Introduction

The seismic refraction method has undoubted value for near-surface characterisation but its use is generally quite limited. This is often ascribed to the cost of purchasing the required equipment. For small systems the cost is often around €800/channel making a 24 channel system around €20,000. In a previous work (Dean et al. 2017) we described how a seismic acquisition system could be built for just over €20/channel. In this paper we describe an alternate, low-cost, method for acquiring seismic refraction data. It involves the use of cheap, widely-available, open-source hardware, and a simple, though innovative, processing method.

Equipment

A typical engineering seismic acquisition system employs a number of geophones connected via cable to a central recording system with data being recorded on a PC. In contrast, our system simply consists of a pair of 3-component MEMs accelerometers (mounted on plastic pegs) connected to an open-source electronics board (in this case an Arduino Mega) for recording the data. There are a wide range of development boards that include accelerometers (or inertial measurement units, IMUs, as they are usually referred to), and we identified at least 10 available for less than €25. We chose the LSM9DS1 chip as it had the lowest noise level (90 μg/√Hz) for a reasonable price (€13). This noise level is higher than that of MEMS specifically developed for seismic applications (for example the Sercel DSU1-508 has a quoted noise level of 15 ng/√Hz) but, as we show, it is sufficient for our application.

The system is controlled via a touch-screen 'shield' mounted on the top of the board (Figure 1). Data read from the accelerometers is stored on an SD card integrated into the base of the screen. A simple comma separated text format is used with the position of the two sensors being written to the file name. The 'natural' sample interval of the system is ~3.5 ms, but can be improved to 2.8 ms if only a single component is recorded. The position of the two sensors can be manually set (using the '-' and '+' buttons) or automatically incremented using the 'NEXT' button.

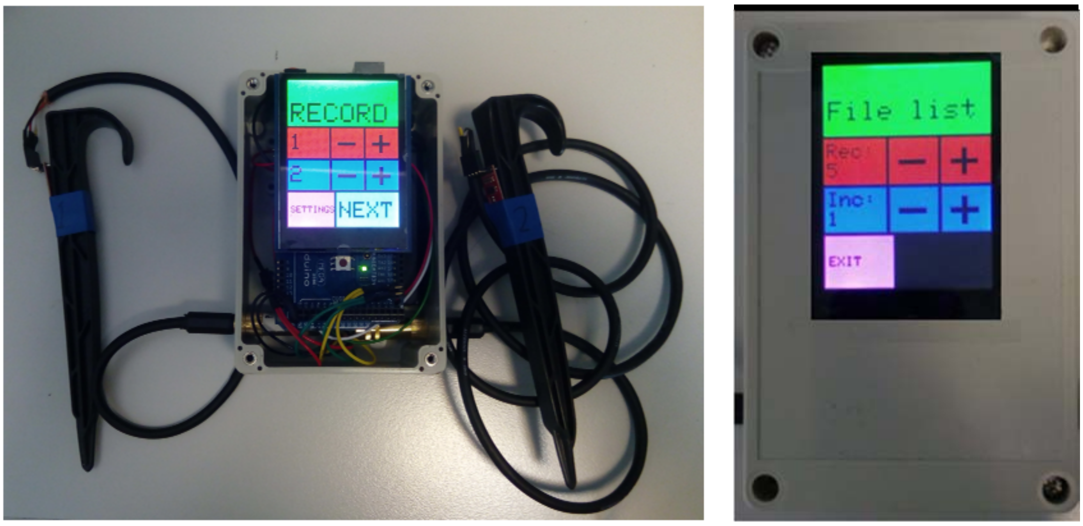

Figure 1*. (Left) Photograph of the refraction acquisition system (with the cover removed) showing the touch screen mounted on the Arduino and the two MEMs sensors mounted on pegs. (Right) Photograph of the system showing the setup screen.*

Table 1 gives a full list of the components used their quantity and price. The full system can be built for less than €100.

