臺灣二ＯＯ八年國際科學展覽會

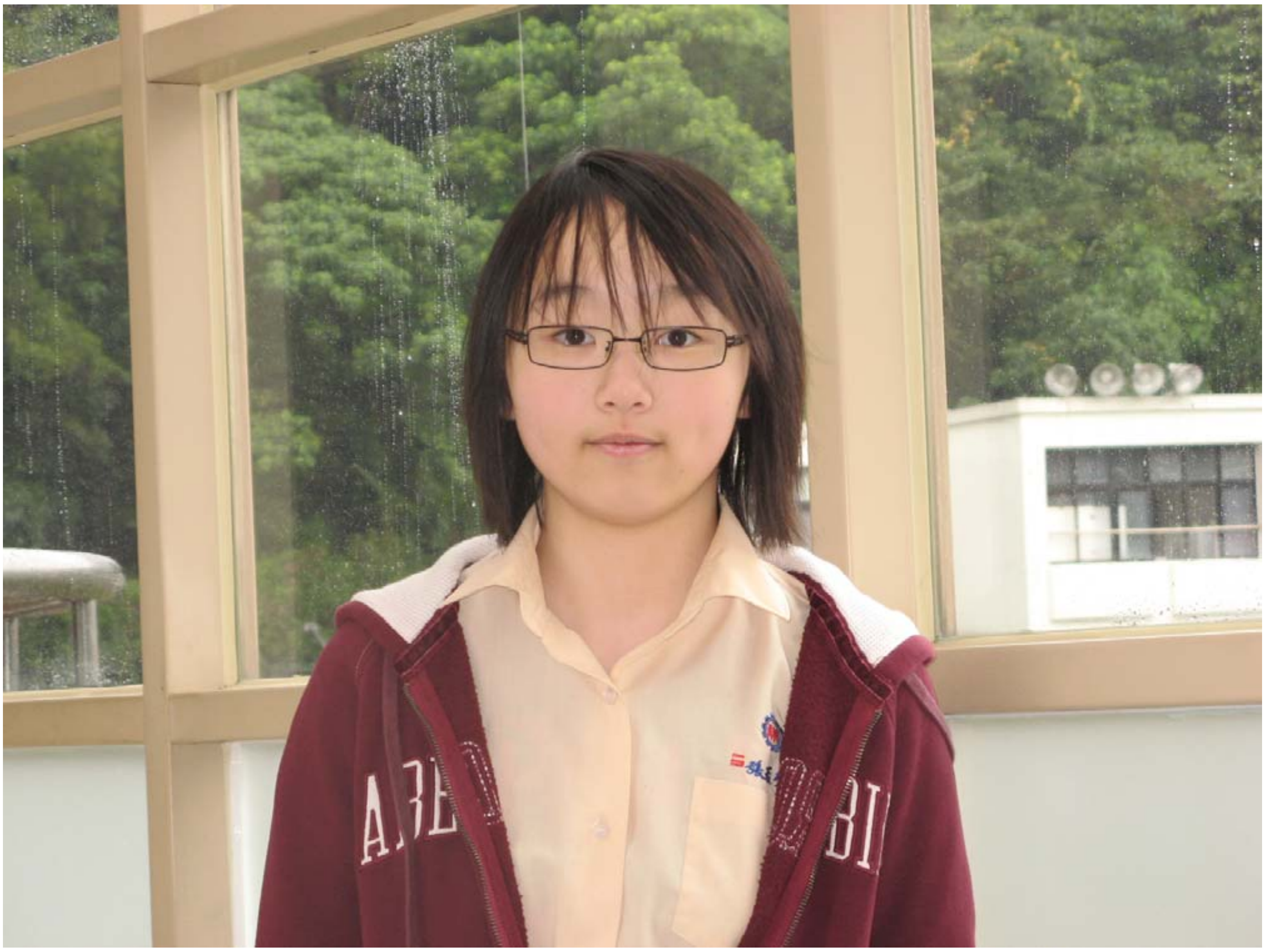
科　　　別：工程學

作 品 名 稱：明察秋毫-動態測微器

得 獎 獎 項：佳作

學校 / 作者：臺北市私立再興高級中學　　　張若萱

作者簡介



我是張若萱，1993年出生於台北，因爲爸爸工作的關係，小時候在國外長大，直到小學三年級才回到台灣上學，目前就讀台北市私立再興中學九年級。從小就對自然科學有著濃厚的興趣，舉凡生物、物理、化學或是地球科學，都令我深深著迷。除了閱讀和旅遊，在樂高積木堆裡拼拼裝裝和替機器人寫程式是我平常最重要的休閒樂趣之一，也因爲如此我曾經參加過許多的樂高機器人大賽，榮獲台北市第一名，也曾代表台灣到大阪參加2005年的Robocup Junior。除此之外，因爲小時候的經歷使得我的英文能力比一般同學流暢一些，所以也曾代表學校參加英語演講比賽。結合了自己的興趣與學校的課業開始此研究，參加科學展覽，也歷經台北科展和全國科展，這次很榮幸能在2008台灣國際科展中與大家分享我的研究。

Abstract

The purpose of this research is to create a device that is able to precisely measure small dynamic changes which cannot be recognized by the human eyes. The Vernier Caliper and the screw micrometer are common tools used to precisely measure lengths of objects. However, things which are measured by the Vernier Caliper or the screw micrometer have to be in a solid state, and the shape cannot be changed. By applying the light lever principle on Lego bricks, this research uses the LabVIEW graphical programming system to design a device which is able to automatically measure small dynamic changes. The precision of this device is higher than that of the Vernier Caliper and the screw micrometer. Moreover, this device is able to precisely detect the small dynamic changes of solids and liquids as well. Through numerous tests, the least count of the device can reach the level of 10^{-3}cm. Also, this device has successfully measured small changes, such as the height of the liquid surface by one drop of water, the evaporation of water in one minute, and the growth of a plant in one hour. By popularizing this device, people will be able to precisely measure small dynamic changes which are difficult to be measured in a short time.

Motivation

The potted plants in the hallway seem to grow a lot taller after a week. That makes me wonder… When do they grow? How tall can a plant grow in one hour? Staring at the plant, it doesn’t seem to be growing, which means the growth of a plant in a short time is so small that it can’t be recognized by the human eyes. How can these small changes be magnified? How can these small changes be measured? So I decided to create a device that is able to measure small dynamic changes precisely.

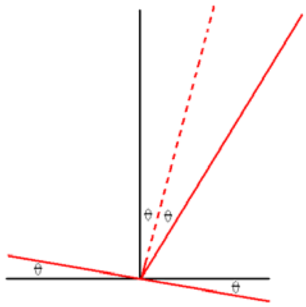
Engineering goal

1. To increase the small dynamic changes to the size that could be recognized by the human eyes by using the light lever principle.
2. To design a small dynamic changes measuring device that is able to be automatic controlled by combing the LEGO bricks and the LabVIEW graphical programming.
3. To solve the problem that many results of experiments can not be observed in a short time.

