EENG663 Project 3: Signal Detection

Project summary

Overview: Use an RTL-SDR software radio dongle to detect a radio transmitter and measure ROC curves.

Setting: Develop in class, then collect data after class (any location).

Curricular elements: both tinkering and gaming

Prerequisites: basic familiarity with MATLAB

Topics/concepts covered: Neyman-Pearson detection, likelihood ratio tests, ROC curves

Learning outcomes: After completing this project, students should be able to:

- Model the measurement distributions under two hypotheses.
- Derive the Neyman-Pearson detector for the two modeled distributions.
- Measure a ROC curve for the derived detector and show how various factors affect it.
- Demonstrate how to set the threshold to achieve a desired false alarm rate.

Expected time to complete: two 2-hour lab sessions and 10 hours of work outside of class

Required hardware/materials: One RTL-SDR dongle, one or more 900 MHz radio transmitters (e.g. baby monitors), and a laptop running MATLAB.

Required instructor interaction: partially supervised, with occasional guidance

Common mistakes/pitfalls: TBD.

Method of assessment: instructor graded, based on final product; plus peer voting on subjective evaluations of the competitions

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1 Getting started

A lot of information is intentionally missing from this lab description; you will need to ask questions the complete this lab.

Pick a lab partner for this project. You will collaborate on the process, but you will write up individual reports and receive separate grades. You must work with a different partner for each project in the class.

Obtain a software radio dongle from the instructor. The default device is a NooElec R820T2 SDR & DVB-T NESDR Mini 2, though for simplicity we will refer to it as an "RTL-SDR" receiver, or simply as an "SDR." Obtain a 900 Mhz transmitter; the default device is a baby monitor ("Sony NTM-910YLW Baby Call 900MHz Nursery Rechargeable Monitor with Transmitter" or "Fisher-Price Time for Sleep Monitor with dual receivers," though you may use others if you wish). Refresh your memory on the MATLAB-based receiver commands from prior projects. Progress to the point where you can turn the device on or off, verify its presence or absence in the spectrum, and numerically assess the power level of the signal. If you can accomplish these tasks, you have sufficient understanding of the hardware interface to complete the entire project.

If you wish, you may also try this project with audio hardware (speakers and a microphone), either as an alternative or in parallel with the radio version.

2 Tasks

This project will make use of the following course concepts: Neyman-Pearson detection, likelihood ratio tests, and Receiver Operating Characteristic (ROC) curves. Videos covering these concepts are available on the course website, and you are encouraged to read additional background material in any of the suggested reference textbooks.

Explore the following issues:

(i) What is the best way to quantify the received power?

(ii) What is the model for the Probability Density Function (PDF) of the received power when the signal is absent (H0) and when the signal is present (H1)? Are there any parameters or environmental factors that affect these distributions?

(iii) Can you analyze the raw received radio signal and choose a better observation to exploit than "received power"?

(iv) Given your pair of PDFs, what is the Neyman-Pearson detector? Do you want to approximate the PDFs at all to make the detector simpler?

(v) Does setting the operating point (NP threshold) require any prior knowledge or calibration of the scenario?

(vi) How can you measure the ROC curve? (Suggestion: you can re-use data by collecting a bunch of traces and then using the entire set of traces for each operating point on the curve; you don't need to re-measure every time you change the threshold.)

(vii) How does the ROC curve change as you change the scenario? What factors can you vary to get significantly different curves? Does the detector perform the same for different transmitters?

(viii) How does the measured ROC curve compare to a simulated ROC curve?

You do not need to do all of these tasks; rather, they are meant as a guide. Feel free to try a more clever or innovative approach, include more data and analysis than was asked for, or diverge from the stated tasks if you think the situation warrants it. "Out of the box" thinking will always be rewarded. Failed attempts are of value too, as long as you can explain why the approach didn't work using lessons learned from the course material.

Table 1: Complexity per operation on scalar data.

Operation	all real	1 real, 1 complex	all complex
add/subtract/comparison	1	2	2
multiply/divide	8	16	34
log/exponential/trig/root	4	N/A	8

3 Deliverables

You will turn in a report written using the LaTeX word processing system. A template is available on the course webpage. The report should conform to the style guide for IEEE Signal Processing Society conferences, such as ICASSP, ICIP, or GlobalSIP. At a minimum, explain your measurement methodology, your data processing methodology, and your results. Both format and content matter – in particular, use correct grammar and spelling, and revise your text as needed to make sure you are explaining yourself coherently. Include code sparingly, if at all; in general, it is better to include an algorithm in pseudo-code as a figure.

You should strive to always explain why you did what you did, not just what you did. Your results should all be repeatable – maybe not exactly, but comparably. That is, another researcher may not have access to the exact same environment as you or record the exact same realizations of random noise, but you want to enable them to follow the exact same process as you. Analysis is also highly encouraged – explain why the results are what they are, not just what they are.

Consider looking through some published IEEE articles for additional guidance on format and content.

4 Presentations and Competitions

You are also required to make a brief presentation of your approach. Since you are already turning in a report, the presentation itself will not be graded. Instead, this allows your peers to see alternative approaches. It also lets you participate in competitions. There are three challenges:

- Accuracy: The instructor will perform a series of trials with a set of baby monitors on various channels. Each group will submit their best guess of the sequence of channels that had active monitors. The most accurate group wins.
- Complexity: Each group will create a low-complexity (not necessarily optimal) detector and demonstrate that it works successfully, then present an evaluation of the complexity of the detector. The lowest-complexity detector (in operations per received sample) wins. Table 1 lists the complexity for each type of operation, assuming scalar inputs.
- Challenge data sets: download the challenge data from Blackboard. The winner will be the group who gets the most correct decisions in the 400 "mixed" collects without getting more than 20% false alarms.

These competitions can mean whatever you want them to mean. If you think your approach is applicable to a given competition, feel free to enter. The first place group in each category will receive a 2-point bonus (for each group member) and the second place group members will each receive 1 point; and no individual may receive more than 2 points total per project.