Table 1*. List of the components used to build the refraction system. Similar components could be substituted as required.*

	Price (€)	Quantity	Total (€)
Funduino Mega	11	1	11
Adafruit LLC 1947 touch shield	40	1	40
Sparkfun SEN-13944	13	2	26
4 pole 3.5 mm jack plug	2.50	2	5
4 pole 3.5 mm jack socket	2	2	4
4 x AA battery holder	2	1	2
Power switch	1	1	1
Pegs	2	2	4
Box	3	1	3
TOTAL			96

Acquisition and Processing

A standard refraction shot involves acquiring a series of receivers for a single shot point (Figure 2a). For the new technique we acquire a single shot point multiple times into pairs of receivers at different positions with one sensor overlapping for each shot (Figure 2b).

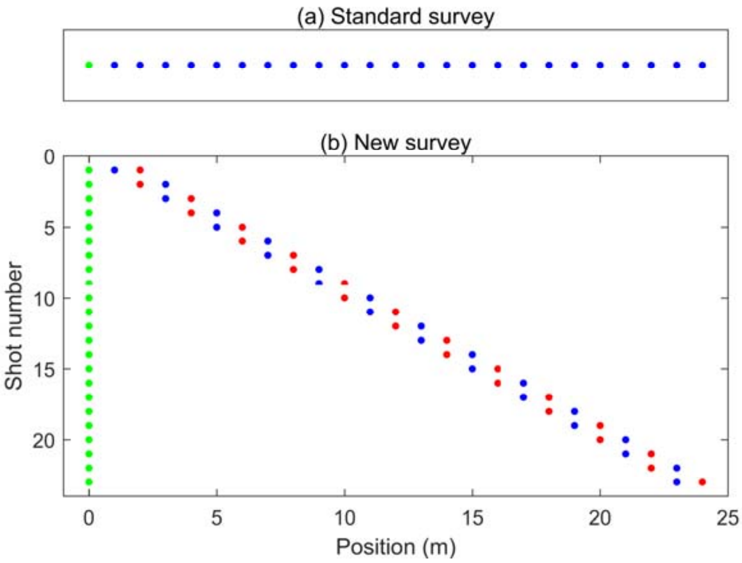

Figure 2*. Layout of (a) a standard survey with a single shot into many receivers, and (b) the new technique with multiple shots into a pair of receivers. The colours in (b) indicate each of the two receivers employed.*

Although a trigger could be easily implemented we decided not to use one; instead the person managing the recording simply presses 'record' and then tells their partner to initiate the source. Of course, this results in the source energy appearing at random times within the record (**Figure 3**a). These time shifts can be removed, however, using a straightforward process. As can be seen from Figure 2b each position is recorded twice, once with the other sensor in front of it and once with it behind. The relative timing of the pair of traces from the very first shot is correct. For the next shot we move sensor 1 to its new position but keep sensor 2 in place. By correlating the traces recorded by sensor 2 for the two shots we can determine their relative time shift, we then apply this time shift to sensor 1 to correct it. For the third shot we move sensor 2 but keep sensor 1 in place, by then correlating the traces from sensor 1 we can identify and remove the shift. We repeat this process for each of the shots resulting in a time corrected record (**Figure 3**b).

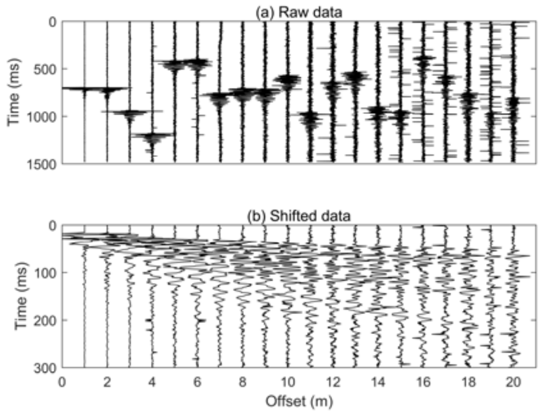

Figure 3. *(a) Raw data showing the variation of the sledgehammer blows in time. (b) Data after the time shifts have been identified using correlation and removed.*

Results

To test the new system we acquired a line of 24 1-m spaced geophones using a conventional system (outlined by the red box in Figure 4) and our new system (outlined by the green box in Figure 4). The conventional system took 20 minutes to setup, 8 minutes to pack-up, and a couple of minutes to record the data, a total of 30 minutes. The new system, in contrast, required only 7 minutes to acquire the data.

