Summary - A Study of Different Plastics

Best Plastic to chose for:

Clear side panel – Acrylic
Bottom Panel – UHMWPE
Electronics shield outside – polycarbonate
High impact Mechanisms – ABS
Solid Side panel – UHMWPE
Light sensor – Acrylic or PETG
Electronics shield inside – PETG

Ranking Plastics (Raw data is on page 8)

Tests from published sources* 5 = Best – 1 = Not Good

	ABS	Acrylic	PETG	Polycarbonate	UHMWPE
Tensile Strength Ultimate Mpa [1]	1	3	4	2	5
Izod Impact strength ft*lbs/in [2]	3	1	2	4	5
Flexural modulus Gpa [2]	5	4	2	3	1
Coefficient of Friction [1]	NA	3	NA	4	5
Compressive Strength Yield psi [2]	3	5	NA	4	2
Heat Deflection Temperature at 66 psi F^{O} [2]	2	3	5	1	4
Surface resistivity ohm/sq [2]	4	3	NA	4	5
Density g/cc [1]	1	2	4	3	5
Cost 30^{cm2} $ [3]	4.05	11.19	2.31	15.59	7.95

Tests by Katherine Silversides**

	ABS	Acrylic	PETG	Polycarbonate	UHMWPE
Ultrasonic cm	No	No	No	No	No
Colour	No	Yes	Yes	Yes	Yes
Compass	Yes	Yes	Yes	Yes	Yes
IR	No	Yes	Yes	Yes	Yes
Light	No	Yes	Yes	Yes	No
My Coefficient of Friction	5	1	2	3	4
Bounce Mean	4	2	3	5	4
Heat 5min	2	3	5	1	4

1 MatWeb. 1996-2012 Material Category Search.[Online]. Availale from: http://www.matweb.com/search/MaterialGroupSearch.aspx Accessed 2012 March 6.
2 Plastics International. Material Properties. [Online]. Availale from: http://www.plasticsintl.com/sortable_materials.php Accessed 2012 March 6.
3 In Canadian dollars, Industrial Plastics, 776 Cloverdale Ave. Victoria , on 2012 March 27
* See appendix A for more information on these tests
** See appendix B for more information on these tests

This Plastic, That Plastic: A Study of Different Plastics

By Katherine Silversides
3yr member of a *FIRST* Tech Challenge team

Purpose: To learn about the differences between the plastics, run tests with the plastics, and compile the information in an easy to understand format for anyone who is choosing which plastic to use for what purpose.

Background

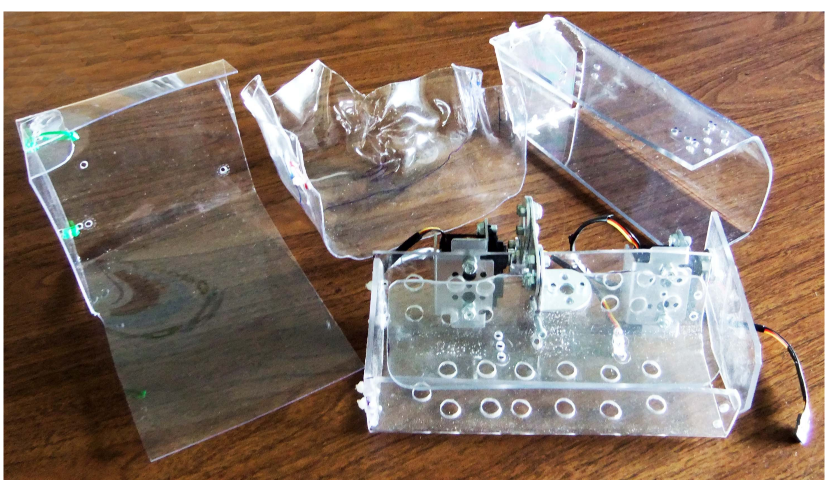
As part of a robotics team, I make some parts for our robots out of plastics. The competition limits teams to non-reinforced plastics. They can't be greater than 1/8" in thickness and must start out as a flat sheet. Other than those limits, it's up to each team to choose which plastic to use in creating functional parts for their robot.

