The Effect of Outdoor Weather on Received Signal Strength Indicators

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***Abstract*—The goal was to determine if relative humidity, temperature, and Received Signal Strength Indicators were sufficient for predicting if the two Raspberry Pis were less than or equal to six feet apart. The Pis advertised and scanned Bluetooth beacons in the same outdoor positions for eight days in July. The logistic regression model trained on the features, relative humidity, temperature, and RSSI, was unreliable to predict whether two devices were at least six feet apart. Models trained on two of the three features or only RSSI performed worse.**

I. Introduction

A. Project Description

Private Automated Contact Tracing (PACT) aims to classify if two people were too close for too long (TCTL). An infectious person who is less than or equal to six feet apart from another person for a minimum of ten minutes is likely to spread their disease. Once the infectious person is identified, the public health database would alert those who were TCTL within the past two weeks. Disease transmission rates will decline once PACT replaces manual contact tracing.

The Received Signal Strength Indicator (RSSI) tells how well the Bluetooth scanner hears a signal from the Bluetooth advertiser. In a perfect world, RSSI is proportional to the distance between the Bluetooth Devices. Bluetooth does not record peoples' locations, and it is integrated into smartphones, so it was ideal for PACT. No one has developed an accurate proximity detection algorithm yet because factors like obstacles, orientation, placement, Bluetooth chipset, and range angle affect RSSI.

This report addresses the reliability of using humidity, temperature, and RSSI measurements to determine if two devices are less than or equal to six feet apart. Outdoor summer weather varies over the span of two weeks, so it is essential to choose the most effective sensors to predict proximity. The advertising Raspberry Pi remained in the same location, and the other Pi scanned at distances from three to nine feet by increments of a foot. Logistic Regression Models were trained to predict proximity.

B. Background Information

The ThermoPro TP55 was used to measure relative humidity and temperature in degrees Fahrenheit. The device has a ± 3 % variation, and the device's measurements were similar to the AccuWeather Report. Relative humidity is the amount of water vapor the air holds compared to the maximum capacity at the temperature.

This report does not address the possibility that temperature and humidity of the air affected the Pis' ability to transmit and scan beacons. Excessive heat and humidity might have lowered the Pis' signal strength, which would increase the overlap between the various distances. Plastic cases may reduce the fluctuation of RSSI because the temperature would be less extreme on the Pis.

This report assumes the WiFi signal strength did not affect the Pi's RSSI because the Pi's were less than twenty feet from the router.

Read about Bluetooth Low Energy (BLE) at [1].

Read about BLE Advertising and Scanning at [2].

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II. Hypothesis/Hypotheses

1. Relative humidity, and temperature, and RSSI measurements are sufficient to predict if two devices are at least six feet apart. A logistic regression model trained on these features will obtain the highest accuracy (out of the four trained).

2. Humidity affects RSSI values more than temperature so that a logistic regression model will perform better given humidity and RSSI features than temperature and RSSI.

3. A trained logistic regression model cannot accurately predict if two devices are TCTL with only RSSI.

- Analyzing the logistic models requires the most investigation.
- PACT's goal is to predict if two people were too close to each other. These hypotheses focus on proximity detection, with only the weather varying.

III. Experiments and Data Collections

I. Experiment Overview

Distance between Pis for each scan (ft)	Hypothesis	Reason	Repetitions
3, 4, 5, 6, 7, 8, 9	Effect of outdoor weather on RSSI of scanning Pi	Observe variation of RSSI values at different weather conditions	21 for each distance

A. Plan and Execution

- Seven days of testing from July 11th to July 18th, 2020 (one day off).
- Testing sessions ranged from 10 AM to 8 PM. Average time: 4 PM.
- One Pi was designated to advertise beacons. The corner of the Pi fitted in the L-shape marking on the foldable chair. A tape measurer was used to confirm that the foldable chair was in the same position for each test.
- The other Pi, with tape on its underside, was used to scan beacons. It sat on another foldable chair and fitted in the L-shape marking. The tape measurer was used to confirm the Pis were three to nine feet apart by increments of a foot
- ThermoPro TP55 (the humidity and temperature sensor) was placed on the chair with the scanning Pi. The ThermoPro did not block the path between the Pis
- The Pis scanned and advertised for sixty seconds at each distance
- The Pis and the chairs faced each other
- Power cords were plugged into the Pis. The extension wires were plugged into the external outlets of the house.

