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Using Lego Mindsorms NXT Robots for Pitch and Line Marking Illustration of Football Stadiums

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ABSTRACT

Teaching robotics to young students is a very good introduction into science and technology. Not only do they learn how to design, construct, and programming a small robot but they also get a more complete idea about what is required for implementing, simulating and commercializing a complete system to act properly in the real world. Educational materials have been developed and summer courses and competitions are organized to encourage young students to develop their skills in these areas. In this paper, students are using Lego Mindstorm NXT robots for carrying out pitch and line marking illustrations which are costly and periodical work in football stadiums. A scaled-dawn football stadium according to FIFA standards is constructed and used to test the accuracy of developed robotic system. An implement unit consisting of a motor drive unit carrying a whiteboard marker pen is constructed for carrying out the line marking illustration. A path planning algorithm for generating the waypoints required for guiding the robot throughout this process is used. The robot unit is programmed to move in straight lines from point to point and in circular lines to carry out the required field operation. The developed kit is very useful in showing students the importance of field robotics and how it can be used for carrying out real life field operations.

Keywords: *Robotics, education; automation, football, autonomous navigation; FIFA*

1. INTRODUCTION

A In an attempt to encourage young students to select an education in Technology disciplines, robots seem a topic that attracts interest. Apparently many young people are very good at using gadgets, but not many of them are interested in how these devices are built. Something needs to be done to make our young people more enthusiastic about technology [1].

Many movies and toys have been created in which robots play a role and children are very interested in them. When allowing children to design, build and program their own robots, they will get involved in many technical activities that also overlap with several other disciplines like Mathematics, Biology, Engineering, Electronics, Information Technology and Science in general. Also they will learn to work in teams and will be faced with many difficult technical decisions which enhance their management skills.

Several initiatives exist all over the world to improve this situation and as part of the ComLab II project children in Dutch schools were stimulated to participate in the RoboCup Junior challenge. Course material has been created as part of the project and several schools have enrolled in the 2007 edition of the RoboCup Junior competitions in the Netherlands.

Robots has been proved reliability in many different areas such as in the rehabilitation field assistant robots, and in surgery [2], endoscopic surgery [3], mining [4], manipulation in space, underwater, construction, and service environments [5], in agriculture such as weed control [6-7], forest fire monitoring [8] and in hazardous environments such as welding ship walls inside double-hulled structures [9] and in nuclear industry [10]. The focus of field robotics research is on large-scale outdoor autonomous systems in applications that are characterized by relatively unstructured, difficult and often hazardous environments. It draws together the most advanced research areas in robotics, including; navigation and control, sensing and data fusion, safety and reliability, and planning and logistics. Guidance systems for autonomous vehicles usually consists of the following three parts; a sensor that supplied the system with the position of the vehicle and hence the position deviation from target position, a controller which generates a system specific correction control signal and finally an actuator that, combined with the forward movement and steering system of the vehicle [11]. For agricultural purposes, several automatic guidance systems have been developed.

Currently, the most sophisticated and accurate automatic guidance and auto-steering systems are based on global positioning system (GPS) [12-16]. The actual position of the vehicle is measured using a GPS device. A path planner calculates the path the vehicle has to follow to move from point to point. The auto-steering system consists of a comparator to calculate the position error, a controller to generate correction signal in relation to the calculated path, and finally an actuator (i.e., steering controller) to apply the control signal to continually adjust the heading angle of the vehicle towards its target position. An additional actuator is required for raising and lowering the implement attached to the vehicle.

In this paper, a promising application of field robotics to carry out a new task which has not been tackled yet is introduced. In football stadiums, periodical operations such as cutting the grass field, pitch and line marking illustrations and lawn striping are done manually in regular bases and require very qualified and expensive personnel who have to keep very high concentration for the output matches with the standards set by FIFA [17]. An algorithmic approach for generating the way points required for guiding an autonomous vehicle using

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GPS throughout the execution of each single operation was developed [18]. Here, a LEGO NXT robot with a marker as an implement is used to carry out the pitch and line marking illustration task on a downscaled football stadium. Constructing and programming the robot are used as an interesting task for junior engineering students.

