

LEGO MINDSTORMS NXT SPRAY PAINTING ROBOT

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In Partial Fulfillment

of the Requirements in

SCIENCE RESEARCH 2

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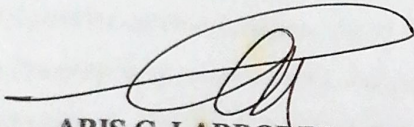
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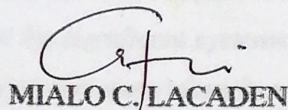
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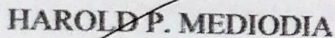
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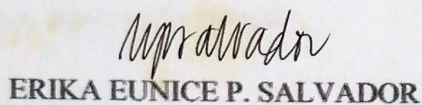
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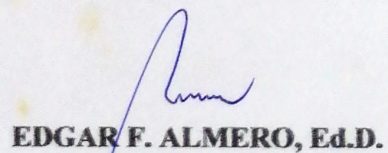


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ABSTRACT

Logos, labels or just plain art, spray painted on walls, can be used to attract people. This makes them very useful especially when there are people who might want to endorse a product or brand name to attract potential customers. Long exposure to Spray Paint fumes can result pneumonitis, cardiac problems, and chronic bronchial asthma that can lead to emphysema. This study was conducted in order to address those health problems with the use of robots. Robots are impervious to the hazardous effects caused by long term exposure to spray paint fumes, and do not tire of repetitive and continuous work. The Lego Mindstorms NXT robotics kit was used during the development of the robot, and composes most of the significant systems required for the robot to operate. The NXT brick along with three servo motors were taken from the kit and then integrated within a wooden structure together with a spray paint can. The NXT brick and two of the servo motors were attached to a wall and then connected to the third servo motor, which is affixed to a wooden structure with a spray paint can, via a pair of timing belts. The robot was programmed using the NXT-G programming language that enabled it to spray paint different designs or figures, such as a square and a triangle.

Keywords: Program, Robot, Spray Paint

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Our Parents who are always there whenever we need them, for their help in allowing us to procure the materials we require, and for supporting us whenever we feel down and lazy.

Our friends who are there every step of the way.

And the almighty - wait for it - GOD.

Your argument is invalid.

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Chapter 1

Introduction

A. Background of the Study

Logos, labels or just plain art, spray painted on walls, can be used to attract people. This makes them very useful especially when there are people who might want to endorse a product or brand name to attract potential customers.

Spray painting is a painting technique where an aerosol can or spray paint can sprays a coating through the air onto a surface. It has various applications due to the fact that it is sprayed through the air onto a surface rather than being applied directly onto the said surface, this result in a more consistent and even layer of paint compared to other painting methods. Consistency means less paint is wasted, which also means less money is wasted.

Long exposure to Spray Paint fumes can result pneumonitis, cardiac problems, and chronic bronchial asthma that can lead to emphysema (Healthcaremagic 2010). Spray paint fumes are dangerous, toxic, needs total concentration and require careful attention to detail this makes spray painting a perfect job for robots. Robots are always consistent and never tire.

There are many different kinds of spray painting robots in the market, but most are for industrial or assembly line purposes and are expensive. These kinds of spray painting robots usually have a large number of degrees of freedom and this allows them to spray paint with pinpoint accuracy and fully coat various factory manufactured parts, such as car frames and spare parts.

According to robot suppliers, the top reason for purchasing paint robots is to eliminate labor costs. A high-quality reciprocator might cost \$15,000 and a robot more than \$100,000 plus the cost needed to integrate the robot into the assembly line but as a \$100,000 robot that replaces a \$30,000 worker per shift, three shifts a day and it quickly pays for itself. (Products Finishing 2011)

Such robots include the Kawasaki K-series spray painting robots which have at least 3 meters of reach (Kawasaki Robotics, 2011), the award-winning SnakeARM robot with a 14 foot

reach (BRIC Engineered Systems, 2011) , the Motoman Series spray painting robots (Yaskawa America, 2011) and Hektor the Spray painting robot (Hektor.ch).

