Applications of RFID Sensing

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ABSTRACT

Radio-frequency identification (RFID) Sensing is used for a variety of applications including but not limited to inventory management, access control and livestock tracking. A commonality between a majority of the current applications is RFID's use of object identification. For inventory management, object identification is done by assigning every item a unique RFID Tag, for access control and livestock tracking every person is given a unique RFID Identifier.

We believe RFID Sensing can be used for other applications. From Pichorim et. al[4], RFID Sensing is being used to measure Soil Moisture Sensing for Landslide Monitoring. The use of RFID devices is a novel, low-cost solution that can provide real-time landslide prediction capabilities. Pichorim's work reveals the ability for RFID Sensing to have widespread use outside of object identification.

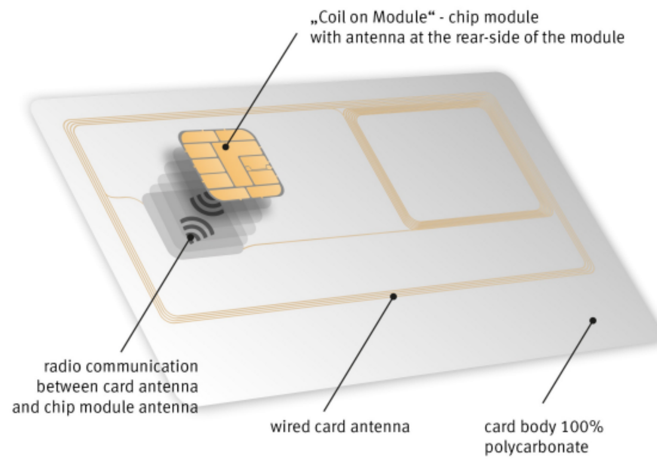
This paper focuses on new applications of RFID Sensing inspired by Pichorim's use of Received Signal Strength (RSS) to estimate Soil Moisture. The new applications we will be focusing on are frequency of rotation of a RFID Tag, Velocity of a RFID Tag in the plane facing the RFID Reader, detection of different materials (in our experiment, phones), the angle of the RFID Tag and estimating the concentration of various soluble materials in water.

1 Background

The RFID wireless technology comes handy in use cases where we don't require a very high range or a large data rate, and require no/low power. RFID Sensing works with two components: tags and readers. RFID Tags have a microchip and antenna as shown in **Figure 1**. Communication is done between the reader and the tag; the RFID Reader will send out a signal and a RFID Tag will respond with its own custom signal that includes identifying information about an object.

The signal generated by the RFID Tag is a result of the radio signal (an electromagnetic wave) that is transmitted from the RFID Reader. The RFID Tag "harvests" energy from the radio signal (the received electromagnetic wave induces a current in the tag's antenna, which then powers the microchip; preparing the RFID Tag for signal transmission) and then sends back a signal to the RFID Reader. The RFID Reader will finally decode the signal.

Figure 1: Labeled Diagram of a Passive RFID Tag with its components [3]



As mentioned earlier, there are two types of RFID Tags; Active and Passive. Active RFID Tags contain their own power source, Passive RFID Tags rely solely on the energy provided by the signal transmitted from the reader. In this paper we will be focusing on applications observed with passive RFID.

Unfortunately, because the signals in Passive RFID rely on harvested energy from the RFID Reader, the signal is not very strong and can attenuate quickly. The measure of the strength of the radio signal that is received by the RFID Reader from the RFID Tag is called "RSS", which stands for "Received Signal Strength.

RSS can be used to estimate distance between the tag and the reader, however, this estimation can be highly inaccurate due to noise and interference. However, in Pichorim's work, RSS was used to accurately estimate soil moisture content. In our experiments, we also use the RSS Values to explore further applications of RFID Sensing.

