How to build your own simple, low-cost, seismic system

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SUMMARY

Acquiring seismic data has typically been an expensive pursuit due to the high price of the acquisition systems. Such systems are also typically not easily adaptable to suit different acquisition scenarios. In this paper we detail how you can build your own simple, low-cost (~$60/channel), seismic acquisition system. Data recorded using such systems is comparable to that obtained using a far more expensive commercial seismograph.

Seismic sources are similarly expensive with the only low-cost option being a sledgehammer. In this paper we also describe how to manufacture a small vibroseis unit from easily available components at a cost of less than $3,000. This unit has a wider, more controllable, bandwidth than an impact source and can be easily adapted to create a shear wave source for MASW surveys.

Key words: land, seismic, acquisition.

INTRODUCTION

Although the acquisition of seismic data is relatively straightforward the cost of purchasing acquisition equipment is often prohibitive. Small acquisition systems (<1,000 channels) often cost around $1,000/channel while even large systems can still be around $500/channel. By the time the cost of ancillary cables is included the total cost of a 24 channel system can reach around $30,000.

The cost of a seismic source for a small-scale acquisition system can be, thankfully, much lower, a large sledgehammer costing no more than $100 being that most commonly used. For larger surveys, hydraulic vibrators are the dominant source due to desirable characteristics such as a wide, controllable bandwidth, high productivity, and repeatability. The hydraulic vibrators typically used for commercial land seismic acquisition, however, are large, costly to operate, and expensive to purchase. This inhibits their use for small-scale surveys such as those of the near surface, where their wide, controllable bandwidth would be advantageous.

In this paper we aim to describe how a simple seismic system can be built using commercially available components in less than a week for less than $XXXX. We begin by describing the source

THE SOURCE

A range of different sized vibrators exist (Figure 1), ranging from the super-heavy (>289 kN force) down to what are termed 'portable vibrators' as they don't require vehicle mounting. Several such vibrators have been built over the years but have failed to achieve widespread use. During the mid-1990s OYO developed a portable vibrator weighing 70 kg and generating 500 N (122 lbf) at frequencies of between 20 and 1,500 Hz (Nijhof 1989, Nijhof 1990). Haines (2006) mounted a commercially available 'tactile transducer', within a specially made housing, that had a peak power of 400 W over a claimed frequency range of 5 to 800 Hz. Brewer, Cartwright, and Pugin (2013) and Pugin et al. (2013) used six tactile transducers bolted to a concrete block to create a 400 W vertical and shear vibrator with a sweep range of 20 to 800 Hz and a peak output force of 3,900 N. Elvis (**El**ectrodynamic-**vi**brator **s**ystem) is a commercially available electromagnetic vibrator that has a theoretical peak force output of up to 1 kN and a frequency range of 20 to 320 Hz (Krawczyk et al. 2012, Krawczyk, Polom, and Beilecke 2013). The recently introduced Lightning (http://seismic-mechatronics.com/seismic-equipment/lightning-seismic-source/) is a commercial electromagnetic vibrator that comes in standard and micro versions (specifications in brackets are for the mico version). It has a peak output of 1.2 kN ('Micro') in p-wave configuration and 1.7 kN and (0.85 kN) in S-wave configuration over a bandwidth of 8 to 400 Hz (5 to 400 Hz). It weighs 90 kg (50 kg) and the actuator is 0.52 x 0.49 x 0.21 m (0.52 x 0.42 x 0.21 m).

