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DESIGN OF LOW COST AND INNOVATIVE DATA ACQUISITION IN SOIL MECHANICS TESTING USING OPEN SOURCE HARDWARE

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Abstract: Sensors are increasingly in our lives, microprocessor technology is evolving and open source hardware is becoming widespread. Preparation of experimental setups using open-source hardware reduces research costs. Arduino is an open source development platform which is operated with an open source software. It consists Atmel AVR microcontroller, circuit elements for interfacing, a 5 volt regulated power and a 16MHz crystal oscillator. With 10 bit ADC, it can read 0-5V voltages in 1024 steps. There are at least six analog inputs and 13 digital input-output pins, which can meet the channel requirements of a soil mechanics laboratory. Together with the "do-it-yourself" civil movement, the use of these platforms by young engineers in particular will gain experience that can be helpful in different applications. This study explains design and development of a low cost and open source data acquisition system for soil mechanics laboratories. The main advantage of making laboratory scientific equipment by using open source hardware is that, shared design promotes a better design as the scientific community can contribute to its design. In modern geotechnical laboratories sensor readings are essential for many setups such as consolidation, uniaxial compression, triaxial compression and shear box tests. Moreover, some tests need temperature and humidity conditioning. In the setup, Arduino Uno model was used as a microcontroller. Sensors with a 5 volt supply can be connected directly, and a booster circuit is added to the circuit for sensors requiring a 10 volt supply. The data of sensors having 0-5 volt input signal can be directly digitized. For sensors with millivolt output such as load cells, a driver circuit is added. The code is written in the C ++ language. The acquired data are tabled on an Excel sheet and it is possible to process the data for specific needs.

Keywords: DAQ, open source hardware, soil mechanics laboratory

Introduction

Automatic controlled electronic devices are preferred to achieve correct, precise and high resolution measurement of soil parameters, and to reduce operator errors in long-term experiments. Incompatibility of the devices produced by the manufacturers increases the cost by purchasing separately for each setup. Sensors are increasingly in our lives, accessibility is becoming easier and prices are falling. Similarly microprocessor technology is evolving and open source hardware is becoming widespread. This situation gets rid of the idea of preparation of experimental setups using economic open-source hardware and peripheral units.

The term "open source" emerged from the open software movement, and expanded to cover many fields such as science, art, technology and design (Vainino and Vaden 2007, Levine and Prietula 2014, Raymond 2001, Pearce, 2012). Free and open-source software is a software that is both a free software and an open source. Open-source hardware is a hardware whose design is made publicly available so that anyone can make, modify and sell the hardware. A development board is a printed circuit board with circuitry and hardware designed to facilitate experimentation with a certain microcontroller. Due to the modular structure, cost advantages and ease of reaching example applications, electronic development boards have become an alternative to electronic assembly needs. Open-source development (prototype) platforms (board) can be a practical solution tool for multi-channel measurement of variables such as pressure, load, displacement/deformation, temperature and humidity. Advantages of use of open source development boards include; i) Automatic control with additional peripherals and to perform numerical processing with easy software and data logging, ii) The modular structure of the equipment will allow the creation of fast and economical experimental setups for individual research and

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application projects, without the need for electronic expertise, iii) Shared design promotes a better design as the scientific community can contribute to its design.

Arduino is an open source development platform with open source software. It is relatively more economical to other platforms for being a product of non-profit organization. The Atmel AVR microcontroller includes the necessary circuit elements for programming and for interfacing to other devices, a 5 volt regulated power and a 16MHz crystal oscillator. There are at least six analog inputs and 13 digital input-output pins. It is possible to receive and process both analog and digital signals. The hardware has an ADC with 10 bit resolution and can read 0-5V voltages with 1024 step resolution. Continuous data transferring and monitoring is possible in every millisecond. 6-16 analog inputs easily meet the channel requirements of a soil mechanics laboratory. Even though Arduino cards don't have fixed memory, this deficiency can easily be overcome. When connected to the computer, a software can be used to write data on an Excel sheet. During standalone use, a memory card shield (SD shield) can be employed. Together with the "do-it-yourself" civil movement, the use of these platforms by young civil engineers in particular will gain experience that can be helpful in different applications. Another feature that makes Arduino a widespread and famous is the fact that many different companies produce their products in accordance with Arduino (D'Ausilio 2011).

