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A Stand-off Seismo-acoustic Method for Humanitarian Demining

Using seismo-acoustics to detect landmines may be an efficient and cost-effective demining method. It may also work in wet soils and allow discrimination between mines and metallic clutter. Bechtel, as a junior in high school, was a finalist in the 2012 Intel Talent Search for her research on seismo-acoustic detection and was invited to present at the second annual U.S. White House Science Fair.

by Marian Bechtel

In humanitarian demining, the most common detection methods are manual approaches that can be tedious, time-consuming and dangerous.¹ One of the issues posed by current demining technology includes that metal detectors, although an important tool because of their low cost and simplicity, cannot detect minimum metal (plastic) mines. Many methods, including metal detectors, probing spikes, etc., also cannot discriminate between landmines and clutter, such as rocks, scrap metal and shrapnel. This results in false-alarm rates sometimes higher than 90%, causing scarce demining funds to be spent largely on trash collection.² Another obstacle is that most electrical and electromagnetic methods are useless when the ground is wet.³

Research is being conducted worldwide to find more efficient methods for demining. However, many new technologies are expensive and complicated, making them impractical in poor, war-torn countries.² In addition, as Colin King, editor of *Jane's Mines and Mine Clearance*, stated: "... some of the demining agencies, having been disillusioned by a stream of ill-conceived ideas, will now hardly consider the possibility that new technologies could help them."⁴

Seismo-acoustic Detection

This study investigated the use of seismo-acoustics in the form of a continuous-wave seismic transmitter (or shaker) to induce vibrations in the earth, which may be amplified by elastically compliant buried mines. Microphone receivers record the coupled acoustic vibrations in the air above them. Noise cancellation is applied to enhance signal-to-noise ratio and create a characteristic sound pattern that allows pinpointing of mine locations. This method is inexpensive, involves no contact with the mine-contaminated ground and has the potential to work well in wet soils—a distinct advantage over ground penetrating radar (GPR), the other common method for detecting non-metal buried targets.⁵

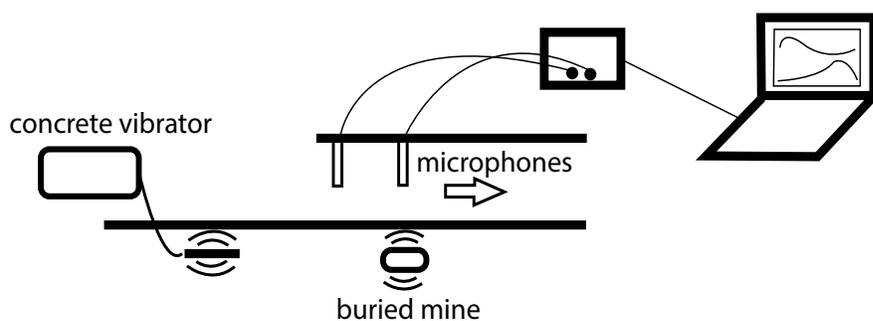


Figure 1. Diagram of phase III set-up in the outdoor test bed.
All graphics courtesy of the author.

The ability to detect landmines with seismo-acoustics is based on resonance between the shaker and elastically compliant targets. Landmines are elastically compliant containers that, when excited by seismic waves with frequency content spanning their natural period, will resonate and cause vibrations in the soil and air above them.⁶ In contrast, many clutter objects (e.g., rocks, bricks, shrapnel) are not compliant and will not resonate like mines. This allows for discrimination between landmines and clutter when using seismo-acoustics and could greatly lower the false-alarm rate in demining.⁷ The fundamentals behind this process are similar to those in methods that use laser Doppler vibrometers. However, using an acoustic receiver rather than a seismic one could help overcome the issue of heavy vegetation, which can be a limiting factor in the efficiency of laser Doppler vibrometers.²

This study follows two previous years of research on seismo-acoustic mine detection. The first year was spent on proof-of-concept testing to see whether mines could be made to resonate, and the results suggested that not only is seismo-acoustic detection possible, but discrimination between landmines and clutter may be possible as non-compliant rocks and steel scrap did not resonate. The second year tested the potential for the creation of acoustic images based on gridded vibration measurements, with each grid cell representing an im-

age pixel. Both of these early studies relied on seismic-acoustic coupling using an acoustic transmitter and seismic receivers. Although this was effective as a scientific exercise and demonstrated that mines could be made to resonate, it would be impractical in the field due to the expense of seismic sensors, the need for direct (and dangerous) ground contact, and the impracticality (and inconvenience) of mobilizing and operating a powerful acoustic source above a minefield. However, these investigations provided the foundation for another year of work to design a practical, cheap and stand-off (non-contact) seismo-acoustic device that could be developed for field use.