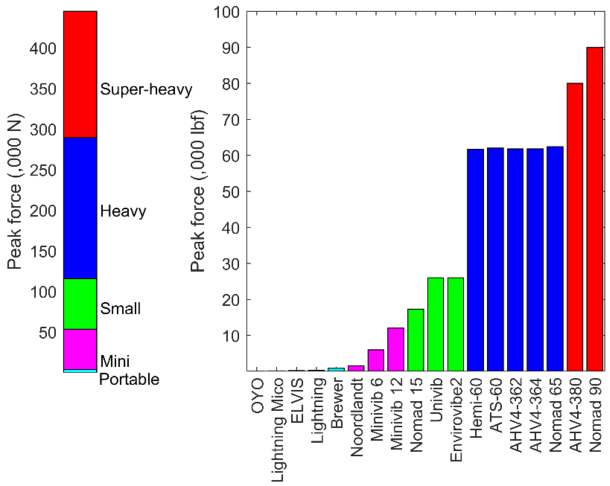

Figure 1. A summary of the peak output force of a range of vibrators. Values for commercial vibrators are taken from their respective specification sheets.

In terms of building your own system we recommend the use of a simple vibrator constructed in a couple of days from commercially available components at a cost of just over $AUD2,000 (Table 1). The vibrator will be briefly described here but further details are contained in Dean, Nguyen, and Kepic (2017).

Table 1. A list of the components used in the construction of the portable vibrator and their cost.

Description	Model used	No. of units	Cost/unit ($AUD)	Total cost ($AUD)
Actuator	Buttkicker LFE	4	300	1,200
Car stereo	JVC KD-X330BT	1	100	100
Pre-amplifier	Pioneer GM-A3602	1	90	90
Amplifiers	Boschmann PCH990-ATX	2	225	450
Car battery	Delkor DK84762	1	80	80
Trolley	Westmix P Handle Trolley	1	100	100
TOTAL				2,020

Figure 2 shows photos of the vibrator and some of its components. The vibrations are generated by four low-frequency actuators (Buttkicker LFE) bolted to the corners of two layers of 30 mm plywood. A small platform was constructed above the four actuators upon which a battery was mounted, providing some of the weight required to hold the baseplate to the ground. The remaining components of the system are mounted on a wheeled trolley. During use the actuators are removed from the trolley to isolate the electronics from the vibrations (Figure 2a). When the unit needs to be moved, the actuators are simply slid onto the trolley's tray and secured with a small length of rope (Figure 2b).