Theory

1. The *Light lever principle*

   If the angle of incidence light is fixed,
   when the mirror turns a θ angle,
   the angle of reflection will turn 2θ angle



2. The calculation of the ruler

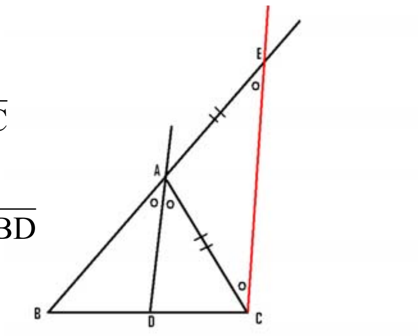
   Angle bisector theorem

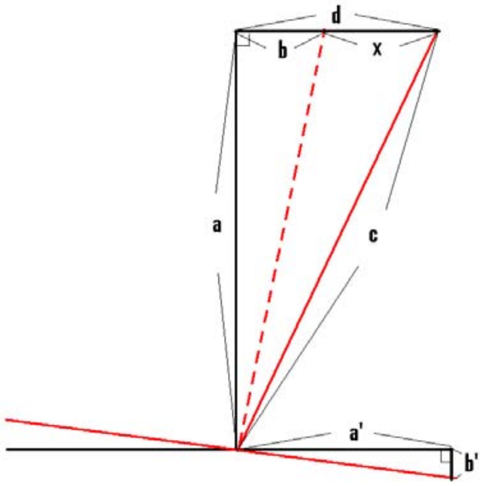
   The theorem can be proofed by using similar triangles.

$$\overline{AE} : \overline{AB} = \overline{BD} : \overline{DC}$$

$$\therefore \overline{AE} = \overline{AC}$$

$$\because \overline{AC} : \overline{AB} = \overline{DC} : \overline{BD}$$





$\because$ c:a=x:b(*Angle bisector theorem*) $\therefore c = \dfrac{ax}{b}$

$$\because c^2 = a^2 + d^2 = a^2 + (b + x)^2$$

$$a = 50\text{cm} \qquad a' = 1\text{cm}$$

$$50b' + \frac{50b'(1 + b'^2)}{1 - b'^2} = d$$

$$db'^2 + 100b' - d = 0$$

$$b' = \frac{-50 + \sqrt{2500 + d^2}}{d}$$

Materials

	name	purpose
1	Plastic board	To measure the change of the measured objects
2	Metal stick	To be the fulcrum of the plastic board
3	Mirror	To reflect the laser beam
4	Lego bricks	To build the structure
5	NXT controller	To run the program and keep record of the results
6	NXT motor (with built in rotation sensor)	To provide the motive force for the light sensor To record the distance from the starting point to the point the light sensor receives the reflected laser light by keeping record of the rotation of the motor
7	Light sensor	To receive the reflected laser light and transfer the result to the NXT controller
8	Touch sensor	To set the starting point to run the light sensor
9	Ultrasonic sensor	To detect the distance between the light sensor and the touch sensor so that the motor can slow down
10	Laser pointer	To shoot laser light
11	Relay	To control the laser pointer to shoot laser light or not


Plastic board

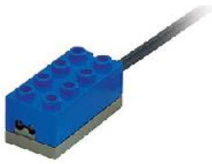

Metal stick


Mirror


Lego bricks

NXT controller


NXT motor


Light sensor


Touch sensor


Ultrasonic sensor


Laser pointer


RELAY

Device Design

By applying the light lever principle on Lego bricks, this research uses the LabVIEW graphical programming system to design a device which is able to automatically measure small dynamic changes.

1. Structure
   - Lever structure

     The main structure is built by using the *light lever principle*. In Fig.1 the gray part is the mirror that reflects the laser light, the blue part is the plastic board lever, and the black part is the metal fulcrum. The laser beam enters the mirror right on top of the fulcrum.

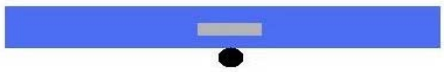


Fig.1

   - Main structure

     The main structure is made of Lego bricks (Fig.2). It provides support for the NXT, the laser pointer and the light sensor. The vertical distance between the light sensor and the mirror is 50cm.

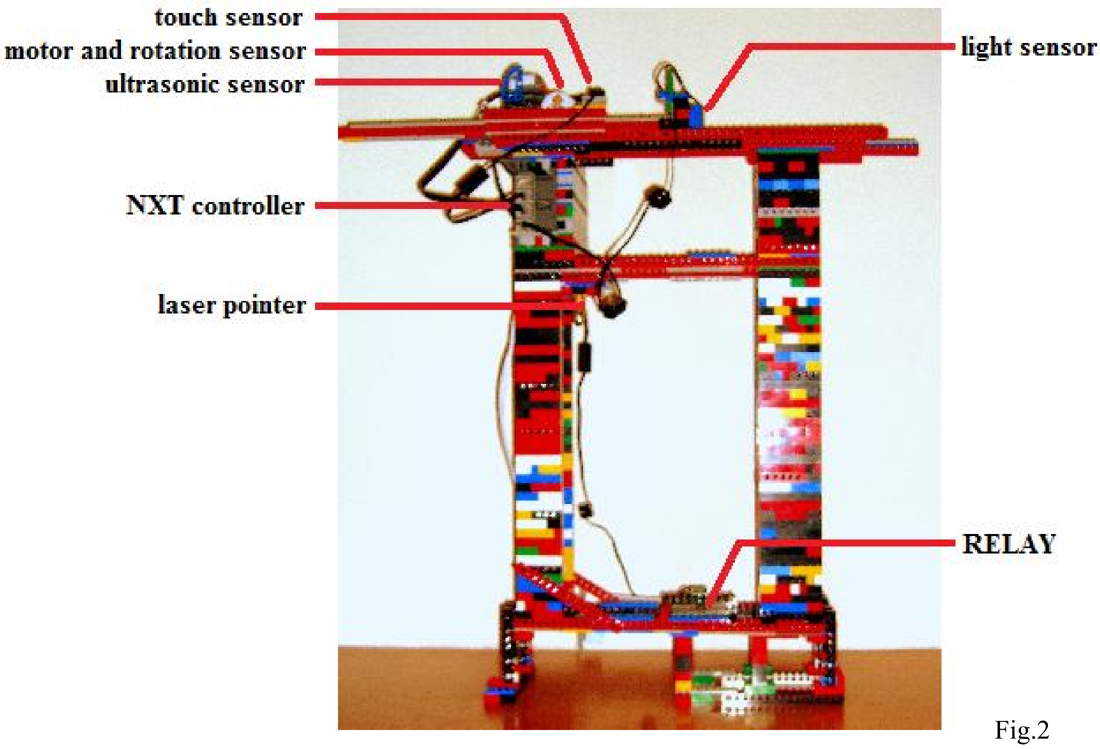


Fig.2

- Light sensor

  The light sensor is connected to a rack which is powered by a motor. It moves horizontally on the top of the device to detect the reflected laser light.(Fig.3)