In modern geotechnical laboratories sensor readings are essential for many setups such as consolidation, uniaxial compression, triaxial compression and shear box tests (Plaisted and Zornberg 2013, Dipova 2016a, Dipova 2016b). Moreover, some tests need temperature (Dunncliff 1993, Dipova 2016b) and humidity conditioning (Delage et al. 2008, Arsha Lekshmi and Arnepalli 2016, Han and Zhou 2013). This study will explain the development of a low cost and open source data acquisition system for soil mechanics laboratories. The main advantage of making laboratory scientific equipment by using open source hardware is that, shared design promotes a better design as the scientific community can contribute to its design. The developed setup is based on the Arduino Uno microcontroller. Sensors having 0-5 volt output were connected directly, and for 10 volt output sensor a booster circuit was added to the circuit. For sensors with millivolt output such as load cells, a driver circuit was added. The code is written in C ++ language. The acquired data is tabled on a spreadsheet to process the data for specific needs.

Design and Development Stages

Design and development stages include; i) Determination of needs, and sensor specification, ii) Selection of open source platform type and peripheral hardware, iii) Assembly of the device, iv) Preparation of software, v) Control and performance tests.

Determination of Needs and Sensor Specification

In soil mechanics laboratories sensor readings are essential for many setups such as consolidation, uniaxial compression, triaxial compression and shear box tests. Electrical data from these sensors are sent to microcontroller for processing for specific needs of the experiment. These sensors are of two types; i.e. analog and digital. Majority of the sensors are of analog type and have linear calibrations. In the traditional analog systems, the sensor converts the measuring parameter into an analog electrical signal. This analog electrical signal is connected to a transmitter via a cable. The transmitter transforms the electrical signal into a readable form (display, current outputs, bus data transmission, etc.). Specifically, we need to convert a raw voltage to the sensor reading using Eq. 1

$$\text{Sensor Reading} = \text{Intercept} + \text{Voltage} * \text{Slope} \quad (1)$$

Most of the sensors are based on resistance change, and actually this is the "voltage divider". According to Ohm's Law, as the resistance changes to set the current constant, voltage should change. For example, a thermistor is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors. So, after calibrating to temperature, it may serve as analog sensor, If the resistance changes, voltage output changes. A large number of sensors are available to monitor and measure many types of physical parameters. The sensors operate at low voltages, and output signals compatible Arduino.

A load cell is a transducer which creates an electrical signal whose magnitude is directly proportional to the load (force) being measured. The force deforms a strain gauge, which measures the deformation (strain) as a change in electrical resistance. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. The electrical signal output of a load cell is in the order of millivolts and requires amplification by an instrumentation amplifier or a high resolution ADC (typically 24-bit) before it can be read by an Arduino. Measuring the existing pressure are important for geotechnical researches, especially in triaxial testing. Sensing

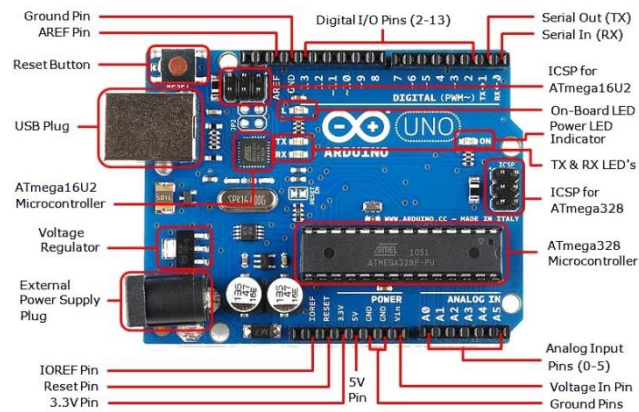
configurations of pressure transmitters typically consist of piezoresistive elements and silicon diaphragms. A change in pressure causes the diaphragm to flex and changes the resistance values of the piezoresistive elements. Since changes are very small, amplification of the output signal to be measured with an A/D converter on the Arduino, is needed. Position Sensors detect the real time position of objects, or they can be used dimension change of an object. The most commonly used position sensor is the potentiometer because it is an inexpensive and easy to use. It has a wiper contact linked to a mechanical shaft in its movement, and which causes the resistance value between the wiper/slider and the two end connections to change giving an electrical signal output. This output is proportional to the actual wiper position on the resistive track, IE, the resistance is proportional to the position. Resistive potentiometer sensors have some disadvantages: wear due to moving parts, low accuracy, low repeatability, and limited frequency response. One type of positional sensor that does not suffer from mechanical wear problems is the Linear Variable Differential Transformer (LVDT). This is an inductive type sensor and a very accurate device for measuring linear displacement and whose output is proportional to the position with high accuracy.

