EK 2370 Build Your Own Radar Project Course
Fall 2023

Task Description

Umer Shah

Task Summary of COTS Radar at 2.4 GHz

1. Write the Matlab code for velocity and range measurement.
2. Build the baseband circuit (Modulator, Video Amplifier)
3. Velocity measurements for multiple targets at the same time in the CW mode.
4. Range measurements for multiple targets at the same time in the FMCW mode.
5. Write the Matlab code for SAR image measurement.
6. Acquision of SAR image of two selected landscapes and overlaying the acquired SAR image over google earth image.

For Higher Mark:

1. FMCW: Simultaneous range and velocity estimation by processing the up and down chirp only for a single target.
2. CW and FMCW: Real-time or pseudo real-time implementation for measuring velocity (CW) and range (FMCW). Show video in the review meeting
3. FMCW: Extract velocity from range using two point finite difference method and compare it to the slope of the range curve.

Task Summary of SDR at 5.8 GHz

1. Velocity measurements for multiple targets at the same time in the CW mode.
2. Velocity measurements for multiple targets at the same time in the Low-IF CW mode.
3. Real-time velocity measurement with CW, Low-IF CW using waterfall plot in GNU Radio.
4. Velocity direction measurement for a single and multiple target in the CW and Low-IF CW mode using the IQ demodulation in SDR.
5. Measure velocity (CW, Low-IF CW) with the provided Power Amplifier connected to the Tx output of the SDR. With a fixed gain on the input Rx stage (USRP Source Block) perform parameter sweep on output Tx gain (USRP Sink Block) and investigate range dependence on output power. Is it the LO leakage, switch isolation or absolute output power the limiting factor? Does the use of power amplifier increase the range?
6. Monitor breathing and heart rate of an individual using Low-IF CW mode. The variation in the range should be shown. The results for Low-IF CW mode should be compared to the results using the CW mode.

For Higher Mark:

1. Range measurement for a single target, at close range (using target motion within the ambiguous range) with two step frequency (square wave) CW mode in SDR.

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Review Meeting: Schedule and Detailed Task Description

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Review Meeting Schedule

Review Meeting Dates
Review Meeting 1 (2023-09-13)
Review Meeting 2 (2023-09-19)
Review Meeting 3 (2023-09-26)
Review Meeting 4 (2023-10-03)
Review Meeting 5 (2023-10-10)
Review Meeting 6 (2023-10-17)

Group Number	Time
Group 1	09:20
Group 2	09:40
Group 3	10:00
Group 4	10:20
Group 5	10:40
Group 6	11:00
Group 7	11:20
Group 8	11:40

- short presentation about what has been achieved during the last week and plan for next week.
- The presentation and other material such as Matlab code and measurement videos must be uploaded to Canvas before 9:00 AM on the day of the review meeting.
- The tasks to be completed for each review meeting can be found in the **Task Description.**
- Each group with 4 students will have two sub-groups with 2 students each working on different tasks. The sub-groups are notified to the teacher in the first review meeting and remains the same throughout. Groups with 3 students do not have sub-groups and all work on the same tasks

Tasks Review Meeting 1: COTS Radar

Sub-group 1:

1. Write the Matlab code for velocity measurements. Plot your results for the test file available on canvas. For the sub-tasks below, show the results in plots, spectrograms etc
   a. Show and explain the effect of variation in T_p (above and below the nominal value) on the velocity resolution.
   b. Show and explain the variation in the results with change in the center frequency.
   c. Show and explain the variation in resullts without MS clutter rejection.
   d. Show and explain the variation in results with more or less zero padding for fft.
   e. Show and explain the variation in results with the two normalization methods.

