Modeling Interference in Passive Wireless Sensor Networks

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Abstract- This research investigates the interference in networks of passive wireless sensors. The motivation behind studying passive wireless sensors is that they are very useful in harsh environments that may be at high temperatures or have moving parts; this is because the sensors do not need a battery or bulky wiring. With surface acoustic wave (SAW) based sensors, it is possible to detect a desired measurand from multiple locations using multiple sensors. This is made possible in part by previous work in devices [1], coding [2], and on signal detection in [3]. However, by the sensor identification process, when the signal is retrieved from the target sensor it is possible for interference to aggregate. The target sensor's signal is embedded within this total signal which, if there is too much interference, degrades the performance of the system. It is important to discover the upper limit of sensors that contribute to this degradation and to find ways of negotiating it. This project models the cumulative effects of inference coming from the network.

1. INTRODUCTION

In order to have effective sensor coverage of a hazardous area, a jet engine for example, it is necessary to have multiple wireless passive devices. However, because the devices are passive, the individual signal of one sensor is in danger of being confused with the signals from all other sensors in the field. This project explores ways of mitigating the interference that is present due to unwanted signals. The point at which it would not be appropriate to use more sensors in a single area and on the same a frequency channel was found.

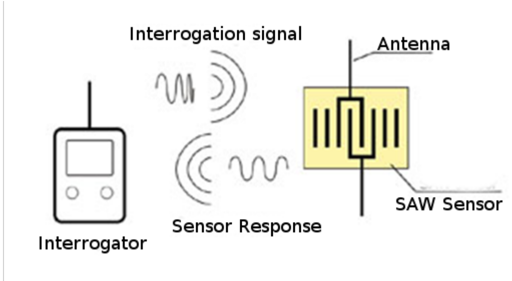

FIG. 1: Schematic of interrogation and signal retrieval. The lines on the SAW sensor represent reflectors mounted on a silicon substrate and they mirror each other perfectly.

2. SAW DEVICES

The signature signal given by surface acoustic wave (SAW) devices was modeled using Matlab. The method of sensor identification employs a binary code set. On either side of the antenna, shown in Figure 1, are reflectors and each reflector corresponds to a 1 or a 0 that act as the device's specific identity. The 1's and 0's depend upon how a reflector alters the phase of the wave. An interrogator sends out a signal which is picked up by the antenna of the SAW device, moves to the inter-digital transducer (IDT) which converts it into a surface acoustic wave that then propagates to the reflectors.

If the interrogator signal matches the hard code on the sensor, the acoustic wave begins to resonate due to constructively interfering piezoelectric distortions, and there is a large reflected signal that gets sent back to the interrogator. The response signal has two peaks that correspond to reflectors on either side of the antenna; they both cause large reflections but one is further away from the center of the device (where the IDT is located). That way, there is a gap between the peaks as depicted in Figure 2.

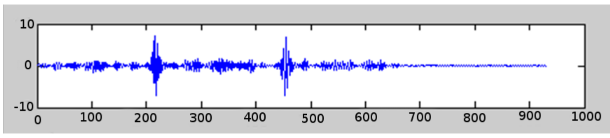

FIG. 2: Two peaks representing signal reflections. The SAW devices had two sets of identical but mirrored reflectors.

The device is made of silicon which is susceptible to distortions from temperature and pressure changes, and these distortions manifest as variation in the distance between the peaks. The variation between the peaks is how the sensor detects a change in a measurand.

3. PROGRAMMING TECHNIQUES

This project was implemented in Matlab using some preliminary code that was done by a former student[2]. It was necessary to learn the fundamentals of Matlab before thorough work was to commence, therefore, a few practice scripts were written. One was taking a 31 by 31 binary array and using a correlation method to find the magnitudes of correlation between them. At the base of the final program is a 31 by 31 code set array, which is what prompted the specific aforementioned

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practice. These 31 codes (1 by 31 each) were predetermined by another project, by use of the 'gold code' method. The gold code method reduces the amount of cross-correlation and auto-correlation between codes. Reducing these is necessary to diminish bumps that may occur in the reflected signal; these bumps may degrade the precision of the signal. The codes act as 31 different sensors that could be out in the field. The first code in the list is the target code. Here is a single code, for example:

1,0,1,0,0,0,1,1,1,0,1,1,1,1,1,0,0,1,0,0,1,1,0,0,0,0,1,0,1,1,0

The way the correlation procedure works is to propagate a wave, which is the 31 bit binary code, against another code. The first code is presumed to represent the hard code that is unique to the sensor. The second code sequence is the sensor the interrogator wants to read information from. As the wave from the interrogator is picked up by the device, if it is a match then there is a large reflection and a peak appears in the return signal. Because there are two sets of identical mirrored reflectors, there will be another peak further along the signal that depends on how far away the second set of reflectors are. A generic matched signal would look similar to Figure 3. Conversely, an unmatched code would look like Figure 4. These are what the signals look like when simulated on Matlab, where the magnitude of the correlations went through various filtering techniques. Moreover, there is no external interference which must be taken into account when the devices are truly used in the field.

