Seismic radio by reverse time mirrors

Sherif M. Hanafy and Ernesto Curiel, King Abdullah University of Science and Technology (KAUST).*

Summary

We present the theory and one field example of using seismic waves to send and receive coded messages. The method requires the recording of one calibration shot gather that will be used to decode the message. Coded messages can be send with a system similar to Baudot code. One field test is recorded in Tucson, AZ., USA, where we send and received 3-short messages. One possible application of this method is to send coded messages from trapped miners to the surface. Advantages of this method are; no velocity model is required, easy and fast to use.

Introduction

Time reversal mirrors (TRM) method (Fink, 1992) allows a very efficient approach to focus pulsed waves through inhomogeneous media. TRM is originally used in physics for ultrasonic waves and made of large transducer arrays, allowing the incident acoustic field to be sampled, time-reversed, and re-emitted. Here, TRM allows one to convert a divergent wave issued from an acoustic source into a convergent wave focusing on the source. TRM has many applications, among them are destroying kidney stones and non-destructive testing of metallurgical samples (Fink, 1993).

Hanafy et al. (2009) introduced a geophysical application of TRM. They used TRM to locate trapped miners in collapsed mines. Results showed that locating trapped miners are very accurate even with a very poor signal to noise ratio. In this work we add another geophysical application of TRM, we show how to receive coded messages from the trapped miners (sending coded messages by trapped miners is also possible). Before receiving and decoding messages, a calibration record is required, this record will be used to decode the coded message and it should be recorded before the mine collapse and with high signal to noise ratio.

Coded message can be send using a 5-bit code, with equal on and off intervals, a system similar to the Baudot code that was invented in 1870 and modified in 1901 by Donald Murray. In this system, each bit is either a signal and interpreted as (1) or no-signal and interpreted as (0), receiving and decoding the string of ones and zeros will give the corresponding letters and spaces. Five elements will be used;

1. Signal is interpreted as (1)
2. No-signal is interpreted as (0)
3. (11111) for the beginning of the message
4. (00000) for spaces between words.
5. Each 5-successive bits will represent one letter

The suggested ceding system is not similar to Morse code, since Morse code is considered as zero-state system. Zero-state systems are systems that have only three states, 1, 0, and -1, in Morse codes they are corresponding to dash, pause, and dot. The system we suggest to use is a non-zero-state system, where it has only on and off, here, are corresponding to signal and no-signal.

In this work we will discuss the theoretical back ground and the field example, however, the table of characters and the corresponding codes will not be included here.

Method

In this method, a calibration record is required to decode the coded message. The calibration record is acquired with a high signal to noise ratio then the coded message is sent from the same excitation point as that of the calibration record. The coded message is then convolved with the time-reversal version of the calibration record (Equation 1) and the result shows the decoded message. If $m(\mathbf{x},t)$ is the decoded message, then we can find it by

$$m(\mathbf{x},t) = \sum_{g} d(\mathbf{g},t|\mathbf{s},t_{source}) * g(\mathbf{x},-t|\mathbf{g},0), \qquad (1)$$

where $d(\mathbf{g},t|\mathbf{s},t_{source})$ represents the coded message recorded at locations $\mathbf{g}$ for a source at $\mathbf{s}$ with unknown excitation time t_{source}. $g(\mathbf{x},-t|\mathbf{g},0)$ is the reverse version of the calibration record and the convolution denoted by $*$ is over the time variable t. This calibration record accounts for the direct wave but also contains all of the primaries and multiples. Equation 1 can be interpreted as the cross correlation of any coded message with the calibration record.

Numerical Test

A field test is conducted in Tucson, Az. (Figure 1). The selected site characterize by a high plateau surrounded with a number of valleys and canyons. A line of 72 receivers running in the x direction is placed at the plateau with a 5 m receiver interval. A point at offset (100 , 30) meters in the y and z directions (Figure 1a) relative to the center of the receiver line is selected to be the shot point. One shot gather is recorded with 30 stacks (Figure 2a) to increase the signal to noise ratio, this shot gather will be used to decode the coded message.

Three short messages are fired at the shot point and received by the line of receivers (Figure 2b). The recorded messages are correlated with the reference shot gather and the results are shown in Figure 3. Here, we did not started the message with (11111) and separated the letters with (00000) to save recording time.

To test the effect of high noises on the final result, we added random noises to the coded messages. The random noises were first band-pass filtered to have frequency content similar to that of the field data. The signal to noise ratio of the coded messages is lowered by a factor of 340 (Figure 2c). The same procedure is repeated and the results are shown in Figure 4. Here, we can see that even with a much lower signal to noise ratio, the message can be accurately decoded. This is due to the supper stacking property of the TRM (Hanafy et al., 2009), where using scattered events increase the resolution with a factor of $\sqrt{NM}$, where N is the number of traces and M is the number of events in the data.