2. MATERIALS AND MATHOD

2.1. Lego Mindstorms NXT

Lego Mindstorms is a line of programmable robotics/construction toys, manufactured by the Lego Group [19]. It was first introduced in 1998 and it was called Robotics Invention System (RIS). The next generation was released in 2006 as Lego Mindstorms NXT (Figure 1). The newest version, released on August 5, 2009, is known as Lego Mindstorms NXT 2.0. Lego Mindstorms is primarily used in secondary education but most universities also use the Lego Mindstorms NXT for their introductory courses in mobile robotics or for projects.

Figure 1. Lego Mindstorms NXT Controller with sensors and a sample mobile robot

Lego Mindstorms NXT is equipped with three servo motors, a light sensor, a sound sensor, an ultrasound sensor and a touch sensor. The NXT 2.0 has two touch sensors, a light, sound and distance sensors, and support for four sensors without using a sensor multiplexor. The main component in the Lego Mindstorms kit is a brick-shaped computer called the NXT Intelligent Brick. It can take input from up to four sensors and control up to three motors. The brick has a 100x64 pixel monochrome LCD display and four buttons that can be used to navigate a user interface using menus. It also has a speaker that can play sound files. It allows USB and Bluetooth connections to a computer. Lego Mindstorms NXT comes with the Robolab [20] graphical user interface (GUI) programming software, developed at Tufts University using the National Instruments LabVIEW [21] as an engine. With Robolab, students use flowchart like "blocks" to design their program. Students that need to write more advanced programs sometimes prefer to use third party firmware and/or high-level programming languages, including some of the most popular ones used by professionals in the embedded systems industry, like Java, C and C# (i.e. ROBOTC). The programs are downloaded from the computer onto the NXT Brick using the USB port or wirelessly using the Bluetooth connection. Programs can also be run on the computer and wirelessly through Bluetooth can control the NXT brick. Some of the programming languages that are used to program NXT Brick are:

- NXT-G: Is the programming software that comes bundled with the NXT. This software is suitable for basic programming, such as driving motors, incorporating sensor inputs, doing calculations, and learning simplified programming structures and flow control.

- C# with Microsoft Robotics Developer Studio: Uses the free tools Visual Studio Express and the Robotics Developer Studio and allows programming using the C# language.

- Next Byte Codes (NBC): Is a simple open source language with an assembly language syntax that can be used to program the NXT brick.

- Not eXactly C (NXC): Is a high level open-source language, similar to C. NXC is basically NQC (Not Quite C) for the NXT. It is one of the most widely used third-party programming languages for the NXT.

- ROBOTC: Developed by the Carnegie Mellon Robotic's Academy. ROBOTC runs a very optimized firmware, which allows the NXT to run programs very quickly, and also compresses the files so that you can fit a large amount of programs into your NXT. Like other NXT languages, ROBOTC requires this firmware to be downloaded from the ROBOTC interface in order to run.

Another addition that allows more rigid Lego Mindstorms designs is TETRIX by Pitsco [22]. The metal building system was designed specifically to work with the LEGO Technic building system through the use of the innovative Hard Point Connector. TETRIX, combined with custom motor controllers from Hitechnic, enables students to use the power of the Mindstorms technology and incorporate and control powerful DC and servo motors and metal gears. Students can build more versatile and robust robots designed for more sophisticated tasks, all while mastering basic wiring, multi-motor control, and much more.

The processing power and programming flexibilities that these systems offer make them ideal for University introductory courses. Many universities are using these robots very successfully. These systems were described earlier in the Mobile robotic platforms for K-12 education section thus the explanation part will be omitted. These robotic kits are primarily used at the introductory level to teach the basic concepts and principles of perception, localization, map building and path planning and navigation.

We often find these type of mobile robots used for projects and/or to develop prototype ideas. Programming at this level is done using high-level languages such as C# with

Microsoft Robotics Developer Studio, NBC, ROBOTC or other high-level languages [23].

2.2. Lego Mindstorms NXT at University Level and first Lego League

The FIRST LEGO League (also known by the acronym FLL) is an international competition organized by FIRST for primary and middle school students (ages 9–14 in the USA and Canada, 9–16 elsewhere). It is an annual competition and each year a new challenge is announced that focuses on a different real-world topic related to the sciences. Each challenge within the competition then revolves around that theme. The robotics part of the competition revolves around designing and programming LEGO Robots to complete tasks. Students work out solutions to the various problems they are given and then meet for regional tournaments to share their knowledge, compare ideas, and display their robots. The Junior FIRST LEGO League is a scaled-down robotics program for children of ages 6–9 [23-24].