I've needed to cut, mold, shape, and generally create many different parts out of plastics. Most of the time, I just use whichever plastic is at hand. From my experience, I found that some plastics seem to be better at different jobs, but it's just been trial and error. At tournaments this year, we noticed that some robot teams had a competitive advantage by knowing which plastic to use for a specific function.

For the study, I've compiled data from Plastics International and MatWebber to gather basic information like density, weight, tensile strength, ect. I have found the cost for each plastic. In addition, I've run my own tests to discover:

- How objects react when they hit the plastic;
- Differences in surface friction;
- How do the plastics react to heat;
- Do sensors we use, gather data through plastic;

For each plastic, there is information on names, test data, description, chemical formula, and final results. At the end, there is a page with all the test data for the plastics, followed by two appendixes explaining the tests and a glossary is in Appendix C.



Poly(Acrylonitrile Butadiene Styrene) - ABS

Other names are; ABS, Cycolac®, Lustran®
Cost 30cm² ~ $4.05

Tests from published sources		
Tensile Strength Ultimate Mpa	27-49	Mid range
Izod Impact strength ft*lbs/in	7.7	Higher end
Flexural modulus Gpa	1.2-5.5	Mid range
Coefficient of Friction	NA	NA
Compressive Strength Yield	2900	Higher end
Heat Deflection Temperature at 66 psi F°	214	Higher end
Surface resistivity ohm/sq	10^{15}	Mid range
Density g/cc	1.03-1.17	Mid range
Tests by Katherine Silversides		
Ultrasonic cm	6	No
Colour	0	No
Compass	98	Yes
IR	0	No
Light	27-76	No
My Coefficient of Friction	0.99	Low
Bounce Tests	130-140	Mid range
Heat	10–7.2	Bendable

Poly(Acrylonitrile Butadiene Styrene)
$(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$

My test sample was 3.17mm thickness and black in colour. It could be flexed, and has a smooth slippery surface.

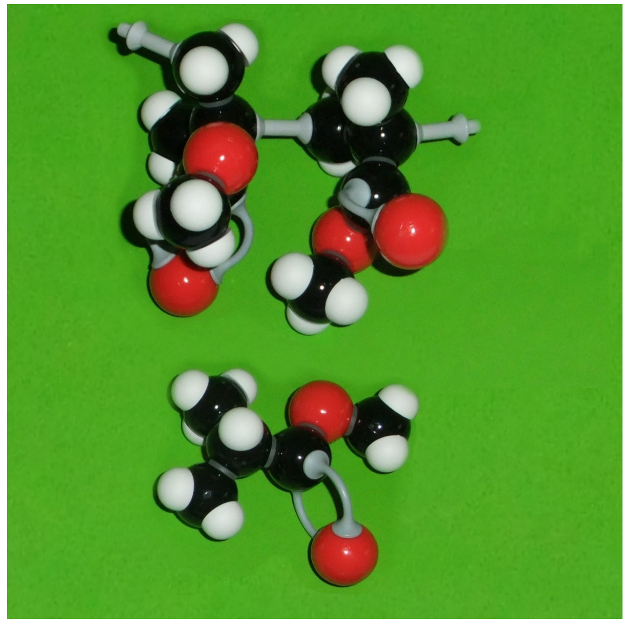
ABS is a good, all around plastic. It's an inexpensive plastic, that can be molded with the heat gun. The sample I used was black which effected some of the sensor tests. I'd like to get a clear piece and then rerun the tests to see if it can be used to protect a sensor. ABS has the strongest compression test results, which means it suitable for a moving part that would be under a lot stress on a robot.

