

MAKER: An Entry-Level Robotic System Design Project for Undergraduates and K12

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My interests of research area lies in robotics and its applications, particularly in service robotics (domestic or industrial), and integrated network of robotics and sensors (Internet of Things).

My involvement of robotic/mechatronic education ranges from robotic club, electronic club, to incubating the students start-ups, to online forum for robotic workshops...etc.

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Abstract

The paper describes the design, construction, and the programming process for a small-scale mobile-robot that can monitor and report the condition of a home while the homeowner is away. Through this endeavor, students can gain insight about engineering systems and how scientific knowledge and technology can blend together to provide meaningful applications to enhance our daily life. To further manifest the close relationship between different engineering fields used in real situation, a robotic project named Max2 is used to show the multi-disciplinary nature of robotics. Max2 is a service robot which can attend the household, or search for anomalous situations in the environment. This system is one example of a project for K-12 or first-year undergraduate students who want to learn the basics of robotics. For example, for the robot to be able to check whether the house light is left on while the owner is out, it needs an algorithm to navigate autonomously in the house environment. Students have to learn how to integrate the motion control and sensing capability so that the robot can estimate the surrounding environment and avoid bumping into any obstacle while moving around, as well as collecting and processing the information about its ambient environment. Furthermore, students have to learn how to set the light sensor so the robot can tell whether the light is on or not. Finally, the communication about how to send back the sensed information which is readable is another task for students to figure out. In this case students will learn Bluetooth and Wi-Fi communication protocols. The project is based on LEGO Mindstorms Kit for its flexibility and scalability [1]. This unit does not end here. Students should augment this project and develop their own robotic projects with additional functions or tasks based on this model. In addition, they should be able to extend it to other robotic platforms, for example, VEX or Arduino microcontroller in the future.

In the class, we divided the project into many smaller task modules during a semester. Students learned functions of robotic components one at a time to accomplish the partial task until they finished all the modules and the entire project was completed to reach the goal as expected. The project was implemented in fall 2015 in an introductory mechatronics class, and was received enthusiastically, resulting in increased motivation to study robotics and automation, as well as mechatronics.

Motivation

We believe “Hands-on” learning and engagement in doing a project is the best way of motivating students to learn STEM courses. Since robotics is a creative way to keep the learning going, adapting robotic project to strike the zealous maker can plant the seed for many future inventors. However, there are many robotic projects available and choosing an adequate one to start with seems to be a crucial issue for educators. Since robot can serve human society in many ways and domestic service is the dearest application if we expect the robot to blend in our daily life [2], we can start out with a robotic project which serves our basic needs. There are two major applications of domestic robotic services. One is the home care for elderly people who live alone; the other is remote monitoring of our home environment. In the event of coming shortage of man-power in the aging society, the demand for elderly home care will be increased exponentially while the human homecare workers cannot fulfill the heavy demand. In order to alleviate the burden of man-power,

the only solution is to include the artificial intelligent helpers in the domestic environment [3] that can do some simple works such as monitoring the elder residents and remind the medical center if anything happen adversely. As for the home security surveillance, many busy professionals constantly have to travel around the world and leave their home unattended for a long period of time. They may be anxious about what would have happened to their nests in their absence. Furthermore, the increasing social statistics reflected more and more parents are concerned with their children's safety and how the baby-sitters have treated them. A domestic service robot can fulfill these demands easily. Therefore, home monitoring and surveillance is a good example of the basic applications that robots can easily do for us, and it can serve as the first step for those who are willing to learn mobile robotics from the scratch to finished products.

In this RET project unit, students will learn how to build the robot which can patrol and monitor our house condition when we are away from home. The challenge of this research project is two-fold. First, the robot must be able to move freely and patrol the area autonomously. Second, it must be able to detect the ambient anomaly and blow the whistle to its owner or operator in a distant site supposedly. This requires the navigation algorithm to integrate the motion control and sensing capability that exemplifies the need to blend the scientific and engineering knowledge in order to implement this project [4]. By using LEGO parts and MINDSTORMS NXT or EV3 Brick microcontroller as the basic building blocks, we can have a robot perform many simple tasks such as security surveillance, patrol guard, and many other domestic duties. In this way, students are required to apply their knowledge of electronics, mechanics, and computer programming skill to make the robot work. During the project, they will learn how to troubleshoot the hardware errors and debug the software logic mistakes. Most of all they will benefit from this hand-on experience by involving in the entire process of construction from the beginning to the end in the field of robotics and automation [5].

A Hand-on introduction Course to robotics

The author teaches an undergraduate-level robotics and automation course for Mechatronics Engineering Technology students at a U.S. university. The course covers the following topics:

- Introduction to generic Robotics and background
[Activity: viewing related video and Q &A; prepare the hardware and the software for the project; set up the teams.]
- Introduction to LEGO Robotics system (hardware & software)
[Activity: Familiarize LEGO parts and open the NXT-G programming environment; verify the functions of the building blocks and parts.]
- Working Principle of robotic motion: Motors and controls
[Activity: recognize the motor blocks and adjust their function parameters within NXT-G environment and effects on actions]
- Working Principle of Measurement : Sensors
[Activity: recognize the different sensors and adjust their function parameters within NXT-G environment and effects on signals]
- Algorithm development and programming for the robotic project.
[Activity: Learn NXT-G and RobotC syntax and coding according to the task requirements.]

- Industrial Robotic Arms and End Effectors.
[Activity: Adding arm and gripper for the Home Patrol Robot and program it to pick up something.]
- Remote control of the robots via PC or Smart phones.
[Activity: download LEGO App and install on NXT robots.]
- Introduction to Robotic communication between NXTs or PC via Bluetooth
[Activity: setup communication link and send/receive messages between robots or PC]

These are the major areas of the knowledge that the students need to know in order to build a functional mobile robot with the specific capability to carry out the duty as a home patrol robot. Also many rules of robotic competitions are based on some functions of duty as criteria of success [6]. Therefore meeting the required goal is the primary consideration of robot designers.

Primarily the course was designed to stimulate the interest of learning robotics and Mechatronics, and therefore more emphasis was placed on hand-on lab activities, literally building a robot. There is some class time devoted to theory if necessary, in order to clarify the basic concepts of robotics and help implement the projects smoothly. However, in order to foster the idea quickly, nothing can be more helpful than do it yourself. A deliberately thought lab topic such as Max2, is given to students as their course hand-on project which they should follow up from the beginning to the end of the class.

The labs project includes two exercises to teach student group (assuming two students in a group) to complete. First one is to follow the instruction of sample project Max2, to build a robot which functions as Max2 as a warm-up exercise. Second one is the real project that the student group has to develop on their own as the final product for their course credit. This one may derive from Max2 with slight modification or may be a totally different design with different functions. The rubrics is the more functions built in the robots, the higher grade will be assigned to the project. A process report should be submitted periodically throughout the semester as part of their grades. The following are some possible examples proposed for student projects:

1. Modify Max2 to listen to the ambient environment instead of observe the lighting condition.
2. Modify Max2 to find the light source and point the light sensor to where the maximum light comes from. This function is particularly useful for solar panel to locate where the sun is.
3. Add an effector as the arm/gripper to pick up or move something in the room.
4. Add message transfer capability from one NXT robot to the host PC or another NXT robot in next room.