Conclusions

We presented another application of the time reversal mirrors method where we can receive and decode a coded message using a previously recorded CSG. This can be used to receive messages from trapped miners. The suggested coding system is a 5-bit per word, where each bit is either a signal (1) or no-signal (0) and we use (11111) to start the message and (00000) to separate words.

No exact velocity model is required for this approach; however, previously recorded shot gather with a high signal to noise ratio is required. This shot gather will be used to decode the message.

Lowering the signal to noise ratio of the recorded message by a factor of 340 did not affect the accuracy of decoding due to the super stacking property of the TRM method.

To accurately decode the message, we need to maintain a steady rhythm, i.e. equal timing for signal and no-signal codes.

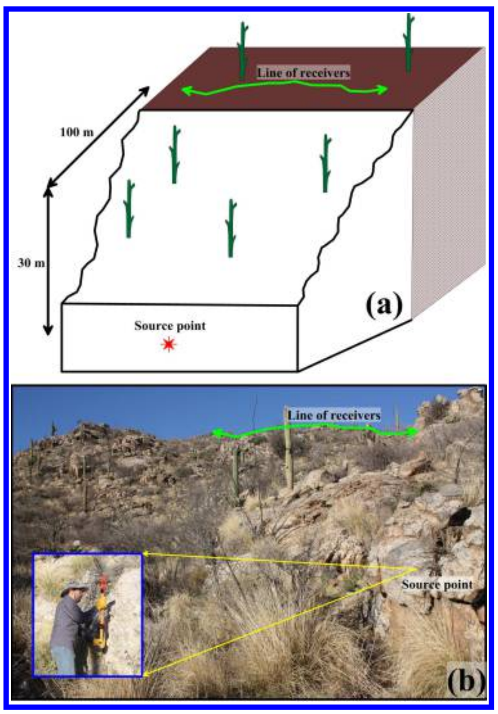

Figure 1: a) A Sketch and b) A photo shows data collection in Tucson, AZ. USA.

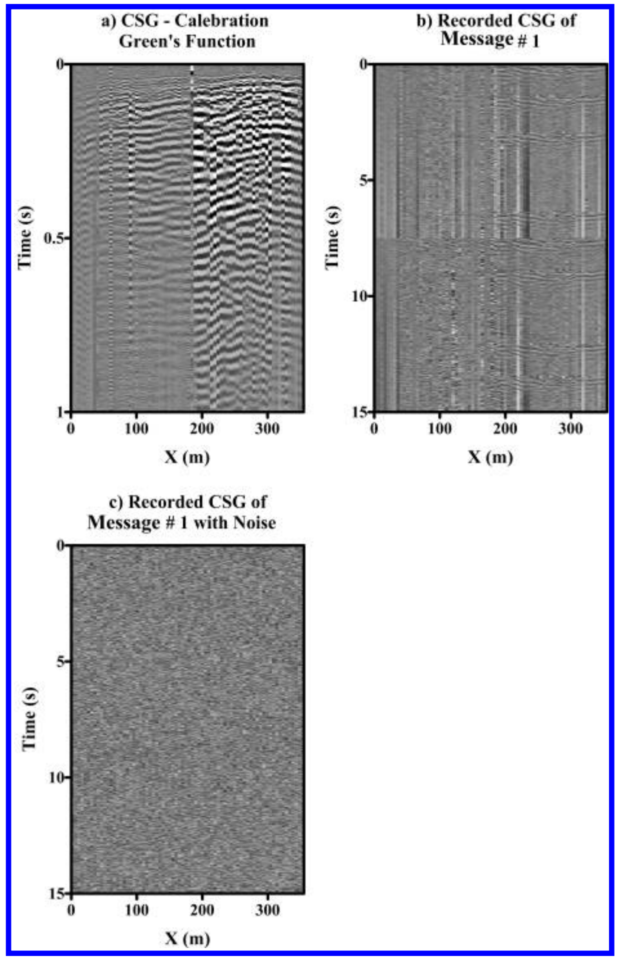

Figure 2: (a) The high signal to noise shot gather used to decode the coded message, (b) part of the coded message 1 as recorded in the field, and (c) same coded message 1 after adding random noise and decreasing the signal to noise ration by a factor of 340.