Poly(methyl methacrylate) - Acrylic

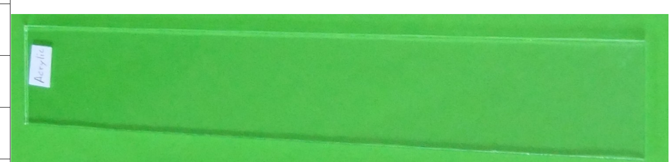
Other names are; Acrylic, PMPM, Plexiglas®
Cost 30cm^2 ~ $11.19

Poly(methyl Methacryate)

$(C_5O_2H_8)_n$



Tests from published sources		
Tensile Strength Ultimate Mpa	30-75	Mid range
Izod Impact strength ft*lbs/in	0.28	Low
Flexural modulus Gpa	1.38 -3.3	Mid range
Coefficient of Friction	0.45-0.8	NA
Compressive Strength Yield psi	17000	Higher end
Heat Deflection Temperature at 66 psi F^O	205	Mid range
Surface resistivity ohm/sq	10^{14}	Mid range
Density g/cc	1.15-1.19	Mid range
Tests by Katherine Silversides		
Ultrasonic cm	6	No
Colour	4or3	Yes
Compass	98	Yes
IR	5	Yes
Light	77	Yes
My Coefficient of Friction	1.04	High
Bounce Tests	150-160	Low
Heat	10 – 6.3	workable



My test sample was 3.17mm thickness, very clear, can be flexed,has a smooth surface.

Acrylic is a very clear plastic. The light sensor tests were almost identical to the readings when there was no plastic. It got most unusual results in the bounce tests, with the ball moving in an arc compared to a straight line for all the other plastics. It might be useful to use this feature, depending on the game rules and game element in a robotics challenge.
Acrylic would be a good covering to protect sensors, but is expensive for use for large parts.

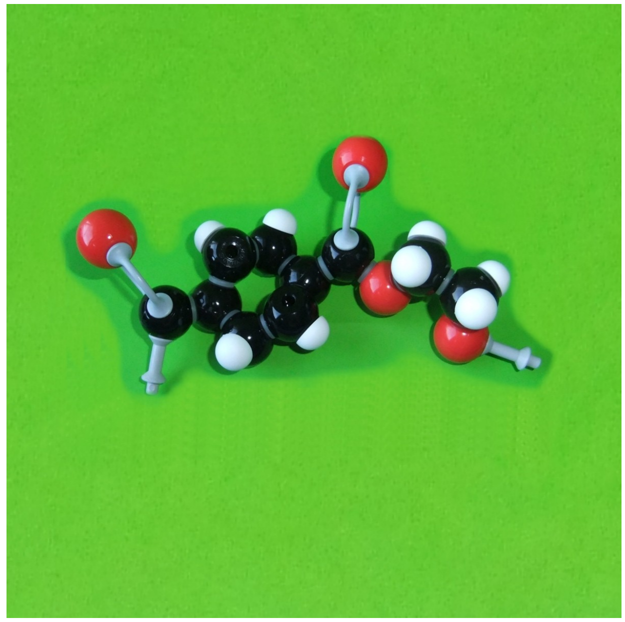
Poly(ethylene terephthalate) glycol - PETG

Other names are; PETG, Vivak®
Cost $30cm^2$ ~ $2.31

Tests from published sources		
Tensile Strength Ultimate Mpa	26-57.9	Mid range
Izod Impact strength ft*lbs/in	1.7	Lower
Flexural modulus Gpa	1.24-2.76	Mid range
Coefficient of Friction	NA	NA
Compressive Strength Yield	NA	NA
Heat Deflection Temperature at 66 psi F°	164	Low
Surface resistivity ohm/sq	NA	NA
Density g/cc	1.22-1.19	High
Tests by Katherine Silversides		
Ultrasonic	5	No
Colour	17 or 4	Yes
Compass	98	Yes
IR	5	Yes
Light	77-78	Yes
My Coefficient of Friction	1.02	Mid range
Bounce Tests	135-145	Mid range
Heat	7.8-3.3	Molded

PET Poly(ethylene terephthalate)

$(C_{10}H_8O_4)_n$



I couldn't find a good example of PETG. This PET molecule needs to be modified with glycol to make PETG.

My test sample is 1.58mm thickness, clear, and flexible. A a large piece can be bent by hand. PETG can be cut with a good pair of scissors. It has a very smooth, hard surface.