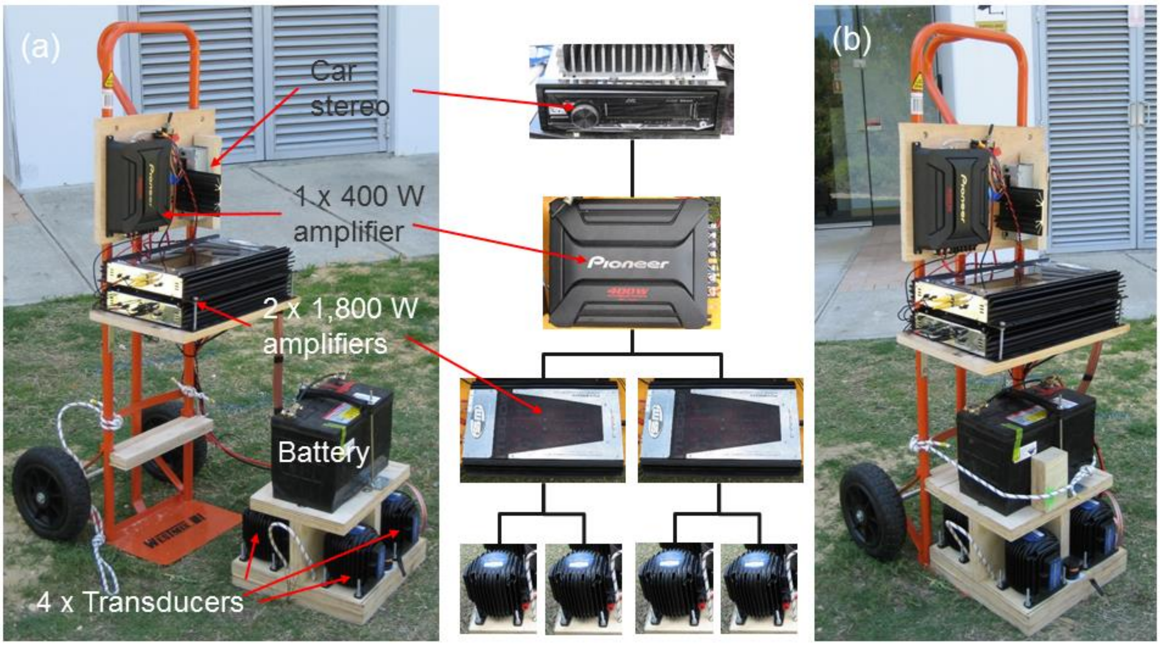

Figure 2. Photos of the portable vibrator. (a) shows the vibrator being operated with the transducers and battery removed from the trolley. (b) shows the transducers placed on the trolley ready to be moved. Reproduced from Dean, Nguyen, and Kepic (2017).

Each of the four actuators (Figure 3a) are connected to the output of one of two 1,800 W audio amplifiers which are in-turn connected to a 400 W audio amplifier (acting as a pre-amp). The system is driven by a car stereo through which signals can be played via USB, Bluetooth or auxiliary port (Figure 3b, which we found to be the most convenient). The trolley with its components weighs 30 kg whilst the transducers and battery weigh 50 kg, despite this we found that the output force was sufficient for the vibrator to decouple and start to ‘walk’ around, hence the requirement for the operator to sit on it (the seat is not shown in Figure 2). During initial testing we found that the baseplate was poorly coupled to the surface resulting in a loss of high-frequency energy, we overcame this by drilling holes in the corners and inserting metal pegs to hold it in place.

Auxiliary data was recorded using a small, 30 mH, coil of wire to the baseplate adjacent to the transducers (Figure 3c). The movement of the magnet inside the transducer induces a voltage within the coil which we can then measure. This voltage was recorded directly by the seismograph as was digital pilot.

Figure 3. Photos of (a) the buttkicker actuator and (b) the stereo with the auxiliary cable connected to a laptop.

The maximum volume setting possible varies with frequency (Figure 4) due to having to avoid the mass hitting the casing at low frequencies (<40 Hz) and the signal distorting at higher frequencies (>40 Hz). If we used a linear sweep to drive the vibrator then the setting would be too low to maximise the output across the full bandwidth. Instead, we used a non-linear sweep design method (Dean et al. 2016, Bagaini et al. 2008) where the instantaneous sweep amplitude was scaled to the maximum stereo volume level appropriately. The decrease in sweep power at each frequency being counteracted by a decrease in the instantaneous sweep rate at that frequency.

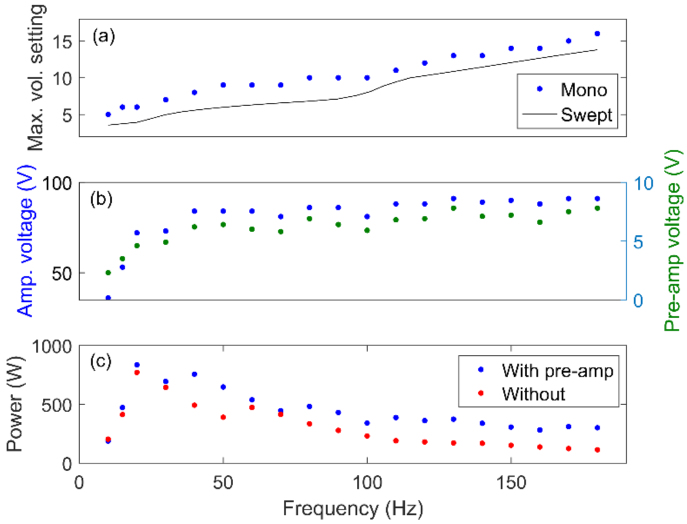

Figure 4. The maximum volume possible and the resulting peak-to-peak voltage measured at the output of the amplifier for a range of mono-frequency sweep frequencies. Reproduced from Dean, Nguyen, and Kepic (2017).

