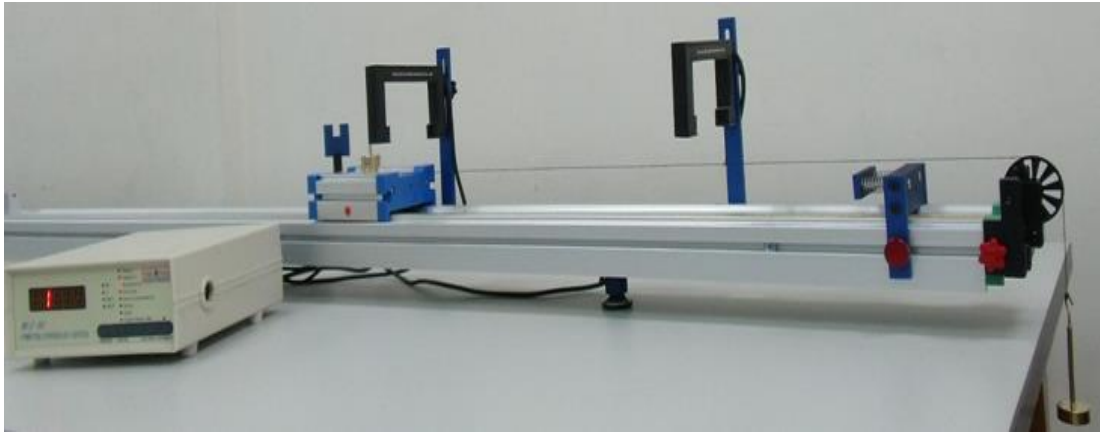


## Exp2 : Verification of Newton's Second Law



Experience System

### I. Purpose

The purpose of this experiment is to study the effects of different experimental methods, equipment and setup.

1. Measuring the changing track and tendency of physical quantities of different motions with time ( $t$ ) of an object moving in one dimension, e.g. the position, velocity, acceleration and net force applied to an object.
2. Knowing how to use the photoelectric Timing counter and photogate to measure the precise values
3. Learn to document motions of objects with digital image capture and analysis software, e.g. Logger Pro (Vernier comp.).
4. Compare the precision of fetched data in differences, advantages and disadvantages among different apparatus.
5. Observe one-dimensional motions of pulley under external force to verify Newton's Second Law in one-dimension.

### II. Theory

Newton's Second Law : The acceleration of a moving object is in direct proportion with the sum of external force but in inverse proportion with the mass of an object.

The equation:

$$\sum_i \vec{F}_i = M\vec{a} \quad \text{or} \quad \vec{F}_{net} = M\vec{a} \quad (1)$$

$\sum \vec{F}_i$  or  $\vec{F}_{net}$  is the vector sum of external forces, or net force. The net force is a vector with magnitude and direction.  $M$  (mass) is a scalar with magnitude only.  $\vec{a}$  is the acceleration of an object. It is also a vector and so has magnitude and direction.

This exp. uses two experimental procedure to verify Newton's Second Law in one dimension.

- (1) Apply different Forces to a fixed object  $M$  (pulley). Measure the relationships between force and acceleration.
- (2) Fixed the magnitude of force( $F$ ), change Mass(pulley). Measure the relationships between Mass(pulley) and acceleration.

Experimental set-up as shown in Fig 1. Consider a cart on a low-friction track. A light string is attached to the cart and passes over a pulley at the end of the track and a hanging mass( $F$ ) is attached to the end of this string. The weight of the hanging mass provides tension in the string, which helps to accelerate the cart along the track. A small frictional force will resist this motion. We assume that the string is massless (or of negligible mass) and there is no friction between the string and the pulley. The theoretical value of moving function and acceleration is as below: (這段從 [https://webassign.net/labsgraceperiod/ncsulcpmech2/lab\\_3/manual.html](https://webassign.net/labsgraceperiod/ncsulcpmech2/lab_3/manual.html) copy)

$$\sum_i \vec{F}_i = mg = (M + m)a_{th} \quad \Rightarrow \quad a_{th} = \frac{m}{M + m} g$$