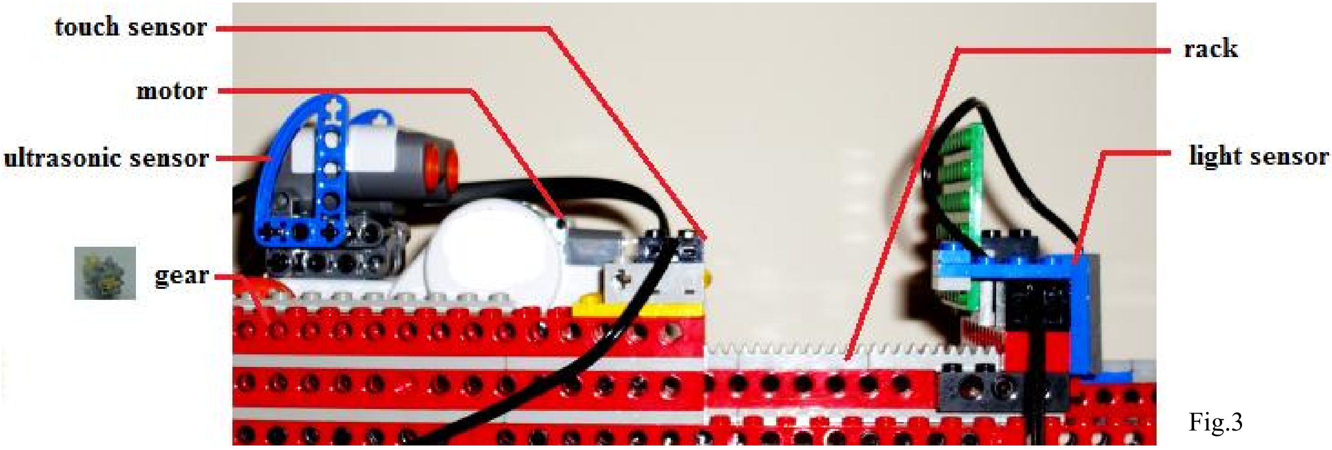


Fig.3

- Laser pointer

  The laser pointer can revolve in all directions by using revolving spindles to aim on the mirror.(Fig.4)

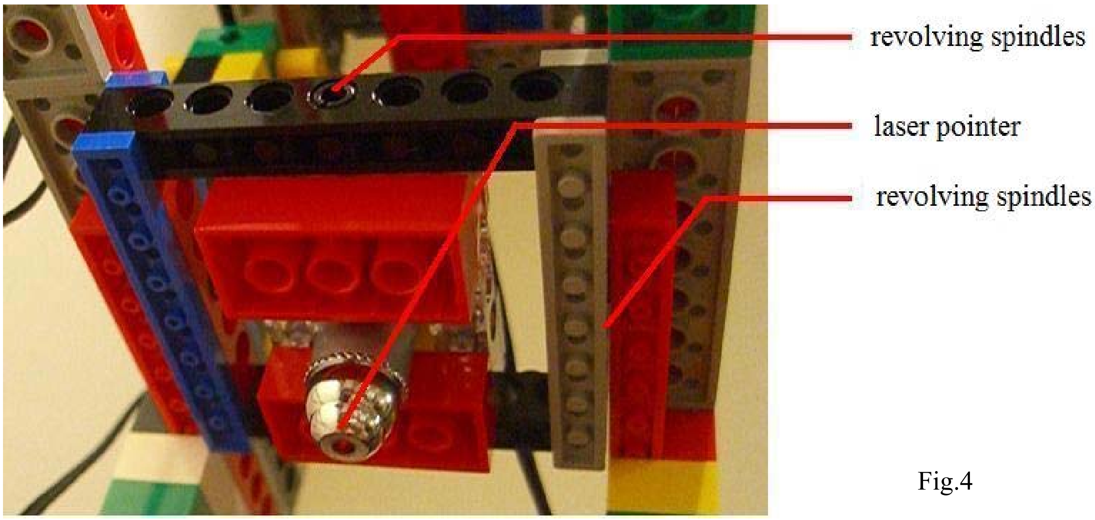


Fig.4

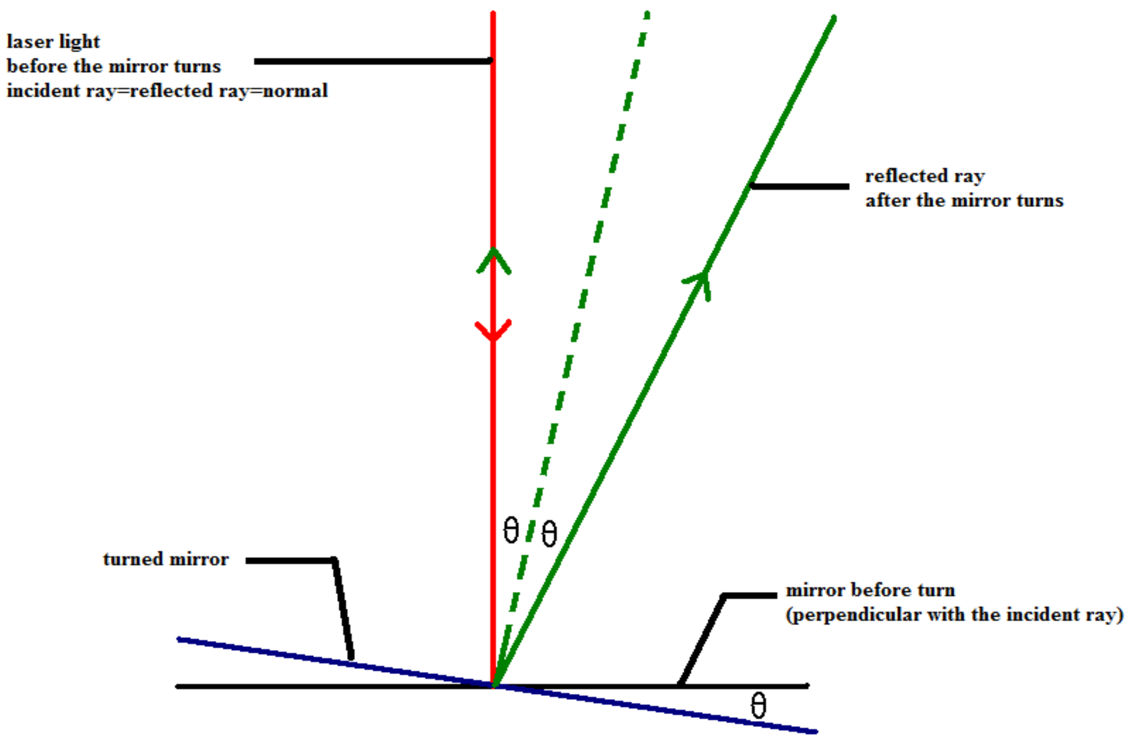
1. Inputs and outputs

   Output: The motor is powered by the NXT controller. The laser pointer is powered by the batteries connected to the relay, which is controlled by the NXT controller.

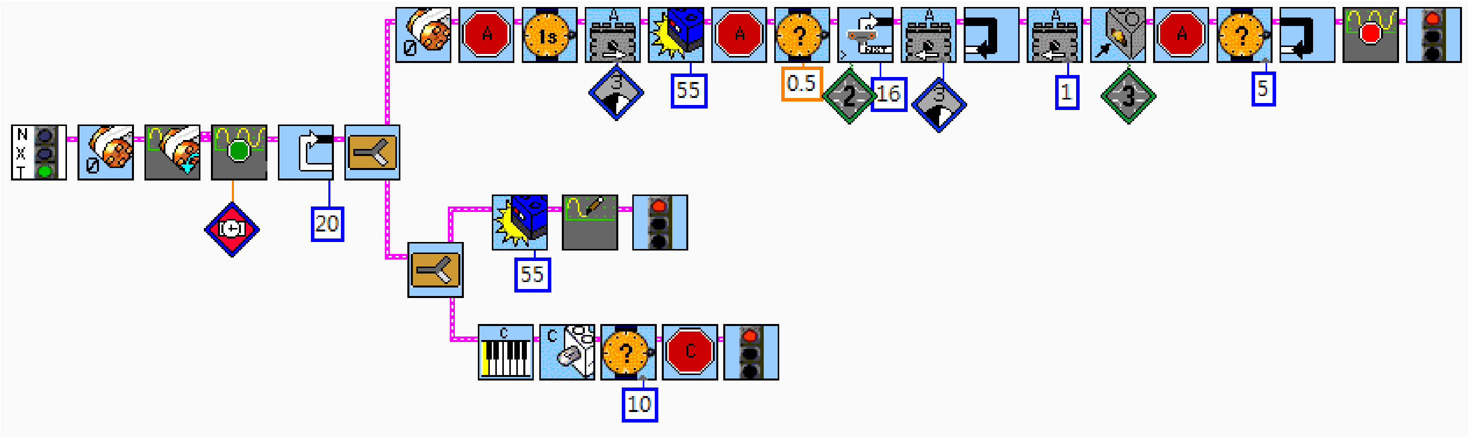
   Input: The light sensor and the angle sensor transmit the results back to the NXT controller.