Figure 5 shows data acquired with a sledgehammer (Figure 5a) and the portable vibrator emitting a 15 to 180 Hz sweep over 24 s (Figure 5b), using a line of 40 10-Hz geophones with 1 m spacing. The portable vibrator data has a higher SNR that the sledgehammer with the ground-roll being particularly energetic. The sledgehammer had larger high-frequency content but this disipated very quickly and is not visible at offsets greater than 20 m.

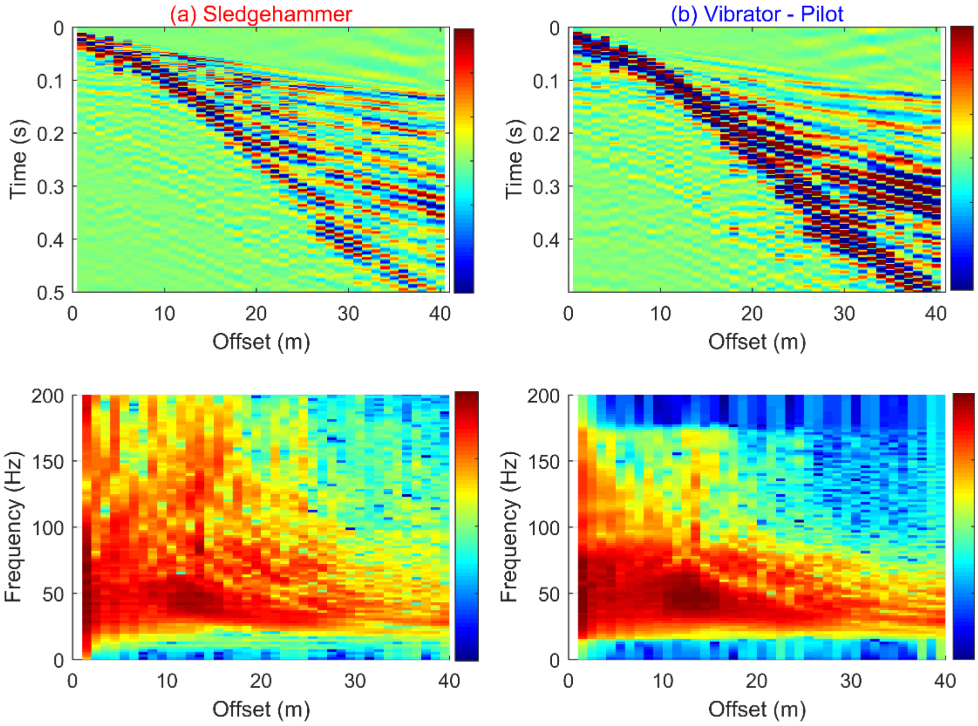

Figure 5. (a) Sledgehammer and (b) portable vibrator data acquired into a spread with offsets of between 1 and 40 m, the traces have been individually RMS normalised. The dynamic range of the frequency-offset plots (traces were not normalised) is 80 dB.

THE ACQUISITION SYSTEM

The acquisition system consists of two major components, the sensors and the recording electronics. Geophones have long been the sensor of choice for seismic surveys, being highly sensitive and robust. When purchased individually elements cost around $60 but prices rapidly decline when the number is increased, dropping to around $20. An alternative to geophones, which measure velocity, are digital MEMS accelerometers, these can be cheaper than geophones, but also tend to be less sensitive.

Whether the sensor is a geophone of a MEMS device the data still needs to be recorded and, as discussed in the introduction, this constitutes the bulk of the cost of an acquisition systems. Recently, however, there has been a boom in what is termed open-source hardware. Such systems, Raspberry Pi and the Arduino being the most common examples, consist of a microcontroller (a small computer), a range of digital and analogue input/outputs, a USB connector as well as various other options such as memory card slots (Teensy) and WiFi (NodeMcu) depending on the model employed. The microcontroller used in such systems is surprisingly powerful, for example that used in the Teensy 3.6 (Figure 6) is a 32 bit processor running at 180 MHz (a similar clock speed to a Pentium processor) with 1 Mb of memory.