System Architecture and the Robotic Platform of Project

A mobile robotic system typically consists of micro-controller, sensors, actuators, and main skeleton of structure. Among these units, the micro-controller is the core of the entire system. Since this class may accommodate up to 20 students per semester and each team shall consist of at most two student members, therefore there may exist at ten different designs in the class. In order to accommodate these variations, reconfigurable robotic systems like LEGO would best suit the need of education. The flexibility of LEGO bricks allows students to try different way of design without using clumsy machinery in the workshop. The plug-and-play feature of LEGO bricks further reduces the possible injury inflicted upon students from working with metal machinery

tools. Besides, all the system components can be reconfigured for different purposes and allow several systems to be integrated into a larger system, or on the other hand, broken down in smaller sub-systems. Therefore the scalability and flexibility makes LEGO the top choice of our proposed platform for this quick start project. For the scale of material used to build the project similar to Max2, here is the part list which roughly estimates the quantity of required parts. Table 1 lists the components of the platform Max2:

Parts	Quantity	Function
NXT-Brick	1	Micro-controller to processor programs
Ultra-sonic sensor	1	Range sensing and Obstacle detection
Touch sensor	1	Provide proximity sensing for bumper
Light sensor	1	Detect the lighting condition
Servo Motors	3	Activate motions
Cables	5	Data transfer between NXT and devices
56x26 Tires	3	Provide surface contact for wheels
30x20 Hub	3	Provide the rigid support for wheels
x-module beam (various length)	10~20	Robotic frame construction
x-module angular beam	5~8	Robotic frame construction
Bushing (various holes)	4~8	Robotic frame construction
X-module cross block	10~20	Robotic frame construction
2 module axle	10~20	Robotic frame construction
Connector peg with friction axe	5~10	Robotic frame construction
x-module axle (various length)	6~10	Robotic frame construction
Other parts	Any	To add the flavor for the design

Table 1. The part list of Max2.

The above table only shows the parts used for this project approximately. If there is some variation in design, and then required parts may be different. Students are encouraged to come up with their own ideas of structural design for improvement.




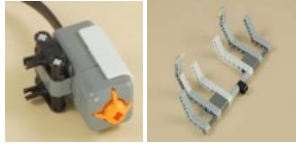












Fig.1 Max2 (left) and other alternatives of robotic frame structures.

Functionality of the project

For Max2, its major functions are to roam around the house and detect the lighting condition. If the light is left on, then report the status to the house owner via a wireless communication link. Therefore, the program must be able to activate these functions. Students are required to develop this program and test it on site in the lab. For more challenge, such as in Exercise II, students are required to modify this program and replace the light sensor with sound sensor or other sensors to implement other functions as mentioned earlier. The functions of Max2 are listed in Table 2.

Table 2. The functions of Max2 and the associated software/hardware components

Task Function	Software Component	Hardware Component	Port
Move around (Both wheels move together by setting both motor B & C ports in the same direction)			B & C
Bumper (prevents robot from colliding with obstacles) by using Touch sensor with guard structure elements.			1
Range detection and obstacle avoidance by using ultrasonic sensor (setting range < 10 in. for optimal operation.)			4
Servo motor providing scanning capability for ultrasonic sensor to scan up to 180 degrees.			A
Light detection by using light sensor or color sensor. Need to tune the threshold carefully.			3
Bluetooth link for wireless communication between NXT, PC, and smart phones.			N/A

Task Function	Software Component	Hardware Component	Port
Data processing – the brainis Mindstorms NXT brick which is core of LEGO robots. All the programs can be downloaded into NXT’s memory during operations whether it is autonomous or controlled by human operators.			1,2,3,4, A,B,C

Note: the hardware devices must match with their respective ports on the NXT Brick. (Refer to the LEGO NXT instruction manuals). For remote control by smart phone, an appropriate NXT Remote Control app must be first downloaded and installed on the cell phone before making connection via Bluetooth. The name of robot NXT must show up in the Bluetooth connection list before the program can be activated (There are many free apps available in cyber world.)

The procedure of implementing the class activities

There are several issues needed to be addressed before we incorporate this project for the regular robotic or mechatronic course. The required knowledge or background of the instructor, expectation from the students, the pre-activity preparation, and the pre-activity assessment are playing important roles to a successful implementation of the class.

- For the teacher:
Possess at least some basic knowledge of computer programming of any language, especially GUI or icon-based programming languages. Familiar with the Instruction manual for this lesson and the program downloaded to the robot, and have done trial run before the class.
- For the Students:
Student teams are expected to be exposed to computerized environment since the project involves in the robotic programming. The entire procedure shall last no more than 3 hours. The details of construction will be provided in the instruction hand-out set.

Before the Activity

Make sure the lab facility as safe and all the computers are running normally and equipments have been calibrated properly. Before implementing the lab, the computer should be setup according to the need of this lab and the NXT-G software should be installed in the right folder. Make sure all the necessary software is installed on each team’s computer. Make sure each team has one a copy of LEGO Mindstorms User’s Guide and the class hand-out for the project lessons (see attachment)

Procedure to conduct the lab activity

- During this session, teacher will carefully describe the goal of the project such as testing whether the robot detects the lighting condition and relay back the message of lighting condition to the human operator. The sample of instruction is given in Appendix 1.
- Teacher should use flowchart concept to lay out the procedure of programming. The example of flowchart is included in the handout instruction set and shown in Appendix II.
- Let student teams start developing their program for Max2 and check to see if they can follow the instruction manuals. Appendix III shows how to initialize NXT-G.
- Teacher then directs and supervises their progress along the way.

Testing and debugging

Once the project has been completed the first time, it must be tested to verify the design. Students may find the robot does not work the way we expect it to act. Therefore debugging is necessary to find where the faults are. Normally setting the correct parameters for the devices is critical for robot to function expectedly. However, due to the different situation, the setting of device's parameters may vary based on the criteria. For example, the light sensor threshold setting will determine whether the lighting condition is considered on or off. If setting is too high, the very well illuminated room would still be considered "dark" and the false signal will be sent back to the owner. Vice versa, if the threshold is set too low, any glimpse of dimmed light will be interpreted as "light is left on". In order to overcome this perplex, students may have to set the conditional threshold by choosing the range of light status under different scenarios. Another example is the setting for ultrasonic sensor. If the detecting range is too far, say > 15 inches, the robot may think it will be surrounded by walls all the time, and keep triggering the obstacle avoidance algorithm too early and thus it can go nowhere except making circle on the spot. If the detection range has been set too short, say <5 inches, then it would have no time to react if it had come to an obstacle.



