REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
15-04-2010

2. REPORT TYPE
Journal Article

3. DATES COVERED *(From - To)*
N/A

4. TITLE AND SUBTITLE
Sticky Bomb Detection with Other Implications for Vehicle Security

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
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5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

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8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Energy
Washington, DC 20585

10. SPONSOR/MONITOR'S ACRONYM(S)
ANL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
66497

12. DISTRIBUTION / AVAILABILITY STATEMENT
A: Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
sticky bombs, IED detection

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
unclassified	unclassified	unclassified	UU	11	Roger Johnston

19b. TELEPHONE NUMBER *(include area code)*
630-252-6168

Sticky Bomb Detection with Other Implications for Vehicle Security*

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Introduction

A "sticky bomb" is a type of improvised explosive device (IED) placed on a motor vehicle by (for example) a terrorist. The bomb is typically attached with adhesive ("duct") tape, or with magnets. This paper reports some preliminary results for a very rudimentary demonstration of two techniques for detecting the placement of a sticky bomb on a motor vehicle. There are other possible security applications for these techniques as well.

Method 1: Tire Pressure

The weight of a truck and its cargo load can theoretically be determined from measurements of the tire pressure.[1] We investigated whether small changes in a vehicle's weight—such as that caused by the addition of a sticky bomb—could be detected by monitoring the vehicle's tire pressure.

The pressure was measured using a Vernier 12-bit analog-to-digital converter to sample a MKS Baratron differential pressure transducer (model 223BD-1ABB, ~$600) with 1 Torr pressure range full scale. The effective differential pressure resolution was approximately 0.001 Torr. (For comparison, there are 760 Torr in a standard atmosphere, and 0.001 Torr ≈ 1/1000 of a mm of mercury ≈ 0.13 Pascal ≈ 19 millionths of a pound per square inch). Much more sensitive pressure transducers are available commercially.

Tire pressure measurements were made on a parked 2004 PT Cruiser automobile (because that is what we had available to experiment on). The engine was off during measurements.

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* Editor's Note: This paper was not peer reviewed.

The Baratron pressure transducer remained external to the car and its tire. Figures 1 and 2 show the experimental setup. Tubing was used to attach one end of the Baratron to the tire's stem. A 'T' in the tubing allowed the other end of the Baratron to be connected to a shutoff valve. Initially, the valve was opened so that the pressure (provided by the tire) was equalized on each side of the Baratron. The shutoff valve was then closed. Next, weight was added or subtracted from the vehicle. Any change, positive or negative, in the differential pressure across the Baratron was measured with the Vernier analog-to-digital converter and recorded with a notebook computer as a function of time.

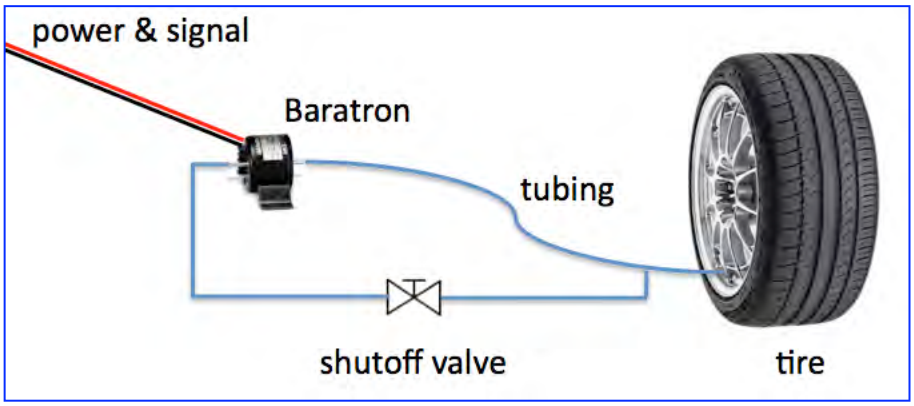

Figure 1 - Schematic of the experiment.