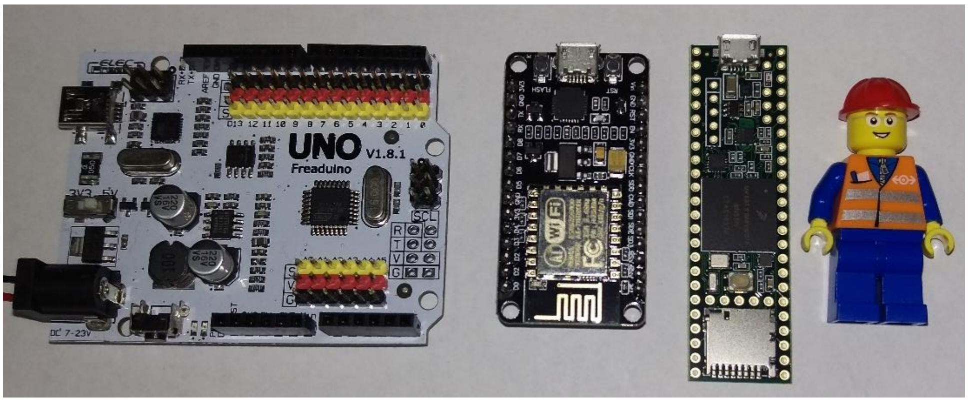

Figure 6. Photos of different Arduino boards (from left): Freaduino ($30), NodeMcu (with integrated WiFi, $10), and Teensy 3.6 (with integrated micro-SD card, $40).

In addition to the base boards a wide range of additional hardware components are available incorporated into what are called evaluation boards including temperature and humidity sensors (Figure 7b), Bluetooth and Wi-fi communications (Figure 7d), GPS receivers (Figure 7e and f) and most importantly for our application, analogue-to-digital converters (Figure 7c) and accelerometers (Figure 7a). As detailed in the caption of Figure 7 the cost of these components is minimal.

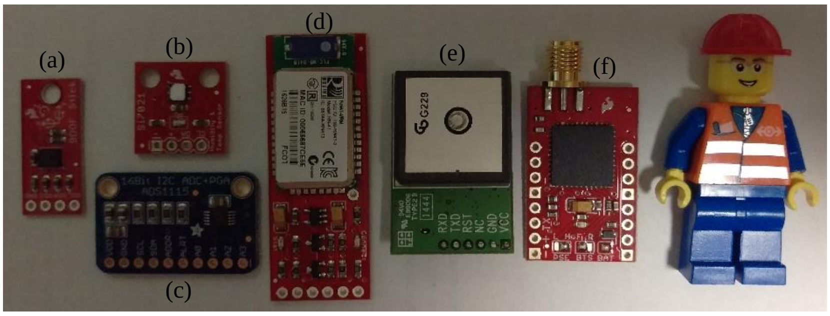

Figure 7. Photo of different evaluation boards available for the Arduino (a) gyro/accelerometer/magnetometer ($20), (b) temperature/humidity ($9), (c) analogue to digital converter ($20), (d) Bluetooth ($30), (e) GPS with built-in antenna ($30), (f) GPS with external antenna ($75).

If geophones are the sensor of choice then you connect a series of analogue-to-digital converters to your main board. For the data shown here we used an Adafruit LLC 1085 (Figure 7c) which incorporates a 16 bit converter (Texas instruments ADS1115) running at 860 Hz. Each main board can support four such converters. Full details of the resulting system are given in Dean et al. (2017) but are summarised here. When compared to a commercial seismograph our experimental system had a higher noise floor (12 μV vs. 0.4 μV) but this is still well below the ambient noise level. The timing error measured over 30 s for the experimental seismograph was 250 μs whilst that for the commercial seismograph was 82 μs. Results from a test acquiring data using both the commercial and experimental seismographs is shown in Figure 8. There is no evident difference between the traces acquired with the commercial seismograph (shown in black) and those acquired using the experimental system (shown in red).