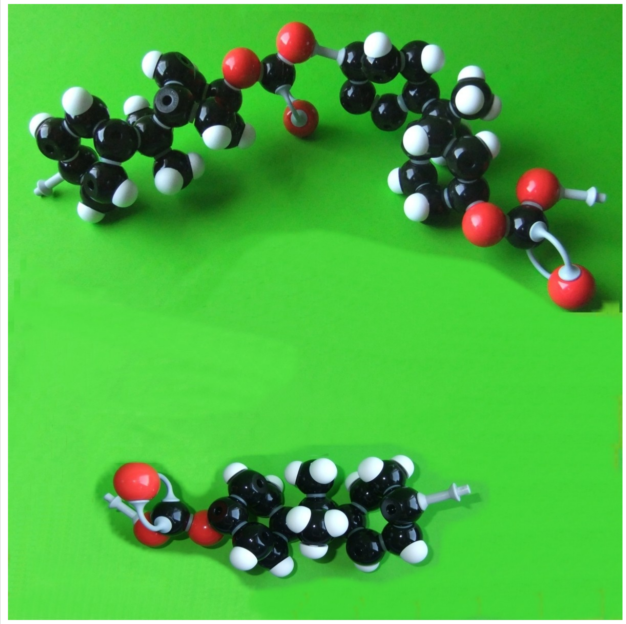
PETG is an inexpensive, thin plastic that is good for prototyping shapes and mechanisms. It is very flexible even without the heat gun. It does not make the best protective shield for the side of a robot, even though it does have the highest density.

Polycarbonate - Lexan

Other names are; PC, Lexan®,Makrolon®
Cost 30cm^2 ~ $15.59

Polycarbonate

$(C_{16}H_{14}O_3)_n$



Tests from published sources		
Tensile Strength Ultimate Mpa	63.3-74	Very high
Izod Impact strength ft*lbs/in	14	Very high
Flexural modulus Gpa	2.09-3.1	Mid range
Coefficient of Friction	0.5-0.6	Higher end
Compressive Strength Yield	12500	Lower end
Heat Deflection Temperature at 66 psi F^O	280	Mid range
Surface resistivity ohm/sq	10^{15}	Mid range
Density g/cc	1.20-1.26	Higher end
Tests by Katherine Silversides		
Ultrasonic	5	No
Colour	17or4	Yes
Compass	98	Yes
IR	5	Yes
Light	76	Yes
My Coefficient of Friction	1.01	Higher
Bounce Tests	132.5	Mid range
Heat	9.5-8.3	Not easy to work

My test sample was 3.17mm thickness, clear, and very stable, but can be flexed. Polycarbonate has a smooth non-slippery surface.

Polycarbonate is a durable, but expensive plastic. Even with the heat gun, it is hard to shape which also showed up in the tensile strength tests. It would be good as a protective panel over electronics or other costly robot parts.

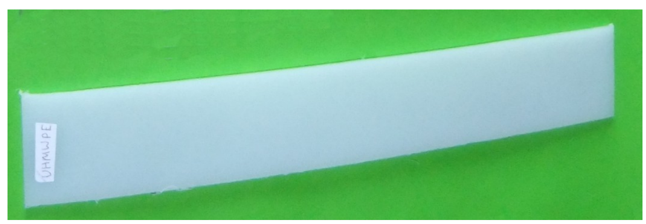
Ultra High Molecular Weight Polyethylene - UHMWPE

Other names are; UHMWPE, UHMW, Tivar®
Cost 30cm^2 ~ $7.95

UHMWPE

$(CH_2)_n$

Tests from published sources		
Tensile Strength Ultimate Mpa	0.13-85.5	Low
Izod Impact strength ft*lbs/in	No break	High
Flexural modulus Gpa	0.4-1.45	Low
Coefficient of Friction	0.02-0.35	Low
Compressive Strength Yield	2400	Mid range
Heat Deflection Temperature at 66 psi F°	180	Low
Surface resistivity ohm/sq	10^{17}	High
Density g/cc	0.93-1.45	High
Tests by Katherine Silversides		
Ultrasonic cm	9-8	No
Colour	4or3	Yes
Compass	98	Yes
IR	5	Yes
Light 2	67	Not good
My Coefficient of Friction	0.99	Low
Bounce Tests	135-140	High
Heat	8.3-5.8	workable



My test sample is 3.17mm thickness, white, opaque, flexible. A small piece can be bent by hand. It has a smooth, feels slippery, and has a natural curve in it.