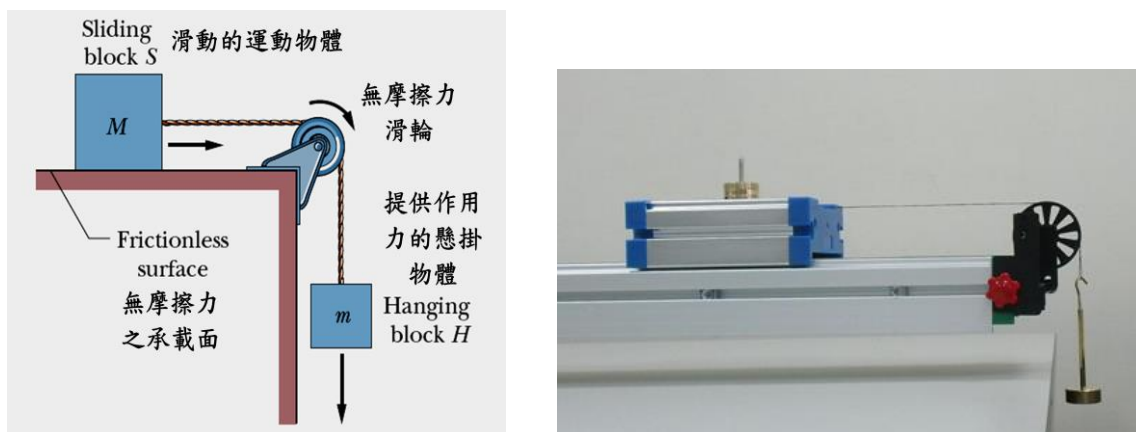


Figure 1: Two-mass System

### III. Equipment

To get precise and accurate experimental results, we must know how to operate all apparatus properly.

#### 1. One dimension moving system

- i. Low-friction track with pulley
- ii. Cart
- iii. String
- iv. Balance
- v. Two photogates
- vi. Assorted masses
- vii. Weight hanger
- viii. Computer
- ix. Signal interface

2. **Multi-functional counter:** photogate measuring system. , It measures 7 kinds of physical quantities of motions See file 1-1.

3. **Video analysis software:** use Logger Pro software (programming by Vernier comp.). See file 1-2. ; or any software that you are used to. (Ex: tracker...).
4. **Ultrasonic module:** use Arduino (open-source electronics platform) and Ultrasonic module to measure distance. See file 1-3
5. Each group must prepare one laptop and one USB flash drive.

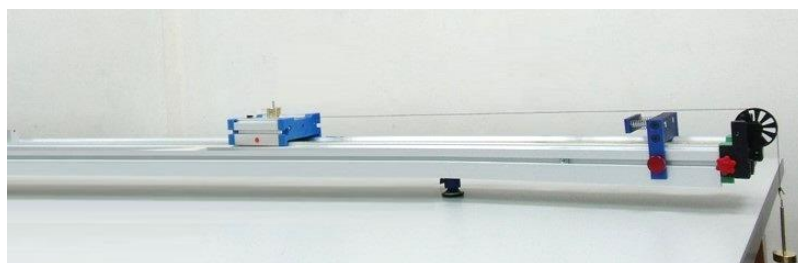
#### IV. Procedure

##### 1. Base Setup---one-dimension track set up

###### (1) Track Leveling:

- (a) Adjust the 3 support points to level the track. With your own design, verify the procedure of track leveling and leveling precision.
- (b) Document in detail the experimental procedures, method of leveling procedure the results as well as its pros and cons. You can also use pictures and graphs.

###### (2) Base setup :



Base setup

- (a) Place baffle and low-friction pulley at one end of track,
- (b) Measure weight of cart and weight hanger and weights receptively. Use string of proper length (~100cm) to connect the cart and weight hanger. Place the cart on the track gently. The weight is hanged down below by the pulley. The connecting string should be parallel to the track and not block the baffle. The string should not be too long, in case that the hanger collides with the floor when it drops.

**Q:** How would experimental data be influenced if the string is not parallel to the track?

- (c) Suppose the friction between the cart and track and the pulley and string, and the mass of string can be ignored. Please infer in theory the relationship among  $x(t)$ 、 $v(t)$  and  $a(t)$ .