Selection of Open Source Platform Type and Peripheral Hardware

Among the hardware that embraces open source philosophy, Arduino development platforms are the most popular. Because of the open source hardware and software that they feature, these boards are inexpensive and have a bundle of clones. Their simple coding environment attracts a lot of beginners and non-professionals. The language supported by the Arduino IDE (Integrated development environment) is basically C++ with some additional features. The Arduino allows expansion through the connection of shields. The shields are connected via mating pins, and simply plug onto the headers on the top of the Arduino board. Arduino libraries allow users to quickly integrate new devices and sensors into projects.

In the setup, the Arduino UNO model was used as a microcontroller. Sensors with a 5 volt supply can be connected directly, and a booster circuit is added to the circuit for sensors requiring a 10 volt supply. The data of sensors having 0-5 volts input signal can be directly digitized. For sensors with millivolt output such as load cells, an amplifier circuit is added.

The main reason for the choice of Arduino board is that the use of a low-cost multi-purpose microcontroller to data acquisition limits the total cost. An Arduino Uno R3 board (Figure 1A) is about \$20 and the coding interface software is free. There are other members of Arduino family (Figure 1B). Arduino is not the only low-cost microcontroller, but it is recognized as very user-friendly and its user community is large. Only basic coding skill is required to operate the Arduino board because many example libraries are available on the internet. In terms of connectivity, it just needs a USB port.



A

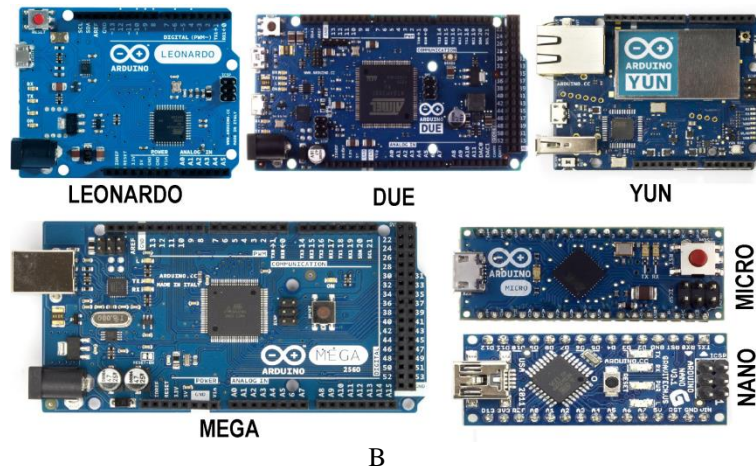


Figure 1. Arduino platforms: A) UNO R3 and its components, B) Other Arduino families

Design and Assemble of the Device

The device consists of three different boards, each one is interconnected by flat cables and fixed on a plastic base: the driver board, the boost up unit and the processing unit (Arduino Uno R3). The overall layout of the design is shown in figure 2. The device, which is connected to the PC through USB, acquires data from the sensors and performs data logging operations. Sensor inputs were provided with 9-pin D-Sub connectors, mounted on rear side of the circuit box. In present conditions, two inputs are adequate, however Arduino Uno board allows 6 input channels. Hence, additional input channels required for other tests (such as multi frame oedometer tests, triaxial tests with pore pressure measurements) can be performed using the device by only adding more D-Sub connector to the side of the box.

The device was designed to be as small as possible (figure 3); it weighs less than 100 g and its dimensions are 12 cm × 8 cm × 4 cm, thus it is portable and fits on the top of a test apparatus, leaving the necessary space for samples etc. It consumes very little current, and power of USB connection is adequate for operations without a need for extra power supply, which will cause extra space, weight and cost.