2. The routine of the light

   If the angle of incidence light is fixed, when the mirror turns a θ angle, the angle of reflection will turn 2θ angle



3. The design chart of the program



There are three tasks in this program.

The first task controls the rotation of the motor. By using the light sensor , ultrasonic sensor and the touch sensor, the motor will be ordered to turn the opposite way, slow down and stop.

The second task is about logging the data. The NXT logs the value of the rotation sensor when the light sensor receives the reflected laser light.

The third tasks controls the laser pointer.

Methods

By applying the light lever principle on Lego bricks, this research uses the LabVIEW graphical programming system to design a device which is able to automatically measure small dynamic changes. The four tests below are done to validate the precision of this device.

Test 1 < The height of a drop of water>

- Calculate the height of a drop of water
  1. Divide 1ml by the amount of drops to calculate the volume of one drop of water. Use <volume=area×height>to calculate the height of one drop of water.
  2. Take a beaker in the diameter of 5 cm
  3. The volume of one drop of water÷the area of the bottom of the beaker =the height of one drop of water
- Measure the height of a drop of water with the small dynamic changes measuring device
  1. Add water in a beaker with the diameter of 5 cm, and put a piece of Styrofoam on the surface.
  2. Make the Styrofoam touch the point on the plastic board that is 1cm from the fulcrum and balance the plastic board.(Fig.5)
  3. Adjust the laser pointer to let the reflected laser light be detected by the light sensor.
  4. Drip a drop of water into the beaker and measure the change of the water level.
  5. Transfer the results back to the computer from the NXT controller.

Fig.5

Test 2<The growth of a bean sprout in one hour>

- Observe the change of the height of the bean sprout in eight hours
  1. Measure the height of the bean sprout and keep record.
  2. Measure the height of the bean sprout eight hours later and record the changes.
  3. Calculate the average of the growth of a bean sprout in one hour.
- Measure the growth of a bean sprout with the small dynamic changes measuring device
  1. Put a bean sprout under the device and adjust it until the top of the bean sprout touches the point on the plastic board that is 1cm from the fulcrum.(Fig.6)
  2. Adjust the laser pointer to let the reflected laser light be detected by the light sensor.(Fig.7)
  3. Start the program which runs every 10 minutes.
  4. Transfer the results back to the computer from the NXT controller

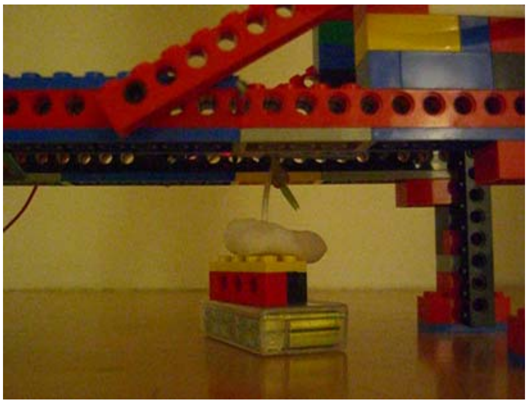


Fig.6

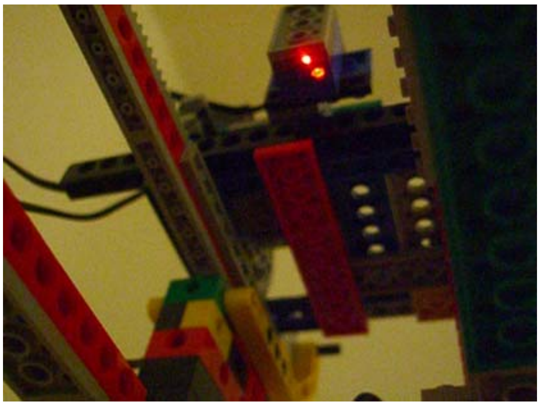


Fig.7

Test 3<The transpiration of celery>

- The transpiration of celery without leaves
  1. Cut off the leaves on the celery and stick it into a glass of water.(Fig.8)
  2. Put a Styrofoam on the surface of the water; make the Styrofoam touch the point on the plastic board that is 1cm from the fulcrum and balance the plastic board.
  3. Start the program which runs every 10 seconds.
  4. Transfer the results back to the computer from the NXT controller.
- The transpiration of celery with leaves
  1. Stick the celery into a glass of water.(Fig.9)
  2. Put a Styrofoam on the surface of the water; make the Styrofoam touch the point on the plastic board that is 1cm from the fulcrum and balance the plastic board.
  3. Start the program which runs every 10 seconds.
  4. Transfer the results back to the computer from the NXT controller.

Fig.8

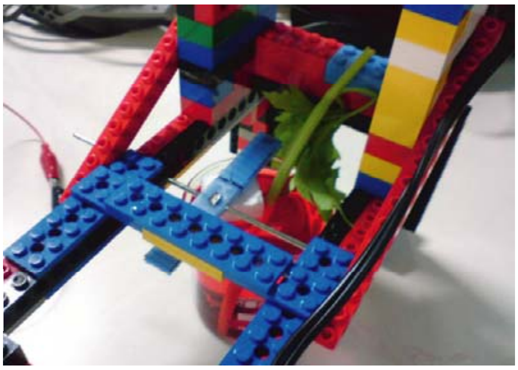


Fig.9

Test 4<The evaporation of water>

- The evaporation of water that is 50°c
    1. Fill a 100ml beaker with water that is 50°c.
    2. Put a Styrofoam on the surface of the water; make the Styrofoam touch the point on the plastic board that is 1cm from the fulcrum and balance the plastic board.(Fig.10)
    3. Start the program which runs every 5 seconds.
    4. Transfer the results back to the computer from the NXT controller.
- The evaporation of water that is 70°c
    1. Fill a 100ml beaker with water that is 70°c.
    2. Put a Styrofoam on the surface of the water; make the Styrofoam touch the point on the plastic board that is 1cm from the fulcrum and balance the plastic board.
    3. Start the program which runs every 5 seconds.
    4. Transfer the results back to the computer from the NXT controller.