These robots are not feasible for this study due to the expense needed to acquire them and that this study aims to develop a spray painting robot that can spray paint a mono-colored pre-programmed design onto a wall. This study has no need for a robot with a large number of degrees of freedom, since the robot only needs to paint a 2D (two-dimensional) object.

Spray painting automation is feasible since most spray paint cans contain very low viscosity paint and therefore require multiple coats of paint in order to achieve the desired finish otherwise the finish will end up either too light or too wet. It is this painstaking repetition that requires the careful attention and consistency of a machine.

The LEGO Mindstorms NXT robotics kit can be used create and control programmable robots that use motors and sensors. It comes in a kit containing many pieces including sensors and cables. The robots can be controlled remotely via wireless Bluetooth or a USB cable, or through programs running autonomously on the robot.

Availability was one of the factors that were considered in using the said robotics kit. The kit itself can be bought online or through retail stores. Another factor that was considered was the kit's flexibility since the Lego Mindstorms NXT kit can be used to create a wide variety of robots.

B. Statement of the Problem

This study aimed to use a Lego Mindstorms NXT that developed a robot that can autonomously spray paint a mono-colored pre-programmed design on flat vertical surfaces.

C. Objectives

1. Development of a system that holds the spray paint can and presses the spray paint can's valve button.
2. Development of a movement system of the spray paint can valve pressing system.

3. Programming a design path for the robot to spray paint.

D. Scope and Delimitation

1. Design size – The Programmable Lego Mindstorms NXT spray painting robot's design size has a limit, it is either that the maximum height the robot can reach is limited by the parts or because of a limited power source.
2. Type of design – The robot can only paint simple and 1 colored designs, because the robot uses only 2 servo motors for movement which allow the robot to have a maximum of 2degrees of freedom.
3. Kind of surface – The robot can only paint walls. Since it is limited to only 2 degrees of freedom.

E. Definition of terms

1. Program – a specific set of ordered operations written for a computer to perform a specified task. (TechTarget)
2. Robot - Reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motion for the performance of a variety of tasks. (RIA 2010)
3. Autonomous - Not controlled by others or by outside forces; independent. (HMC 2009)
4. Degrees of freedom – The available ways a component can move in three-dimensional space along an axis. Robots typically have 3 to 6 degrees of freedom. (Tooling University 2011)
5. Spray Paint – Paint applied with a spray gun or a spray paint can. (Thefreedictionary 2011)

Chapter 2 Review of Related Literature

A. Principles of Materials

A.1. Spray paint can

A spray can is technically known as an "aerosol" device. It consists of a vessel that can withstand significant internal pressure (the can); a spray nozzle that incorporates a sealing device that won't let the pressure out of the can until called for; a tube inside the can that brings the fluid (paint) to the nozzle; and the two critical elements: pressurized gas (usually carbon dioxide) and the paint. (Second Chance Garage 2011)

A.2. LEGO Mindstorms NXT kit

Lego Mindstorms NXT kit is a programmable robotics kit used in constructing different kinds of robotic projects. The advantages of Lego Mindstorms NXT to other robotics kits are its availability and flexibility. The kit consists of 577 pieces, including: 3 servo motors, 4 sensors (ultrasonic, sound, touch, and light), 7 connection cables, a USB interface cable, and the NXT Intelligent Brick. The Intelligent Brick is the "brain" of a Mindstorms machine. It lets the robot autonomously perform different operations. The kit also includes NXT-G, a graphical programming environment that enables the creation and the downloading of programs to the NXT. (Robots and Androids 2010)

A LEGO Mindstorms NXT robotics kit will be used to construct a spray painting robot. Most of the major systems will be constructed from this kit. Availability was one of the factors that we considered in using the said robotics kit. The other Factor that was considered in using the kit is its flexibility. Lego Mindstorms NXT kit can be used to create a wide variety of robots because of the interchangeability of the parts. Lego Mindstorms NXT is easier to build because manufacturing of the parts is unnecessary.