Testing the concept of a seismic source exciting resonance in a mine, which could then be detected by recording the coupled acoustic field above the mine, was broken down into three phases.

Phase I Testing

Phase I focused on confirming that a noise-cancelling microphone system could detect the sound of an object resonating below the level of ambient noise and locate it based on the spatially variable acoustic field.

To create the microphone receiver system, two high sensitivity, broadband microphones (loaned by Earthworks) were set at a fixed separation on a hand-held bar (a broom handle). The microphones were connected to a Mackie Onyx Blackjack two-channel amplifier and



Figure 2. Photo of phase III testing.

analog-to-digital converter with a USB connection to a laptop running GoldWave digital audio editing software.⁸

To simulate the “sound” of a buried, resonating mine, a small speaker was placed beneath a thick, folded blanket on the lab floor. Computer-simulated tuba notes were played through the speaker at sound levels well below ambient noise levels. The tuba notes were rich in low frequencies intended to match the resonant frequencies of anti-personnel (AP) mines. Ambient noise was created by running a drill press and other lab tools.

The microphone system was swept over the hidden speaker (or lack thereof in control tests) to record the simulated sound of a resonating buried mine. Noise cancellation was performed manually in GoldWave (see Data Analysis).

Phase II Testing

Following analysis of the Phase I data, which confirmed the ability of the microphone system to detect and pinpoint the location of resonating objects, the next step was to test whether a ground-coupled seismic source could cause a mine to resonate.

A concrete vibrator (the seismic shaker) was placed in one corner of a 3.05 m x 3.05 m (10 ft x 10 ft) sand test bed. On the opposite side, three geophones (Oyo 100 Hz natural frequency) were placed on top of the sand using flat steel snow plates instead of typical geophone spikes. Buried beneath one of the geophones was a mock mine, while the others rested on uniform sand. The mock mines were cylindrical metal and plastic mint containers filled with RTV silicone rubber, which simulated the dimensions and physical properties of AP mines.⁹ With the vibrator running, the geophones recorded the vibrations of the material beneath them onto a Geometrics StrataView digital seismograph. Even before spectral analysis of the geophone records, it was clear simply by looking at the seismic wiggle traces that the two geophone recordings over featureless sand were nearly identical, while the one over the mine was different.

Phase III Testing

Combining the first two phases (testing of receiver and source respectively), the microphone system was taken to the outdoor sand test bed. In the next set of tests, the microphone system was swept along a test strip in the sand, beneath which a mine was buried at the midpoint (see Figures 1 and 2). Control tests with no target and tests with buried plastic and metal mine simulants were completed with the microphones about 5 to 10 cm (1.97 to 3.94 in) above the ground. Test results of this distance from the ground determined it to be the optimum sensor height.¹⁰ For all of these outdoor tests, the test bed was near a major road, so background noise was substantial and non-systematic.

An important goal of this project was to test mine detection in soils with high moisture content. Therefore, tests were run in matching sets in which a metal or plastic mine was buried. Detection was done with dry sand and then with thoroughly wetted sand.

For all tests, the exact time that the two microphones were centered over the buried mine was recorded. This was critical since the microphones were swept by hand with consequently variable speed.

Data Analysis

First, the geophone recordings from the Phase II tests were Fourier-transformed from raw time domain wiggle traces to frequency domain vibration spectra. Correlation coefficients were calculated between spectra for multiple geophone-over-sand (no mine) records and for geophone-over-sand to geophone-over-mine (mine) spectra. For all tests, the correlation coefficient for no-mine/no-mine spectra was significantly higher than any mine/no-mine pairings. This spectral analysis quantified the apparent visual difference between the wiggle trace records for ground vibrations above mine and no-mine conditions.

To analyze the microphone data for the Phase I testing over a mock mine sound source and Phase III testing over resonating mines (excited by the shaker), the critical component was noise cancellation. This was necessary because the sound level of the vibrating mine was much

lower than ambient noise. For the microphone testing, the sound from each microphone was recorded on a separate track in a stereo sound file so the recordings would be separate but perfectly synchronized (Figure 3). Initially, the sound from the matched microphones was recorded with the same polarity, and one track (one microphone) was inverted and added to the other track, creating a single, digitally noise-cancelled recording (Figure 4).