2 Experiments

We performed our experiments with very simple components as stated below:

2.1 Experimental Apparatus

1. For All Experiments:
   (a) 1 Arduino Uno
      i. 7 Arduino Jumper Cables
      ii. 1 USB 2.0 Printer Cable
      iii. Laptop (to Interface with Arduino)
   (b) 1 RC522 RFID Reader
   (c) 1 S50 White Card (RFID Tag)
2. Extra Equipment for Effect of Different Materials Experiment:
   (a) iPhone with RFID Blocking Case
   (b) Android Phone with RFID Chip
3. Extra Equipment for Estimating Concentration of Some Soluble Materials
   (a) 1 Glass for holding liquid
   (b) Salt
   (c) Sugar
   (d) Coca Cola

Figure 2: Experiment Setup to estimate RSS using RC522 RFID Reader, Generic

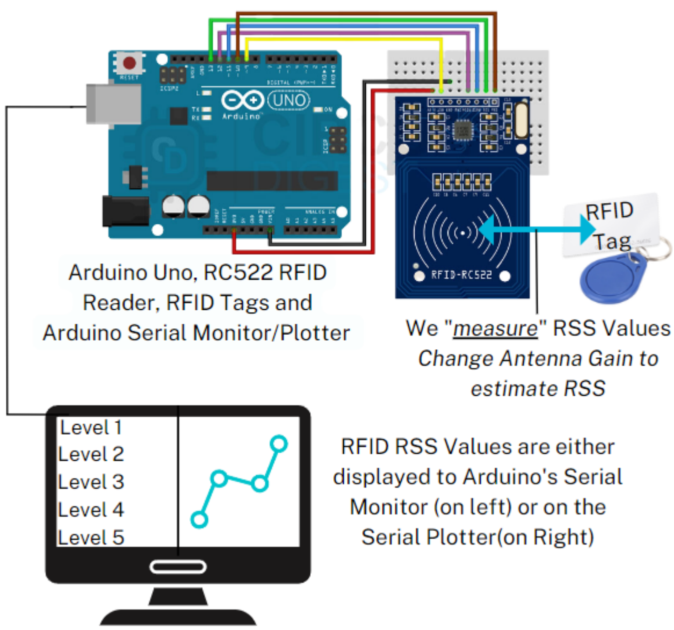


Figure 2 shows how the experiment was setup and how RSS Values were measured and displayed to the computer.

Note: The RC522 RFID Reader does not directly measure RSS, instead, Antenna Gain is adjusted to estimate RSS. When the tag is situated at greater distance, more Antenna Gain has to be set in order to detect a signal reflected back from the RFID tag. Therefore, A higher Antenna Gain implies a lower RSS and vice versa.

We used the work done by Chang Liu as a starting point for estimating RSS using the RC522 RFID Reader. [2] We had to further "upsample" the Antenna Gain to get a higher resolution reading of the RSS.

We then did experiments testing new applications such as frequency of rotation for a RFID Tag, velocity of a RFID Tag, detection of different materials, angle of RFID Tag and estimating the concentration of various soluble materials in water.

2.2 Description of Experiments

2.2.1 *RFID Tag Frequency of Rotation*

(a) Ensure RFID Tag Antenna and Sensor are facing RFID Reader.
(b) Ensure RSS Reading in Serial Plotter is displayed.
(c) Rotate RFID Card on Axis.
(d) If done correctly, RSS peaks and valleys should be seen periodically in the Serial Plotter.

2.2.2 *RFID Tag Velocity*

(a) Ensure RFID Tag Antenna and Sensor are facing RFID Reader.
(b) Ensure RSS Reading in Serial Plotter is displayed.
(c) Move RFID Tag towards and away from the RFID Reader.
(d) If done correctly, RSS value should be seen changing linearly with time in the serial monitor.

2.2.3 *Detection of Different Materials*

(a) Ensure RFID Tag Antenna and Sensor are facing RFID Reader.
(b) Ensure RSS Reading in Serial Plotter is displayed.
(c) Place Material in front of RFID Tag.
(d) Observe Effect of Material in Serial Plotter (It is possible that there is no effect).

2.2.4 *RFID Tag Angle*

(a) Ensure RFID Tag Antenna and Sensor are facing RFID Reader.
(b) Place RFID Tag at the base of the RFID Reader.
(c) Ensure RSS Reading in Serial Plotter is displayed.
(d) Slowly tilt the top of the RFID Tag away from the RFID Reader.
(e) Observe Effect of changing the angle in the Serial Monitor/Plotter.