B. Principles of methods

B.1. Assembly

B.1.1 Spray Paint Can Valve Pressing System

The spray paint can valve will need to be opened or closed to be able to paint. A servo motor attached to the spray paint can holder will allow it to close or open the spray paint can's valve.

B.1.2. Movement System

Two servo motors were enclosed in a structure or frame, which was each attached to the upper right and upper left corners of a wall.

B.2. Principles of Programming

B.2.1. NXT-G Programming Language

NXT-G is a tool used to allow robots to perform a specified task. NXT-G allows users to create programs that can be uploaded to an NXT robot. These programs can be simple or advanced instructions. NXT robots can be built with a variety of motors and sensors. (Kelly J. F. 2007)

NXT-G is installed on a computer, either Windows or Macintosh versions, and exists as software.

B.2.2. Spray Paint Can Valve Pressing program

The servo motor was connected to a beam which stands as the spray paint can valve presser. When the servo motor rotated, the beam pressed the spray paint valve open and released the paint and it rotated the other way around to close it.

B.2.3. Movement Program

Two servo motors were used to control the movement of the spray paint can valve pressing system. Values were assigned to each of the motors so that the spray paint can valve pressing system moved upward, downward, left, right, diagonally, or in any direction.

B.2.3.1. Movement Analysis

The motion of the robot involves two different kinds of principles:

1. Physics principles involving the tension of two strings.

When a rope, cable, string, etc. is attached to a body and pulled taut, the rope pulls on the body with a force directed away from the body and along the rope. Therefore it has a direction and a magnitude. The force is often called a tension force because the rope is said to be in a state of tension. The tension in the rope is just the magnitude of the force on the body. (stewartcs 2008)

2. Vectors

One way to represent motion between points in the coordinate plane is with vectors. A vector is essentially a line segment in a specific position, with both length and direction, designated by an arrow on its end. (SparkNotes 2011)

A vector is determined by two coordinates, just like a point—one for its magnitude in the x direction, and one for its magnitude in the y direction. The magnitude of a vector in the x-direction is called the horizontal, or x-component of the vector. The magnitude

of a vector in the y-direction is called the vertical, or y-component of the vector. (SparkNotes 2011)

Two vectors with the same length and direction are the same vector. They may have origins at different points, but they are still equal. The length of a vector is formally called its magnitude.

Given the coordinates of a vector (x, y) , its magnitude is $\sqrt{x^2 + y^2}$. (SparkNotes 2011)

B.3. Spray painting

A spray can is technically known as an "aerosol" device. It consists of a vessel that can withstand significant internal pressure (the can); a spray nozzle that incorporates a sealing device that won't let the pressure out of the can until called for; a tube inside the can that brings the fluid (paint) to the nozzle; and the two critical elements: pressurized gas (usually carbon dioxide) and the paint. (Second Chance Garage 2011)

Spray paint can nozzles are precision-engineered to provide a reasonably high-quality spray, with consistent droplet sizes. The spray pattern they provide isn't adjustable like air-powered spray guns are, but that isn't why so many people have a hard time getting smooth, shiny results. Those very people would encounter the same problems if they used a spray gun. The reasons good finishes are difficult are: 1) the user isn't painting properly, and 2) the paint itself is very thin or low viscosity. (Second Chance Garage 2011)

There are several wrong ways to apply spray paint, all of which end up with different shades of their chosen color or an uneven finish. People that use spray paint can either hold the can at an improper distance or move with varying speeds that will result in an uneven finish. Spray paints are heavily thinned (more solvent-to-paint content) in order for them to be pushed out of the can and turned into an aerosol spray. Thicker paint would require greater gas pressure and a more sophisticated nozzle, hence leading to an air-powered paint gun. The solution to getting good results with thinned paint is simply to

remember that it is, in fact, thinner and prone to runs. That means more thin coats. (Second Chance Garage 2011)