This noise cancellation produced a visible and audible swell-null-swell pattern in the waveform. This pattern was presumably due to the microphones recording identical waveforms for remote-source ambient sounds, differing waveforms when one microphone was close to the resonating mine, and identical sounds when the microphones were exactly equidistant (spanning) the resonating mine. The sound swells as each microphone passes over the mine, but when centered over the mine, the combined signal cancels. This null did not appear in the noise-cancelled waveforms of control tests, where no mine was buried.

Of course this visual and audible difference is exactly the sort of simple and real-time result that a device should produce for a deminer in the field. But as a scientific matter, it was important to evaluate the significance of the apparent difference in the mine versus no-mine sound records. In order to get statistical results that support the visual/audible evidence, a mathematical model of the noise-cancelled waveforms was developed.

The noise-cancelled waveform files were saved as ASCII text files and opened in Microsoft Excel.¹¹ The time-series sound-level samples for each test were squared to produce a sound-power time series then de-spiked with a very narrow, low-pass filter, which removed values that exceeded the average over a five-sample rolling window, to remove transient outliers or pops in the sound. The overall shape of the sound-power time series (or sound envelope) was calculated for each record by applying a wide, low-pass filter, which included maximum power values over 300-sample rolling intervals. By examining these sound envelopes, the minimum of the sound power clearly indicated the location of a mine.

These test envelopes were next compared to a theoretical envelope, modeling the expected results when the two microphones passed over the resonating buried landmine. This theoretical envelope was created mathematically by multiplying the formulas for sound attenuation due to geometric spreading and material loss. Test envelopes were compared to this theoretical envelope, and a root mean square (RMS) residual value was calculated to represent how well the test matched the model. In the model formula, variables (attenuation coefficient in air, microphone height, sweep velocity, etc.) were adjusted to provide a best-fit between the model and each record. To minimize the model-test RMS residual, this was done with an iterative Monte Carlo inversion (Figures 5 and 6).

The theoretical envelopes were then compared to several control test envelopes, in which no mines had been buried, and an RMS value was found for each. Looking at the raw numbers, the control (no-mine) RMS values appeared to be significantly higher than the target (mine) RMS values (Figure 7). To confirm the significance of this difference, Dixon's Q-test for outlier detection was used to determine whether the RMS residuals for the control (no-mine) tests were in fact statistically and significantly different from the target (mine) RMS values—in other words, to test whether the control RMS values were outliers in the full set of RMS data values. The results of this statistical test showed that, at a 99%

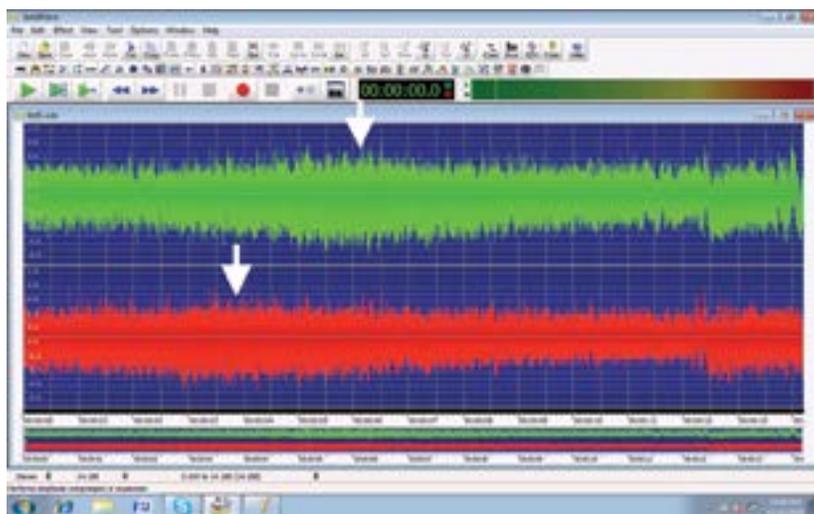


Figure 3. Raw recordings of the two microphones sweeping over a buried mine, displayed as separate channels in a Goldwave stereo file.