Fig. 2. The testing of light sensor's threshold setting.

Assessment of learning outcome

In order to verify the learning outcome and the value of education, an assessment is necessary. We implement three section assessments – before the class, during the class, and after the class.

Pre-Activity Assessment

Teacher may ask each team to submit a flowchart of the program they intend to develop for Max. This rubric verifies how much they understand the project, as well as the programming logic thinking.

In-session Assessment

A short in-class quiz can be used to verify students' progress and the performance during the lab. Sometimes a periodic progress report can be alternative for evaluation. However, none of these forms can replace the on-the-spot observation by the teachers or lab assistants.

Post-Activity Assessment

There are three criteria to assess the learning outcome.

- First, check whether your robot can run freely in a cluttered room without getting trapped. This rubric verifies the navigation capability of the robot.
- Second, check whether the robot can detect the lighting condition of the room. This rubric verifies the sensing capability of the light sensor and the proper setting of threshold to make Boolean decision. The NXT brick displays the status of household lighting as follows:



Fig. 3 When robot detects that light is on; it will display the status of condition as “Light is on” on its onboard screen.

- Third, check whether the data message is passed to host computer or mobile control device. This rubric verifies the data communication link between robot and host PC at the other end.

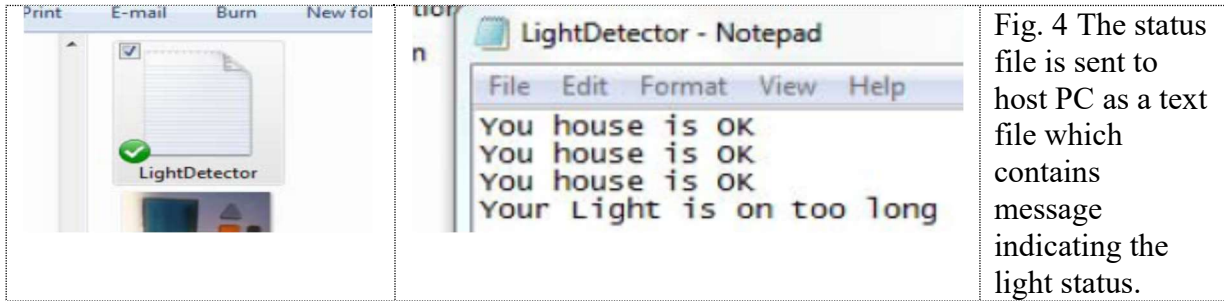


Fig. 4 The status file is sent to host PC as a text file which contains message indicating the light status.

- If the PC is connected to a network which can access internet, this status file can be delivered to anywhere universally. Another way to send message over the internet is to install a WiFi-dongle on the robot and set up the virtual web server on an internet-enabled host PC. However, it is beyond the scope of this experiment and may be further investigated by more advanced students who are network or IT savvy [7] [8].
- For Remote control mode which can be used to override the autonomous mode in case of emergency or certain critical situation. This mode can also be implemented on mobile devices such as cell-phone or wireless tablet. The control is shown below:

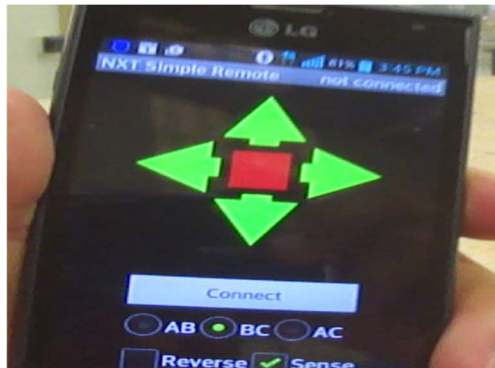
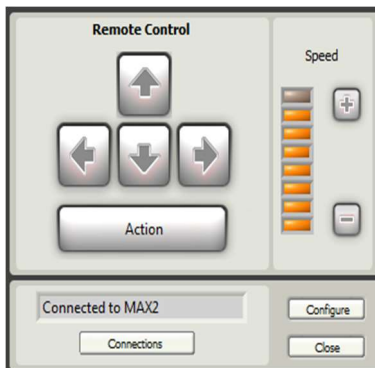







Fig. 5 The remote control on NXT-G programming environment (left). The remote control app on my LG cell phone to control Max2.

Outcome and comments on students learning

As a snapshot on our rubric template taken from one of the student in MCE101 class, we can view the outcome of student learning and the motivation given in this course project.

Mark "X" in the boxes if you think you belong to one of above category.					
Lesson 1 – Building and Setup					
Name(s): _____ Date: _____					
Goals	Bronze	Silver	Gold	Platinum	Notes
Mark the box that best describes how you did.					
Objective: After completing this lesson, you will be able to build the Driving Base, connect the EV3 Brick to the computer, download and run programs that control the robot's behavior.	I have built the Driving Base and written one program with Sound, Motor or Display text blocks.	I have built the Driving Base and written two programs with Sound, Motor, and Display text blocks.	I have built the Driving Base and written two programs with appropriate Sound, Motor and Display text blocks.	I have built the Driving Base and added extra elements to make an animal. I have also added an animal sound.	
				X	

Note:

“I have built the driving base by following the instructions from the Building Instructions Booklet that was included in the set. The instructions were straightforward and easy to assemble. I did not have any difficulties in assembling the robot. First, I sorted out the parts into different compartments of the tray, so the parts were easy to find, and then put the parts together according to the instructions. The brick takes several hours to charge, so the care must be taken to charge it before programming. All the USB cables must be inserted the correct way, otherwise the robot would not work.

I made the robot display images and make sounds, using the programming software. To make the robot look and sound like an animal, I tried different eye expressions (angry, crazy, tear, crazy, neutral and other), mouth expressions (mouth open, mouth shut and other), face expressions (swearing, talking, swearing, talking, wink and other), colors (black, white, blue, yellow, brown, green and red), images (night, snow, forest and other), text (e.g. “MINDSTORM”) and sounds (elephant call, cat purr, dog bark snake hiss and other). To select a programming block, I picked the block from the bottom of the screen and dragged it into the program lineup. At the end of the class, the robot was displaying angry eyes, open mouth, forest image, text “ELEPHANT”, brown color, talking face expression and sounding an elephant call.”



The world-wide impact of domestic service robots

The research of domestic service robotics has gained a tremendous momentum in the past decades because the trendy demand of this kind of assistance of aging world is imminent. It also inspired many start-up companies to plunge in this segment of the market. As the trend moves along, we can predict the booming of this industry is expedited at an exponential rate. In the effort to promote domestic service robots, there is a competition dedicated to domestic service robotics called HumaBot Challenge [9]. In the HumaBot Challenge, the robot is an integral part of the house and helps its occupants to live there better. In this edition, several tests will be held in the kitchen of the house. The task challenges include:

- (1) putting off fire on the stove.
- (2) Making up a shopping list for the occupants by inspecting the shelf to check which items are missing (when comparing with a given list of must-to-have goods.)