Sub-group 2:

2. Write the Matlab code for range measurements. Plot your results for the test file available on canvas. For the sub-tasks below, show the results via plots, spectrograms etc.
   a. Show and explain the variation in the results with change in the BW (with larger and smaller BW).
   b. Show and explain the variation in resullts without MS clutter rejection.
   c. Show and explain the variation in results with more or less zero padding for ifft.
   d. Show and explain the results for both 2-pulse and 3-pulse MTI clutter rejection

Tasks Review Meeting 2: COTS Radar

Sub-group 1 and 2 together:

1. Build the baseband circuit (Modulator, Video Amplifier)
   a. Show the image of the breadboard identifying the different circuit parts (modulator, video amplifier, filter, voltage regulator, etc) and the tuning resistors
   b. Show the adjusted Vtune triangle signal (i.e., Vpp = 2.2 to 3.4 V and up+down chirp period = 40 ms) and the square sync signal.
   c. Plot the 3 dB roll off of the active filter using both a multimeter and an oscilloscope. Compare the plots.
   d. Show with audacity that clipping occurs when the gain is set too high. Set the gain to a value where there is no clipping.
2. Make and show a video of the ”first test” as shown in Lecture 3.

Tasks Review Meeting 3: COTS Radar

1. **Velocity Measurements in CW mode. (Sub-group 2):**
   a. Velocity Measurements of a single target: captured data plot (also show zoom in), velocity vs time plot **(hint: take the strongest scatterer),** velocity vs time spectrogram
   b. Velocity Measurements of multiple targets: captured data plot (also show zoom in), velocity vs time plot **(hint: take the two strongest scratterers for two targets, multiple local maximas have to be used)**, velocity vs time spectrogram
2. **Range Measurements in FMCW mode. (Sub-group 1):**
   a) Range measurements of a single target: captured data plot (also show zoom in), captured sync plot (also show zoom in), captured parsed up-chirp data overlayed over the sync plot (also show zoom in), range vs time plot **(hint: take the strongest scatterer)**, range vs time spectrogram
   b) Range measurements of multiple targets: captured data plot (also show zoom in), captured sync plot (also show zoom in), captured parsed up-chirp data overlayed over the sync plot (also show zoom in), range vs time plot **(hint: take the two strongest scratterers for two targets, multiple local maximas have to be used)**, range vs time spectrogram
3. **Range Measurements in FMCW mode. (Sub-group 1 and 2 together):**
   a) Movie of real-time/ pseudo real-time velocity measurements (for higher mark)
   b) Movie of real-time/ pseudo real-time range measurements (for higher mark)

Tasks Review Meeting 4: COTS Radar

FMCW Radar Tasks:

Sub-group 1 and 2 together (for higher mark):

1. **Extract velocity from range using two point finite difference method and compare it to the slope of the range cure (for extra mark). Hint: Use moving average filtering to clear the oscillations**
2. **FMCW Mode: Simultaneous range and velocity estimation by processing the up and down chirp only for a single target (for extra mark)**

SAR Tasks:

1. Write the Matlab code for SAR image measurement. Show all the results (data images) for the test file.
   a. **Sub-group 1 is responsible for data parsing and applying Hilbert Transform and Hann Window to the parsed data.**
   b. **Sub-group 2 is responsible for the Range Migration Algorithm code taking the data from Sub-group 1**

Tasks Review Meeting 4: COTS Radar

Sub-group 1 and 2 together:

1. Acquision of SAR image of **2 landscapes**, overlay the images over google earth image.
2. Show results with and without using the Hann window. (for your own SAR data matrix)
3. Show results with and without multiplication of the down range data with the square of the down range vector. (this is on the last slide of the algorithm) (use your own SAR data matrix)

Sub-group 1: (all plots for your own acquired SAR data matrix)

a. Plot the entire data and the sync signal (zoom in to illustrate) **(Lec.4, slide 32)**.

b. Show that the data is parsed correctly by plotting the parsed (according to the position of the radar on rail) backscatter data together with the parsed sync data. **(Lec.4, slide 33).**

c. Plot the integrated data to show that the data is parsed correctly according to the up-chirp. **(Lec. 4, as shown in lower right figure on slide 34).**

Sub-group 2: (all plots for your own acquired SAR data matrix)

a. Show variation in the final image with change in cr1 and cr2 (cross range limits).

b. Show variation in the final image with change in dr1 and dr2 (down range limits).

c. Show the effect of variation in scan time T_{rp} (amount of time spent in one position on the rail) on the resolution or SNR of the final image . Increase and decrease T_{rp} to illustrate