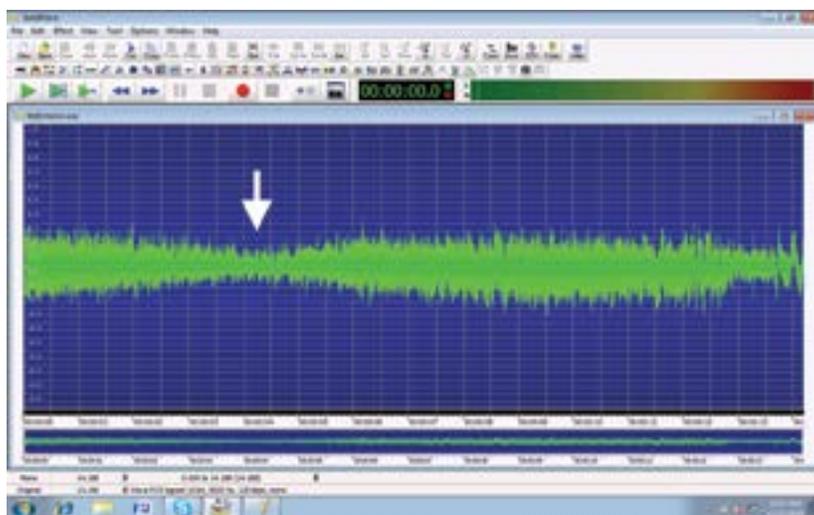


Figure 4. Digitally noise-cancelled waveform from recordings in Figure 3.

confidence level, the control RMS values were outliers and were incredibly unlikely ($p=0.01$) to be produced in this data set simply by random chance. These statistics provided overwhelming evidence that there was a statistically significant difference between sound recordings for mine versus no-mine noise-cancelled sound records.

Discussion and Conclusions

The goal of this study was to demonstrate the feasibility of a seismo-acoustic system that used a shaker to make buried mines resonate and a dual microphone noise-cancelling sensing system to pick up the sound of the resonating mine and pinpoint its location. This goal was met in an observational as well as statistical sense.

One of the most significant findings was that the method worked for both metal and plastic mines buried in wet sand (Figure 5). Currently, the only efficient method for detecting plastic mines in wet soil is direct, intrusive probing with a sapper spike. This is because moisture raises the electrical conductivity of soils, making them highly lossy for electromagnetic signals (e.g., GPR). Seismo-acoustics, however, rely on mechanical properties, and moisture will not affect the ability to detect mines, metal or plastic. In some cases, moisture in the ground could actually improve results simply because water is a low attenuation material for seismic and acoustic waves.

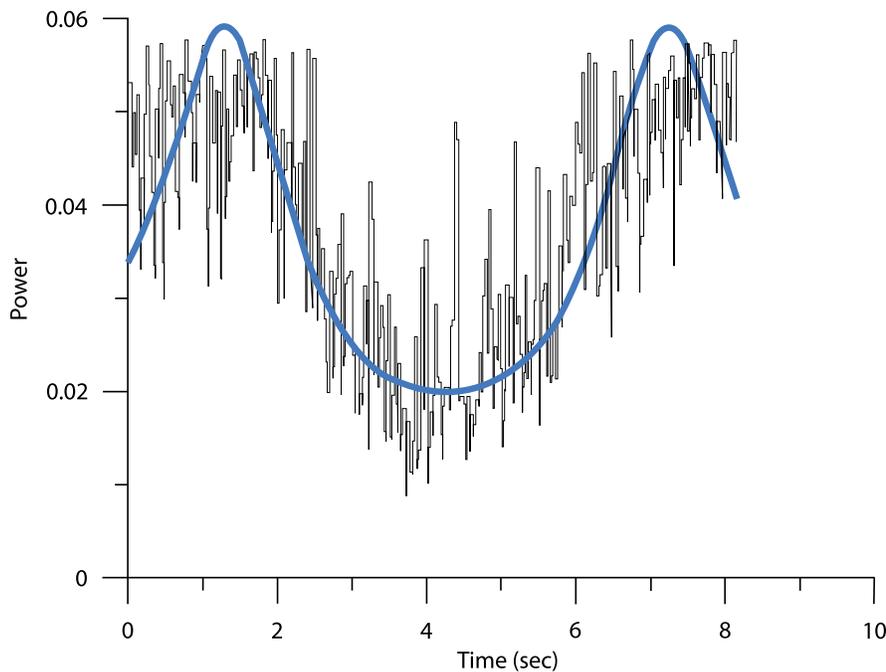


Figure 5. Model sound envelope compared to observed sound power data for a plastic mine buried in wet sand.