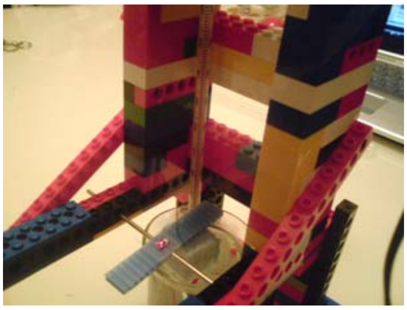


Fig.10

Results

1. The height of a drop of water
   - Calculated value

     The height of one drop of water (0.1ml)in a beaker with the diameter of 5cm is 0.005093cm.
   - Measurement value

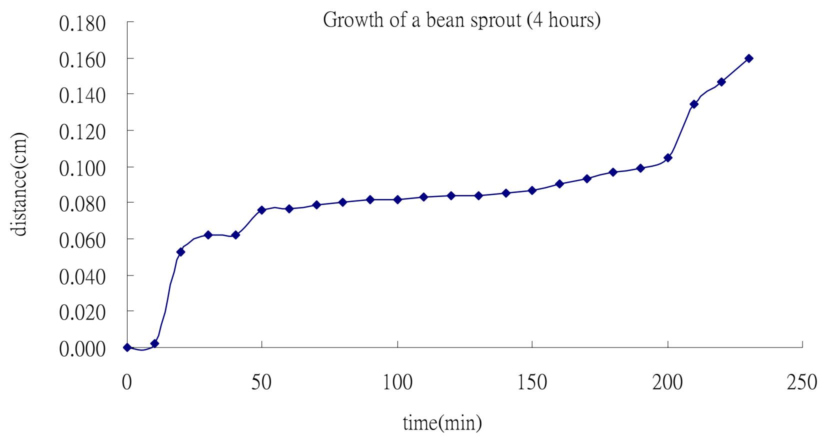
     The measurement value of a drop of water is between 0.00450~0.00568cm
2. The growth of a plant in 8 samples
   - Calculated value

plant	1	2	3	4	5	6	7	8
7:30	18.5	14.5	13	7	9	13.5	10	11.7
15:30	19.2	15.3	13.8	8	10.1	14.2	10.8	12.4
Changes in 8 hrs	0.7	0.8	0.8	1	1.1	0.7	0.8	0.7

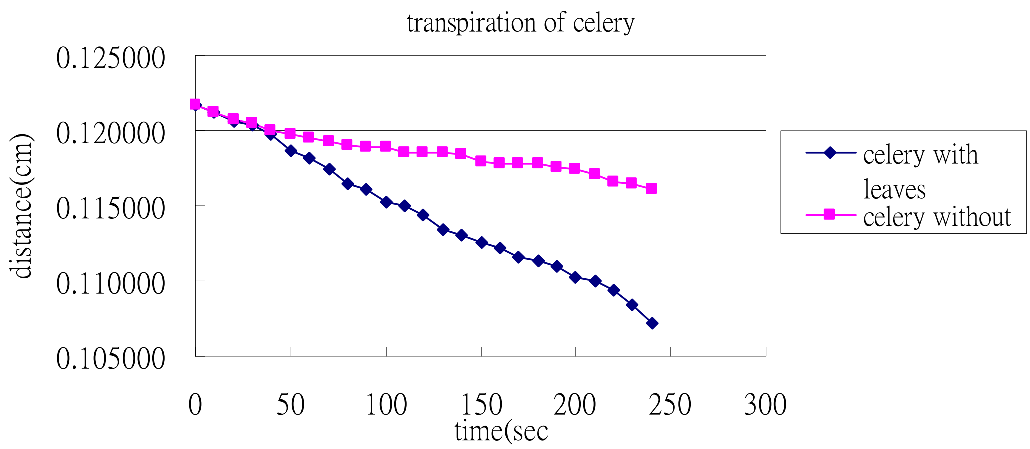
Unit: cm

The bean sprout grows 0.7~1.1cm in 8 hours, the average growth in one hour is 0.0875~0.1375cm

   - Measurement value



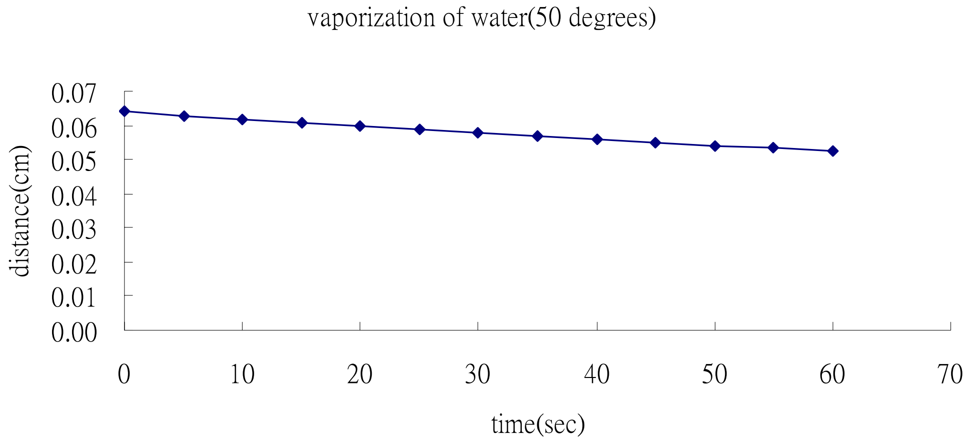
3. Compare the transpiration of celery between celeries with and without leaves



4. The evaporation of water in 1 minute

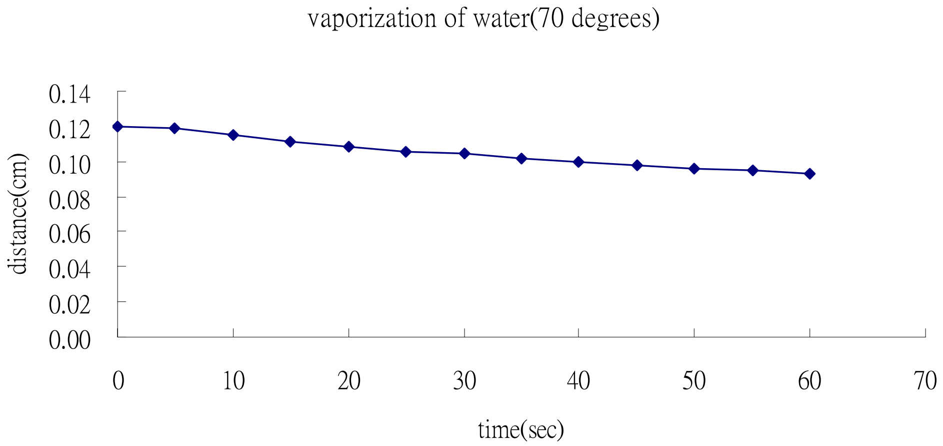
The evaporation of water that is 50°c

Time(sec)	0	5	10	15	20	25	30
Distance(cm)	0.0641	0.0629	0.0617	0.0606	0.0599	0.0586	0.0577
Time(sec)	35	40	45	50	55	60	
Distance(cm)	0.0567	0.0560	0.0550	0.0540	0.0532	0.0524	