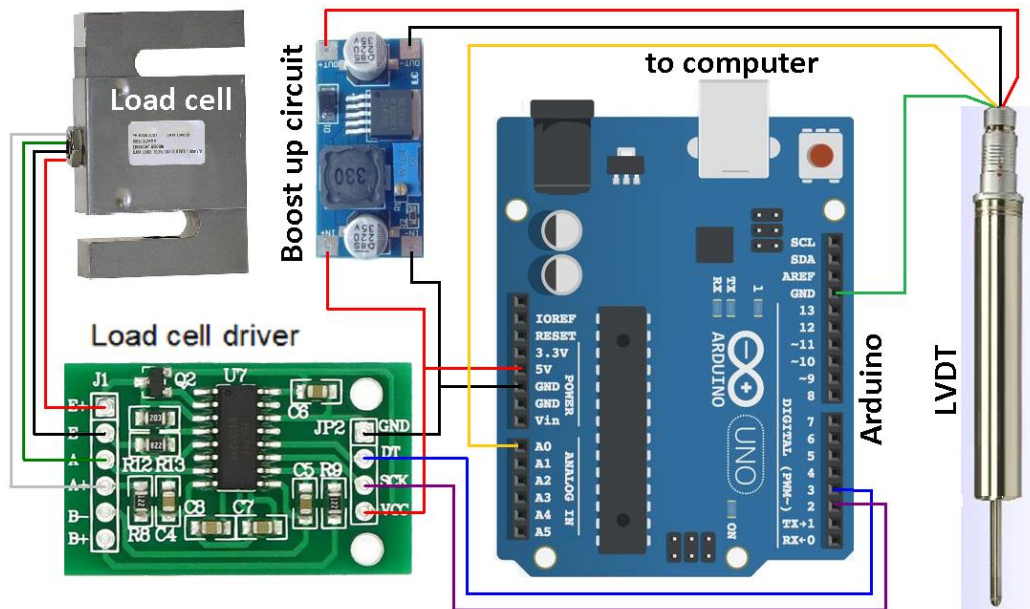


Figure 2. Design of the Circuit

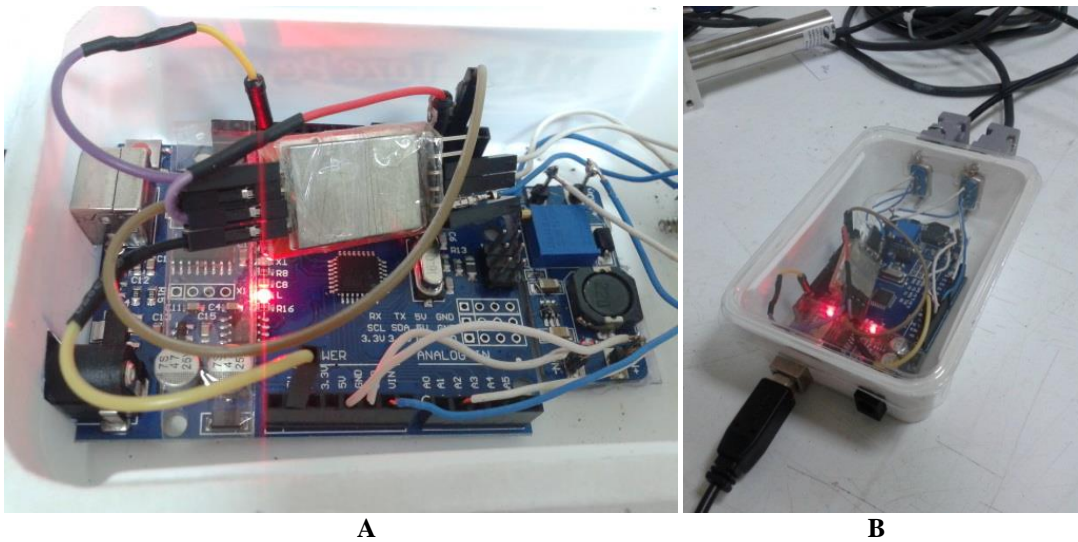


Figure 3. A) Assembled device, B) Device that is connected to a computer and the sensors

Development of the Software

Communication with Arduino board is done through serial data transfer. The code for Arduino are known as sketches, which are written in C++. Every sketch needs two void type functions, setup() and loop(). A void type function doesn't return any value. The setup() runs just after the Arduino is powered up, and the loop() method runs continuously afterwards. The setup() is initialisation step, and in the loop() code run over and over again. As an open-source project, the Arduino benefits from the collective efforts and expertise of developers. Libraries, which contain routines and sample codes are available to download, use, and modify as needed. The IDE, libraries, and sample code can be accessed via the Arduino project website (Arduino, 2017).