##### 2. Verify Newton's Second Law $F = ma$ . Total mass is fixed. Measure : relationships between the magnitude of force, and acceleration of a moving object

###### (1) Verification of Newton's Second Law : $F = ma$

- (a) When the mass of an object is fixed, measure the relationships between external force  $F$  and acceleration  $a$ .
  - (b) When the external force  $F$  fixed, measure the relationship between mass of the moving object  $m$  and its acceleration  $a$ .
- (2) Conduct the experiment with your own design. Document experimental results. Every function must contain at least 5 sets of data so that precise fitting functions can be calculated.

- (3) Based on conditions and data of the experiment, explore whether your results meet  $F = ma$ . Discuss the source of errors and methods to reduce them.

### **Data Acquisition:**

#### **3. Measure by—Photodetector: (see file 1-1)**

- (1) Document motions of external forces on a pulley with two photogates in each group. Document the  $x(t)$  function of one-dimensional motions of a moving object using Gravity Acceleration on the photodetector and U-shaped baffle. At the same position, use the function of Acceleration to fetch the values of time, velocity and acceleration. Take at least 10 sets of data;  $(x_i, t_i)$ ,  $i = 1-10$ . Record data in table 1-1 and graph the changing tendency. Write down in detail how you get  $x(t)$ .
- (2) With 10 sets of fetched data, find the best fitting curve  $x(t)$  using least square regression. Decide which motion the cart was in and calculate related physical quantities of motions.
- (3) Based on the best fitting curve  $x(t)$ , calculate the velocity ( $v$ ) and acceleration ( $a$ ) of the cart when it passed 10 different positions. Record results along with those of Procedure 1. Compare above theoretical results of  $x(t)$ ,  $v(t)$  and  $a(t)$  and estimate errors.
- (4) Under the same experimental conditions, change to different functions of the gate and take 5 sets of time, velocity and acceleration data. With the data fetched with method (1), graph the changing tendency of  $v(x)$ . Calculate the best fitting curve of  $v_j(x)$ . Do you think the velocity here is instantaneous velocity? Is the acceleration here instantaneous acceleration?
- (5) Under the same experimental conditions, change the function of the gate to Acceleration, Take 10 sets of data. Graph  $a(x)$  and calculate the best functions of fitting curve  $a_j(x)$ .
- (6)①Use  $v(x)$  and  $a(x)$  to get the function of  $x(t)$ . Record it in the data sheet.  
②Compare  $x(t)$  with step(1) and step(2).  
③Describe in detail similarities and differences in motional function  $x(t)$  from measured data of time, velocity and acceleration. Which do you think is the most accurate?
- (7) Which factors will affect the exp. results and the extent of influence?

#### **4. Measure by ---Video analysis software: (see file 1-2)**

- (1) Under the same experimental conditions as (6), exchange the gate with a digital recording device. Record the motions of cart on the track.
- (2) Use Logger Pro or other similar softwares that you are used to and analyze the video. Get motion tracks of  $x(t)$ . With least square regression, calculate the best fitting curve of  $x(t)$ .
- (3) Get  $v(t)$ ,  $a(t)$  from  $x(t)$  data by inference and analysis.
- (4) Which factors will affect the exp. results and what are the sources of errors?
- (5) Compare physical quantities fetched from both recording and the gate. What do you think are the pros and cons of these two methods?

#### **5. Measure by ---Ultrasonic module: (see file 1-3)**

- (1) Install Arduino Driver, and CoolTerm.
- (2) Connect test box to laptop, and run CoolTerm. Test data will be collected automatically.

## **V. Questions**

1. Is the friction between the cart and track related to the velocity of the cart? Why?
2. How to measure friction?
3. If mass changes too little or too hugely, what will happen to your exp. data?
4. Does your fitting curve pass the original point? Why?

## File 1-1 Multi-functional counter and Photodetector

This experiment uses 2 photogates and the “Acceleration” function: measured instantaneous velocity at one point and acceleration between 2 points. Use the “Timing II” function on photogates to measure more points of time and velocity.