UHMWPE is easy to shape with or without a heat gun. It is a low friction surface which could be a useful feature depending on what the robot needs to do. It is opaque making it unsuitable as a shield over a light sensor and it would block our view into the robot if it was used as side panels. However, from the impact strength test, it should not break even when hit by another robot. Also, it has the highest electrical resistance of the plastics, which would make for a less conductive robot frame or part.

Test Data Summary

Tests from published sources*

	ABS	Acrylic	PETG	Polycarbonate	UHMWPE
Tensile Strength Ultimate Mpa [1]	27 – 49	30 – 75	26 – 57.9	63.3 – 74	0.13 – 85.5
Izod Impact strength ft*lbs/in [2]	7.7	0.28	1.7	14	no Break
Flexural modulus Gpa [2]	1.2 – 5.5	1.38 – 3.3	1.24 – 2.76	2.09 – 3.1	0.4 – 1.45
Coefficient of Friction [1]	NA	0.45 – 0.8	NA	0.5 – 0.6	0.02 – 0.35
Compressive Strength Yield psi [2]	2900	17000	NA	12500	2400
Heat Deflection Temperature at 66 psi F° [2]	214	205	164	280	180
Surface resistivity ohm/sq [2]	10^{15}	10^{14}	NA	10^{15}	10^{17}
Density g/cc [1]	1.03 – 1.17	1.15 – 1.19	1.22 – 1.33	1.20 – 1.26	0.93 – 1.45
Cost 30^{cm2} $ [3]	4.05	11.19	2.31	15.59	7.95

Tests by Katherine Silversides**

	ABS	Acrylic	PETG	Polycarbonate	UHMWPE	Control
Ultrasonic cm	6	6	5	5	9 – 8	24-25
Colour	0	4 or 3	17 or 4	17 or 4	4 or 3	4
Compass	98	98	98	98	98	98
IR	0	5	5	5	5	5
Light	27 - 26	77	77 - 78	76	67	77-78
Friction mean	1562.4	1494.0	1522.4	1538.6	1565.4	1558.4
My Coefficient of Friction	0.997	1.041	1.023	1.013	0.996	1.000
Bounce Low	130	150	135	120	135	
Bounce High	140	160	145	140	140	
Bounce Mean	138.33	154	140	132.5	139	
Heat start	10	10	7.8	9.5	8.3	
Heat 1min	8.6	8.9	3.5	8.2	6.6	
Heat 2min	8.7	8.4	3.3	8.2	6.1	
Heat 5min	7.2	6.3	3.3	8.3	5.8	

1 MatWeb. 1996-2012 Material Category Search.[Online].
Availale from: http://www.matweb.com/search/MaterialGroupSearch.aspx Accessed 2012 March 6.

2 Plastics International. Material Properties. [Online].
Availale from: http://www.plasticsintl.com/sortable_materials.php Accessed 2012 March 6.

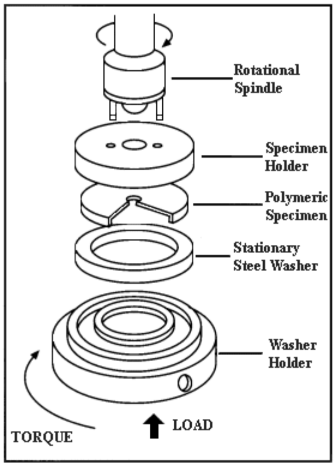
3 In Canadian dollars, Industrial Plastics, 776 Cloverdale Ave. Victoria , on 2012 March 27

* See appendix A for more information on these tests

** See appendix B for more information on these tests

Appendix A - Tests from published sources

Data for these tests came from MatWeb and Plastic International. A description for each of the measurement units can be found in the glossary.

