding torque was unnecessary, and RoboSAR's stepper motors are disabled when the mobile platform is not moving. This also conserves battery and reduces the amount of heat dissipated into the stepper motor.

Sensors

The Novelda Impulse Radar used in RoboSAR is a development kit based on a NVA6100 radar system-on-a-chip. This development kit features a small board with the Novelda IC, an FTDI interface to communicate with the chip over USB, and two Vivaldi antennas, which project and receive ultra-wideband signals in a plane polarized beam. One antenna is used as a transmitter and the other as a receiver. The antenna beam pattern is estimated to be 50° in plane of the antenna (E-plane) and 20° in the perpendicular plane (H-plane), directed out the open end of the waveguide. This wide beam reduces the angular resolution of a scan, significantly reducing the precision at which RoboSAR can locate targets.

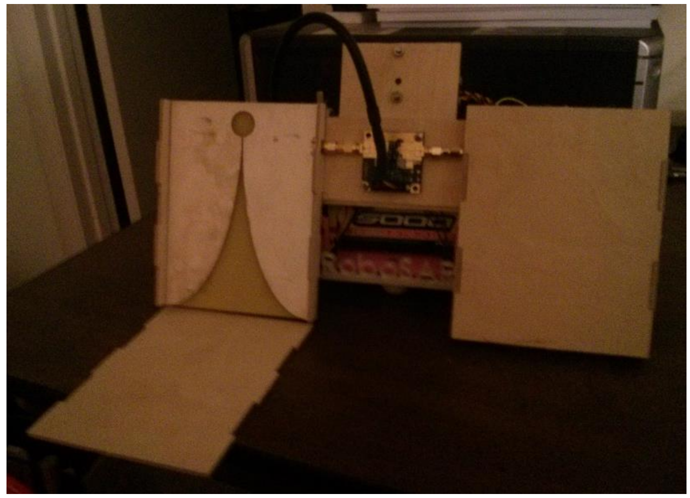

Figure 6: Balsa Wood Housing with Radar showing Vivaldi Waveguide

The Novelda uses unique fabrication and sampling methods to achieve a high sampling rate of 35 GS/s at its receiver antenna. Electromagnetic impulses only nanoseconds in length are transmitted by the Novelda and reflected by targets in the antennas' beam. The high sampling rate allows the Novelda to measure the time of flight of these pulses effectively and the range targets with millimeter resolution. By periodically sampling, the movement of a target at this millimeter scale can be detected. In RoboSAR's scans, the Novelda performed collections at a frequency of 25 frames/s, and collected 128 frames at each angle.

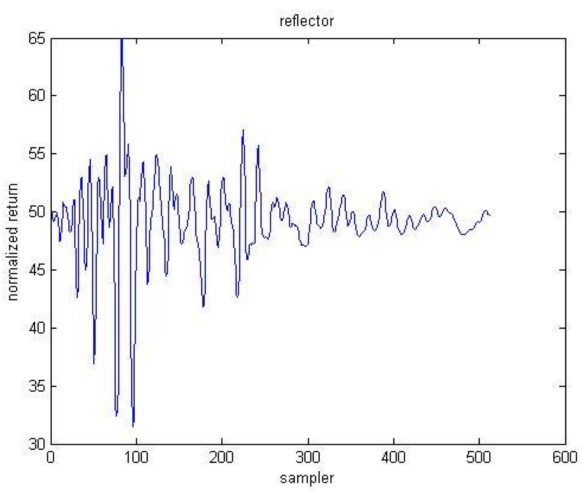

Figure 7: Sample Raw Data from the Novelda Impulse Radar

These short collection bursts are then analyzed for movement using a method of spectral estimation similar to what I have used to measure heart rate and respiration rate with the Novelda. When collecting data with the Novelda, the radar is limited by its architecture to collecting 512 sample frames. Each of these samples corresponds to a specific range in a 4.5 m window and in radar terminology are known as a range bins. Each range bin is analyzed as it develops over the course of the periodic collections, known as slow time. To look for periodic movements over slow time (like heart beat and respiration), an FFT is performed across the range bin in slow time, but for the case of motion detection, one simply needs to remove the DC bias. This method practically removes the returns of non-moving targets from the radar data. The resulting data could be analyzed more in-depth to determine the direction and speed at which the target is moving. To simplify this data for RoboSAR, the absolute values of the data was taken to avoid missing moving targets with no net movement over the course of the collection burst and the data was summed across slow time for each range bin.

The end result of this method is a 512 value frame similar to the original data of the Novelda but measuring the movement in each range bin rather than the return pulses. With only one movement frame, a moving target can be detected and ranged. By actuating the radar on the pan-tilt system and collecting movement frames at several different beam angles, a motion scan is developed, and a moving targets can be located in a spherical coordinate system.