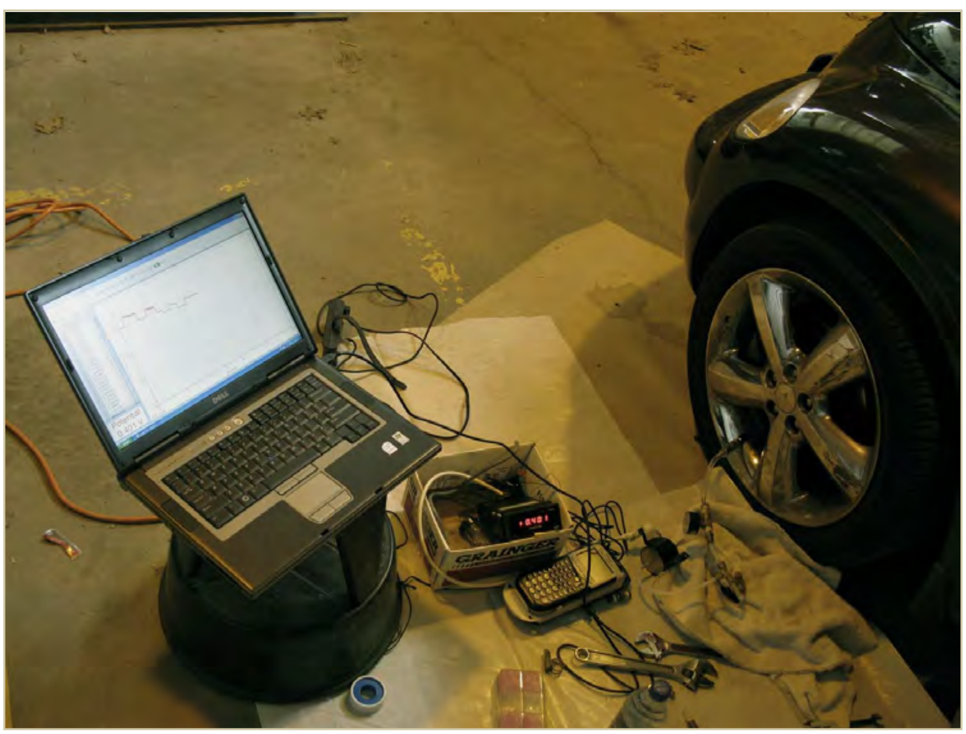

Figure 2 - The actual experiment.

Experimental results are shown in Figures 3-8. Figure 3 shows that the addition of a 10-pound weight to the car can be easily detected by the increase of air pressure in the front, driver's side tire.