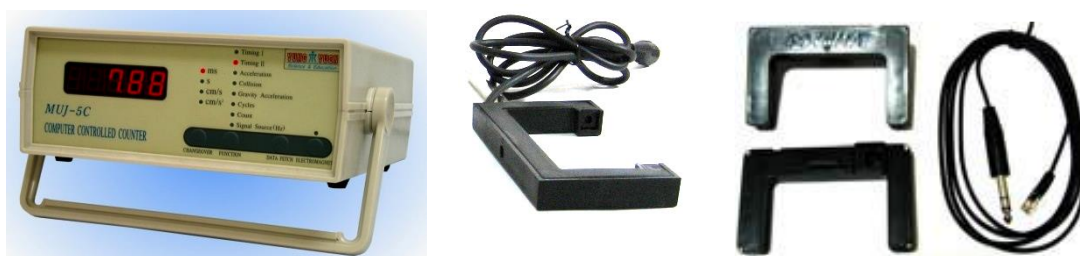


Fig. 1-1-1

Multi-functional counter:

Apparatus as shown in the Fig2.

### I. Panel

**1. Front panel:** The 4 black buttons are cycle switches.



Fig. 1.1.2 Multi-function counter

**(1) 5-digit display: show measurement results.**

**(2) “Changover” button:**

(a) change unit of results. ms, s for timing and cm/s for velocity;  $\text{cm/s}^2$  for acceleration.

(b) Pressing more than 1 second, you can change the shading sheet width or gap width: 1.0cm, 3.0cm, 5.0cm, 10.0cm by release button.

**(3) “Function” button:**

**(a) Reset :** if photogate has been shaded before pressing the function button, it can be reset by pressing it again.

**(b) Function Change: 8 function.** if photogate is not being shaded, pressing function button can choose from 8 functions in cycle.

1. **Timing I (S1) :** sheet shading time of the same gate.

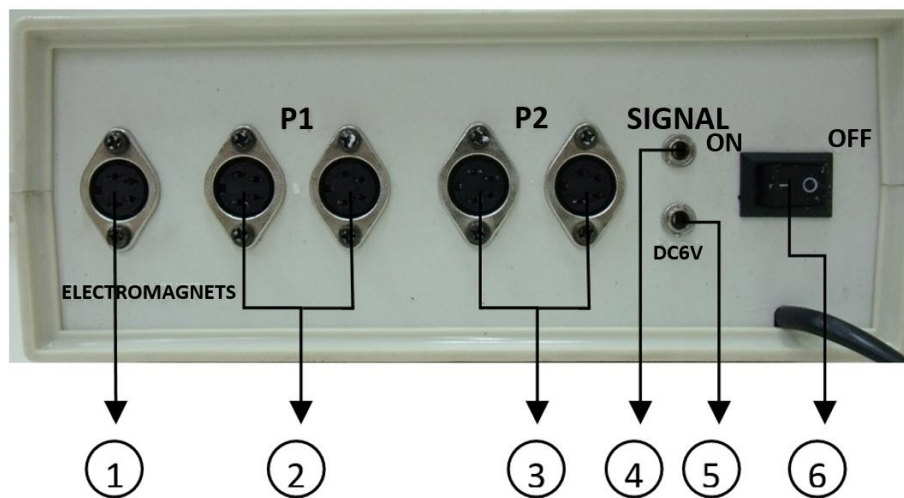
2. **Timing II (S2) :** measure timing between 1<sup>st</sup> and 2<sup>nd</sup> shading of the same gate.

3. **Acceleration (a)** : calculate acceleration of linear motion.
4. **Collision (Pzh)** : calculate velocity before and after collision.
5. **Gravity Acceleration (G)** : timing of free-fall from different heights.
6. **Cycle (T)** : cycling times for simple pendulum experiment.
7. **Count (J)** : shading times counting.
8. **Signal Source (Hz)** : signal generator, provide 1 Hz 、 10 Hz 、 100 Hz 、 1 kHz 、 10 kHz pulse signal, output amplitude is about 5V. Output socket is on ear panel.