The paint pigments have most likely separated during storage, so the paint pigments need agitation to properly mix again. Shake the spray paint can before using until the little ball inside, called pea, rattles. And test the spray on a piece of cardboard or paper. (Second Chance Garage 2011)

Trial and error will help in finding the best distance to spray from and how thick the paint should be for your application. (BMC 2008) Once you can see the "wetting" effect; that is, the paint falls onto the surface and just starts to become shiny, it's time to move the can along the surface. Keeps it moving at all times and the correct speed is that in which the volume of paint coming out wets the surface. Moving too fast applies a "dusting" of paint that is too little for the components to "float out" to become a smooth surface. Too fast applies the paint too thick and because it is a thin fluid it will start to run and drip. (Second Chance Garage 2011)

Good paint finishes are always built up from several layers of paint. The idea is that the paint you sprayed 10 minutes ago is still uncured and soft, so the new coat will not only stick well but its solvents will tend to "re-melt" the last coat and allow the finish to create a smoother, flatter surface. Fresh paint comes off very easily and you can re-do the whole thing in short order. (Second Chance Garage 2011)

C. Related Technologies

C.1. Hektor the Spray Painting Robot

Hektor is a portable spray paint output device for laptop computers. It is made of two motors, timing belts, and a spray paint can holder. Hektor moves along a programmed drawing path and decides when to open and close the spray paint can valve.

Each of Hektor's motors is attached to a timing belt which is attached to the spray paint can system. The number of rotations on each of the motors controls the length of each of the timing belts. The resulting lengths of the timing belts correspond to a point on an imaginary Cartesian plane, and a series of these points create a path for the spray paint can system. Each path has a "start" and "end" point, Hektor then starts spray painting at the start point and stops at the end point. This can create a line or a figure that will eventually complete the programmed design. (Lehni and Franke 2002)

C.2. Motoman Painting Robots

These application-specific paint robots can be used for primer, base coat, finish coat, clear coat and spray dispensing, using water-based, solvent-based, powder, glaze and glue/adhesive materials. They efficiently coat complex parts of nearly any size and shape, including recesses, curved and contoured surfaces -- without runs or sags. (Yaskawa 2011)

C.3 Kawasaki Painting Robots

Kawasaki developed these robots with their "Simple but Friendly" design concept. These robotic painting systems are explosion proof and contain collision and overload detection sensors and have up to three meters of reach. These robots are easy to program, as they have auto path generating software. (Kawasaki robotics, 2011)

Chapter 3

Methodology

A. Components

A.1. Spray Paint Can

In this study a full cone nozzle spray paint can was used.

A.2. Framework

A.2.1. Spray Paint Valve Pressing System

A wooden frame held the spray paint can along with a servo motor that pressed the spray paint can's valve and was attached to two timing belts.

A.2.2. Movement system

Each of the servo motors had a wooden structure that held it in place and attached it to a wall. A timing belt is also attached to each of them which were then connected to the Spray Paint Valve Pressing System.

A.3. Timing Belt

The Valve pressing system needed two timing belts attached to it with each belt connecting the spray paint valve pressing system to each of the motors located on the upper left and upper right corners of the wall.

A.4. LEGO Mindstorms NXT kit

This is the robotics kit that was used to create the spray painting robot.

A.4.1. Servo motors

The LEGO Mindstorms NXT kit contains 3 servo motors. These motors give the robot the ability to move objects or it. This study used all 3 motors in order to construct the spray painting robot. The first and the second servo motors were

used to control the spray paint valve pressing system's movement and the third servo motor was used to press the spray paint can valve open.

A.4.2. NXT Brick

The LEGO Mindstorms NXT kit contains 1 NXT Brick. It serves as the brain for the robot and controls all of the servo motors. Programs were uploaded and executed by the NXT Brick.

A.4.3. Miscellaneous Parts

All the remaining parts in the LEGO Mindstorms NXT kit that was used to construct the frame, determine the physical appearance of the robot according to the design such as beams, pegs, connectors, wheels, etc. Cables that are longer than those provided in the kit were used in the study.