2.2.5 *Estimating Concentration of some Soluble Materials in Water*

(a) This procedure is more complicated and requires modifying the base code of Chang Liu's word [2] to scan through all Antenna gain values to measure the exact Antenna Gain Value at which the RFID Tag is detected.

(b) Ensure RFID Tag Antenna and Sensor are facing RFID Reader
(c) Ensure RSS Reading in Serial Plotter is displayed
(d) Place Empty Glass in same location where valid reading was obtained
(e) Fill Glass with liquid (any liquid)
(f) Submerge RFID Tag in Liquid
(g) Observe Effect of changing the liquid on the RSS Reader. (It is possible there is no effect)

3 Results and Discussion

We were able to notice trends in all of the experiments we ran. However, we could not quantify our results to the extent we wanted to. We discuss our improvements in the future work section.

3.1 RFID Tag Frequency of Rotation

1. Rotating the tag resulted in peaks where RSS Increased whenever the RFID Tag face (with the chip and antenna) was directly facing the RFID Reader.

2. When the RFID Face was perpendicular to the RFID Reader (i.e the thin part of the RFID Tag was facing the RFID Reader) RSS decreases to 0. This resulted in valleys in the graph.

   This is because the RFID Tag was unable to harvest the RFID Reader's transmitted Radio Signal. Therefore, the RFID could not transmit to the RFID Reader, causing RSS to decrease.

3. Using these results, we can determine the frequency of rotation by analyzing the period of the RSS Signal. The period of the RSS Signal is half the frequency of rotation.

4. Using this simple setup we could measure angular speed up to 100 rpm with an accuracy of 93%

5. Here we can also use FFT to accurately measure the frequency from the periodic signal.

3.2 RFID Tag Velocity

1. Moving the RFID Tag towards the RFID Reader resulted in RSS spikes with positive slope (RSS Increased over some time).

2. Moving the RFID Tag away from the RFID Reader resulted in RSS spikes with negative slope (RSS decreased over some time).

3. The above results make sense as RSS can be used to estimate distance in a noiseless environment.

   Velocity is just change in distance over time, so we can take the derivative of RSS to get velocity.

4. Using these results, we can determine the velocity by analyzing the slopes of the spikes generated by moving the RFID Tags. The velocity is correlated to the slope of the spikes. By using the slope, we get both the speed and direction. The speed is given by the magnitude of the slope and the direction is deciphered from the sign of the slope.

5. Using this method, we were able to achieve 97% accuracy in the measurement of the velocity of the tag up to 40 cm/s.

3.3 Detection of Different Materials

1. We only experimented with phones but noticed some interesting results

2. iPhone decreases the RSS Value, however, Android increased it or had no effect

3. iPhone:

   (a) We initially tested an iPhone with a RFID Protective case. We believed the RFID Protective case was decreasing the RFID Reading
   (b) However, the iPhone by itself was also decreasing RFID Reading
   (c) This may be due to the metallic body of the iPhone which is blocking RFID Signals

4. Samsung Galaxy S20 FE 5G

   (a) We placed the 4 corners of the Galaxy in front of the RFID Tag
   (b) For 3 of the corners, there was no effect on RSS
   (c) However, for one corner, the RSS Spiked.
   (d) We looked at documentation for the device, and saw there is a RFID in the Samsung phone itself at that location, which is likely what accounted for the spike in RSS.
   (e) What is more interesting, is that the metal that the Galaxy is made of is different than the iPhone - it would be worthwhile to explore if the choice of a RFID Blocking/Non Blocking material was a conscious one.

3.4 RFID Tag Angle

1. As we gradually increased the angle, we noticed that the RSS decreased. This decrease occurred as a result of the distance from the RFID Reader increasing as the angle increased.