Fig. 6 an overview of kitchen environment used in HumaBot competition (left).Participants with their robots (mostly NAO) at the HumaBot Challenge held on Nov. 18-20 in Madrid during the IEEE Humanoids Conference (right).

Conclusion and future direction

In this paper, we described the motive, design, and results related to a project-based activity to enhance undergraduate students' learning about mobile-robotic system design and integration. The activity provides an excellent opportunity for students to integrate their knowledge of robotic building blocks (such as sensors, actuators, servo motors, switches, communication links and human interfacing) in real-life problem solving. The experience enhances students' hand-on capability and prepares them for entering real world career in robotics and system automation [10]. Future plans include combining multiple robots to form a large robotic network system which can collaborate in the large area surveillance and patrolling in multi-room scenario, exchange sensed data among them and stitch each piece of fragmental information into a big picture which reflects an overall view of the entire environment. This kind of data processing can be sent to Cloud for further analysis for any response to be taken if necessary. Besides the domestic service applications, the same idea can be applied to industrial environment as well, especially for patrolling the hazardous area such as toxic gas or radiation contaminated areas. As a result, we verify the educational theories on "Learning by doing" [11] [12] and "Active learning by doing things in different way if encountering the difficulties" [13].

Acknowledgements

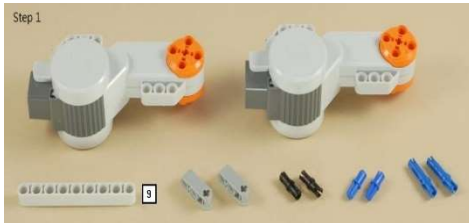
This material was supported by grants from the National Science Foundation's Research Experience for Undergraduates (REU) Program (Award No. 1263293). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Appendix 1: A glimpse of Max2 building instruction.

First build the robot, then develop the program to activate the robot, Max2, so that Max2 can perform the task to check our home's lighting condition and inform us about the status.

- LEGO block Building Instructions:
(Refer to User's guide for list of parts and corresponding labels.)

1. Find the following parts and assemble them accordingly.

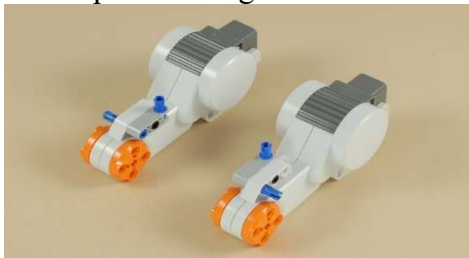


2 motors and connecting elements

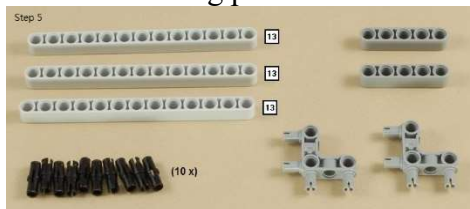
2. Then...put them together as follows:



3. Then...put them together as follows:



4. Find the following parts:



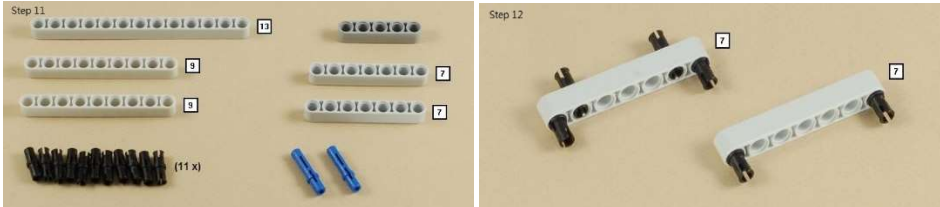
5. Assemble them as follows:



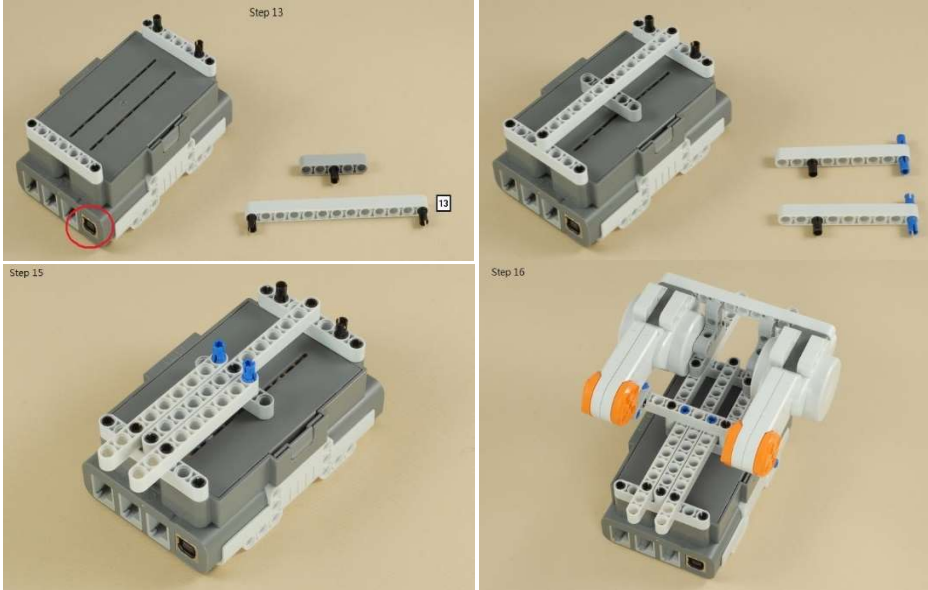
6. Then put them together with the motors as follows:



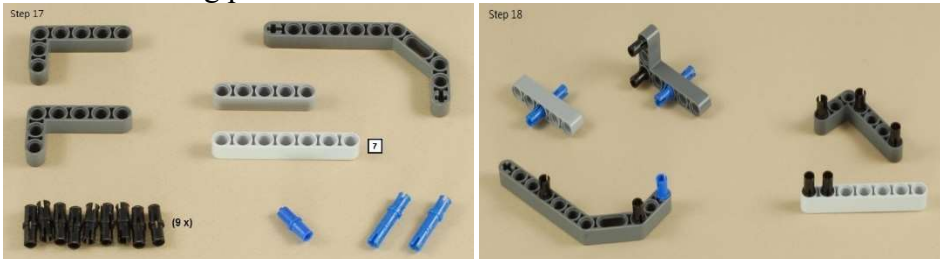
7. Find the following parts again and assemble them as follows:



8. Locate the NXT brick and notice the position for assembly.



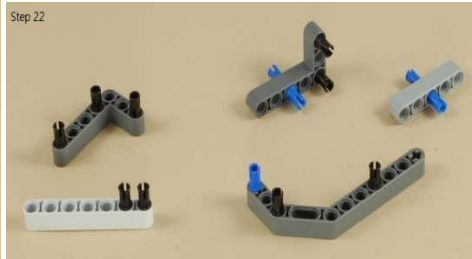
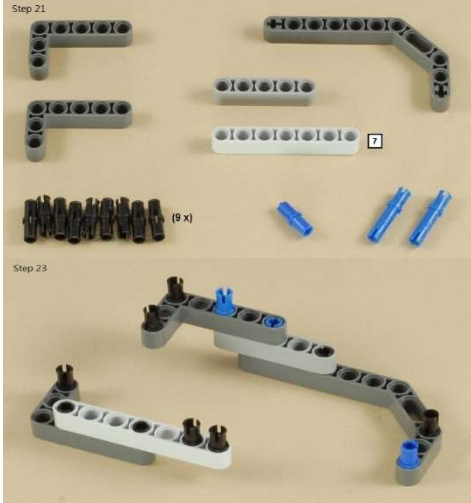
9. Find the following parts and assemble them as follows:



10. Mount the motors on the NXT Brick as follows:



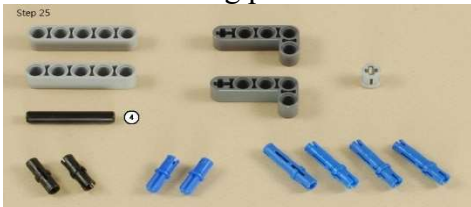
11. Get the following elements and assemble them accordingly.



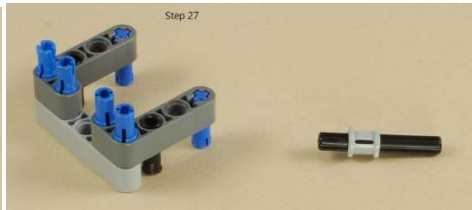
12. Again, mount the rack for the other side of the NXT Brick:



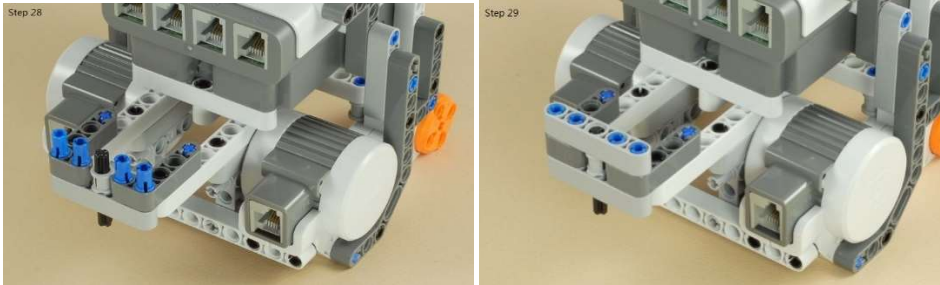
13. Find the following parts...



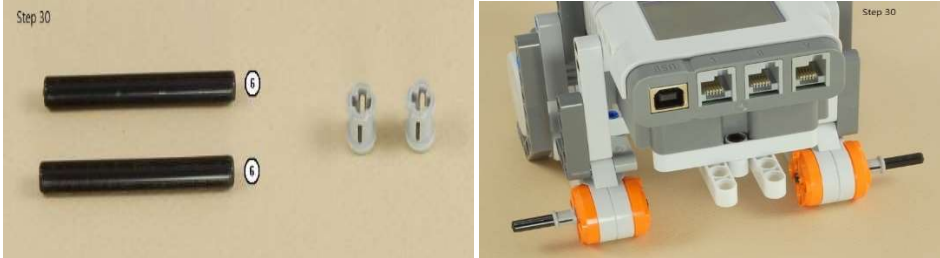
14. Assemble them as follows:



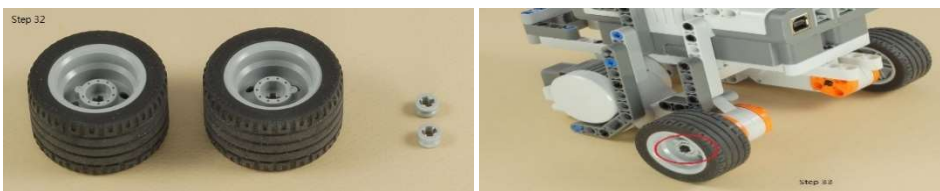
15. Mount the assembly onto NXT Brick as follows:



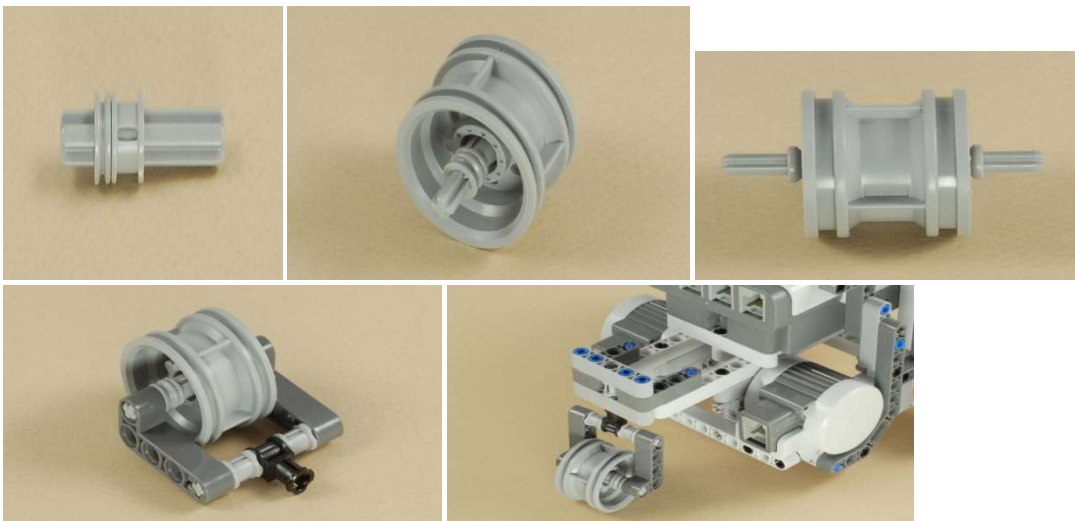
16. Find those parts and put them as axes for wheels.....



17. Then install the wheels as follows:



18. Find the following parts.....and make the castor wheel



19. Find two data cables with appropriate length to connect driving motors with NXT Brick.
Use port B for right wheel motor, port C for left wheel motor.
Find two data cables with appropriate length to connect driving motors with NXT Brick.

Use port B for right wheel motor, port C for left wheel motor.