B. Data Relevance

This scenario simulates when two phones on opposing seats advertise and scan beacons. A newly infected person may not show symptoms for up to two weeks. This person may come in contact with people during their incubation. The data shows how RSSI varied when a Bluetooth device came in contact with another for eight days. This experiment's results prove whether humidity and temperature sensors are necessary to predict whether someone was TCTL.

C. Examples

FIG 1.

	humidity	temperature	RSSI	tctl	f
0	65.0	88.2	-52.250000	1	3
1	82.5	79.2	-51.033898	1	3
2	65.5	80.7	-60.380952	1	3
3	37.0	102.0	-56.666667	1	3
4	37.0	102.0	-56.666667	1	3
...	...	...	...	...	...
140	62.0	72.3	-58.103448	0	9
141	66.0	66.2	-62.017241	0	9
142	24.0	114.6	-54.278689	0	9
143	38.0	86.4	-54.034483	0	9
144	62.0	77.0	-62.355932	0	9

Fig 1. stores Relative humidity, temperature (F), mean RSSI value, TCTL, and distance (ft) for each 60-second scan. Distances greater than six were set to zero in the TCTL column and otherwise set to one. Mean RSSI was chosen for consistency because the standard deviation ranged from 0.7% to 9.6% when the Pis were three feet apart.

IV. ANALYSIS AND ALGORITHMS

A. Description

Four logistic regression models were trained to predict if the Pis were less than or equal to six feet apart. Each model was trained on the same training examples, but with different features. Fifty-seven percent of the training examples were positive. One model had RSSI as the feature, the second model used RSSI and humidity, the third had RSSI and temperature, and the final model used RSSI, humidity, and temperature. The sigmoid, gradient, and cost function were given to the SciPy optimize minimize function. The model used these parameters to predict the probability that the Pis were TCTL. The goal was to compare the models' accuracies depending on the features to help the people of PACT decide which combination of sensors to use.

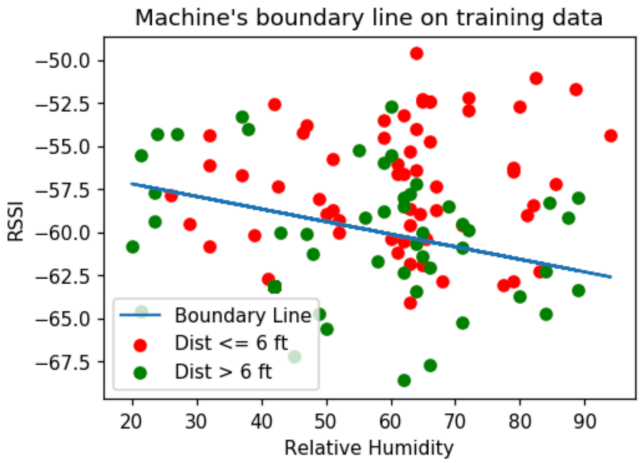
B. Results and Examples

FIG 2.

The RSSI values tend to weaken as the distance increases.

Relative humidity ranged from 20 to 94 percent. Temperature ranged from 66.2 to 117.2 degrees Fahrenheit. These diverse weather conditions most likely caused a significant overlap of RSSI in Fig 2.