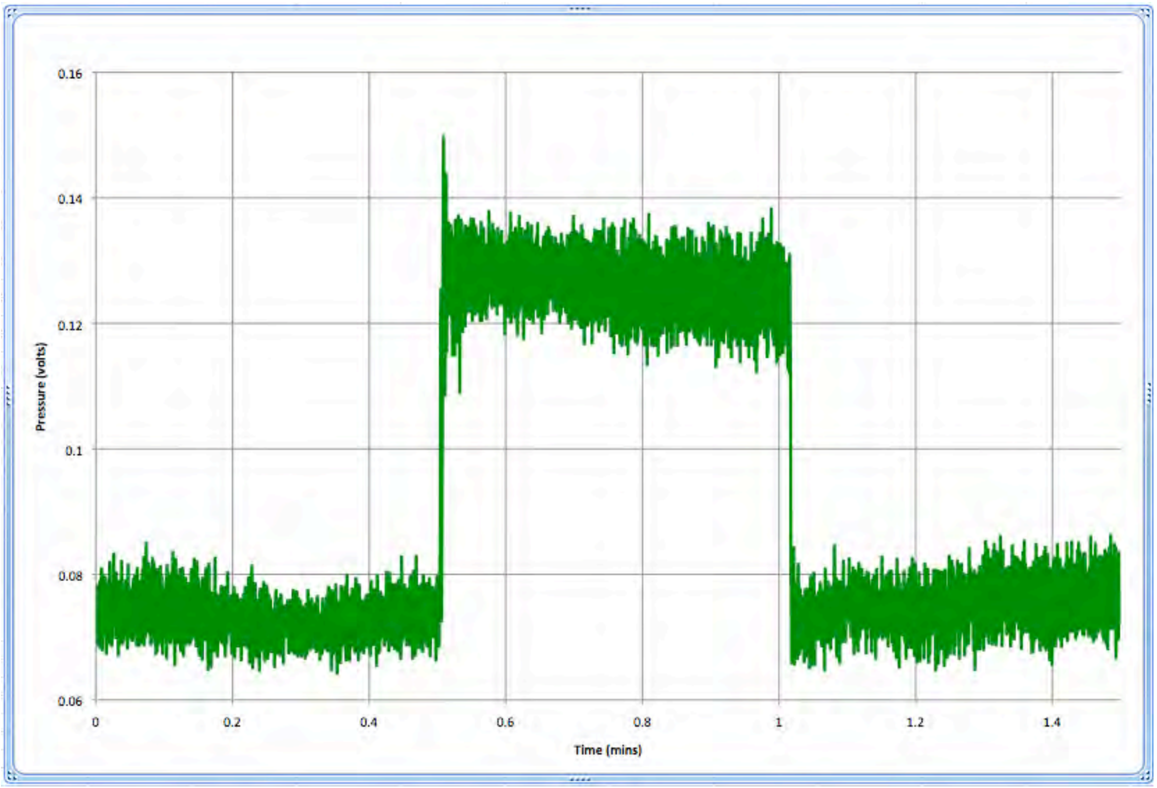

Figure 3 - 10 lb weight. Differential tire pressure as a function of time. While monitoring the pressure of the front, driver's side tire, a 10-pound weight was added to the driver's floor area at 0.5 minutes, then removed at 1 minute. (No driver was in the vehicle at the time.) A real sticky bomb would most likely be placed on the vehicle's exterior or the under carriage. The tire pressure increased when the weight was added, then returned to its original value when the weight was removed. A 0.010 volt change in the vertical axis corresponds approximately to a pressure change of 0.001 Torr.

Though we did not study the issue carefully, we believe the noise shown in figure 3 and subsequent graphs is a combination of electronic noise, analog-to-digital conversion noise, and background mechanical vibration/acoustical noise transmitted to the tire through the air and ground. Only the latter would cause true pressure oscillations in the tire. (The experiment was conducted in a relatively noisy environment about 2 km from a construction site.)

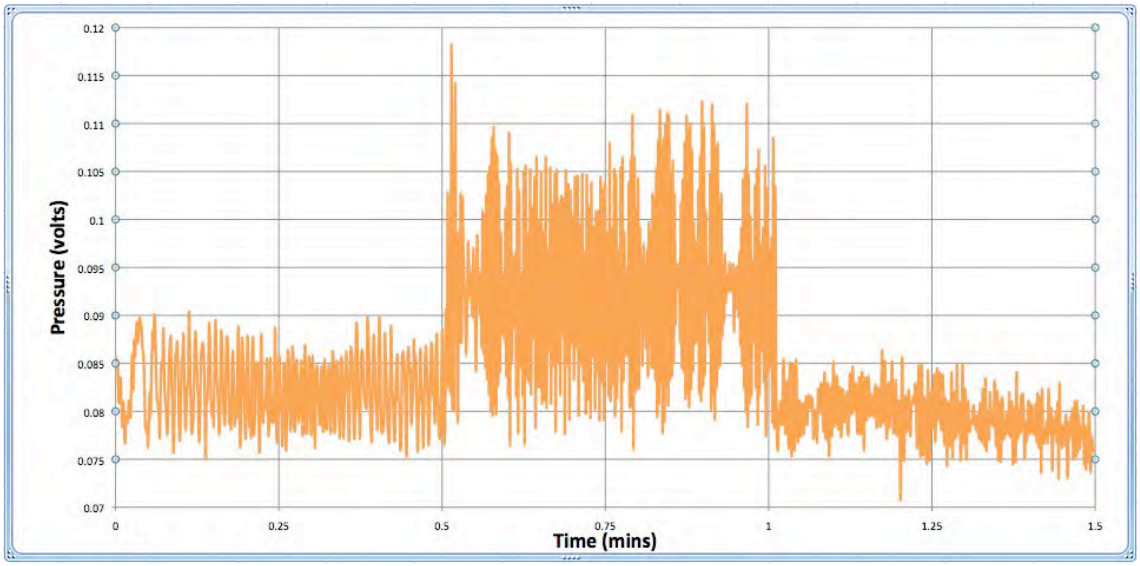

Figure 4 - Results for the same experiment in figure 3 except that the weight was 2 pounds, a value closer to the minimum effective mass of a sticky bomb used to attack a vehicle.