20. Then assemble the following supporting rack.

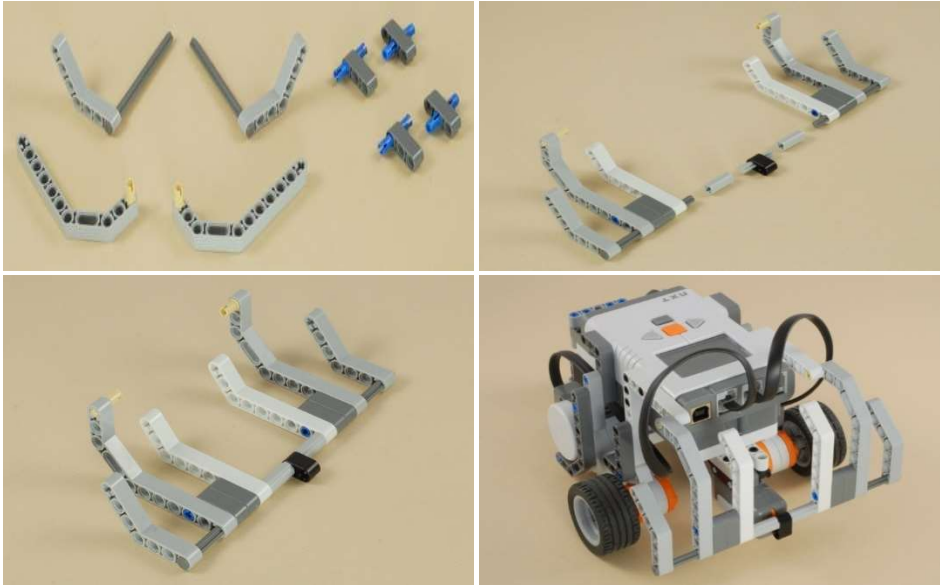


21. Now find these parts and install the Touch sensor...

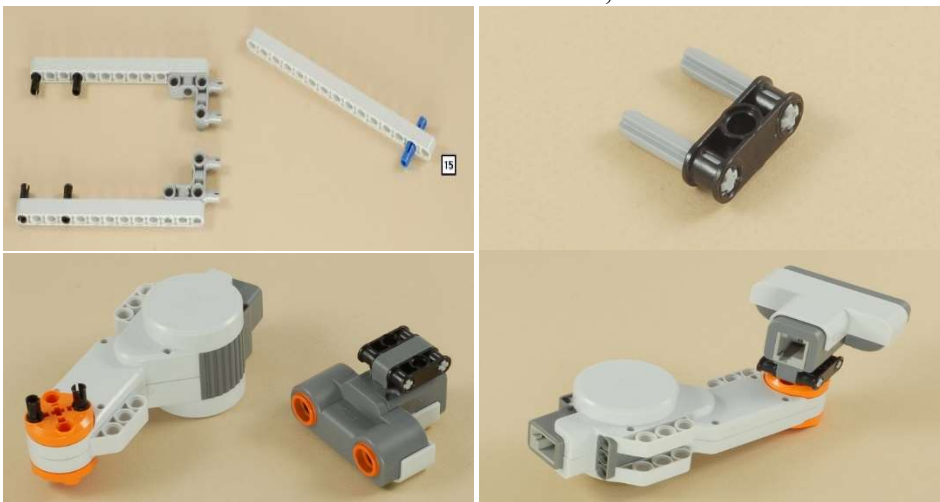


22. Now put the touch sensor on the front part of NXT Brick.

23. Look for the following parts to assemble the bumper guard...and install the bumper guard onto the NXT robot....



24. Find these parts to build the mounting rack for ultrasonic sensor and its scanning motor... Look for ultrasonic sensor and a motor, and connectors...