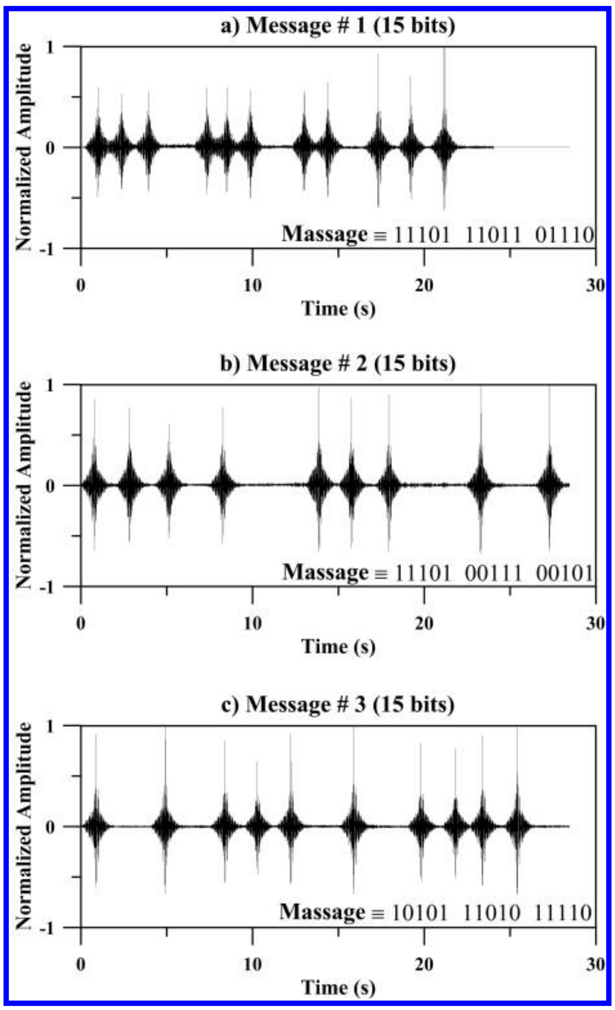

Figure 3: The decoded messages. Each message contains 15 bits which represents three letters (5 bits per letter).

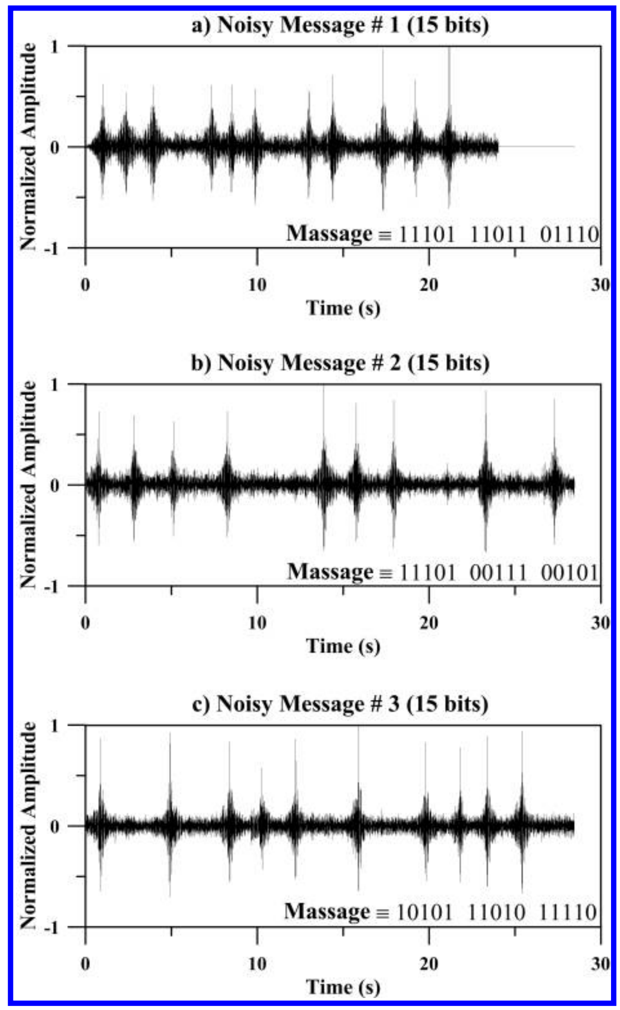

Figure 4: Decoding of the messages after adding random noises and decreasing the signal to noise ratio by a factor of 340.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2010 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Fink, M., 1992, Time reversal of ultrasonic fields: basic principles: IEEE Trans. Ultrason. Ferroelectr. Freq. Control 555-566

Fink, M., 1993, Time-reversal mirrors: J. Phys. D: Appl. Phys, 1333-1360.

Hanafy, Sh. M., Cao, W., Schuster, G. T., 2009, Using super-stacking and super-resolution properties of time-reversal mirrors to locate trapped miners: The Leading Edge, 302-307.