(4) **Data Fetch**: recorded 20 data when at function timing I, timing II and Cycle (T)

(5) **Electromagnet**: switch of electromagnet on /off

2. **Rear panel**: Fig. 1.1.3



- |                               |                           |
|-------------------------------|---------------------------|
| ① Electromagnet signal socket | ② Photogate socket set P1 |
| ③ Photogate socket set P2     | ④ Signal output socket    |
| ⑤ 6V DC output socket         | ⑥ power                   |

Fig. 1.1.3 Rear panel

## II. Display description

### (1) Timing I :

sheet shading Timing/velocity of the same gate. The width of the sheet needs to be set. Measuring continuously and saving the first 20 sets of data automatically. Pressing “Data Fetch” to check data.

### (2)Timing II : 計時 2, S<sub>2</sub>

measure timing/velocity between 1<sup>st</sup> and 2<sup>nd</sup> shading from the same gate. Measuring continuously and saving the first 20 sets of data automatically. Pressing “Data Fetch” to check data.

### (3) Acceleration(a)

measure timing/velocity go through 1<sup>st</sup> and 2<sup>nd</sup> photogate using by U-shaped sheet. You can connect 2~4 photogates, too. It will show as:

1 (1<sup>st</sup> photogate)  
 0.00 (1<sup>st</sup> photogate measured data:  $t_1/v_1$ )  
 2 (2<sup>nd</sup> photogate)  
 0.00 (2<sup>nd</sup> photogate measured data:  $t_2/v_2$ )  
 1-2 (1<sup>st</sup> to 2<sup>nd</sup> photogate)  
 0.00 (1<sup>st</sup> to 2<sup>nd</sup> photogate measured data:  $t_{1-2}/a_{1-2}$ )

If there are more than 2 photogates, it will keep showing:

3 (3<sup>rd</sup> photogate)  
 0.00 (3<sup>rd</sup> photogate measured data:  $t_3/v_3$ )  
 2-3 (2<sup>nd</sup> to 3<sup>rd</sup> photogate)  
 0.00 (2<sup>nd</sup> to 3<sup>rd</sup> photogate measured data:  $t_{2-3}/a_{2-3}$ )

Press “function” to reset data.

**(4) Collision (Pzh) :** calculate velocity before and after for collision experiment.

Put Set 2 photogates between 2 carts, using by U-shaped sheet. Make sure collision will happen between 2 photogates. Each photogate connects to P1 & P2 at the rare-panel. It will show as:

P1.1 (passed through P1 photogate for 1<sup>st</sup> time)  
 0.00 (measured data:  $t_{1.1}/v_{1.1}$ )  
 P1.2 (passed through P1 photogate for 2<sup>nd</sup> time)  
 0.00 (measured data:  $t_{1.2}/v_{1.2}$ )  
 P2.1 (passed through P2 photogate for 1<sup>st</sup> time)  
 0.00 (measured data:  $t_{2.1}/v_{2.1}$ )  
 P2.2 (passed through P2 photogate for 2<sup>nd</sup> time)  
 0.00 (measured data:  $t_{2.2}/v_{2.2}$ )

Or go through P1 3 times, then it will show:

P1.3 (passed through P1 photogate for 3<sup>rd</sup> time)  
 0.00 (measured data:  $t_{1.3}/v_{1.3}$ )

Press “function” to reset data.

**(5) Gravity Acceleration :** timing from free-fall through photogates

Connect electromagnetic controlled wire to “Electromagnet signal socket” on the rare panel. Put 2~4 photogates under the electromagnet. Put a steel ball on electromagnet when electromagnet light on, the steel ball will fall down when pressing “electromagnet” bottom. It will show timing count from start to photogate. It will show as:

1 (passed through P1 photogate)  
 0.00 (measured data:  $t_1$ , timing from start to P1)  
 2 (passed through P2 photogate)



0.00 (measured data:  $t_2$ , timing from start to P2)

And so on.

**Cycle (T)** : cycle times for simple pendulum experiment.

Used 1 photogate. When exp. is finished, it will show Sum of exp. timing (0~9999 cycle max.).

**(a) not set cycle time:** reset data. It will start when sensing the shielding, and end by pressing "CHCNAGEOVER" ., it will show:

0.00 (measured data:  $t_1$ , timing for cycle 1)

**(b) set cycle times:** long press "CHCNAGEOVER" to choose cycle times you want to count. It will be counted backwards.

0.00 (measured data:  $t_1$ , timing for cycle 1)

"DATA FETCH" can show top 20 data.