3. PITCH AND LINE MARKING ILLUSTRATION

In this section, the algorithmic approach used to generate waypoints required for robot navigation throughout the execution of pitch and line marking illustration of football playing fields is introduced [18].

3.1. Standard FIFA dimensions of football playing field

For all matches at the top professional level and where major international and domestic games are played, the playing field should have dimensions of 105m × 68m. These dimensions are obligatory for the FIFA World Cup™ and the final competitions in the confederations' championships [17]. Other matches can be played on a playing field with different dimensions and the Laws of the Game stipulate the maximum and minimum dimensions. However it is strongly recommended that new stadiums have a 105m × 68m playing field area. In this paper, standard dimensions are adopted.

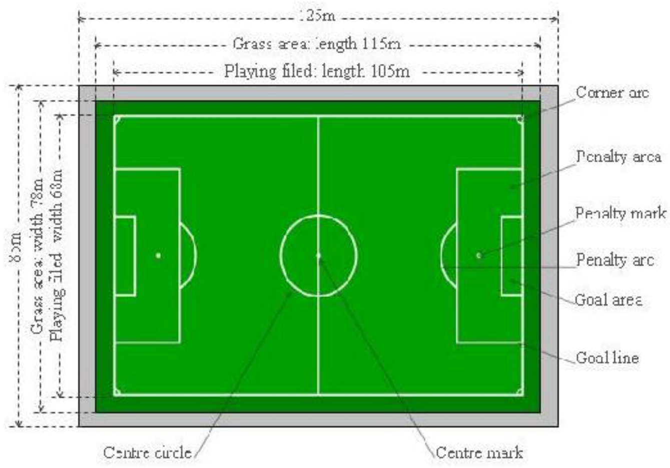

Figure 2. Dimensions of the playing field (FIFA, 2007).

Additional flat areas are required beside the playing field, ideally behind each goal line, where players can warm up. This area also allow for the circulation of assistant referees, ball boys and girls, medical staff, security staff and the media. It is recommended that there should be a minimum of 8.5m on the sides and 10m on the ends. This result in an overall playing and an auxiliary area dimension of length: 125m and width: 85m. Playing field dimensions are shown in Figure 2. In this area, a minimum of 5m on the sides or touch lines and 5m behind the goal lines must be of the same surface material as the playing field (grass or artificial turf).

The remainder of the auxiliary area can be either of the same surface material as the playing field or it can be a concrete-type surface material which facilitates the movement of service and security vehicles and ambulances. Any part of this additional auxiliary area that will be used as a warm-up area should have the same surface as the playing field. However, with grass fields or artificial turf of the highest quality could be used. Details of a playing field are shown in Figure 3.

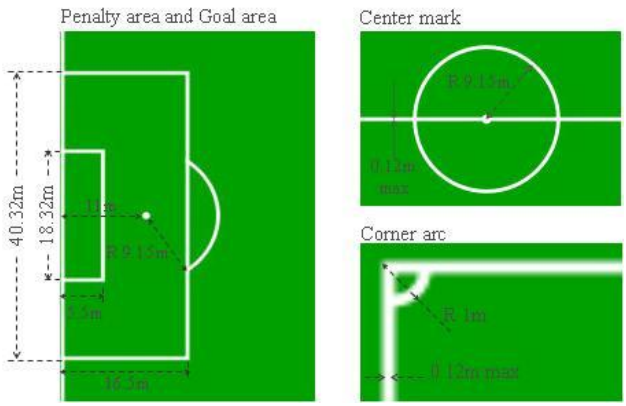

Figure 3. Dimensions of penalty and goal area (left), central mark (up right) and corner arcs (bottom right) (FIFA, 2007).