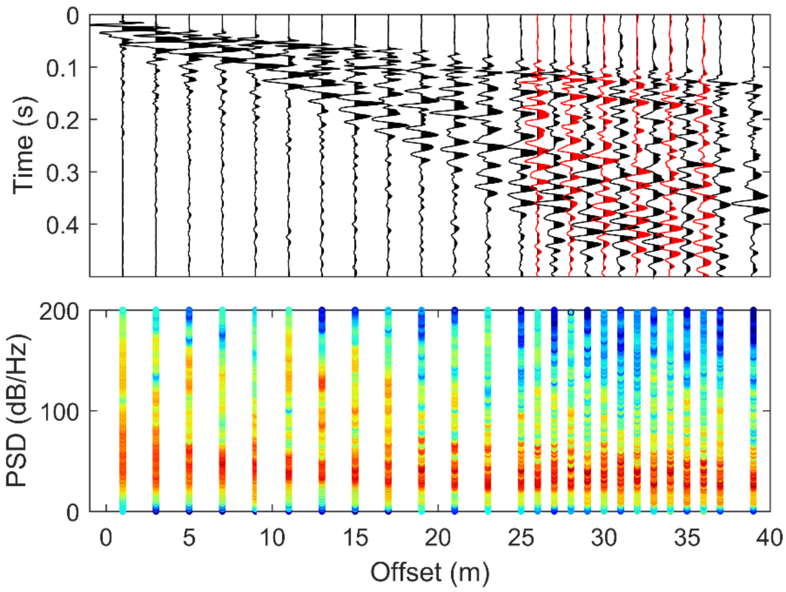

Figure 8. Data recorded using the commercial (black traces) and experimental (red traces) seismographs with a sledgehammer source. Reproduced from Dean et al. (2017).

A simpler and cheaper alternative would be to use the accelerometers on evaluation boards, such as that shown in Figure 7a, to record data. Unfortunately, the noise level of MEMS sensors is considerably higher than geophones, particularly those available on Arduino boards. Figure 9 shows an example of data recorded simultaneously using a geophone and a MEMS (in this case a LSM9DS1), the MEMS data is considerably noisier and contains several anomalous spikes, although these could be easily filtered out. The MEMS chips currently available on development boards are far noisier than those specifically designed for seismic acquisition (for example the Sercel DSU1-508 has a quoted noise level of 15 ng/√Hz) but recently introduced MEMS have noise levels of around 1 µg/√Hz, although the price does tend to increase with sensitivity. Ideally you would connect multiple MEMS equipped evaluation boards in series to a single Arduino allowing the use of cables with only four cores (1 each for ground and power and 2 for the communications) but the boards are generally limited in the number of different addresses they support and thus boards that can be connected (for example the LSM9DS1 supports only two addresses). Possible alternatives include using multiple Arduino boards that serve two sensors being controlled by a more powerful central Arduino or using a series of wireless connected Arduinos.

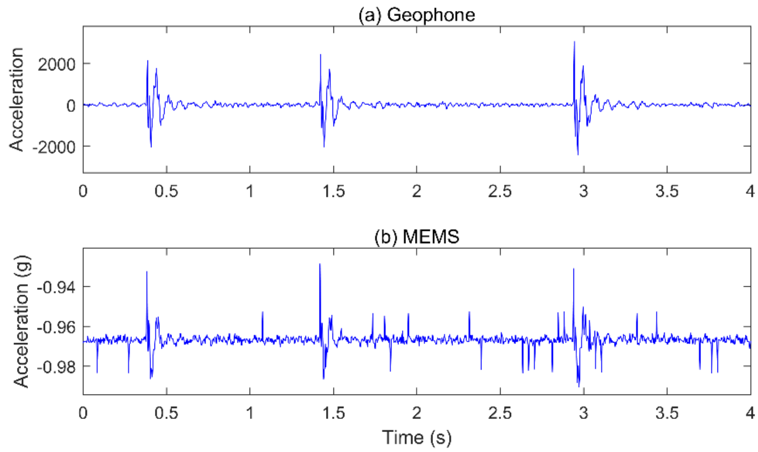

Figure 9. A comparison of data recorded using (a) Geophone and (b) MEMS sensors.