**(6)Count** : counting shading times.

**(7) Source Signal (Hz)** : signal generator, provide 1 Hz 、 10 Hz 、 100 Hz 、 1 kHz 、 10 kHz pulse signal, output amplitude is about 5V. Output socket is at rear panel. Press "CHANOVER" to set up signal frequency.

### III 、 specification

1. With 12MHz Quartz crystal oscillator, precision is about  $2 \text{ MHz} \pm 20 \text{ Hz}$  (10 ppm).

2. Measured range:

- (a) Timing: 0.00 ms ~ 999.99 s.
- (b) Velocity: 0.00 ~ 1000.0 cm/s ◦
- (c) Acceleration: 0.00 ~ 1200.0 cm/s<sup>2</sup> ◦
- (d) Counting: 0 ~ 99999 ◦

It will show "0.0.0.0." when out of range.

3. Display function:

- (a) 5-digit display.
- (b) 4 LED light for units.
- (c) 8 LED light for functions.
- (d) Store 20 test data ◦

4. Signal out:

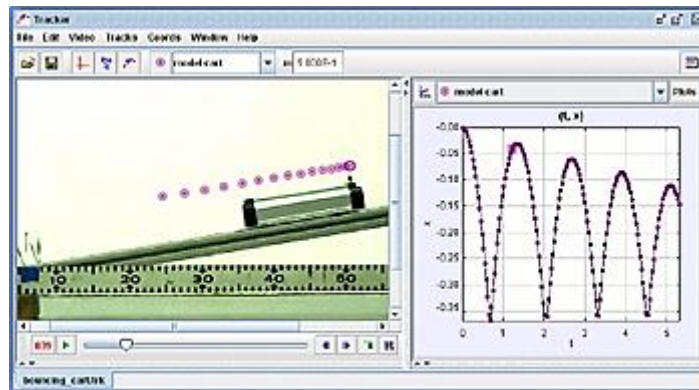
- (a) signal generator, provide 1 Hz 、 10 Hz 、 100 Hz 、 1 kHz 、 10 kHz pulse signal, output amplitude is about 5V.
- (b) DC 6V, 0.5A output.

## File 1-2 Video analysis software

### A. Tracker (<http://physlets.org/tracker/>)

Tracker is a free video analysis and modeling tool built on the [Open Source Physics](#)(OSP) Java framework. It is designed to be used in physics education.

Tracker **video modeling** is a powerful way to combine videos with computer modeling. For more information see [Particle Model Help](#) or AAPT Summer Meeting posters [Video Modeling](#) (2008) and [Video Modeling with Tracker](#) (2009).



Installing and using Tracker

To install Tracker, download and run the appropriate installer using the links at the top of the page. Tracker includes a JRE runtime and Xuggle video engine. For help see [Installer Help](#).

### B. Logger Pro:

(1) Logger Pro Introduction : <http://www.vernier.com/products/software/lp/>

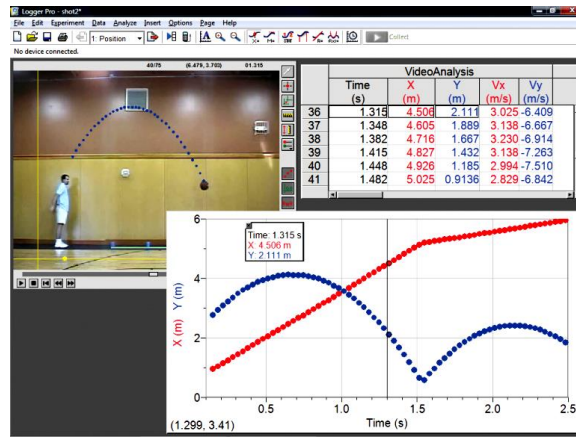
(2) NTHU copyright download site:

[http://www.phys.nthu.edu.tw/~gplab/file/Common%20equipment/Logger%20pro%203\\_En.zip](http://www.phys.nthu.edu.tw/~gplab/file/Common%20equipment/Logger%20pro%203_En.zip)