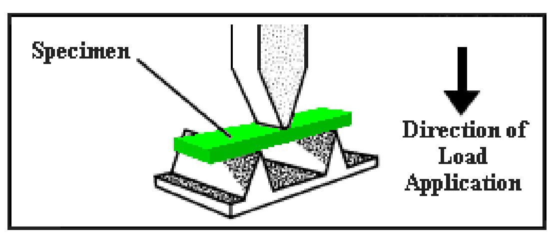


Coefficient of Friction, Matweb
ASTM D3702:
A polymeric sample specimen is mated against a steel thrust washer. The test apparatus is rotated and the torque required is measured. Other Coefficient of Friction test methods are ASTM D1894.
http://www.matweb.com/reference/coefficient-of-friction.aspx

Compressive Strength Yield, Plastic International
psi - Pounds per square inch
ASTM D695:
Compressive strength is the pressure required to yield or break a material when a compressive force is applied across a specified area. It is usually measured in lb/in2 or psi. The higher the compressive strength the stronger the material is in compression applications.
http://www.plasticsintl.com/explanations.php?property=compressive_strength
http://www.plasticsintl.com/sortable_materials.php?display=mechanical&sort=

Density, MatWeb
g/cc
The mass density or density of a material is defined as its mass per unit volume.
http://en.wikipedia.org/wiki/Density
http://www.matweb.com/

Flexural Modulus, MatWeb
Gpa - Gigapascals
ASTM D790:
Specimen of 1/8" x 1/2" x 5" is placed on two supports and a load is applied at the centre. The load at yield is the sample material's flexural strength.
http://www.matweb.com/reference/flexuralstrength.aspx

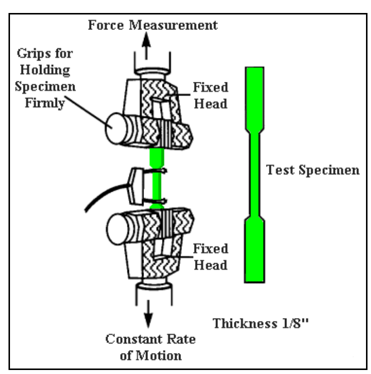


Heat Deflection Temperature at 66 psi, Plastic International
F° - Degrees Fahrenheit
ASTM D648:
Heat deflection temperature is defined as the temperature at which a standard test bar deflects a specified distance under a load. It is used to determine short-term heat resistance. It distinguishes between materials that are able to sustain light loads at high temperatures and those that lose their rigidity over a narrow temperature range. The higher the heat deflection temperature the more heat it can withstand under load.
http://www.plasticsintl.com/explanations.php?property=heat_deflection
http://www.plasticsintl.com/sortable_materials.php?display=thermal

Izod Impact Strength, Plastic International
ft*lbs/in - Foot*pounds/inch
ASTM D256:
Notched Izod Impact is a single point test that measures a material's resistance to impact from a swinging pendulum. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. This property is useful in comparing materials general toughness. The higher the value, the more impact resistance the material has and is also considered tough.
http://www.plasticsintl.com/explanations.php?property=izod_impact
http://www.plasticsintl.com/sortable_materials.php?display=mechanical&sort=

Surface Resistivity, Plastic International
ohm/sq - Ohms per Square
ASTM D257:
The surface resistivity of a material is the ratio of the potential gradient parallel to the current along the surface of a material to the current per unit width of the surface. Surface resistivity is numerically equal to the surface resistance between opposite sides of a square of any size when the current flow is uniform. Surface resistivity can also be thought of as the resistance to leakage current along the surface of an insulating material. The higher the surface/volume resistivity, the lower the leakage current and the less conductive the material is.
http://www.plasticsintl.com/explanations.php?property=surface_resistivity
http://www.plasticsintl.com/sortable_materials.php?display=electrical