The source code of the developed software is shown in figure 4. LVDT sensor data can be directly acquired from analog input A1 using command "sensorvalue=analogRead(A1)". On the other hand, load cell data cannot be directly acquired, because of an auxiliary driver board, which converts analog signals of the load cell to amplified digital data thru 24 bit ADC. Therefore, load cell data input is acquired as digital input. An open-source header file for load cell driver (HX711.h) and a complimentary C++ source code file (HX711.cpp) were included in the code which is shown in figure 4. These codes are open source and available in Github Inc. (2017).

```

lvdtandellikilo  HX711.cpp  HX711.h
#include "HX711.h"
#define DOUT 3
#define CLK 2
HX711 scale(DOUT, CLK);
float calibration_factor = 87650;
float b;
int c;
float m;
float startTime;
float elapsedTime;
void setup()
{
  Serial.begin(9600);
  startTime = millis();
  scale.set_scale();
  scale.tare();
}
void loop()
{
  int sensorValue = analogRead(A1);
  Serial.print(sensorValue);
  Serial.print("\t");
  scale.set_scale(calibration_factor);
  b=scale.get_units();
  c=(b*1000);
  Serial.print(c);
  elapsedTime = ((millis() - startTime - 120)/1000);
  m = (elapsedTime/60);
  Serial.print("\t");
  Serial.println(m, 3);
  if(Serial.available())
  {
    char temp = Serial.read();
    if (temp == 't')
    {
      scale.tare();
    }
    delay(20000);
  }
}

```

Figure 4. The source code of the developed software

Results and Findings

Laboratory tests were performed on gray clays which were obtained from Antalya (Turkey) city center. Clays were mixed with water and remoulded in cylindrical molds. Because tests was for only trial for use of data logger device, index geotechnical properties are not determined. Unconfined strength tests were conducted to measure the unconfined compressive strength of prepared soil samples ASTM D2166. Figure 5 shows the device while operating with unconfined test apparatus.

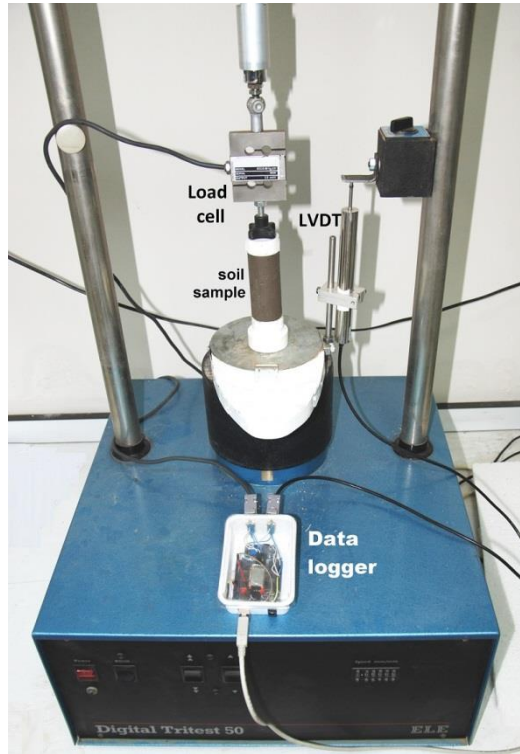


Figure 5. The developed device operating with unconfined test apparatus

Before the test started, sample is centered between upper and lower platens, zero load condition are provided using unconfined test device buttons. Time intervals that readings wanted to be acquired should be set in the software. Before the unconfined test device is started, the software should be started. Load and deformation values are acquired from LVDT and load cell sensors, and these values will appear on serial monitor. The acquired data can then be processed in a spreadsheet to obtain stress and strain values. An example test result is shown in figure 6.

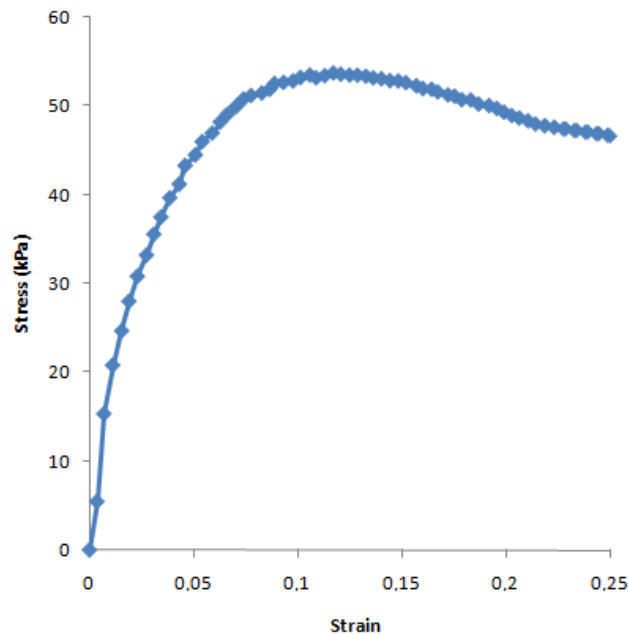


Figure 6. An example unconfined test result acquired with developed device

Conclusion

This study explains the development of a low cost and open source data acquisition system for soil mechanics laboratories. The major conclusions are summarized below:

- Open-source and low-cost development platforms, such as Arduino, opens the route to simple implementation of geotechnical projects.
- These platforms can be started and learned quickly. Thanks to its modular structures, low prices and extensive libraries, it has become an alternative for electronic assembly needs.
- The main advantage of making electronic laboratory equipment, such as datalogger, by using open source hardware is that, shared design promotes a better design as the scientific community can contribute to its design.
- The development platforms, which allow pressure, load, deformation and temperature measurements, automatic control of the devices and data logging, may serve as alternative solution tool for soil mechanics laboratories.
- Parallel to "do-it-yourself" civil movement, the use of these platforms by young geotechnical engineers in particular will give them experience that can also be applied in different applications

References

- Arduino (2017). Arduino - Home, An Open-Source Electronics Prototyping Platform. <https://www.arduino.cc/>
- Arsha Lekshmi, K.R., & Arnepalli, D.N. (2016). A methodology to determine water vapour diffusion characteristics of geomaterials. *Indian Geotechnical Conference IGC2016 15-17 December 2016*, IIT Madras, Chennai, India.
- ASTM D-2166 (2013). *Standard Test Method for Unconfined Compression Strength of Cohesive Soil*. ASTM International, West Conshohocken, PA
- D'Ausilio A. (2011). Arduino: A Low-cost Multipurpose Lab Equipment, *Behav Res* 44,305–313.
- Delage, P., Romero, E., & Tarantino, A. (2008). Recent developments in the techniques of controlling and measuring suction. In *Proceedings of the 1st European Conference on Unsaturated soils: Advanced in Geo-Engineering, Durham, UK, 2–4 July 2008*. Edited by D.G. Toll, C.E. Augarde, D. Gallipoli, and S.J. Wheeler. Taylor & Francis Group, London, UK. pp. 33–52.
- Dipova, N. (2016a). Infrared ısıtma ve nem yoğunlaşturmaya dayalı bir su içeriği cihazı geliştirilmesi, *Zemin Mekaniği ve Geoteknik Mühendisliği 16. Ulusal Kongresi, Erzurum, 13-14 Ekim 2016, cilt.2*, pp.1017-1024.
- Dipova, N. (2016b). Kızılötesi ve peltier teknolojili bir dijital hidrometre tasarımı ve geliştirilmesi, *Zemin Mekaniği ve Geoteknik Mühendisliği 16. Ulusal Kongresi, Erzurum, 13-14 Ekim 2016, cilt.2*, pp.997-1006.
- Dunncliff, J. (1993). *Geotechnical Instrumentation for Monitoring Field Performance*. John Wiley and Sons, New York.
- Github Inc. (2017) An Arduino library to interface the Avia Semiconductor HX711 24-bit analog-to-digital converter (ADC) for weight scales. <https://github.com/bogde/HX711>.
- Han J.B., & Zhou, Z.F. (2013). Dynamics of soil water evaporation during soil drying: laboratory experiment and numerical analysis. *Scientific World Journal*, 2013, 240-280.
- Levine, S.S., & Prietula, M.J. (2014). Open Collaboration for Innovation: Principles and Performance. *Organization Science*, 25, 1414–1433.
- Pearce, J. (2012). The case for open source appropriate technology. *Environment, Development and Sustainability*, 14, 425–431.
- Plaisted, M., & Zornberg, J.G. (2013). Determination of the Swell-stress Curve of an Expansive Soil Using Centrifuge Technology. *Proceedings of the 5th International Young Geotechnical Engineers' Conference – 5th iYGEC 2013, 31 August-01 September, Paris, France*, pp. 443-446.
- Raymond, E. S. (2001). *The cathedral and the bazaar: Musings on Linux and Open Source by an accidental revolutionary*. Beijing, O'Reilly.
- Vainino, N., & Vaden, T. (2007). *Free software Philosophy and open Source, Handbook of reserch an Open Source Software*, Information Science Reference, pp. 1-11