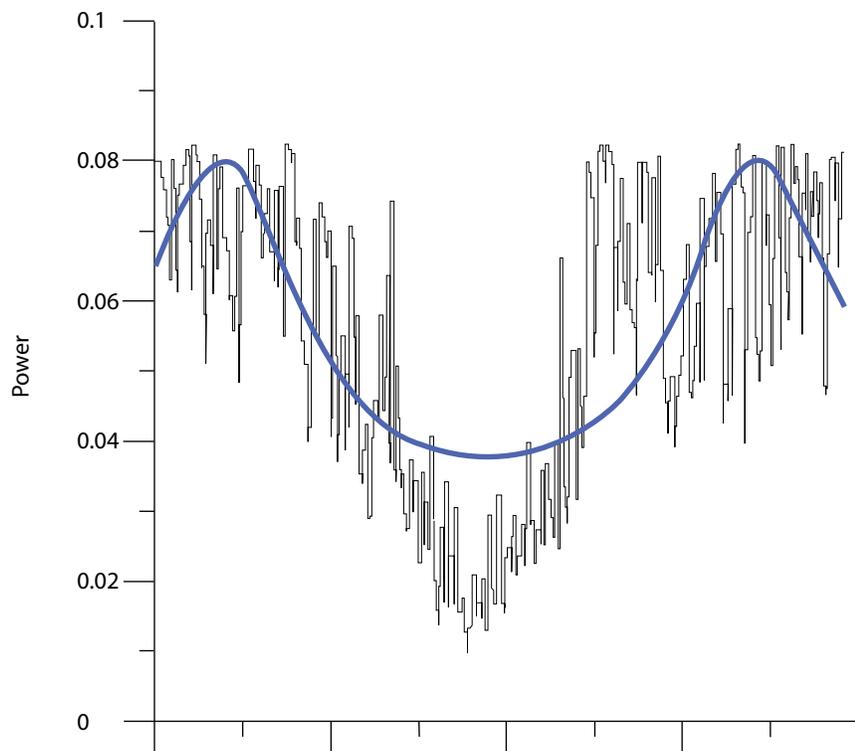


Figure 6. Model sound envelope compared to observed sound power data for a metal mine buried in dry sand.

Another significant benefit to this method was safety and simplicity. The microphones were not in contact with the ground, which minimizes the danger of setting off a mine. Moreover, the actual tests were simple, quick and produced real-time results (when the microphones were wired to do real-time noise cancellation in the prototype described be-

low). The simplicity of the method is a key factor in applying it in the real world. Many deminers have little advanced technical training and deserve a device that does not require special expertise. As Colin King put it, "All they want is a beep."²⁴

This method could also reduce false-alarm rates relative to metal detectors or even ra-

dar as elastically noncompliant clutter items in a minefield will not resonate with the seismic source, and thus would not be detected. Also, the noise-cancellation system provides its own reference or site-specific tuning: It is constantly adjusting to the background signal for no mine in a new location with new soil and/or ambient noise conditions. These results suggest that seismo-acoustic detection is not only possible, but could be a very effective, simple and relatively cheap humanitarian demining method.

Building a Prototype

Based on the proof-of-concept results described above, a prototype detection device was built using inexpensive, off-the-shelf and recycled or repurposed materials. The total cost was less than US\$500. The skeleton of the device was an old metal detector rescued from a dumpster. Attached to the bottom at a fixed horizontal separation, as in the original tests, were two microphones similar to the ones used in testing phases but significantly cheaper and of lower quality. The microphones were connected to a small two-channel amplifier affixed to the bracket where the metal detector controls were, with a set of noise-cancelling headphones connected to the amplifier (Figure 8).

The signal from the microphones was fed through two identical phase inverters into the amplifier; one was set to invert the sound 0°, the other to 180°. The two signals were summed in analog by passing through a stereo-to-mono converter plugged into the headphone slot as the summed signal fed into the headphones. The device conducted analog noise-cancellation in real time and fed it directly into the headphones so the user could listen for the swell-null-swell pattern.

Some field tests were done with this prototype in the outdoor test bed with inert landmines, including a small AP landmine (Chinese type 72), as well as a larger anti-tank mine (Italian VS-9). The results for this first prototype were very promising. When the device was swept above a buried landmine, it was possible to hear the characteristic swell-null-swell pattern in the sound—even without being associated with the research and not having been previously instructed in what to listen for. Obviously there is still much research, testing and improvement to be done, but tests with this simple prototype show great potential for the eventual development of an effective detection device.