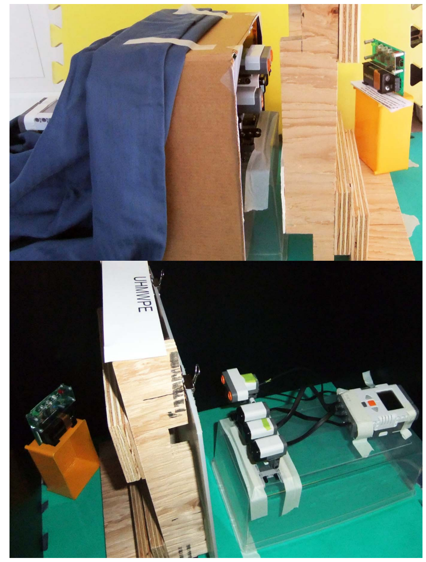
Tensile Strength Ultimate, MatWeb
Mpa - Megapascals
ASTM D638:
For this test, plastic samples are either machined from stock shapes or injection molded. The tensile testing machine pulls the sample from both ends and measures the force required to pull the specimen apart and how much the sample stretches before breaking.
http://www.matweb.com/reference/tensilestrength.aspx



Appendix B - Tests by Katherine Silversides

Sensor Tests

I had to build a base to hold the five sensors; light, ultrasonic, infrared (IR), compass, and colour. I used the same vertical stand as the bounce test to hold the plastic in front of the sensors. Then I wrote a program in NXT-G to display the readings from the sensors on the screen of the MINDSTORMS NXT. The first test was done without a cover. I realized that the reading on the light and colour sensors might have been effected by ambient light in the room. In the second test, the infrared sensor results might be effected by the sunlight coming thorough a window. Since the test was just to see if the sensor works through the sheet of plastic, the results are still useful.



Sensor Test set up

Ultrasonic

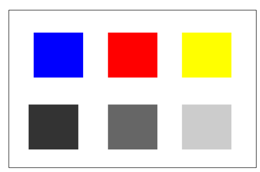
Ultrasonic Sensor uses the same scientific principle as bats; it measures distance by calculating the time it takes for a sound wave to hit an object and come back – just like an echo. The ultrasonic sensor is measurement in cm.

Compass

The compass sensor use the earth's magnetic field to get a reading. The compass sensor calculated to the nearest 1° and send it as number between 0 – 359.

Light

The light Sensor enables the robot to distinguish between light and darkness, to read the light intensity in a room, and to measure the light intensity on coloured surfaces.



This is what your eyes see.

This is what the robot sees using the light sensor.

Colour

The colour sensor readings are not like light sensor readings. Each number represents a different colour:

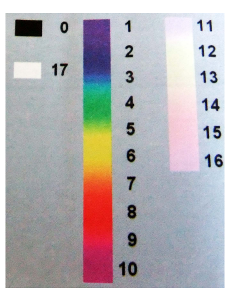
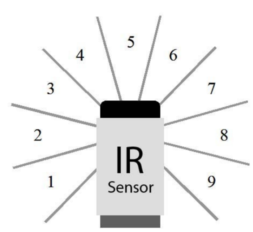


Chart comes form the user guide that came with the colour senor

Infrared

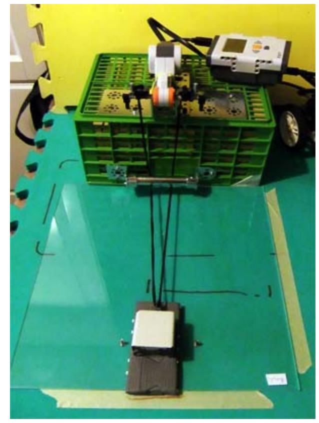


picture came with the programming block

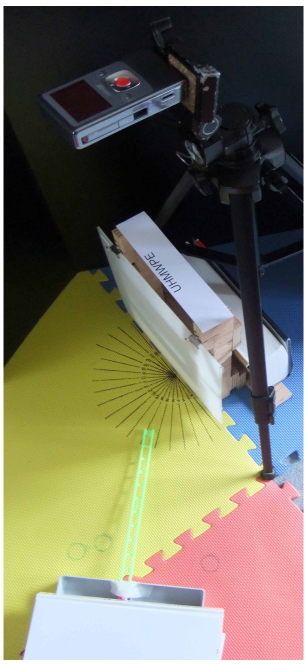
The infrared sensor reads infrared light from the beacon. It is possible to get a reading of background infrared light, usually from sunlight. In NXT-G, the sensor gives a reading between 1-9 indicating the direction of the beacon.