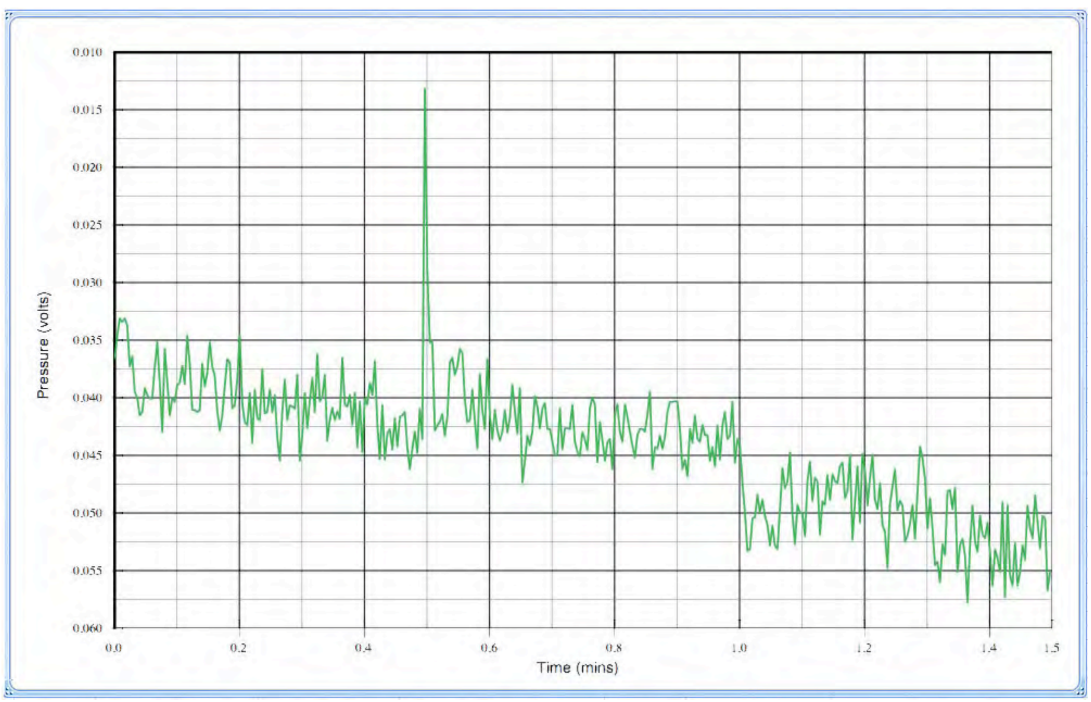

Figure 5 - The same experiment for 1 pound. The overall downward drift in the differential pressure may be due to some combination of a slow leak, temperature changes in the tire, and an incoming weather pressure front.