An Addition to the Toolbox

Although this research produced exciting and promising results, it is important to note that seismo-acoustics is not, and probably will

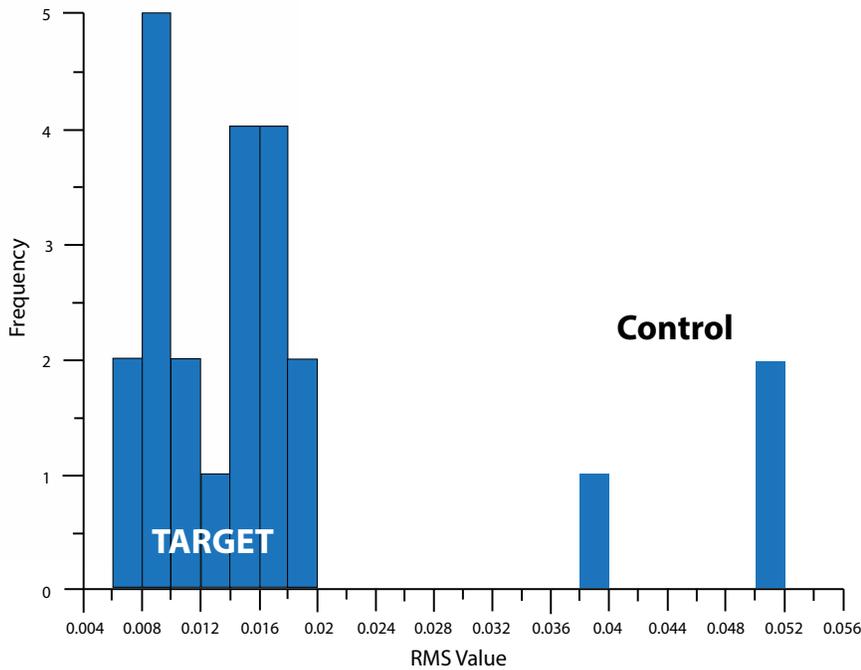


Figure 7. Histogram of model versus data RMS residual values for target (mine) and control (no mine) tests. Note the lack of overlap between target and control value ranges.

never be, a perfect demining tool. It does, however, have certain unique advantages, namely that it can effectively detect plastic mines in wet environments, that could give it a specific and important niche in the ever-developing landmine detection toolbox. ©

See endnotes page 66

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Figure 8. Photo of the prototype.



Marian Bechtel is a rising sophomore at Bryn Mawr College in Pennsylvania, where she is studying physics and geology. She was named a 2011 Davidson Fellow and chosen as a finalist for the 2012 Intel Science Talent Search. She also participated in the Royal Society of London's 250th Summer Science Exhibition as a member of the RASCAN Group research team.

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1. Mine Action Equipment: Study of Global Operational Needs.” Geneva International Centre for Humanitarian Demining, 2002. <http://tinyurl.com/k5raaea>. Accessed 20 May 2013.
2. MacDonald, J., and Rand Corporation. *Alternatives for landmine detection*. Santa Monica, CA: RAND, 2003.
3. Borgioli, G., A. Bulletti, M. Calzolari, L. Capineri, P. Falorni, L. Masotti, S. Valentini, and C. Windsor. “Research Activity of Acoustic Methods for Landmine Detection.” PowerPoint slides, 2008.
4. King, Colin. “Demining: Enhancing the Process.” *Landmines and Human Security* (2006): 139-47.
5. Daniels, D., *Ground Penetrating Radar*. 2nd ed., vol. 1. The Institution of Engineering and Technology, 2004.
6. Bulletti, A., S. Valentini, G. Borgioli, L. Capineri, M. Calzolari, and M. Mazzoni, et al. “A Study of Acoustic Methods for Compliant Landmines Detection by Using the Surface Acceleration Parameter.” *IEEE International Geoscience and Remote Sensing Symposium*. 5 vols. (2009): 368–371.
7. Sabatier, James M. “Acoustic/Seismic Methods (Paper I).” *Alternatives for Landmine Detection*, edited by J. MacDonald and J.R. Lockwood, 149–154. Santa Monica, CA: RAND, 2003. <http://tinyurl.com/kae9acl>. Accessed 20 May 2013.
8. USB stands for Universal Serial Bus.
9. RTV stands for Room Temperature Vulcanizing.
10. This statement refers to some very brief tests the author did specifically to find an optimum sensor height for her tests.
11. ASCII stands for American Standard Code for Information Interchange.