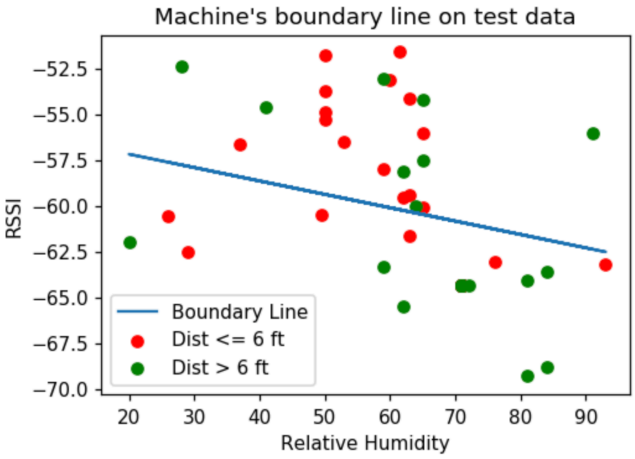
FIG 3



The model found parameters to draw a boundary line on seventy-five percent of the data (108 samples) collected.

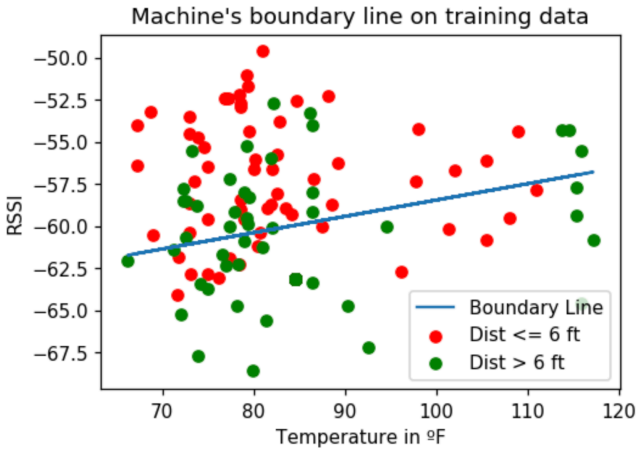
As the relative humidity increased, the range of "too close" RSSI values increased. Two Bluetooth devices can be too close in humid weather, even if their RSSI is weak because water vapor block Bluetooth signal.

FIG 4



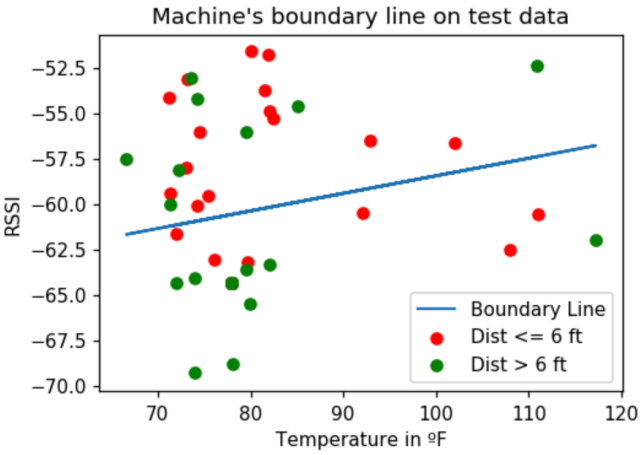
Boundary line plotted on the test data. 37 test examples.

FIG 5



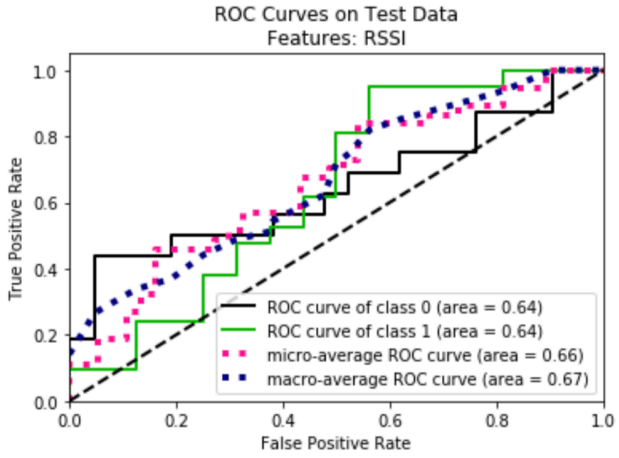
As the temperature increased, the range of "too close" RSSI values decreased. Two Bluetooth devices can be more than six feet apart in hot weather and have a strong RSSI because air becomes less dense as temperature increases.

FIG 6



Boundary line plotted on the test data. 37 test examples.