Figure 4. *Conventional seismic acquisition system outlined by the red box and the new system outlined by the green box. The hammer and plate in the centre were used as the source for both systems.*

The results of the test are shown in Figure 5. The geophone and accelerometer datasets are very consistent. There are some differences in amplitudes but this is due to the RMS trace scaling that is applied. Even subtle features (indicated by the red arrows) can be observed on both datasets. The noise levels at the farther offsets are higher for the accelerometer data but these can be improved by stacking. Stacking weak signals does not require a time trigger as the signal is still sufficient for them to be aligned successfully using a correlation approach (e.g. Figure 6).

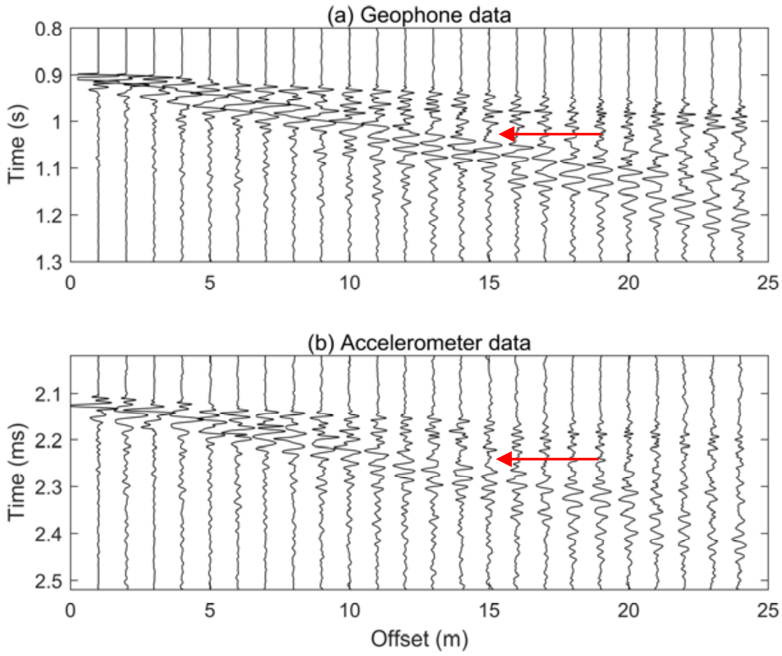

Figure 5. *Data recorded using (a) standard seismograph, (b) the new system described here. The red arrows indicate subtle feature that are consistent between the two datasets.*

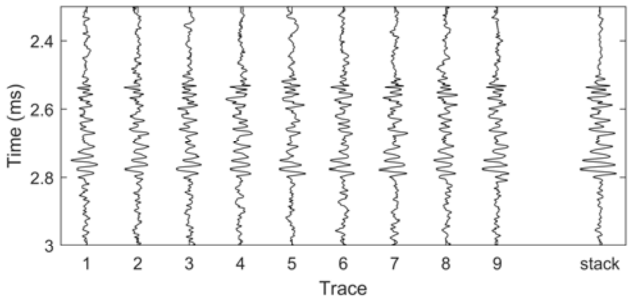

Figure 6. *Nine traces recorded using a sledgehammer source at an offset of 30 m. All the traces have been time-aligned using correlation and then stacked (the trace on the right).*

Discussion and Conclusions

Despite the value of near-surface velocity information it is seldom acquired due to the cost of the acquisition systems (>€20,000). In this paper we have demonstrated that a simple seismic refraction system can be built from widely available parts for less than €100, a decrease in price of two orders of magnitude. As well as the cost of the equipment, the new system also allows data to be acquired more quickly (8 minutes vs. 30 minutes for the example shown here). Although the data acquired is lower quality, due to the higher noise level, it is still sufficient for shallow applications and can be improved by stacking.

We hope that the successful trial detailed here will allow refraction surveys to become more widespread as well as encouraging others to experiment with open-source hardware. Full details on how to build a system, including the Arduino firmware code and MATLAB processing routines, are available on GitHub (github.com/timdeangeo/RefractionSeismograph).

References

Dean, T., Nguyen, N., Kepic, A., Armitage, B. and Rossiter, H. [2017] The democratization of seismic acquisition. SEG Technical Program Expanded Abstracts 2017, 201-205.