B. Major Systems to be constructed

B.1. Valve Pressing System

The Valve Pressing System consisted of a servo motor attached to a lever and to a wooden frame that allows it to push open the spray paint can's valve.

B.2. Design Path Control System

The Valve pressing system was moved by 2 servo motors using a timing belt attached to both left and right corners of the valve pressing system with the two servo motors enclosed in a structure which is each attached to the wall.

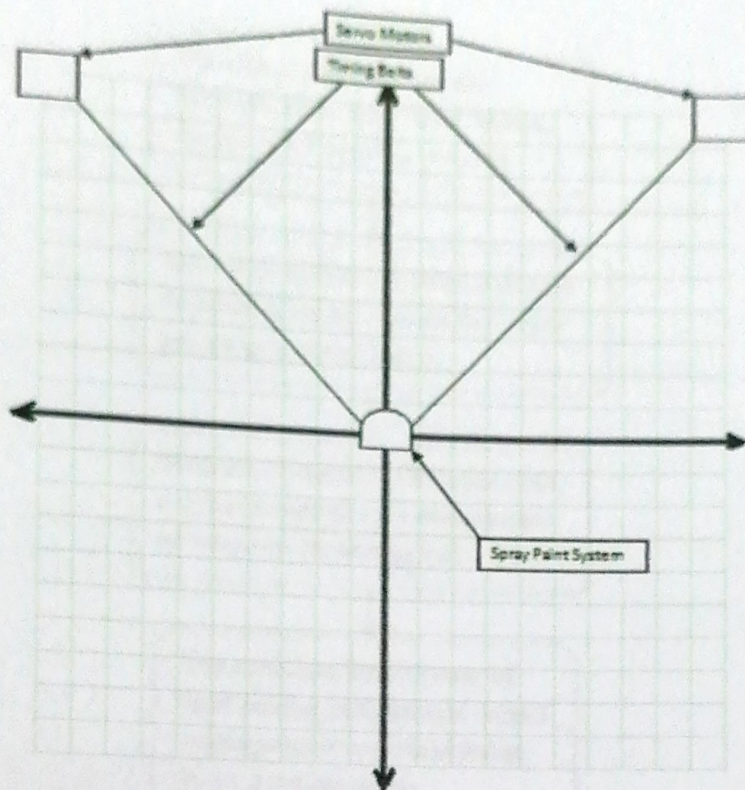


Figure 1. Spray Painting Robot Diagram

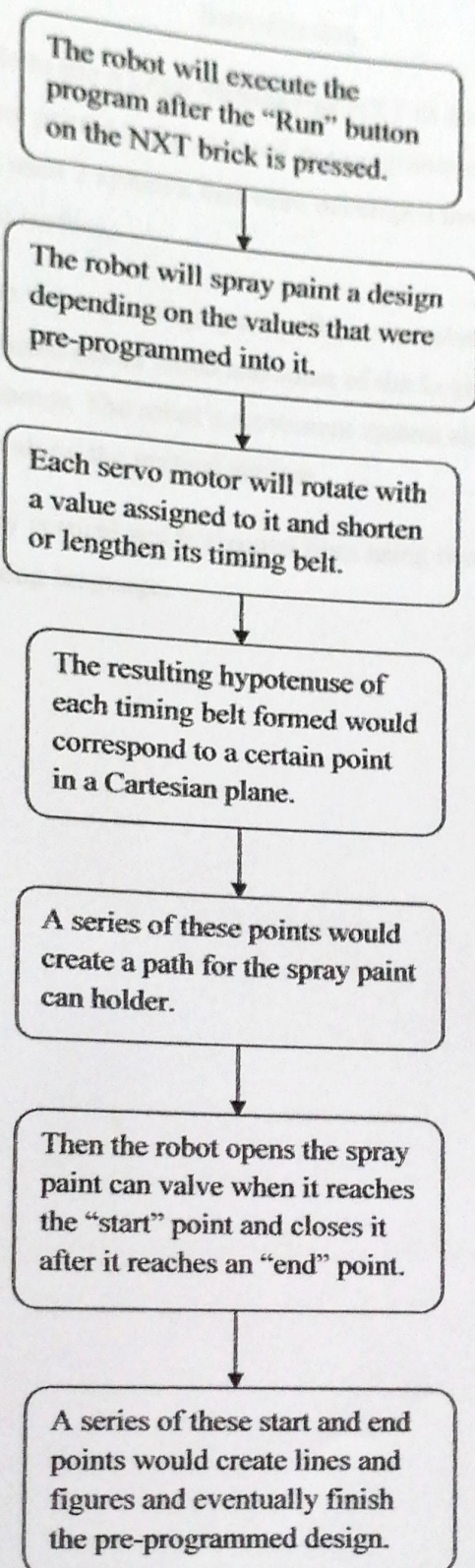
D. Programming

D.1. Spray Paint Can Valve Program

This was used to control the motor that opens and closes the valve in the spray paint can.

D.2. Movement System Program

This program controlled the movement of the spray paint can valve button system using the rotation of the servo motors. Each of the servo motors was given an assigned value for it to shorten or lengthen the timing belt.



Chapter 4

Introduction

This study was able to use a Lego Mindstorms NXT to develop a robot that can autonomously spray paint a mono-colored pre-programmed design on a flat vertical surface. The robot used 2 systems that were developed that allowed it to move and apply its spray paint onto surface.