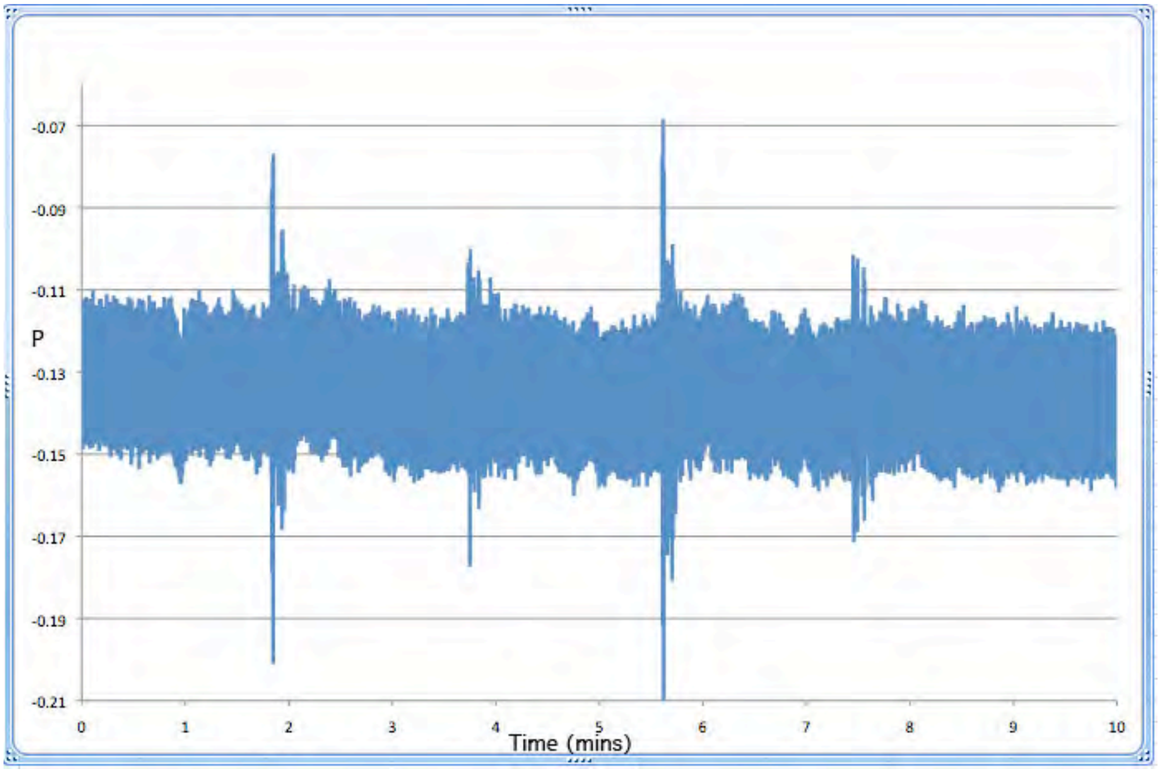

Figure 6 - The same experiment using a 4-ounce weight fairly gently placed on the driver's floor. The weight was added at approximately 2 minutes, removed at 4 minutes, replaced at 6 minutes, and removed at 8 minutes. While it is difficult to see the step functions caused by the extra weight amid the noise, pressure spikes clearly indicate when the weight has been added or removed. Wind or rain, however, might create similar spikes.

Discussion: Tire Pressure

Figures 3-6 indicate little difficulty in detecting the addition (or subtraction) of 1 or 2 pounds from the automobile. Figure 6 arguably suggests that as little as 4 ounces can be detected.

Improvements to this measurement technique should be possible by increasing the pressure sensitivity, reducing the high frequency noise in the pressure measurements, and moderating (or correcting for) the long-term drift. The latter, however, is not much of a problem since we are looking for only very short-term changes to the tire pressure.

Note that the change in tire pressure would be less for a vehicle that had more than 4 tires, such as a large truck.

Our results are for a parked vehicle. Making measurements on a moving vehicle would be more challenging, though perhaps a multi-axis accelerometer and measurement of the tire temperature could be used to correct (at least partially) for engine noise, road vibrations, and thermal changes. Wind and rain would no doubt also complicate the interpretation of the measurements. We suspect this technique would work at some level for a moving vehicle, but at a reduced sensitivity.

Placing the pressure transducer inside the tire—as is currently done with the much lower sensitivity tire pressure sensors used in modern cars to report low tire pressure—would probably be required for monitoring the tire pressure of a vehicle in motion.

There are other potential security applications for this technique beyond sticky bombs. Theft of a vehicle's contents, or smuggling unauthorized cargo onto a vehicle could be easily detected. It might be possible to detect the placement of a surreptitious Global Positioning System (GPS) or other illicit tracking device on a vehicle if the surreptitious package included a long-life battery, radio frequency transponder, and antenna.

Figure 7 and 8 also suggest that monitoring the tire pressure could be used to detect vehicle intrusion. Figure 7 shows what happens to the tire pressure when a person entered the back seat of a vehicle, then left 30 seconds later. Figure 8 demonstrates the intriguing idea that we can determine which door of the vehicle is opened by monitoring the pressure on just one tire.