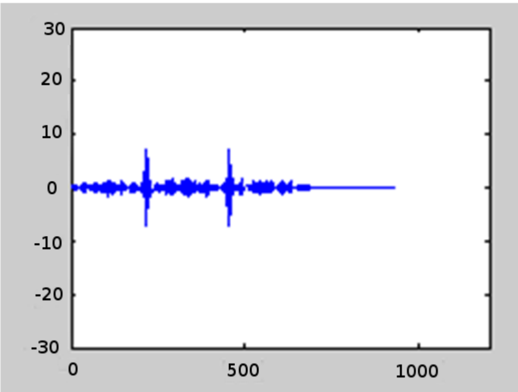

FIG. 3: A matched signal with no other contributing factors.

4. INTERFERENCE

At this point it is possible to start modeling what the interference will look like. Adding the signals after filtering is an efficient and elegant way of doing it. With each new unmatched signal that is added, the initial peaks distort and shift location. After enough sensors are added one can no longer distinguish the original peaks and the method of sensor identification is lost in the new signal. Relatively, the original peaks become shorter compared to the growing bumps from the interference. Figure 3 contains an original match while Figure 5 is the original plus three unmatched signals.

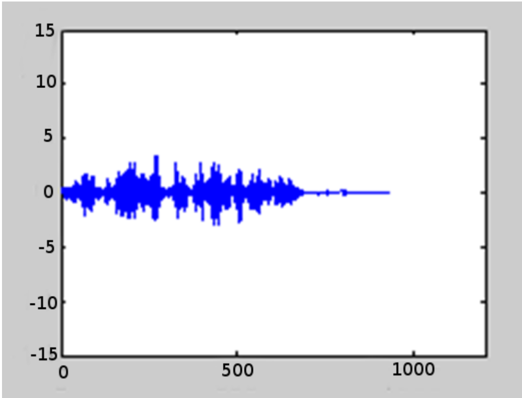

FIG. 4: This is what the signal looks like to the interrogator when the signal transmitted does not match the signal that is received.

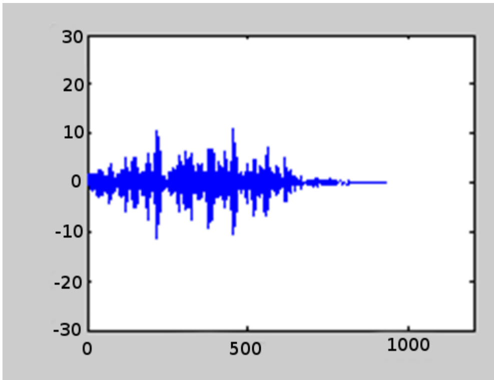

FIG. 5: The is a matched signal but with three unmatched signals that were also transmitted from the interrogator.

5. PEAK TO SIDE-LOBE RATIO

The objective of this project is to find when the system is over saturated with sensors. This breaking point is determined by the peak to side-lobe ratio. This is the original height of the double peaks added together and then divided by the combined height of the next two highest peaks. The reason the two sets of peaks are added is to make it an average which was considered more prudent. In this script, the number of sensor that can be accommodated is six; up to six signals will not distort the original signal enough that it cannot be found. Figure 6 shows how the peak to side-lobe ratio drops off exponentially.

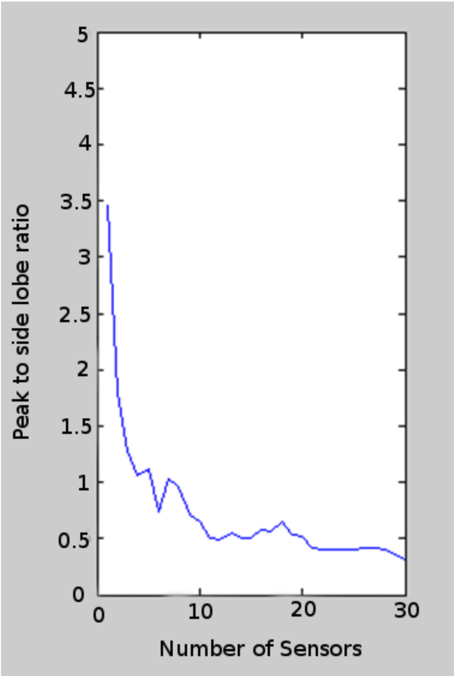

FIG. 6: Peak to side-lobe ratio-The ratio dips below 1 after six sensor signals are included.

6. CONCLUSION

As stated, this script shows that up to six sensors can be used before signal degradation makes the system unusable. Variability must also be taken into consideration because by alternate signal filtering or different code sets altogether, more or fewer sensors may be accommodated. Near the end of the summer, different code sets were tested and they resulted in obviously different looking outputs; but the most pronounced difference was in the peak to side-lobe plot. There are bumps and discontinuities in the one that is shown but new codes alter these bumps, this offers evidence in favor of finding the best code sets possible: ones that auto- and cross-correlate the least. Another way to accommodate more sensors would be to use different frequencies. For example, if one had five frequencies containing six sensors each then thirty sensors could be used. Finally, it would be possible to implement time delays in the system so that the signals are not coming in on top of each other. If, for example, four different lengths of delays were used with the five frequencies, then up to 120 sensors could be accommodated.

[1] P. da Cunha, *Wireless Multiple Access Surface Acoustic Wave Coded Sensor System* (IET Electronics Letters, vol. 44, no. 12, pp. 775-776, June 2008).
[2] D. Abedi, *Orthogonal Code Design for Passive Wireless Sensors* (QBSC'08 Kingston, Canada., June 2008).
[3] Abedi, *Signal detection in passive wireless senor network based on back propagation neural networks* (IET Wireless Sensor Systems, December 20, 2010).