Applications of the Arduino electronics in the kinematics

Chin-Chung Yu, National University of Kaohsiung, Taiwan
Jia-Han Hsu, National University of Kaohsiung, Taiwan

The Asian Conference on Education & International Development 2017
Official Conference Proceedings

Abstract

Due to high precision, quick response, open source and low price, Arduino electronics, including motherboards and sensors, have potential to be the main parts of physical experiments. Especially, the experimental data can be easily transferred to smartphones and tablets through the Bluetooth communication that greatly enhances the portability of the experimental equipment. There are many commercially available detectors compatible with the Arduino motherboards such as ultrasonic sensors and photoelectric switches which are good choices for the detections of the linear and rotational motions, respectively.

In this article, numerous sensors related with the kinematics are introduced. And we also demonstrated a controllable damping oscillation in a spring-mass system. The motion of the oscillator was detected by an ultrasonic position sensor. The damping force was provided by the coupling between an electromagnet and a permanent magnet mounted on the oscillator. By tuning the strength of the magnetic field, the damping constant can be manipulated. All of the motion detection and the signal access were based on the Arduino sensors and electronics. Such a dynamical motion can be well monitored and the data can be simultaneously transmitted to a computer or a hand-held personal device. This shows that Arduino electronics can replace the expensive equipment for the kinematic experiments.

Keywords: Arduino electronics, motional sensors, oscillation motions

Introduction

Recently, Industry 4.0 and Internet of Things (IoT) are major trends in the industry and scientific activities. (Lukas, 2011 and Vermesan, 2013) On the other hand, due to the STEAM advocated by educational circles, science-related issues gradually be taken seriously. (Maeda, 2012) In response to the change of the course outline of the high school in Taiwan R.O.C., development of new scientific programs to make learning activities more diversified is necessary.

As a result of the popularity of intelligent products, such as smartphones and tablets, and hand-held sensors and detectors, the Makers use low cost and high innovation to promote their merchandise and creative design in all areas. (MacMillan, 2012) Among them, Fablab Berlin located in Berlin, Germany promoted a well-known activity named the Junior Lab. which is specifically for the 8 to 14-year-old teens to learn the Arduino electronics, Raspberry mainboard, 3D printers, and programming, and then to do some gadgets by themselves. The Arduino mainboard was developed by Banzi, Cuartielles and Mellis in 2005. (Kushner, 2011) The electronic circuit contains a microcontroller to analyze (or transmit) the digital and analog signals. Consequently, it can respond to sensor's signals or control some active devices such as motors. Only DC 5V is required for the operation of the Arduino mainboard. And it can output 3.3V and 5V as a power supply of the sensors or the light emitted diodes (LED). Through the universal serial bus (USB), Bluetooth (BT), or WIFI, the Arduino electronics can communicate with computers, smart phones, and tablets. One of the common mainboards is the UNO board as shown in the Fig. 1. Based on the concept of the open source, the circuit design of the mainboards is distributed on the internet. The hardware of the Arduino electronics follows the Creative Commons license and is allowed to reproduce and redesign. So it can be produced massively and the cost is quite low.

Various types of Arduino sensors have been developed, such as ultrasonic distance sensor, infrared reflection (IR) detection, temperature, and humidity sensors. The prices of most sensors are of around 5USD. The programing of the Arduino electronics is based on the C++ language and the integrated development environment is user friendly and freely for download. The control and sensing programs of the sensors are usually open source and can be found on the internet. Due to the easy access of 3D printers and hardware tools, the public can use computers, smart phones, Arduino electronics and sensors to set up suitable physical experiments instead of buying commercially available equipment with high costs.

Figure 1: Arduino UNO mainboard

Sensors for the motional detections

The linear and rotational motions are two main topics in the physical courses of the high school. The kinetic quantities including distance, velocity, acceleration, rotation speed, and rotation acceleration are the main concerns in the experimental measurements. The corresponding Arduino sensors for distance are the ultrasonic sensor and the IR reflection detection which based on the principle of the echolocation. Figures. 2(a) and 2(b) are commercially available HC-SR04 ultrasonic sensing modules and TCRT5000 reflective optical IR sensor, respectively. The detection distances of the ultrasonic and IR sensors are in a range of 2-400cm and 1-25mm, respectively. (Cytron Technologies, 2013 and Vishay Semiconductors, 2009) Providing the resolution of the time detection in the Arduino mainboard is in the range of microsecond, the velocity and acceleration are then derived except some extremely conditions.

For the detection of the rotational motion, the optoelectronic switch, based on the blocking of the IR light, will be the best choice for the detection of the revolution in the rotational motion. Figure 2(c) is the FC-03 module for the detection of the optoelectronic switch. Combining the on-off signals from the switch and time detection in the Arduino mainboard, the period of the rotational motion can be obtained. Consequently, the angular velocity and the angular acceleration can be derived.