The spray paint can valve pressing system allows the robot to use the spray paint. This system was constructed out of wood and some of the Lego Mindstorms NXT parts, including a servo motor. The robot's movement system allows the spray paint can valve system to navigate along the vertical surface.

The robot can spray vertical and horizontal lines using two different programs written in NXT-G programming language.

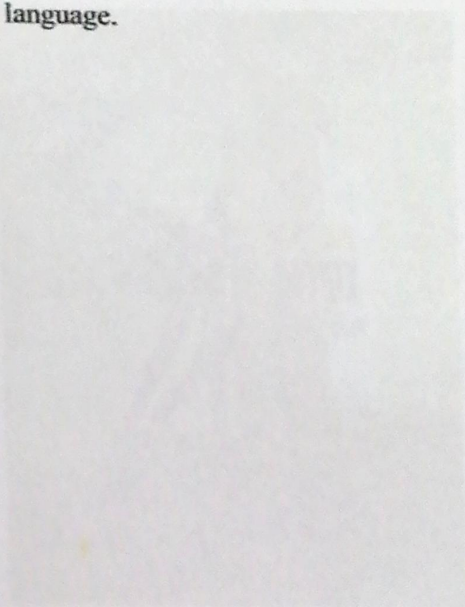


FIGURE 4.1. Spray Can Valve Pressing Painting System

Results

A. Hardware

A.1. Spray Paint Can Valve Pressing System

The Spray Paint Can Valve Pressing System focuses on a system design that was lighter than the previous systems but strong enough to press and hold the spray paint can's valve. This new system presses the spray paint can's valve using a lever, made of *Lego's*, and a fulcrum, made of metal to prevent bending, attached to a servo motor. When the servo motor rotates, it pushes the lever upward on one side and because of the fulcrum the lever pushes downward on the other and presses the spray paint can's valve. The Spray Paint can and the servo motor is held together by a wooden structure. The Spray Paint Can Valve Pressing system is then attached to the Movement System using a flat rubber belt.



Plate 1. Spray Can Valve Pressing Painting System

A.2. Movement System

The Movement System is a pair of servo motors, each attached to a wooden frame, that rotate each of their rubber tires that control the length of a pair of flat rubber belts which support the Spray Paint Can Valve Pressing System.