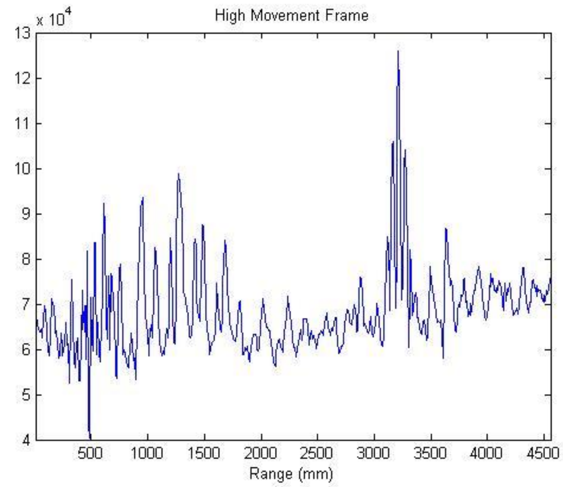

Figure 8: Sample Motion Detection Frame

This motion detection method is sensitive enough to detect a person from the motion of their respiration alone. However, false positives remain a significant challenge when using this method for human detection. The high bandwidth of the Novelda's pulses offers a significant advantage of penetrating power: many targets only reflect part of the electromagnetic pulse, allowing targets behind it to also be detected. Because of this, RoboSAR often finds unexpected, hidden movement such as computer fans or air ducts. Additionally if a moving target has a stationary target behind it, the remainder of pulse that passes through the moving target is altered as the first target moves, and the stationary target is mistaken to be moving as well.

Behaviors

When searching for movement, RoboSAR's radar base first performs a scan composed of nine collection bursts separated by 22.5° in the polar dimension. The azimuth of the radar beam was not adjusted over the course of the scan, remaining level with the ground. This scan can take a significant amount of time, as the servos require a half second to move and stabilize and each collection burst takes five seconds.

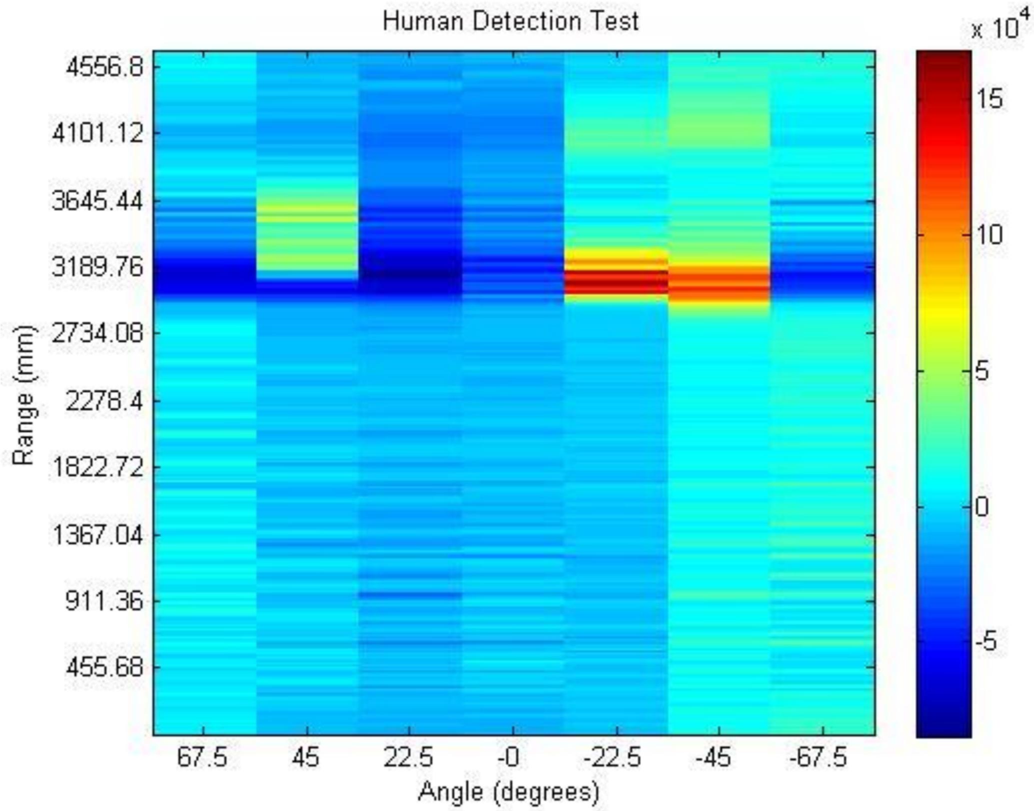

Figure 9: Sample Motion Detection Scan with Prominent Moving Target (Dr. Schwartz)

Once the scan is complete, all nine movement frames are combined into a single two dimensional radar image. From this image, targets are selected based on a calibrated threshold. The angular coordinates of the closest significant target are determined from scan angle and range bin. These coordinates are then converted from degrees and millimeters to motor steps based on the geometry of the robot and movement testing.

$$Driving\ Steps = \frac{D * 200}{90mm * 3}$$

$$Turning\ Steps = \frac{(\frac{A}{360°} * 220mm * \pi) * 200}{90mm * 3}$$

Upon receiving these coordinates over a TCP connection, the mobile platform will carry out the movement by first turning in place for the given number of turning steps, then moving forward for the given number of driving steps. With each step forward, the Arduino checks the IR range sensors against a threshold and checks the digital state of the bump sensor to detect an obstacle and stop accordingly. As the Novelda often detects moving targets through or around obstacles, it is common that the mobile platform will not be able to reach its target location. In this case, the Arduino will record the remaining distance to the target for future reference. This also allows RoboSAR to return to his home base using the number of steps that actually traveled rather than the given number of distance steps.

Resources

Xethru by Novelda (Radar Developers)
https://www.xethru.com/

Flat Earth Inc (North American Retailer/Support)
http://flatearthinc.com/

Antenna Design for UWB Radar Detection Application
http://publications.lib.chalmers.se/records/fulltext/133826.pdf