In the three-dimension kinematics, tri-axis accelerometers and tri-axis gyroscopes are used instead of the ultrasonic sensors, IR sensors and optoelectronic switches. The tri-axis accelerometer and gyroscope are based on the capacitance change in the devices of the Micro-Electro-Mechanical Systems (MEMS). The tri-axis accelerometer measures the accelerations along the x-, y-, and z-directions and obtains the orientation of an object. The MMA7361 chip in the Fig. 2(d) is the common available MEMS sensor for the measurements of the tri-axis accelerometer with a capability from -3G to 3G. (Apex Electrix, LLC, 2013) The gyroscope L3G4200D with a resolution of around 8.75 mdps/LSB can measure the angular velocity rotated around x, y, and z axes. (STMicroelectronics, 2010) It can be applied in the field of the virtual reality input devices, Motion control with MMI (man-machine interface), GPS navigation, appliances, and robotics.

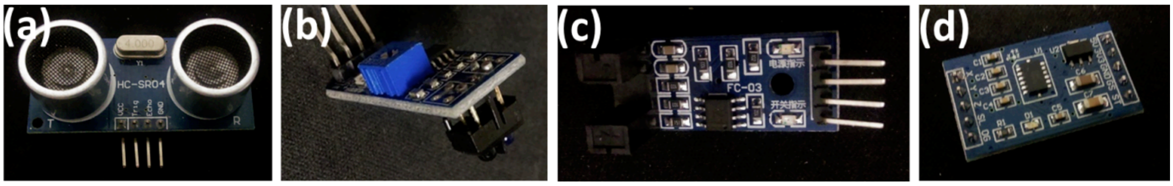

Figure 2: Typical Arduino sensors for the kinematics. (a), (b), (c), and (d) are for the ultrasonic sensor, the IR detector, the optoelectronic switch, and the tri-axis accelerometer, respectively.

Type of the oscillatory motions

Usually an ideally oscillatory motion displays a sinusoidal behavior in the diagram of the position of the oscillator versus time. However, the amplitude of the oscillation gets smaller due to the damping effect provided from the air. Such a damped oscillation can be formulated by the Newton's second law with a restoring force and a damping term as written in eq.(1).

$$m\frac{d^2x}{dt^2} = -kx - m\lambda\frac{dx}{dt} \quad \ldots(1)$$

where m is the mass of the oscillator, x is the position of the oscillator, t is time, k is the force constant, and λ is the damping constant.

The position of the oscillator $x(t)$ can be solved analytically and has the following form.

$$x(t) = x_0 e^{-\frac{\lambda}{2}t}\cos\left[\left(\sqrt{\left(\omega_0^2 - \frac{\lambda^2}{4}\right)}t + \phi\right)\right] \quad \ldots(2)$$

The $x(t)$ is a sinusoidal function with amplitude decay as sketched in Fig. 3. The decay originates from the exponential term $exp(-\lambda t/2)$ in eq.(2). Consequently, the damped oscillation is characterized by the damping constant λ.

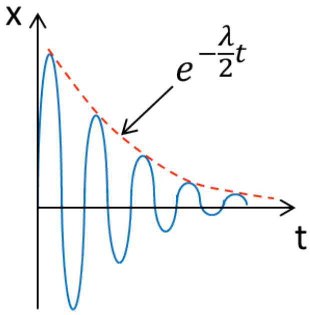

Figure 3: A damped oscillation with a damping constant λ

Electromagnetically coupled oscillator

Usually an oscillator was hanged under a spring and the motion of the oscillator was detected by an ultrasonic sensor. The real-time position of the oscillator was then recorded by the Arduino mainboard and sent to the computer through the serial communication. Figures 4(a) and 4(b) were the illustration and the photo of the experimental setup, respectively. Figure 5(a) sketched the natural oscillation of the system with a $\lambda = 0.69$. Here, an innovative design for manipulating the damping constant by an electromagnetically coupled magnet that was mounted on the middle position of the spring was introduced as shown in Fig. 4(a). The damping constant increased as elevating the coupled magnetic field. Figure 5(b) showed the oscillation trajectory as magnetic field equal to 67 Oe and resulted in a damping constant equal to 3.03.