The evaporation of water that is 70°c

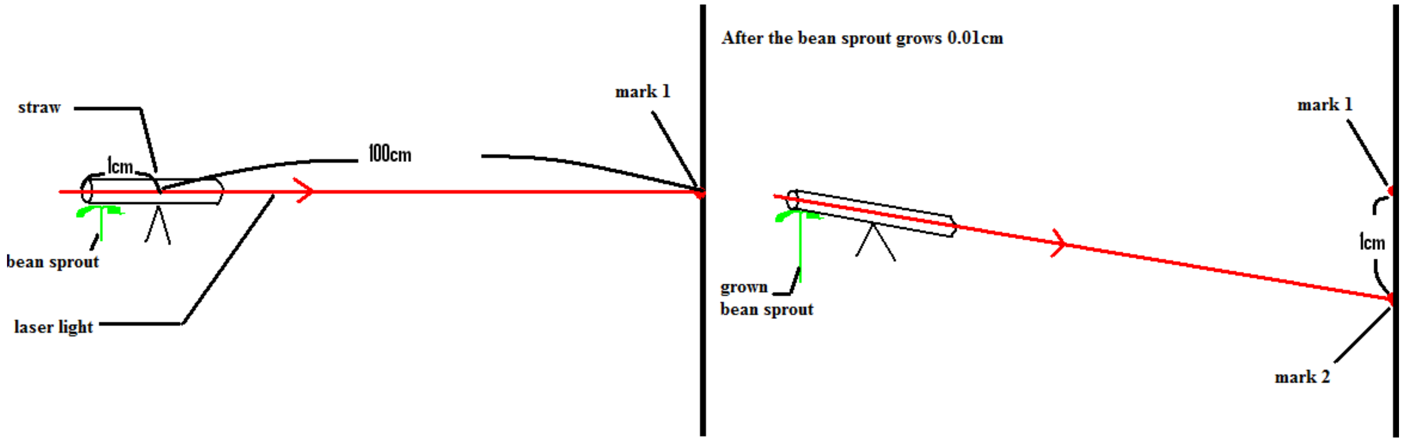
Time(sec)	0	5	10	15	20	25	30
Distance(cm)	0.1202	0.1187	0.1153	0.1108	0.1088	0.1057	0.1041
Time(sec)	35	40	45	50	55	60	
Distance(cm)	0.1017	0.1001	0.0982	0.0962	0.0949	0.0931	



Discussion

1. Compare and contrast between the lever principle and the light lever principle

   At the beginning of this research I once thought about using the lever principle. The lever principle is simpler, but it has a problem of using a big space. After I switched to use the light lever principle, the space that the experiment needs reduced.



2. Why did I use LEGO?

   In our everyday life, there are lots of things that could be used as the material for the structure, such as: popsicle sticks, chopsticks… But the effects from the outside environment often cause the deformation of these materials. Also, materials like acrylic or metal are not flexible to be easily rebuilt. I started to play with LEGO bricks when I was little, so I am very familiar with it. I know that every brick has its constant standard, which reduces the error. It is also convenient to improve the device by only assembling the bricks.

3. Compare the small dynamic changes measuring device created in this research with the Vernier Caliper and the screw micrometer

   The Vernier Caliper and the screw micrometer are common tools used to precisely measure lengths of objects. The object has to be placed between the jaws while being measured by these two instruments, so deformable things such as bean sprouts can not be measured. A Vernier caliper has a least count of 0.02 mm; and the least count of the screw micrometer is 0.01 mm. The small dynamic changes measuring device created in this research also has the least count of 0.01 mm and is able to measure the changes of liquids and plants as well, but this device still cannot measure the inside and outer dimensions of objects.

4. The evolution of the prototype

I designed several prototypes and each of them played an important role in the evolution of this small dynamic changes measuring device.

● **Structure**

a. The first generation: The first generation is created by using the light lever principle. I had a problem of controlling the distance between the ruler(Fig.11-1) and the mirror(Fig.11-2).

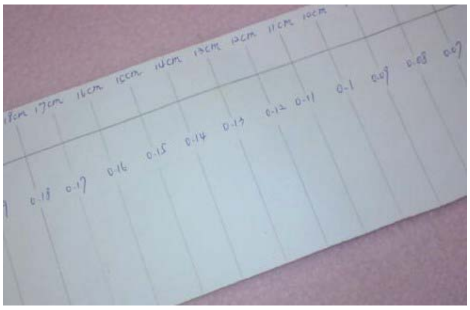


Fig.11-1

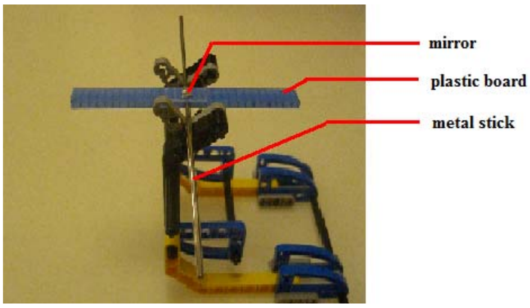


Fig.11-2

b. The second generation: I used plastic LEGO sticks to build a structure so that the vertical distance between the ruler and the mirror is fixed. But the structure made from plastic LEGO sticks is not stable enough and caused the inaccuracy of the experiment.(Fig.12)

Fig.12-1

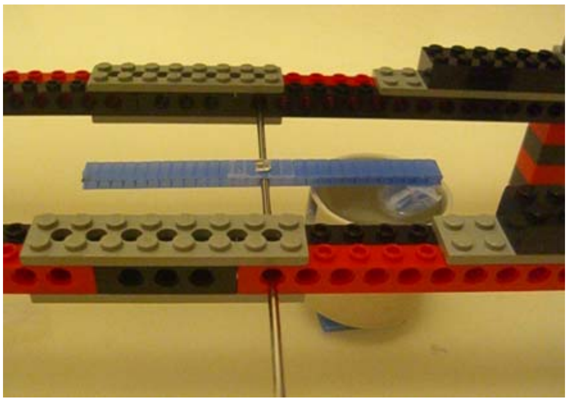


Fig.12-2

c. The third generation: In the third generation, I used solid bricks instead of plastic rods to improve the stableness of the structure.(Fig.13)

Fig.13-1

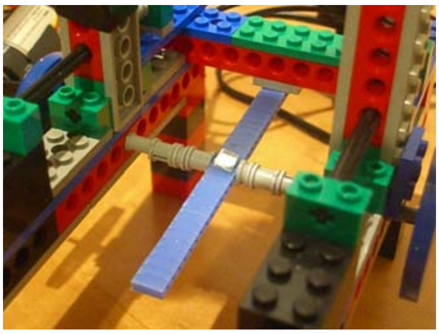


Fig.13-2

d. The fourth generation: In order to make the experiments more convenient, the fourth generation used automatic control and sends results to the computer. I decided to set a motor and light sensor on the structure.(Fig.14-1) In order to support the weight above, I created a stronger structure. (Fig.14-2)

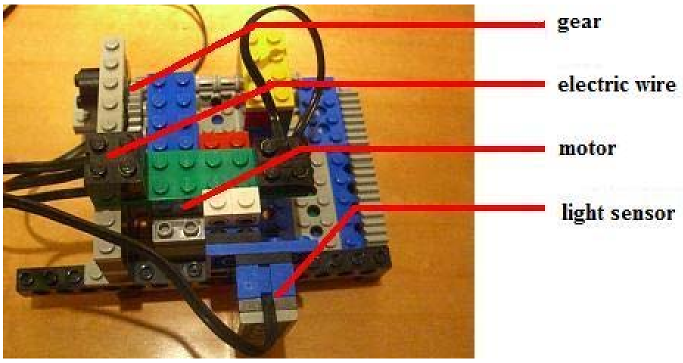


Fig.14-1

Fig.14-2

e. The fifth generation: In the process of the experiment, I found that the laser light got weaker as the time went by. Therefore, I added a RELAY on the fifth generation so that the switch of the laser pointer can be controlled by the RCX controller.(Fig.15)

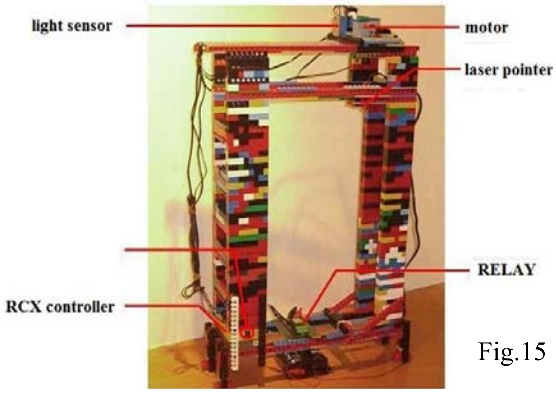


Fig.15

f. The sixth generation: In the sixth generation I used the NXT controller and the NXT motor with a built in rotation sensor instead of the RCX and RCX motor. I also added an ultrasonic sensor to detect the distance between the touch sensor and the light sensor. In the fourth and fifth generation, the vibration of the device was a big problem, I fixed the motor on the main structure and slowed down the speed of the motor in the sixth generation. (Fig.16)