Information for the Ultrasonic and light senors come form
http://cache.lego.com/downloads/education/9797_LME_UserGuide_US_low.pdf
Information for the compass, colour and Infrared senors come form
http://www.hitechnic.com/products

Friction
I used a small piece of rubber mat with a 295g weight on top of the mat. There was a string attached to the mat that could be wound around the motor for the robot. For each test, I put a different type of plastic under the mat. The control was run on a large piece of mat. I measured the number of degrees the NXT motor turned in 2.5 seconds. The tests were repeated 5 times, with the results averaged and then standardized, comparable to the Coefficient of Friction.



Friction test set up



Bounce test

Bounce
I made a frame that held the plastics vertically. In front of the frame was a diagram showing the different degrees. There's 28 cm long ramp with a 10 degree elevation. The ramp was angled so that the ball would hit at the centre of the diagram. I held the ball still, at the top of the ramp, and let it go. A video camera was set-up, over head, so that I could review the tests to confirm my observations. I recorded the angle the ball bounced out at, and averaged it over 5 tests.

Heat
I clamped one end of a 30cm x 5cm x 0.317cm piece of plastic with rest of the plastic hanging in mid air. Place the heat gun above the hanging plastic at a specific spot. Heat at 350C, and measure the amount the the plastic bends at timed intervals.

Heat Test

Cost
I went to a local plastic store (Industrial Plastics, 776 Cloverdale Ave. Victoria, on 2012 March 27) and price checked a 30cm x 30cm piece for each of the plastics in my tests.

Appendix C – Glossary from Wikipedia http://en.wikipedia.org/wiki/Main_Page

ASTM ASTM International
ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM), is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. The organization's headquarters is in West Conshohocken, Pennsylvania.

ft*lbs/in Foot*pounds/inch
The foot-pound force (symbol: ft·lbf or ft·lbf), or simply foot-pound (symbol: ft·lb) is a unit of work or energy in the imperial units of measure. It is the energy transferred on applying a force of one pound-force (lbf) through a displacement of one foot. The corresponding SI unit is the joule.

g/cc grams per cubic centimetre
The mass density or density of a material is defined as its mass per unit volume.

Gpa Gigapascals (1GPa = 10^9Pa)
See pascal.

Mpa Megapascals (1Mpa = 10^6Pa)
See pascal.

Newton
The newton (symbol: N) is the SI derived unit of force. It is named after Isaac Newton in recognition of his work on classical mechanics, specifically Newton's second law of motion.

ohm/sq ohms per square
The bulk resistance is multiplied with a dimensionless quantity to obtain sheet resistance, the units of sheet resistance are ohms. An alternate, common unit is "ohms per square" (denoted "Ω/sq"), which is dimensionally equal to an ohm, but is exclusively used for sheet resistance. The reason for the name "ohms per square" is that a square sheet with sheet resistance 10 ohm/square has an actual resistance of 10 ohm, regardless of the size of the square.

Pascal
The pascal (symbol: Pa) is the SI derived unit of pressure, internal pressure, stress, Young's modulus and tensile strength, named after the French mathematician, physicist, inventor, writer, and philosopher Blaise Pascal. It is a measure of force per unit area, defined as one newton per square metre.

Pounds per square inch
The pound per square inch or, more accurately, pound-force per square inch (symbol: psi or lbf/in^2 or lbf/in^2 or lbf/sq in or lbf/sq in) is a unit of pressure or of stress. It is the pressure resulting from a force of one pound-force applied to an area of one square inch. (1psi ≈ 6894.757 Pa)