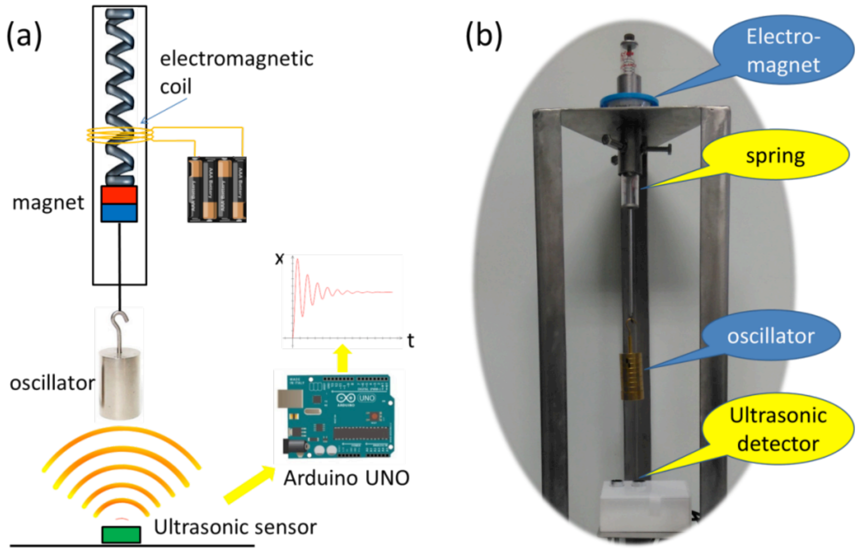

Figure 4: Experimental setup

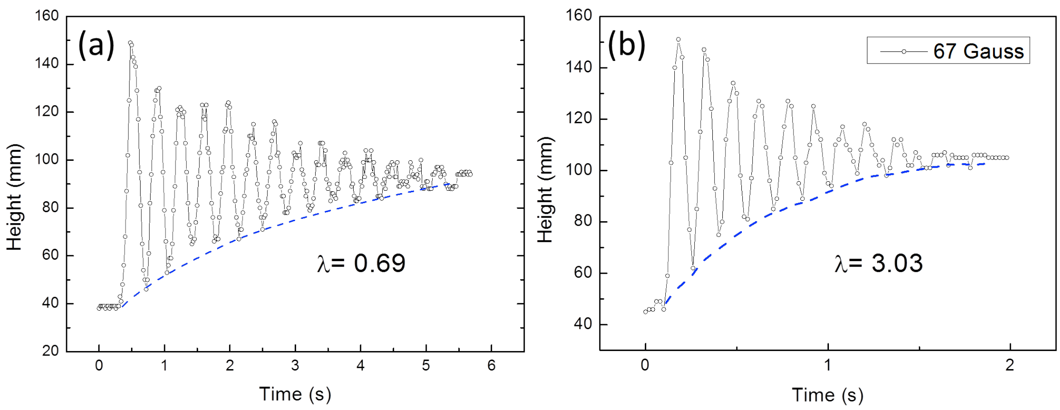

Figure 5: Oscillatory trajectories of (a) the natural oscillation and (b) the electromagnetically coupled oscillation.

Conclusion

Considering the prices, the circulation, the data transmission, the programing and the extensibility, Arduino electronics are undoubtedly the first choice for physical experiments. In this article, we used a simple ultrasonic sensor to detect the motion of an oscillator and obtained well behaved damping oscillations with controllable damping coefficients. In practice, all the experiments constructed by the Arduino related electronics can communicate with the mobile phone and the tablet via BT and can be manipulated by the Android or iPhone apps. This greatly enhances the portability of the experimental equipment.

In order to use the available resources on the Internet to carry out the experiment setup, the teachers must have the concept of programming and the basic knowledge of electronic circuits. To promote the use of Arduino electronics in the classroom still need more teachers to participate in this field and develop related teaching materials.

Acknowledgements

This work was supported by the National University of Kaohsiung and the Ministry of Science and Technology, R.O.C. under Grant No. MOST 104-2511-S-390-002 and MOST 105-2511-S-390-001-MY2.

References

Lukas, Von H. K. W-D (2011). *Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution*. VDI-Nachrichten.

Vermesan, O. & Friess P. (2013). *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems.* Denmark: River Publishers.

Maeda, J. (2012). *STEM to STEAM: Art in K-12 Is Key to Building a Strong Economy*. Edutopia.

MacMillan, T. (2012). *On State Street, "Maker" Movement Arrives*. New Haven Independent.

Kushner, D. (2011). *The Making of Arduino*. IEEE Spectrum.

Cytron Technologies Sdn. Bhd. (2013). User's Manual V1.0 of the HC-SR04.

Vishay Semiconductors (2009). Datasheet of the Reflective Optical Sensor with Transistor Output. Document Number: 83760.

Apex Electrix, LLC (2013). User's manual of MMA7361 3-Axis Accelerometer Module.

STMicroelectronics (2010). User's manual of L3G4200D MEMS motion sensor:ultra-stable three-axis digital output gyroscope.

Contact email: yucc@nuk.edu.tw