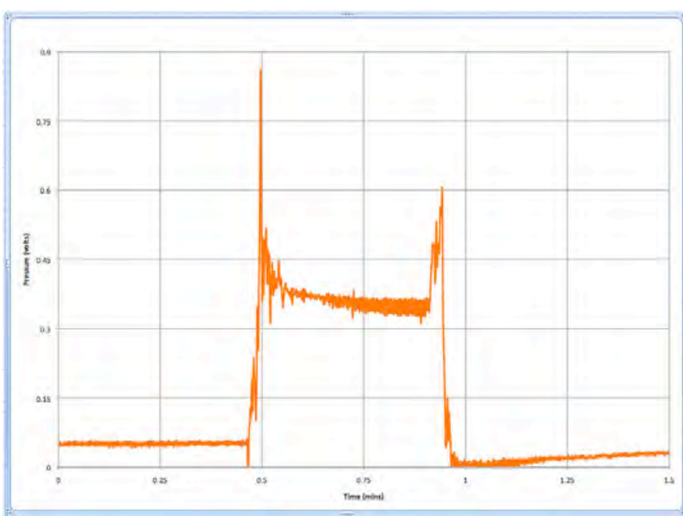

Figure 7 - Detecting a masher entering a parked car. A 145-pound man entered the back seat of the car at 0.5 minutes, then left at approximately 1 minute. The back door remained open throughout. Being in the back seat, his weight was distributed unevenly between the 4 tires, only one of which was being monitored for pressure changes (the front, driver's side tire).