3.2. Pitch and line marking illustration algorithm

In this section, the algorithm for generating waypoints for the vehicle to navigate through the field for pitch and line marking illustrations is introduced. The input to the algorithm is the UTM coordinates of the grass field vertices. The UTM coordinates of the vertices of the rectangle-shaped playing field, penalty area, goal area, central mark and corner arcs are generated. According to standards of FIFA, the playing field has a length of lp = 105m and width of wp = 68m. The dimensions for the center circle and penalty kick arcs are measured from the center of the field and penalty spot respectively, to the outside of the lines. The radii of corner arcs are 1m and the radii of the center circle and goal circle are 9.15 m. The inside faces of the goal-posts should be 7.32m apart and the distance between the ground and the underside of the crossbar is 2.44m.The width of the playing lines should be 120mm maximum and the goal-line should be marked the same width as the depth of the goal posts which should be considered in the design of the pitch and track marking

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implement. Line color is not specified but is traditionally white. The external dimensions should include the width of the lines. The center of the penalty spot is measured from the outside of the goal line. The UTM coordinates of the playing field for pitch and line marking illustrations are obtained as follows.

a) **Playing field boundaries:** The dimensions of a playing field, according to standards of FIFA, are 105×68 m, as shown in Figuer 2. In order to obtain the UTM coordinates of the four corner points (i.e., vertices) of the rectangle-shaped playing field, if the grass field is rectangle, the grass field is de-expanded by a distance r, given by Eq. (1) where lg, wg are the length and width of the grass field and lp, wp are the length and width of the playing field, respectively.

$$r = (lg - lp)/2 = (wg - wp)/2 \quad (1)$$

If the grass field is not a rectangle, it should be rectanglized first by finding the intersection points between each two touch (i.e., longest edge of the playing field) and goal (i.e., shortest side of the playing field) and repeating this process until we obtain the four vertices.

b) **Center line:** Center line is the line connecting the two center points located exactly at the middle of each of the two opposite touch lines. A center point is obtained by locating the UTM coordinates of the point dividing the length of the touch line by two.

c) **Center mark:** Center mark is the point located exactly at the middle of the center line. It is obtained by locating the UTM coordinates of the point located on the center line at distance of its half length from one of its ends. The center mark is illustrated by a circle of radius of 0.15 m.

d) **Center circle:** The center circle is illustrated by a circle of radius 9.15m centered at the center mark.

e) **Penalty area:** Penalty area is the area bounded by penalty lines (forming a rectangle of area 40.32×16.5 m2). There are two penalty areas in the field, each consists of penalty lines, penalty mark and penalty arc.

f) **Penalty line:** Penalty lines are three lines; one line is of length 40.32 m parallel to the goal line and two parallel lines of length 16.5 m and perpendicular to the goal line and at distance of 40.32 m. Two vertices of the perpendicular penalty lines are located on the goal line at distance of (68-40.32)/2 and (68+40.32)/2 from one of its ends, respectively. The other two vertices are located at the parallel penalty line and at distances of (68-40.32)/2 and (68+40.32)/2 from one its ends. The parallel penalty line is the line parallel to the goal line and at distance of 16.5m from it.

g) **Penalty mark:** Penalty mark is a circle of 0.15 m radius centered at a point located at distance of 11 m from the end point of a line parallel to the touch line (i.e., longest edge of the playing field) at distance of 68/2 m from it to the inside side if the field.

h) **Penalty arc:** Penalty arc is an arc of a circle of radius 9.15 m centered at the penalty mark.

i) **Goal area:** Goal area is the area bounded by the goal lines (forming a rectangle of area 18.32×5.5 m2). Goal lines are three; one of length 18.32 m parallel to the goal line and two of length 5.5 m perpendicular to the goal line. The UTM coordinates of the vertices of this rectangle are obtained by allocating two points on the goal line at distances of (68-18.32)/2 and (68+18.32)/2 from one of its ending points. The other two vertices are allocated on the line parallel to goal line (i.e., the short side of the playing field) at distance of 5.5 m from and at distances of (68-18.32)/2 and (68+18.32)/2 from one of its ending points.

j) **Corner arcs:** There are four corner arcs in the field located at each corner point of the playing field with radius of 1 m.

A program generates the above vertices has been developed using Matlab® programming language and it is available for interested readers by contacting the corresponding author.