Tasks Review Meeting 5: SDR Radar

1. **Velocity Measurements in CW mode without Power Amplifier. (Sub-group 2)**
   a. Velocity Measurements of a single target. Signal processing using your Matlab code for the COTS radar: captured data plot (also show zoom in), velocity vs time plot **(hint: take the strongest scatterer)**, velocity vs time spectrogram, GNU Radio schematic
   b. Velocity Measurements of multiple targets. Signal processing using your Matlab code for the COTS radar: captured data plot (also show zoom in), velocity vs time plot, velocity vs time spectrogram, GNU Radio schematic
   c. Movie of real-time velocity measurements using the waterfall plot in GNU Radio

2. **Velocity Measurements in Low-IF CW mode without Power Amplifier. (Sub-group 1)**
   a. Velocity Measurements of a single target. Signal processing using your Matlab code for the COTS radar: captured data plot (also show zoom in), velocity vs time plot **(hint: take the strongest scatterer)**, velocity vs time spectrogram, GNU Radio schematic
   b. Velocity Measurements of multiple targets. Signal processing using your Matlab code for the COTS radar: captured data plot (also show zoom in), velocity vs time plot, velocity vs time spectrogram, GNU Radio schematic
   c. Movie of real-time velocity measurements using the waterfall plot in GNU Radio

Tasks Review Meeting 5: SDR Radar

3. **Velocity direction detection for a single and multiple targets in the CW mode using IQ demodulation in SDR without Power Amplifier. (Sub-group 1)**
   a. Velocity direction measurements of a single target. Signal processing using your Matlab code for the COTS part: captured data plot (also show zoom in), velocity vs time plot **(hint: take the strongest scatterer)**, velocity vs time spectrogram, GNU Radio schematic
   b. Velocity direction measurements of multiple targets. Signal processing using your Matlab code for the COTS part: captured data plot (also show zoom in), velocity vs time plot, velocity vs time spectrogram, GNU Radio schematic
   c. Movie of real-time velocity measurements (single, multiple targets) using the Waterfall plot in GNU Radio, GNU Radio schematic
4. **Velocity direction detection for a single and multiple targets in the Low-IF CW mode using IQ demodulation in SDR without Power Amplifier. (Sub-group 2)**
   a. Velocity direction measurements of a single target. Signal processing using your Matlab code for the COTS part: captured data plot (also show zoom in), velocity vs time plot **(hint: take the strongest scatterer)**, velocity vs time spectrogram, GNU Radio schematic
   b. Velocity direction measurements of multiple targets. Signal processing using your Matlab code for the COTS part: captured data plot (also show zoom in), velocity vs time plot, velocity vs time spectrogram, GNU Radio schematic
   c. Movie of real-time velocity measurements (single, multiple targets) using the Waterfall plot in GNU Radio, GNU Radio schematic

Tasks Review Meeting 6: SDR Radar

Sub-group 1 and 2 together:

1. Measure velocity with the provided Power Amplifier connected to the Tx output of the SDR. With a fixed gain on the input Rx stage (USRP sourse block), perform parameter sweep on output Tx gain (USRP sink block) and investigate range performance depending on output power. (**Hint: at a large value of Tx gain (USRP sink block) you will lose the target**)
   a. Is it the LO leakage/switch isolation or absolute output power which is the limiting factor?
2. Compare the result obtained form the previous task to the case when there is no power amplifier at the output of the Tx stage of the SDR. With a fixed gain on the input Rx stage (USRP sourse block), again perform parameter sweep on output Tx gain (USRP sink block) and investigate range performance depending on output power.
   a. Is it the LO leakage /switch isolation or absolute output power which is the limiting factor?
   b. Does the power amplifier increase the range when compared to the case without the power amplifier?

Tasks Review Meeting 6: SDR Radar

Sub-group 1 and 2 together:

3. Monitor breathing pattern of an individual using **Low-IF CW** mode. The variation in the range should be shown. Perfrom the fft on the data and see if you can identify the heart rate. (hint: use the static phase term to calculate the range).
4. Monitor breathing pattern of an individual using **CW** mode.
   a. Do you see any resonable data?
   b. If not, give a reason as to why the breathing pattern is not observed in this mode?
5. Range measurement for a single target, at close range (using target motion within the ambiguous range) with two-step frequency (square wave) CW mode in SDR. Use the step height of 100 MHz which means that the unambiguous range is 1.5 meters. (hint: use the command port to send a timed message to change the center frequency)