(3) Logger Pro3 Demo : <http://www.vernier.com/downloads/logger-pro-demo/>

Basic Features

- Auto-ID sensors make setup effortless.
- Collect live data from more than 80 different sensors and devices.
- Draw predictions on a graph before collecting data.
- Use a variety of data-collection modes, as needed, for your experiment: time-based data, selected events, events with typed-in entries, photogate, radiation counting, and more.
- Manually enter data for graphing and analysis.
- Import data from Vernier interfaces.
- Lay out graphs, tables, and text as needed across multiple pages to describe your experiment.
- Read values and slope from graphs using examine and tangent line tools.
- Print graphs and data tables.



[http://www.vernier.com/images/magnify/screenshot.lp\\_videoanalysis.001.png](http://www.vernier.com/images/magnify/screenshot.lp_videoanalysis.001.png)

### C. Other video analysis Software:

## File 1-3 Ultrasonic module

Use Arduino (open-source electronics platform) and Ultrasonic module to measure distance.

### Software download:

1.HC-SR-04 drive for Arduino Uno : (made by cn)

---Mac: [http://www.wch.cn/download/CH341SER\\_MAC\\_ZIP.html](http://www.wch.cn/download/CH341SER_MAC_ZIP.html)

---Windows: [http://www.wch.cn/download/CH341SER\\_EXE.html](http://www.wch.cn/download/CH341SER_EXE.html)

2. CoolTerm: <http://freeware.the-meiers.org>

Used Coolterm to get database and load out to EXCEL for graphing.

### Set up:

After loading Arduino driver and CoolTerm.

Open CoolTerm,



1. Options/ Serial Port/ Port : choose com"x" or wchusbserialxxxx (press "Re-scan Serial Port" if not showing out.)

2. Options/ Serial Port/ Baud rate: 9600 or 115200

3. "Connect" to start getting data. Data will show on the window.