25. Find two cables with appropriate length to connect the ultrasonic sensor and the scan motor to NXT ports...



26. Mount this rig onto NXT robot's main body, and then connect sensor and motor to port #4 and port A respectively.

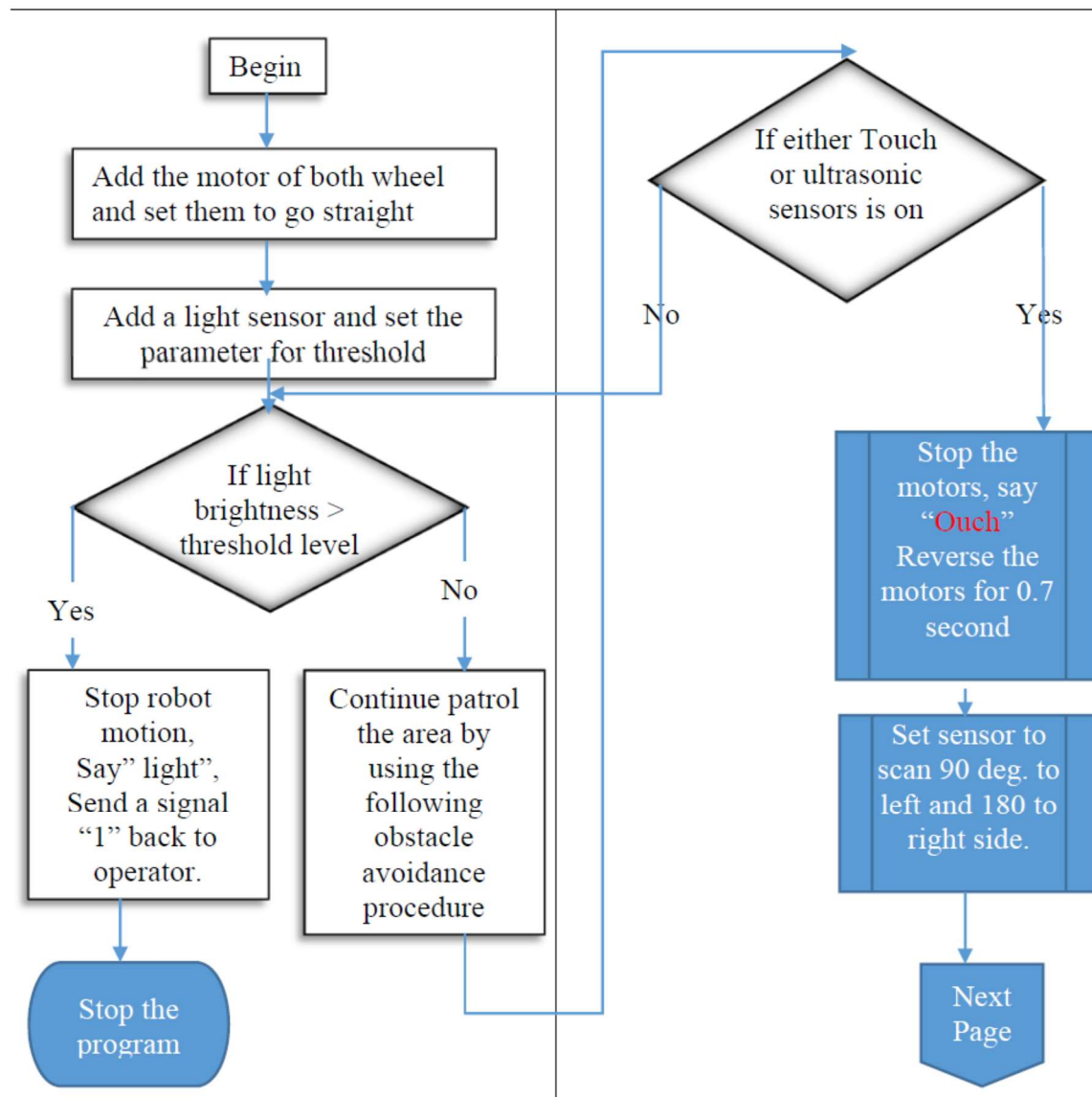


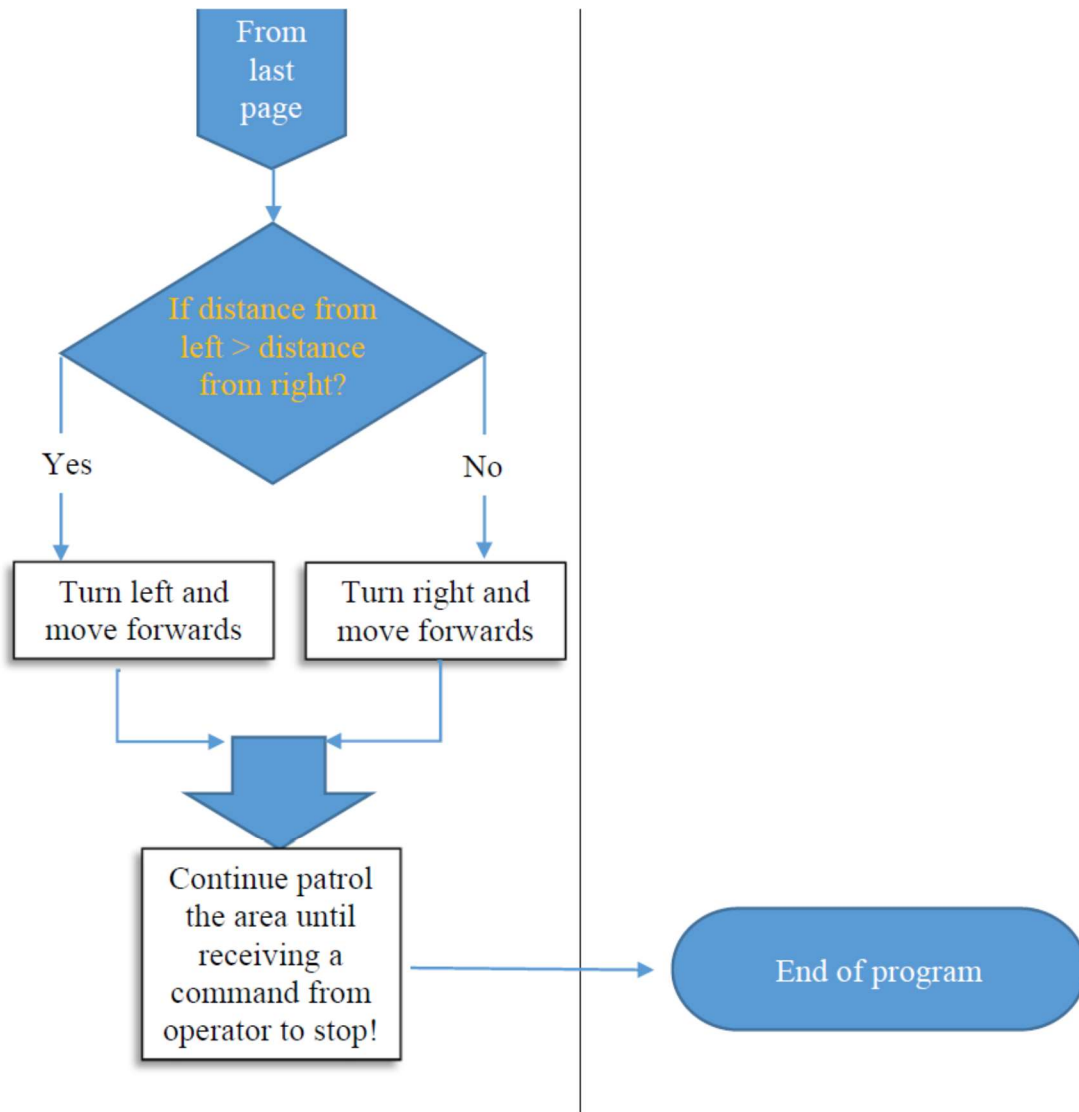
27. Your hardware assembly work is complete!!!

Appendix II: Flowchart of Max2 program.

The following section is the instruction for developing the software to harness the robot. As a programmer, we normally start with a flowchart to provide a guiding roadmap in developing this software application. The flowchart is shown as follows:

Flowchart diagram for Max's room patrolling routine

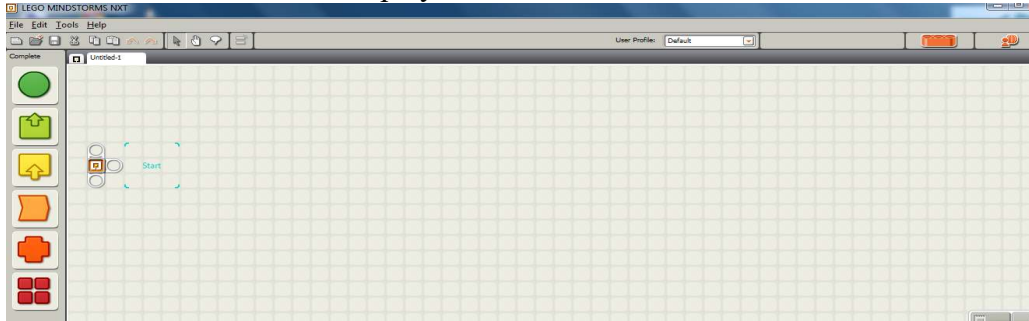




Appendix III: Programming procedure: (refer to NXT User's guide for beginner)



- (1) Open NXT-G on your desktop by clicking the icon.
- (2) You should see the screen displayed as follows:



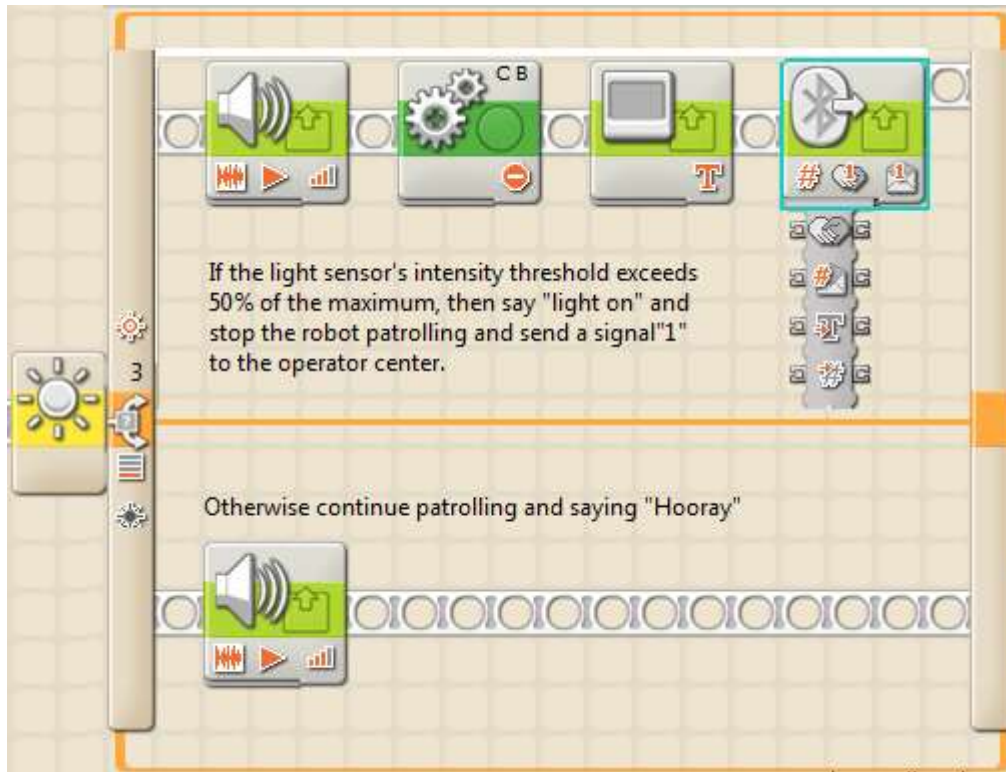
- (3) This is your NXT-G program development environment, often called "palettes". The programming palettes contain all of the programming blocks that you need to create programs. Each programming block includes instructions the NXT can interpret. You can combine the blocks to create a program.
- (4) Start out programming by putting a "Move block" onto the sequence beam as shown in image below. Note that BC stands for wheel motors connected to B & C ports.



- (5) Configure "Move block" the parameters on configuration panel so as both wheel shall move in the same direction.



- (6) Now add a light sensor switch (Note: different from light sensor). Also add elements in two decision branch sequence beams.



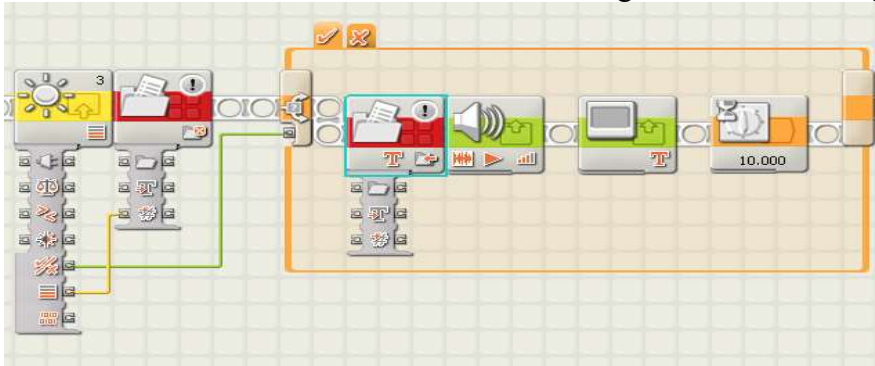
- (7) Insert a sound block, motor block, display block, and two Bluetooth control blocks, and a Bluetooth Send Message block into upper branch sequence beam as shown in diagram above. Also insert a sound block in the lower branch sequence beam.
- (8) Set light threshold at 42 in light sensor switch.



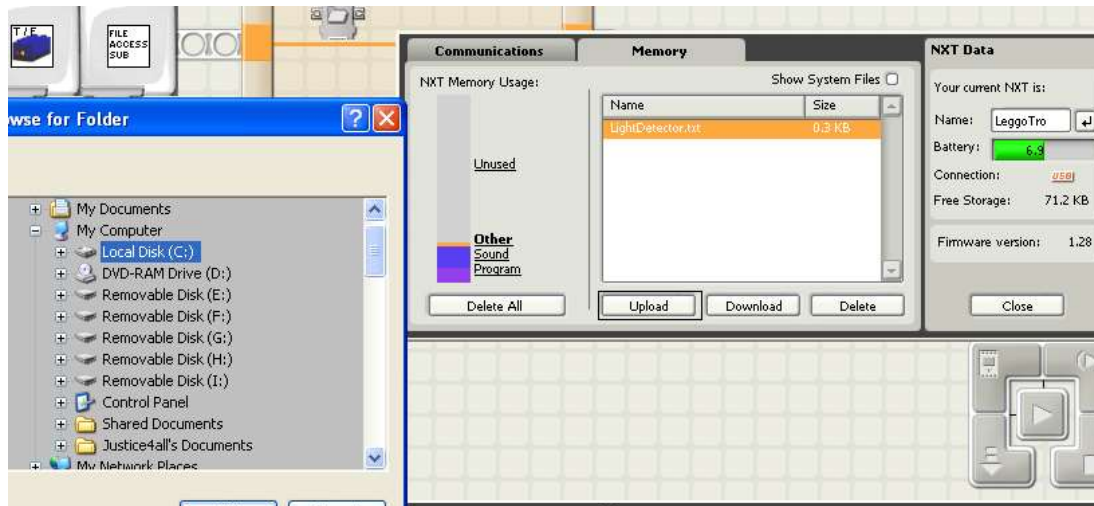
- (9) If detected ambient light is greater than 50 (up to you to decide how to adjust this threshold), then go to the upper branch sequence beam and execute the following commands:
 1. Say "light"
 2. Display the message "light is on" on NXT's screen such as follows:



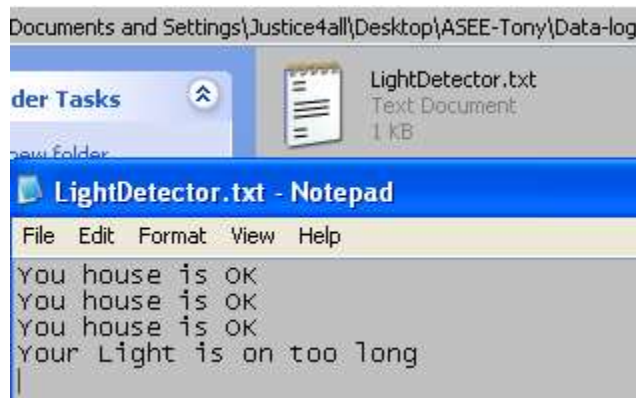
3. Use file block to store the status data and give it a name – “LightDetecor”



4. Upload the status file after running the program to your host PC in a text document.



5. You may open the status file “LightDetector.txt” to see the message sent to your PC.



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