Plate 2. Rubber Belt

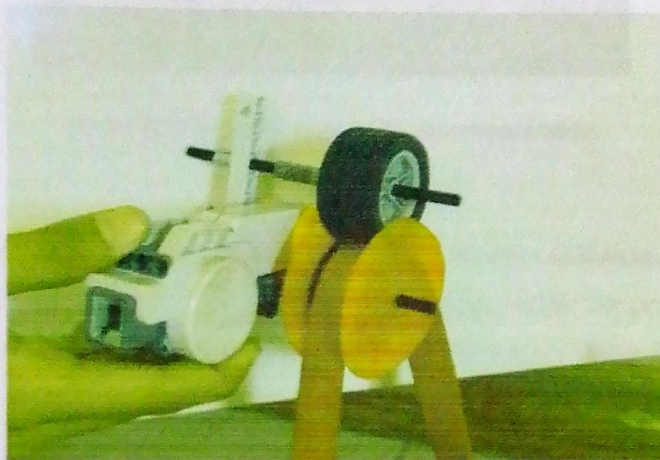


Plate 3. Movement System

A.3. Cable Connection

The cables provided in the Lego Mindstorms NXT kit were long enough to connect each of the movement system's servo motors to the NXT brick, but the longest cable wasn't long enough to connect the Spray Paint Can Valve Pressing system's servo motor to the NXT brick so a longer cable was needed. An extended LEGO Mindstorms NXT cable was constructed to connect the NXT brick to the Servo motor in the Spray Paint Can Valve Pressing system. The Lego Mindstorms NXT cable was cut and then spliced into a Cat5 cable following a color coding rule.



Plate 4. Extended Lego Mindstorms Cable

B. Software

The top and bottom rows of program blocks in the robot's software, control the upper left and upper right servo motors of the movement system, while the program block in the middle row controls the servo motor of the Spray Paint Can Valve Pressing System.

B.1. Vertical spray program

This Program tells the Spray Painting Robot to spray paint a vertical line at the center, from top to bottom.

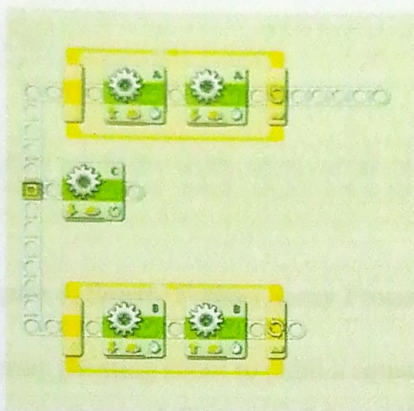


Figure 2. Vertical Spray Program

B.2. Horizontal spray program

Program that tells the Spray Painting Robot to spray paint a horizontal line at the center, from left to right.

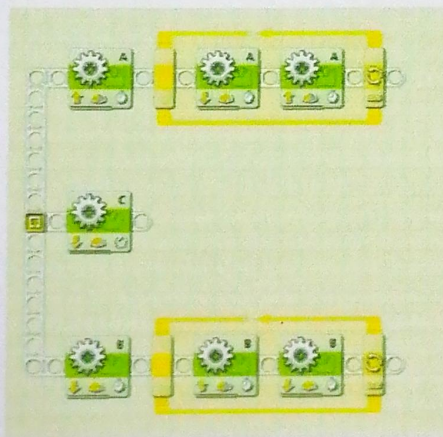


Figure 3. Horizontal Spray Program

B.3. Square Pattern spray program

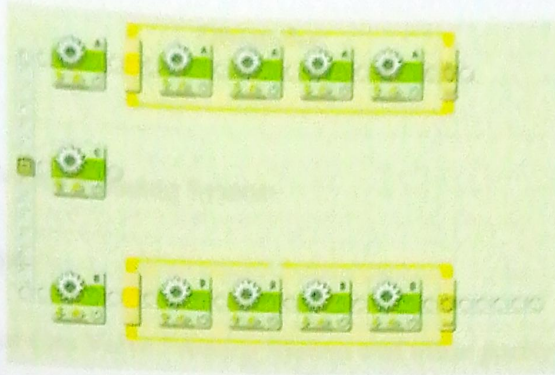


Figure 4. Square Pattern Spray Program

This program tells the spray painting robot to paint a square. The *motor blocks* on the top row tells the servo motor, on the top left corner of the wall, the speed, and the direction of the rotation as well as when to rotate.