Table 2. MEMS evaluation boards currently manufactured by SparkFun sorted by price. The board shown in bold is that used to record the data shown in Figure 9. * Manufactured by Analog Devices.

Chip	Price ($)	Sensors included (A: accelerometer, G: Gyroscope, M: Magnetometer	Noise level (µg/√Hz rms) horizontal/vertical
LIS3DH	6.50	A	220
ADXL337	13.00	A	175/300
MMA8452Q	13.00	A	99
LSM6DS3	13.00	A/G	90
ADXL335	19.60	A	150/300
ADXL362	19.60	A	250/350
MPU-9250	19.60	A/G/M	300
LSM9DS1	**19.60**	**A/G/M**	**90**
ADXL377	32.70	A	2700/4300
MPU-6050	52.00	A/G	400
ADXL355*	58	A	25

To enable the acquisition system to be triggered we have developed a custom 'trigger board' that is capable of accepting rising-edge, falling-edge and contact closure triggers. This can be constructed using development boards (Figure 10 left) but we also created a custom board (Figure 10 right).

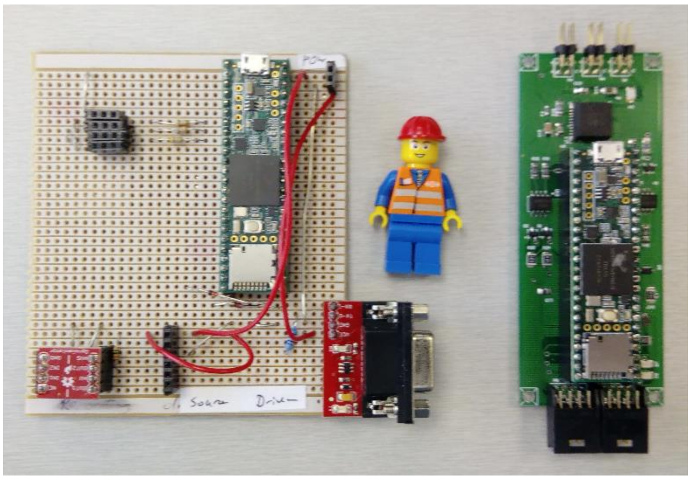

Figure 10. Trigger board manufactured from a Teensy 3.6 and opto-isolator (bottom left) and RS232 level shifter (bottom right) development boards. The board on the bottom right is a custom manufactured version of that shown on the left.

DISCUSSION AND CONCLUSIONS

In this paper we have described how you can build your own seismic acquisition system at relatively low-cost using commercially available mechanical and electronic components. A list of the components required and their approximate cost is given in Table 3. By employing a sledgehammer source and MEMS receivers the total cost of a 24 channel system could be as little as ~$1,400. Data recorded using a geophone-based system is comparable to that obtained using a far more expensive commercial seismograph. Whilst that acquired using a MEMS based system, although noisier, is likely to be adequate for refraction surveys.

Table 3. Estimated cost for a 24 channel 2 m spaced refraction seismic acquisition system.

Item	Price/unit ($AUD)	Total price ($AUD)
Source - Sledgehammer		
Sledgehammer	100	100
Trigger interface	250	250
Source – Portable vibrator		
Portable Vibrator	2,000	2,000
Trigger interface	250	250
Receiver - Geophones		
Geophone elements (24)	20	480
Electronics (6)	150	900
Receiver - MEMS		
Evaluation boards (24)	20	480
Arduino boards (12)	25	300
Cables		
24 core (52 m)	6/m	300

ACKNOWLEDGMENTS

We thank Dom Howman who assisted in the construction of the portable vibrator.

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