FIG 7



The model with the feature RSSI had the largest area under the ROC Curve (AUC) by a small margin. See [3] for information on micro-average vs. macro-average ROC curves

FIG 8

	Humidity, Temperature, RSSI	Humidity, RSSI	Temp, RSSI	RSSI
Training Accuracy	0.650	0.630	0.630	0.630
Test accuracy	0.590	0.590	0.590	0.570
F1 Score (Training)	0.548	0.535	0.524	0.512
F1 Score (Test)	0.516	0.516	0.516	0.500
Micro-average ROC Curve Area (Training)	0.710	0.710	0.710	0.710
Micro-average ROC Curve Area (Test)	0.640	0.640	0.650	0.660
Macro-average ROC Curve Area (Training)	0.710	0.710	0.710	0.700
Macro-average ROC Curve Area (Test)	0.640	0.640	0.660	0.670

Columns list the features that were given to the logistic regression model. The F1 Score was calculated when the threshold was 0.5.

Training and test accuracies were higher when more features were given. The model trained on humidity and RSSI had equivalent accuracies and F1 Score (Test) as the model trained on temperature and RSSI. However, the F1 Score (Training) was higher when humidity and RSSI features were provided. Further data collection is needed to prove that humidity is a more useful measurement than temperature. The models trained on temperature and RSSI or RSSI alone had equivalent AUCs. These results suggest the logistic regression models need more training data to generalize better.

V. CONCLUSIONS

A. *Hypothesis Evaluation*

1. False in the summer: Relative humidity, and temperature, and RSSI measurements are sufficient to predict if two devices are at least six feet apart. A logistic regression model trained on these features will obtain the highest accuracy (out of the four trained).

- A Sixty-five percent training accuracy is unreliable for PACT.
- The ROC Curve Area was equal or worse to the AUCs of models with other features.

2. Indeterminate: Humidity affects RSSI values more than temperature, so a logistic regression model will perform better when given the humidity and RSSI features than temperature and RSSI.

- Both measurements affected RSSI
- The model trained on humidity and RSSI and the model trained on temperature and RSSI had similar training accuracies, F1 Scores, and AUCs.

3. A trained logistic regression model cannot accurately predict if two devices are TCTL with only RSSI

- True. The model with only RSSI as the feature performed the worst in training accuracy and F1 Scores.

B. *Noteworthy Conclusions*

Outdoor summer weather creates sufficient ambiguity in RSSI and relative humidity, temperature, and RSSI measurements cannot reliably determine proximity. These sensors slightly increase the logistic regression model's accuracy, so implementing PACT in the summer requires more useful sensors.

VI. NEXT STEPS

There may be less fluctuation in RSSI during the fall, winter, and spring because excessive heat is less frequent. Further research is needed to discover if temperature and humidity sensors are sufficient for PACT during these seasons. Implementing PACT in the winter may be a worthy focus since the transmission of disease increases.

The experiment should be repeated, but have the Pis scan and advertise for ten minutes at each distance. One minute of scanning may have contained many fluctuations of the RSSI so that the mean would vary more. The Pis should also wear cases so the heat is not as extreme.

The logistic regression models need more training data to generalize better.

If previous experiments confirm that humidity and temperature sensors are insufficient in all scenarios, PACT must find which sensors can be implemented into smartphones and predict if two devices are TCTL when the outdoor experiment repeats.

REFERENCES

1. https://www.novelbits.io/basics-bluetooth-low-energy/
2. https://learn.adafruit.com/introduction-to-bluetooth-low-energy/gap
3. https://datascience.stackexchange.com/questions/15989/micro-average-vs-macro-average-performance-in-a-multiclass-classification-settin

Thank you to all the people who made piPact possible. I was never introduced to scientific research before, and I learned valuable things from this experience. (My town endorses art and sports, not STEM.) Because of piPact, I learned about Bluetooth devices, Raspberry Pis, pandas, machine learning, writing scientific papers, and persevering through an experiment (even when it's a hundred degrees.) I woke up in the middle of the night several times to code my piPact project. So thank you for giving the opportunity to learn real-world science.