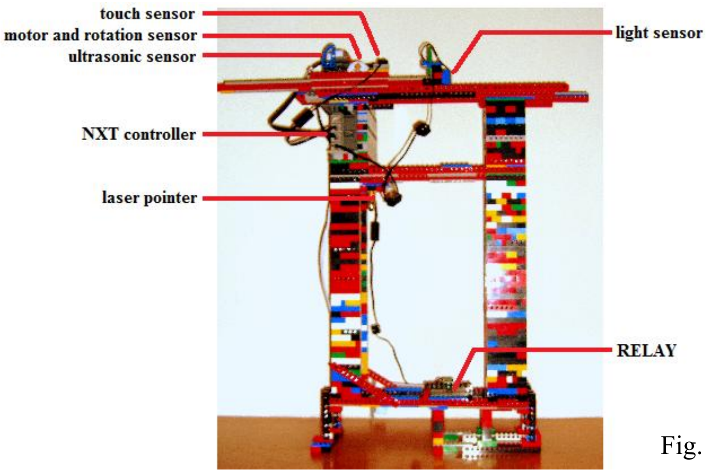


Fig.16

- **Laser pointer**

a. In the first and second generation, the laser pointer is fixed on a acrylic box.(Fig.17)

b. In the third generation, I stuck the laser pointer into an eraser and put it in a set of LEGO bricks. It can let the laser pointer make small adjustments, but the laser pointer is still not easy to control. (Fig.18)

Fig.17

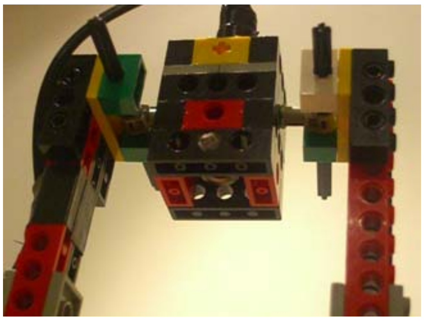


Fig.18

c. The revolving spindles allow the laser pointer in the fourth and fifth generation to turn in all directions.(Fig.19)

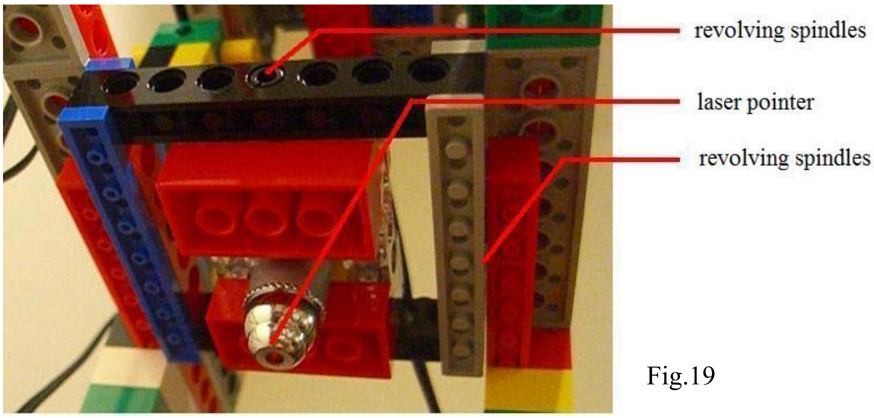


Fig.19

d. Because the laser light gets weaker as the time goes by, I added a RELAY on the fifth generation so that the switch of the laser pointer can be controlled by the RCX controller.(Fig.20)

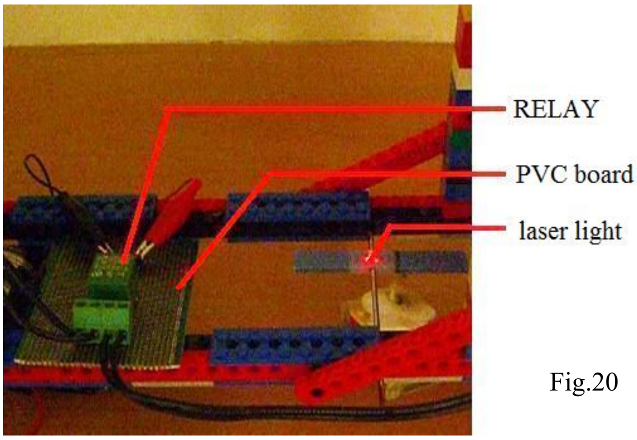
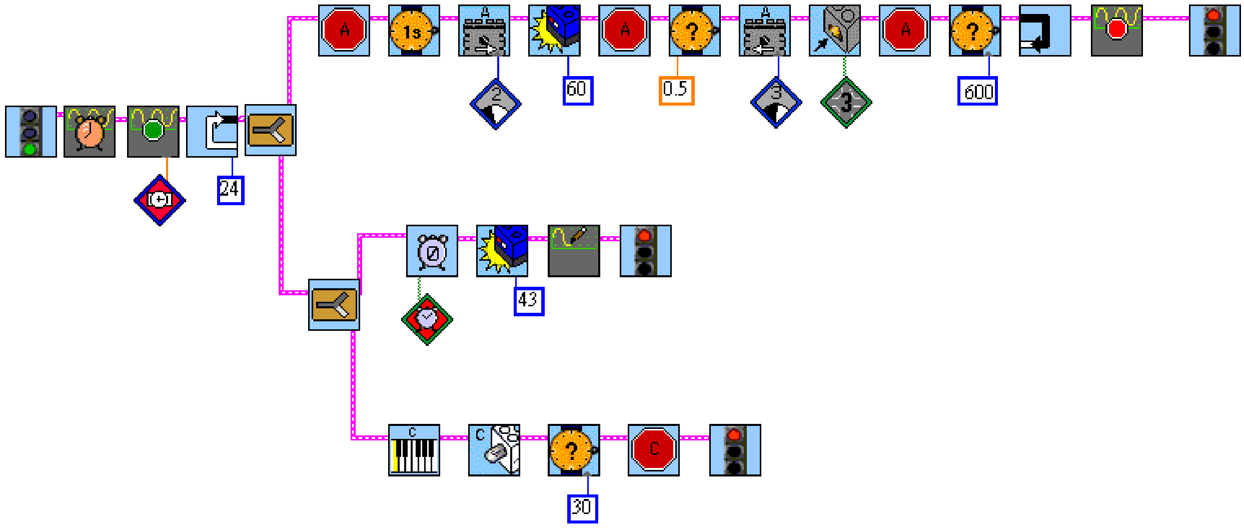