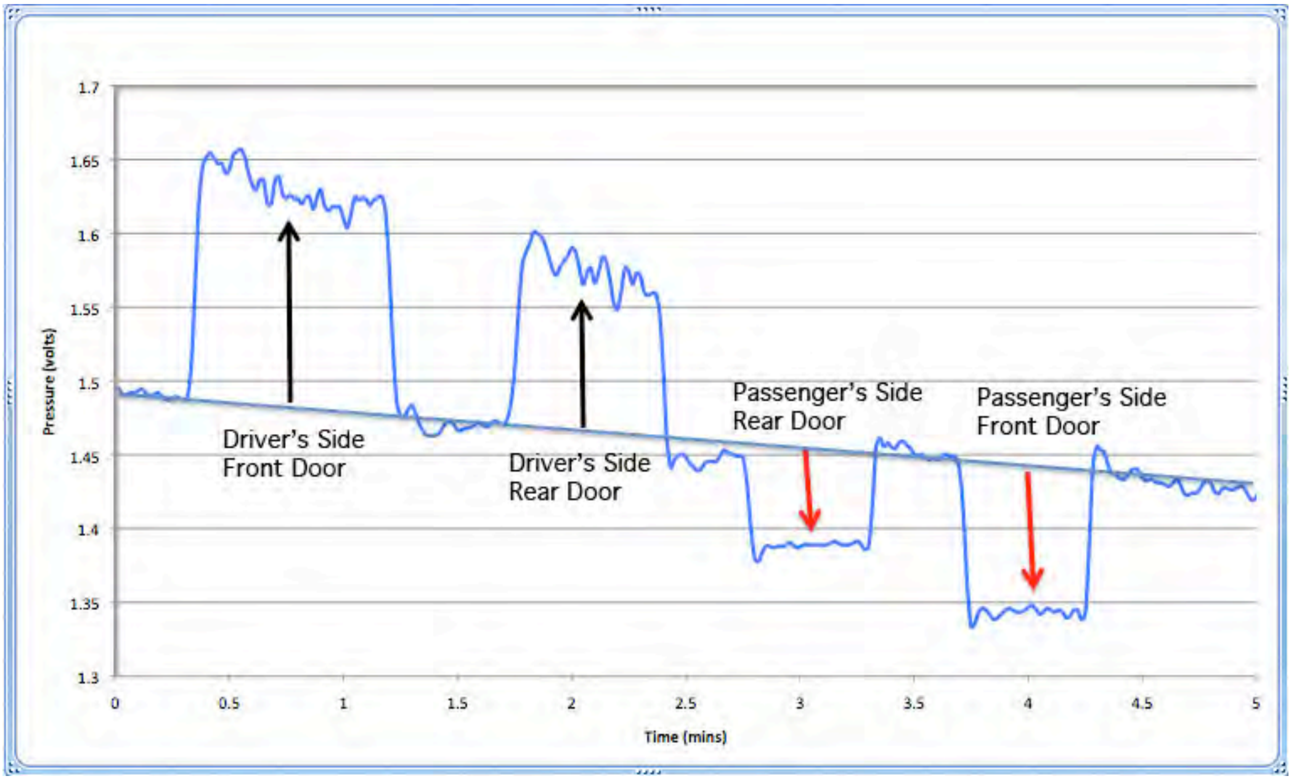

Figure 8 - By monitoring the pressure of the front, driver's side tire, it is possible to determine which of 4 doors are opened. Each of the 4 doors was opened for approximately 1 minute, then closed. The pressure *increases* when the driver's door was opened, because of the lever arm of the door. The pressure increase is less for the rear door on the driver's side because that door is not immediately located over the tire being monitored. Opening either passenger-side door causes the tire pressure to *decrease* because the car leans in the opposite direction due to the weight of the open door hanging out to the side of the vehicle. As in figure 5, the largely irrelevant overall downward drift in the differential pressure may be due to some combination of a slow leak, temperature changes in the tire, and an incoming weather pressure front.

Method 2: Magnetic Measurements

Instead of detecting the sudden weight change to a vehicle when a sticky bomb is attached, we investigated whether sticky bombs (or surreptitious tracking devices) that were attached with magnets could be detected by looking for sudden changes in magnetic field around the vehicle. While DC magnetic field lines can be significantly deviated directionally by ferrous metals, attenuation of the overall magnetic field strength is typically minor.

For this experiment, we compared the performance of two commercial magnetometers. The first was a handheld Walker Scientific Triaxial FluxGate Magnetometer with a 1 nanoTesla (nT) resolution along each of 3 axes. The other magnetometer was a PNI V2XE 2-axis Digital Compass with an effective resolution of about 50 nT along each axis.[3] (By comparison, the amplitude of the Earth's magnetic field at Argonne, IL is approximately 45,000 nT at the surface.)

Readings from the Walker magnetometer were recorded manually from the liquid crystal display. PNI readings were recorded with an Apple notebook computer via a custom USB interface. Both magnetometers measure DC magnetic fields, but are not much affected by AC fields above a few hertz in frequency.

The cost of the Walker and PNI magnetometers in (retail) quantities of 1 are ~$2.5K and $75, respectively.

The automobile used for this experiment was a 1993 Subaru Legacy station wagon. We place the magnetometers on the driver's seat of the vehicle (see figure 9), even though this is not the optimal location for detecting sticky bombs applied to a car's exterior. A rare earth magnet was then placed at different locations near or on the vehicle's exterior, with the magnet's North pole oriented perpendicular to the vehicle's surface. (These locations, shown in figure 10, are not necessarily realistic for sticky bomb locations.)

The magnet we used for this demonstration was a 1" long, 1" diameter cylindrical rare earth magnet (~$1). Its holding strength was 60 pounds for a clean, optimal magnetic metal surface, but substantially less when attached to an automobile. A magnet this strong might be overkill for a sticky bomb weighing a few pounds applied to a parked vehicle, but could be appropriate if the terrorist wanted to be sure the sticky bomb remained on the vehicle as it traveled along bumpy roads. Results for weaker magnets would scale linearly with the strength of the magnet.

The results of our magnetic measurements are shown in table 1, and schematically in figure 10. The values shown are the amplitude of the change in magnetic field strength when the magnet was brought near or placed on the automobile. For the Walker magnetometer (being 3-axis), the change in amplitude was the quadrature, i.e., the square root of the squares of the changes in the magnetic field strength in the x, y, and z (vertical) directions. The 2-axis PNI magnetometer measured magnetic field strength only in the horizontal plane. Thus, the values shown for the PNI magnetometer in table 1 and figure 10 are the square root of the squares of the changes in magnetic field strength in the x and y directions only.

The results for the Walker magnetometer shown in table 1 and figure 10 are within about 20% of what we predicted theoretically for the magnet used in this demonstration by ignoring the presence of the metal in the car.