Figure 5. First Spray Paint Clear Wall Painting System.

Discussion

A. Hardware

Spray Paint Can Valve Pressing System

A.1. First Prototype

The first Spray Paint Can Valve Pressing System was made purely out of Lego Mindstorms NXT Parts (Plate 5) was feasible because it was very light that it would not hinder the movement system. The problem was that the servo motor could not exert enough force to open the spray paint can's valve and the *Lego*'s that make up the structure that holds the spray paint can, cannot handle the force exerted by the servo motors and give way after repetitive movements of the servo motor.



Plate 5. First Spray Paint Can Valve Pressing System

A.2. Second Prototype

The second Spray Paint Can Valve Pressing System focused on maximizing the force exerted by the servo motor and strengthening the structure that holds the spray paint can. The structure was constructed out of wood so that it won't break under the stress. The servo motor was attached to a linear actuator (Plate 6.) that converted its rotational motion into linear motion and then attached to a hydraulic system that increased its force exerted on the spray paint can's valve. The Hydraulic system consisted of two syringes of different volumes and the linear actuator was constructed completely of *Lego*'s. The system worked, however it had a long delay before it could press the spray paint can's valve and after repeated use the linear actuator kept breaking and the hydraulic system was losing its efficiency because of air bubbles entering the system. The entire system was bulky and heavy which could pose a problem if it was attached to the movement system.

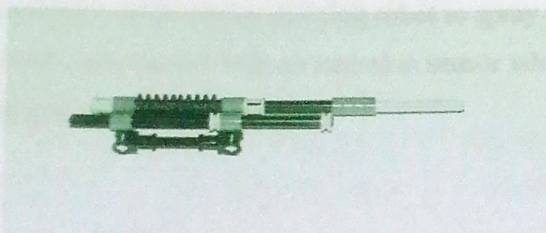


Plate 6. Linear Actuator

B. Observations

The robot can spray paint a pre-programmed design accurately, however, there were times when the robot spun the servo motors too fast that it caused the Spray paint can valve pressing system to vibrate and paint some blurry lines. Also the robot worked well in an isolated environment so long as the belt between the robot's movement system and spray paint can valve pressing system isn't disturbed. The surface must be flat and is oriented at a 90 degree angle, not tilted to prevent the robot from hitting the surface when it extends the belt's lengths.

C. Advantages and Disadvantages

C.1. Advantages

The Lego Mindstorms NXT Spray Painting robot, compared to the spray painting robot, is easier to program, and the materials used in the construction of the spray painting robot can be easily procured. The Lego Mindstorms NXT Spray Painting Robot, aside from being cheaper compared than industrial spray painting robots, has the ability to spray paint on flat vertical surfaces which makes it more appropriate rather than buying expensive industrial robots.

C.2. Disadvantages

The Lego Mindstorms NXT Spray Painting Robot uses NXT-G as Programming Language. The NXT-G software, compared to other programming languages used in programming microcontrollers, is less accurate and the values on the software are harder to control. Aside from the inability of the spray painting robot to spray paint more than one colored designs, it was not constructed with an emission sensor which allows the robot to discharge uncontrolled excess spray paint.

D. Main Features

The Lego Mindstorms Spray Painting Robot, spray paints autonomously, much like other spray painting robots in the market but it paints only on vertical, two-dimensional surfaces which made it ideal for spray painting on walls. Compared to its industrial counterparts that feature three-dimensional spray painting and expensive price tags, the Lego Mindstorms Spray Painting robot is much cheaper. Most Spray painting robots in the market have limited reach, while the Lego Mindstorms Spray Painting robot's reach was only limited by the length of the timing belts and cables, by using a longer cable and timing belt, the robot could overcome this limitation.