3.3. A prototype football playing field

A prototype field of the dimension 100:1 of the standard dimensions has been used for testing and demonstrating the robot ability to carry out pitch and line marking illustrations with high accuracy. The downscaled testing field has dimensions of 105cm × 68cm. A white paper representing the football field of the new dimension has been used to represent a regular football field. An implement with a motor has been developed to carry the marker, at the end of a line, the implement raise the marker up and them make a turning then it lower the marker to start a new line, etc.

TABLE I. THE UTM COORDINATES OF THE GRASS FIELD OF BORG EL ARAB FOOTBALL STADIUM IN ALEXANDRIA, EGYPT

Point Number	Easting	Northing
1	30.998929	29.729200
2	30.999009	29.729159
3	30.99981	29.729001
4	30.999895	29.728999
5	31.000016	29.729693
6	30.999936	29.729731
7	30.999106	29.729900
8	30.999037	29.729897

4. RESULTS

In this section, the developed algorithm will be tested using a real world football stadium. The latitude and longitude UTM coordinates of the grass fields of Borg El-Arab football stadium, Alexandria, Egypt, is given in Table 1. A satellite image of the stadium and the output of the program are shown in Figure 4.

Figure 4. Satellite image of the Egyptian Army (i.e., Borg El Arab) football Stadium (right) and its pitch and line marking aillustration using the program (left).

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Now the football is downscaled to the range of 100:1 and tested using the NXT robot. The program used for carrying out pitch and line marking illustration is shown in Figure 5. The robot and its implantation are shown in Figure 6.

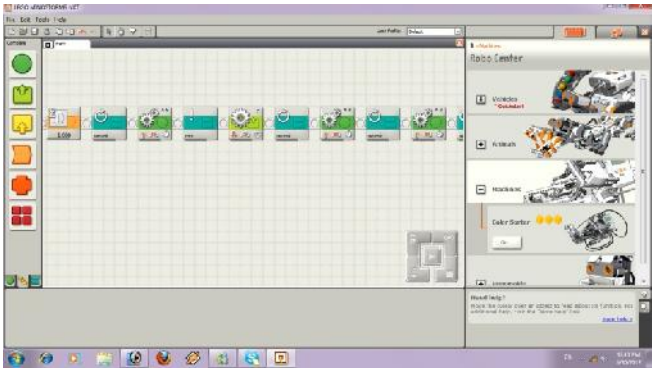
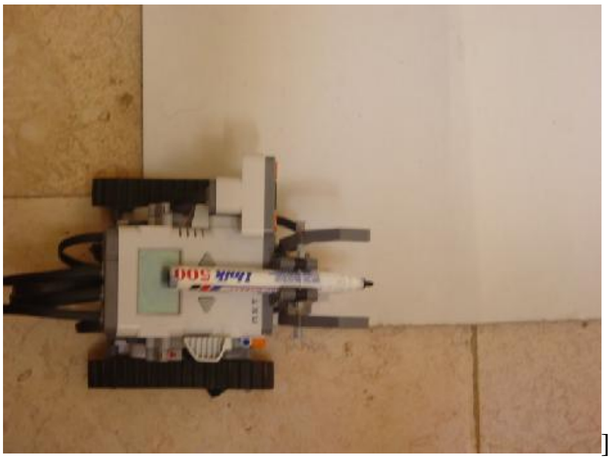


Figure 5. The programming environment of the NXT robot and the developed program for carrying out pitch and line marking illustration.

5. CONCLUSIONS

Mobile robots are becoming part of our everyday life in many forms. The mobile robot industry, other organizations and universities are developing mobile robots for all imaginable applications. There is a need today for specialized mobile robotics engineers and scientists. This is now possible because of the development of various types of mobile robots and simulators. The existence of various mobile robotics competitions gives extra motivation to students and educators to do more work in mobile robotics. More efforts should be given to create special courses and more focused training to improve the skills of students in the area of mobile robots and its applications.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The robot and its implement during the execution of the field operation.

Teaching robots from the early stages will better prepare students for high school mobile robotics education and competitions. At the university level, introductory level mobile robotics courses must be offered. More advanced mobile robotics courses must also be offered that specialize in topics such as vision, localization, navigation, etc. At the graduate level, students must concentrate on research and projects. This will create a continuation on mobile robotics education and thus creating better prepared graduate students, developing more research interest and creating skilled graduates for the many jobs that are opening up in the mobile robotics industry.

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