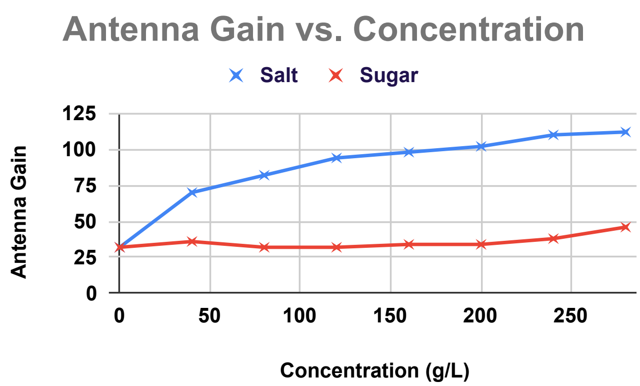
2. However, we initially did not get very precise answers (i.e threshold changed too slowly to estimate the angle accurately)

3. We attempted to resolve this issue by upsampling the antenna gain, this gave us more precise results, but, our improvements were marginal.

4. We believe these results occur because the Sine of the angle is what is really being measured (the distance of the tag from the reader is proportional to the sine of the angle the RFID card is making with vertical) and as we know the sine does not increase linearly. This should account for the large "windows" we observed in the measured levels for large angles.

5. We estimated the following angles : 0, 30, 45, 60, and 90 degrees and we could accurately measure them with an average error of 12%

Figure 3: Variation of Antenna Gain with Concentration of Soluble



3.5 Estimating Concentration of some Soluble Materials in Water

Measuring the effect of various liquids (keeping the distance between tag and reader constant) on the RSS of a RFID Tag gave surprising results. Refer to Figure 4 for summary.

3.5.1 Air

1. Antenna Gain Value: 32

2. This was the control value, the value of the RFID Card by itself.

3.5.2 Water

1. Antenna Gain Value: 32

2. This was the RSS obtained by submerging the RFID Card in bottled water.

3. This result was surprising as water is a known RFID Blocker

4. We learned that RFID blocks water due to its polar nature - which results in a high dielectric constant, affect the RSS.[1]

5. However, the effect of water is highly affected by the amount of water present, in our experiment we could only test with limited amounts of water due to the RC522's limited range.

6. Also, because we are experimenting with a small range in our setup and the water is still therefore it is not attenuating the signal observably as compared to air. And we can't achieve very high precision in our setup because of the limitation of our apparatus.

3.5.3 Sugar Water

1. Antenna Gain Value: 40

2. This was the RSS Value obtained by submerging the RFID Card in Sugar Water

3. This was also surprising as we were expected the addition of sugar (a polar substance) to affect the RSS significantly as additional substances in the water ought to block RSS.

4. **NOTE:** We ended up significantly increasing the concentration of sugar in the solution and the measured Antenna Gain did slightly increase. This implies that the polarity of the water was increased to affect the dielectric constant. But the blocking is very minimal even with saturated sugar solution. Refer to Figure 3.

3.5.4 Coca Cola

1. Antenna Gain Value: 36

2. This was the RSS Values obtained by submerging the RFID card in Coca Cola

3. This was as surprising as sugar water because we expected the addition of additional substances to affect RSS, but it was almost the same as water. And because Coca-Cola contains some sugar, we see a slight increase in the Antenna Gain.

3.5.5 Salt Water

1. Antenna Gain Value: 112

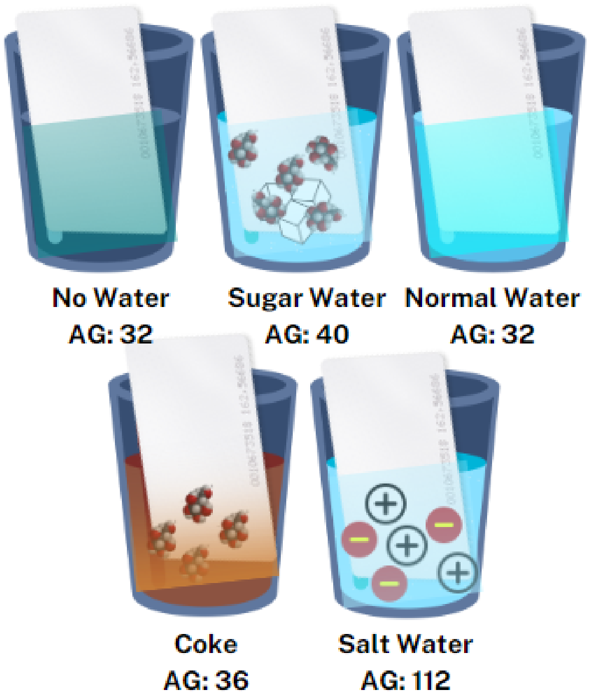
2. We did not expect the extreme effect of salt water considering sugar had a very minimal effect.