Fig.20

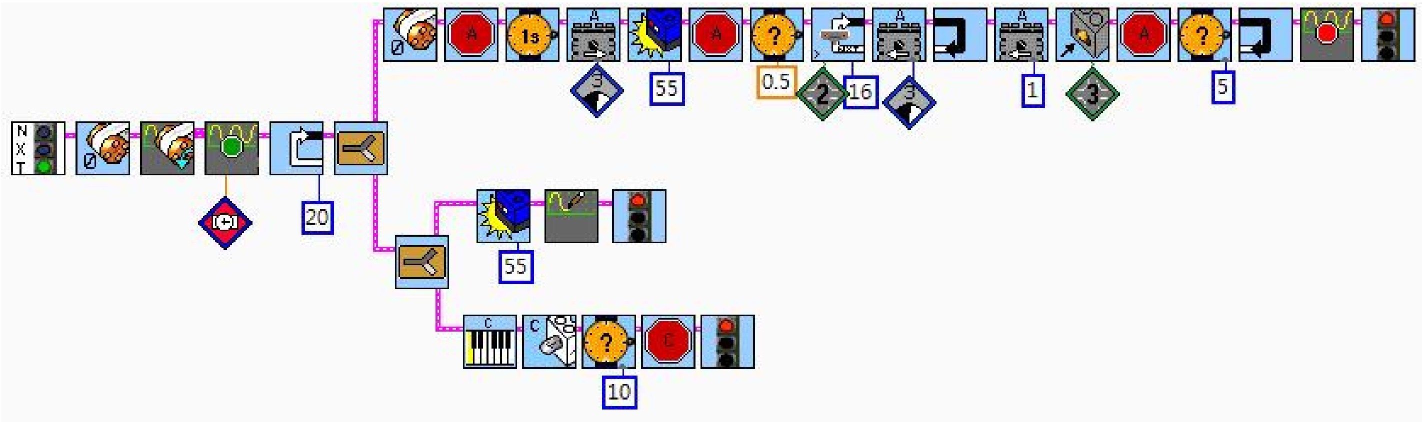
- **Program**

a. The program of the fourth and fifth generations



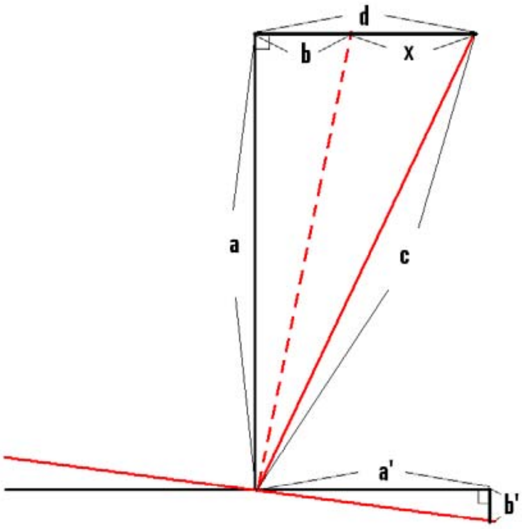
In the fourth and fifth generation, I used the timer to calculate the distance (time × speed).

b. The program of the sixth generation



In the sixth generation, I used the NXT controller and the NXT motor instead of the RCX controller and the RCX motor, because the NXT controller has more input ports and the NXT motor has a built in rotation sensor. By using the value of the rotation sensor to calculate the distance (rotated degrees/360 × 2.984) we don't have to consider whether the speed of the motor is constant. I can also use the difference of the speed of the motor to reduce the vibration of the device.

5. The calculation of the ruler



$$a = 50cm \qquad a' = 1cm$$

$$\frac{c^2}{a^2} = \frac{x^2}{b^2}$$

$$\frac{a^2 + (b+x)^2}{a^2} = \frac{x^2}{b^2}$$

$$b^2a^2 + b^2(b+x)^2 = a^2x^2$$

$$b^2a^2 + b^2(b^2 + 2bx + x^2) = a^2x^2$$

$$b^2a^2 + b^4 + 2b^3x + b^2x^2 = a^2x^2$$

$$(a^2 - b^2)x^2 - 2b^3x - (b^2a^2 + b^4) = 0$$

$$x = \frac{2b^3 \pm \sqrt{4b^6 + 4(a^2 - b^2)(b^2a^2 + b^4)}}{2(a^2 - b^2)} = \frac{2b^3 \pm \sqrt{4b^2a^4}}{2(a^2 - b^2)} = \frac{2b^3 \pm 2ba^2}{2(a^2 - b^2)}$$

$$\frac{2b(b^2 - a^2)}{2(a^2 - b^2)} = -b(\text{不合})$$

$$\frac{2b(b^2 + a^2)}{2(a^2 - b^2)} = \frac{b(a^2 + b^2)}{(a^2 - b^2)}$$

$$x = d - b$$

$$d - b = \frac{b(a^2 + b^2)}{a^2 - b^2} \quad \text{又 } b = 50b'$$

$$50b' + \frac{50b'(1 + b'^2)}{1 - b'^2} = d$$

$$db'^2 + 100b' - d = 0$$

$$b' = \frac{-50 \pm \sqrt{2500 + d^2}}{d}$$

6. The difference of the meaning between the average value of 8-hour growth of bean sprout and that in one hour
7. In normal situations, people cannot tell if a plant grows in a short time. However, according to the measurements of this small dynamic changes measuring device, the growing rate of a plant is not all the same in each hour. This device is able to not only measure small dynamic changes, but also provide a more accurate result for scientists who researches on plants.
8. Applications

The measurement of the small changes of the water level

a. The small dynamic changes measuring device is able to measure the change of the water level after dripping a drop of water.
b. The evaporation of water

If the substance is hotter, then evaporation will be faster. Although this fact can be observed in experiments, there are still many factors influencing the rate of evaporation. The temperature of the water will decrease as the time goes by so there will differences between the theory and the actual measured results. By using this small dynamic changes measuring device, the evaporation of water can be measured in a shorter time and the influence of different factors will be reduced.

The measurement of the growth of a bean sprout

In biology class at school, we seldom make observation of plants, because the growth of a plant is too slow to be observed in the time of a class. By using this small dynamic changes measuring device, these observations can be finished in less than an hour.

The measurement of the transpiration of celery

This test is done to investigate the evaporation of water from the leaves of the celery. The fact that the transpiration of celeries with leaves is bigger than the celeries without leaves can be observed in three minutes.

9. The error between the calculated value and the measurement value
The percent error is 1.15％.
10. The error may be caused by factors, such as having bubbles in the pipettor or the water adhering on the beaker.

Future work

1. The future research will be focused on further research in the growth of a plant in a short time.
2. To add a mirror in the middle of the device so that the space that the experiment needs can be reduced.
3. To make a device that can adjust its height in order to measure objects or plants in different sizes.

Conclusions

1. Functions

   This small dynamic changes measuring device can increase the small dynamic changes to a 1000 times bigger value which makes observing small dynamic changes easier, such as, the growth of a plant in a short time, the vaporization of water, the evapotranspiration of celery, or the thickness of damped paper.

2. Advantages

   a. This device is able to increase the small changes to the size that could be recognized by the human eyes.

   b. This device is able to measure dynamic changes.

   c. This device is automatic controlled and is able to record the results.

References

1. 陳可崗 譯(2004)。觀念物理 IV 聲學、光學。天下文化。117-118。
2. 商兆編輯部/編。實用物理公式定理辭典。商兆文化。
3. 國中數學部編版第四冊，第二、三單元商高定理、一元二次方程式。
4. 國中理化南一版，3-2 面鏡成像。

評語

1) 本作品結合樂高積木與 LABVIEW 程式的控制，並利用光槓桿原理設計出可自動量測連續性微小變化的儀器。透過多次系統結構的改良，量測精度可達 10^{-3}cm，並可測知植物每小時的生長高度變化量；作品是不可多得的佳作。

2) 本文若能在系統結構及微小變化的設置改良上多加改善，其結果將更具吸引力，值得多加鼓勵。