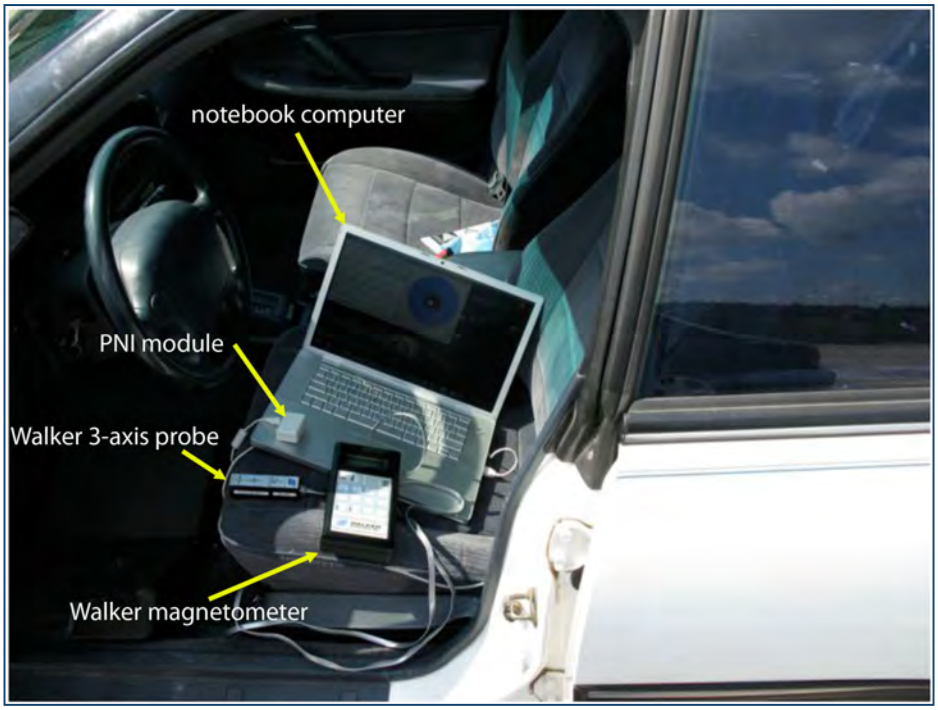

Figure 9 - The driver's seat location of the magnetometers and notebook computer used to record the PNI readings. The PNI module, which we built, consisted of the PNI magnetometer plus a USB interface circuit.

Table 1 - Experimental results for changes in the amplitude of the 3-dimensional (Walker) and 2-dimensional (PNI) magnetic field strength when the rare earth magnet was placed on or near the car. The approximate uncertainties for these measurements are ±3 nT for the Walker magnetometer and ±70 nT for the PNI magnetometer.

location	Walker (ΔnT)	PNI (ΔnT)
7 feet in front of the front license plate	361	0
left (passenger's side) front fender	289	251
front license plate	391	52
right (driver's side) front fender	3364	1577
rear, driver's side door	2472	909
right (driver's side) rear fender	1785	272
rear license plate	449	146
left (passenger's side) rear fender	283	251

Figure 10 - The results from table 1. The orange dots indicate the location of the magnet. The Walker readings are shown in green for each location, with the PNI readings in black parenthesis.

Differences in the readings for the Walker magnetometer vs. the PNI magnetometer are probably due to the PNI not measuring in the z (vertical) direction, the fact that the magnet and the PNI magnetometer were not in the same plane, the fact that the surface of the automobile where the magnet was attached was not always vertical, and our rather crude calibration and nulling (zeroing) techniques for the PNI magnetometer. (The Walker magnetometer displays results directly in nT and has a sophisticated built-in nulling algorithm. The PNI magnetometer gives results only in arbitrary units and lacks an amplitude nulling algorithm. This is because it is fundamentally a compass, interested only in magnetic angles.)

Discussion: Magnetic Measurements

Table 1 and figure 10 show that both the Walker and PNI magnetometers could easily detect placement of the magnet used in this demonstration. Based on these results, the Walker magnetometer should have little problem detecting a magnet one-tenth as strong. With the PNI magnetometer, however, a weaker magnet might necessitate the use of 2 to 4 PNI magnetometers, placed in different locations around the vehicle so they would be closer to the magnet. A larger vehicle might also require multiple PNI magnetometers.

Conclusion

This was a rather crude demonstration. We were greatly constrained by the small amount of time and funding available for exploring either the tire pressure or magnetometer techniques. The preliminary results, however, would seem to suggest these two concepts warrant further investigation, either for sticky bomb detection or for other vehicle security applications.

References

1. See, for example, US Patent 6449582, "Vehicle Weight and Cargo Load Determination Using Tire Pressure", September 10, 2002

2. MKS, Type 223 Pressure Transducer, http://www.mksinst.com/docs/UR/223.pdf

3. PNI V2Xe 2-Axis Compass Module, http://www.tri-m.com/products/precisionnav/files/specs/v2xe_spec.pdf