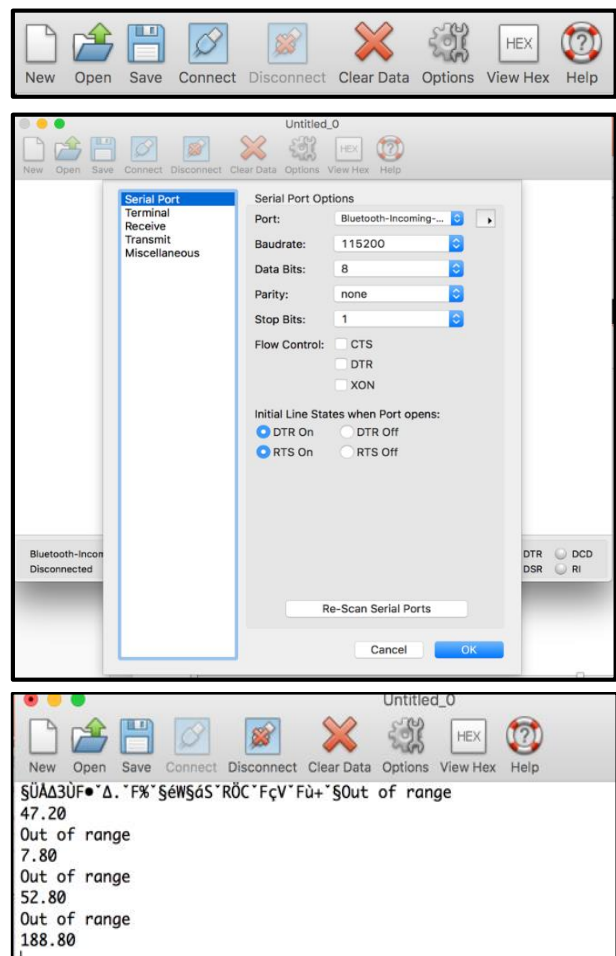
**Data take:** store in test file

1. Connection/ Capture to Textfile / Start: Start to take data to text file.

2. Connection/ Capture to Textfile / Stop: Stop to take data to text file.

3. Open Excel, choose Data/ From text: Load data to Excel to plot.

4. If forget to capture, select data (or Edit/ select All), Edit/ copy, and past it to excel.



**Arduino Introduction:** <https://www.arduino.cc/>

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

**HC-SR04 Ultrasonic sensor :** <https://www.arduino.cc/en/tutorial/ping>

The SEN136B5B is an ultrasonic range finder from Seedstudio. It detects the distance of the closest object in front of the sensor (from 3 cm up to 400 cm). It works by sending out a burst of ultrasound and listening for the echo when it bounces off of an object. It pings the obstacles with ultrasound. The Arduino or Genuino board sends a short pulse to trigger the detection, then listens for a pulse on the same pin using the pulseIn() function. The duration of this second pulse is equal to the time taken by the ultrasound to travel to the object and back to the sensor. Using the speed of sound, this time can be converted to distance.

**CoolTerm:** <https://coolterm.en.lo4d.com/windows>

CoolTerm is a freeware serial port terminal software app filed under network software and made available by Roger Meier for Windows.

# Exp 1 Newton's second law of motion experimental record

(by using photogates)

Class \_\_\_\_\_ name \_\_\_\_\_

## Exp 1-1a. Acceleration (Measure by Photodetector and function "Acceleration")

Cart Weight:  $m_{\text{cart}} =$  \_\_\_\_\_ g; U-shaped sheet spacing: \_\_\_\_\_ cm.

**Total Weight constant: M fix** (Hanging Weight+ Cart Weight)

Hanging Weight $m_1$ (g)	Cart Weight $m_2$ (g)	Total Weight M	Acceleration: a (cm/s <sup>2</sup> )					Average acceleration	Theoretical acceleration	Error (%)
			1	2	3	4	5			

Graph; fitting curve function: \_\_\_\_\_ ;  $R^2 =$  \_\_\_\_\_

Exp. g \_\_\_\_\_ ; Theoretical g = 978.14 cm/s<sup>2</sup>

Error % \_\_\_\_\_

## Exp 1-1b. Acceleration (Measure by Photodetector and function "Gravity Acceleration")

Take one set up of Exp. 1-1a's weight.

Hanging Weight:  $m_1 =$  \_\_\_\_\_ g

Cart Weight:  $m_2 + m =$  \_\_\_\_\_ g

Total Weight: M = \_\_\_\_\_ g

(use "I" type sheet)	Gate 1	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6
Position of photogate (cm)	0	10	20	30	40	50
timing (s)	0					
Average velocity with next gate (cm/s)						
Average acceleration with next gate (cm/s <sup>2</sup> )						

Average acceleration: \_\_\_\_\_

Graph x(t) : fitting curve function: \_\_\_\_\_ ;  $R^2 =$  \_\_\_\_\_ ; acceleration: \_\_\_\_\_

Q: Compare with Exp 1-1. Acceleration result. Which method's result is more accurate? Why?

**Exp 1-2** Cart Weight constant:  $m_2$  fix.

Hanging Weight $m_1$ (g)	Cart Weight $m_2$ (g)	Total Weight M	Acceleration: a (cm/s <sup>2</sup> )					Average acceleration n	Theoretical acceleration
			1	2	3	4	5		

Graph; fitting curve function: \_\_\_\_\_ ;  $R^2 =$  \_\_\_\_\_

Exp. g \_\_\_\_\_; Theoretical g =978.14 cm/s<sup>2</sup>

Error % \_\_\_\_\_

**Exp 1-3** Hanging Weight constant:  $m_1$  fix

Hanging Weight $m_1$ (g)	Cart Weight $m_2$ (g)	Total Weight M	Acceleration: a (cm/s <sup>2</sup> )					Average acceleration n	Theoretical acceleration
			1	2	3	4	5		

Graph; fitting curve function: \_\_\_\_\_ ;  $R^2 =$  \_\_\_\_\_

Exp. g \_\_\_\_\_; Theoretical g =978.14 cm/s<sup>2</sup>

Error % \_\_\_\_\_

Question:

1. If the friction between the cart and the track is related by velocity? Why?
2. How to estimate the friction between the track and the cart by experiment?
3. If mass change too less or too large, what will happen to your exp. data?
4. If your fitting curve pass through the original point? Why?