3. This result likely occurs due to the fact that salt dissolves into Positive and negative ions in water, amplifying the same polar effect that occurs in regular water and sugar water.

4. Also the dissolved ions can cause absorption and scattering of electromagnetic waves like RFID signals. The ions also create a conducive environment that causes interference and significantly reduces the signal strength which makes it difficult for the reader to detect the RFID tag.

5. Thus, the dielectric constant of the solution changes more extremely, causing the Antenna Gain to increase, decreasing RSS.

Figure 4: Results of the effect of soluble materials on Antenna Gain



4 Future Work

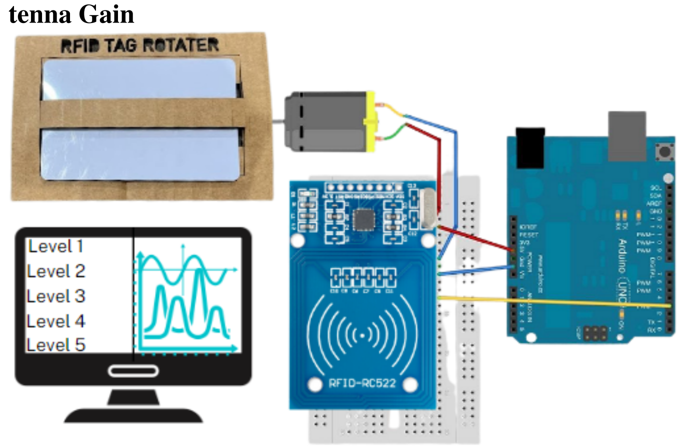
We realized new applications of RFID Sensing, however, we believe we can improve our results to achieve more interesting insights; specificially, by quanitfying some of our measurements.

Future Work for each Experiment:

1. RFID Tag Frequency of Rotation:
   (a) Create an experiment setup that allows us to set the frequency by using a motor as in **Figure 5**.
   (b) This would be useful to assess the performance of using the Period if the RSS to measure the frequency of rotation at higher frequencies.
2. RFID Tag Velocity:
   (a) Placing the RFID tag on an object that moves on a rail with a specific velocity towards/away from the RFID Reader
   (b) This would allow us to quantify what the slope of the RSS Spikes corresponds to in meters/second as opposed to just indicating the velocity of a spike compared to another spike.
3. Detection of Different Materials:
   (a) Creating an experiment to see what materials, and at what thickness, block RFID Signals.
   (b) Exploring whether or not phone manufacturers are intentionally choosing materials that block/allow RFID Signals would be very interesting.
4. RFID Tag Angle:
   (a) What is necessary is a higher resolution RFID Reader to better measure the distance.
   (b) This would in turn provide higher resolution measurements for angles.
5. Estimating Concentration of some Soluble Materials in Water:
   (a) We began some initial experiments of increasing the concentration of sugar and salt in water; it would be beneficial to continue these experiments.
   (b) Ideally, we would be able to measure a correlation between the concentration of soluble materials and the measured Antenna Gain Value, from there we could use the Antenna Gain Value on a random sample of water to measure the concentration of soluble materials.

We can now extend these principle for motion sensing applications. Because we can measure the distance and velocity of the tag, we can decipher the initial and final position of an object with an RFID tag. We can also get a sense of the trajectory through which the object is moving, i.e. we can easily detect simple trajectories like a straight line, circle, etc. In the case of a circular trajectory, we can compute the diameter by comparing the max and min RSS values.

Figure 5: Results of the effect of soluble materials on Antenna Gain



5 Conclusion

In this project, we showcased different use cases where RFID sensing can be useful. We also proposed a very simple experimental setup, with minimal apparatus for each of the use cases, and analyzed the results. We encountered some unexpected results (e.g. sudden decrease in RSS for saltwater) which motivated us to do more research to determine the underlying reason for the phenomena. Although our setup has some limitations we are still able to get measurements that are coherent with the existing explanations. There are many more things that we couldn't explore due to time restrictions.

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7 References

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