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# Build your own turtle robot

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## ABSTRACT

Research into a robotics learning environment is outlined. Developments required in the LOGO language are discussed. A modular turtle robot constructed from Fischertechnik components is introduced. Design principles and approaches to robot construction are discussed.

## 1. Introduction

Papert's research [1] included a vision of a mathematical environment, to be created using computer technology and working physical models, where learning is natural and fun. Mathsland [2] is a practical application of Piaget's assertion that children learn by doing and by thinking about what they do. His research included the development of LOGO; a computer language in which communication with a turtle takes place. A turtle robot is a computer-controlled cybernetic animal developed from the tortoise used by Grey Walter in his cybernetic research [3]. To Papert the turtle serves no other purpose than being good to program and good to think with.

Interest in LOGO, Screen Turtles and Turtle Robots has grown rapidly because they not only provide an environment in which learning mathematics is natural but also an environment in which computer awareness, computer programming and logical thinking is natural. In this country LOGO's greatest application is in computer awareness and introductory programming courses [4]. Its popularity in these areas is largely due to the superb human engineering of the language. Children relate well to turtle robots and gain a sense of power and achievement from controlling them. Commercially available turtle robots can be manipulated very effectively as objects within the LOGO environment but can not be easily modified.

## 2. Robotics

The age of programmable mechanical machines (robots) is upon us before most of the population has come to terms with programmable electronic machines (computers). As a consequence the social re-adjustment and re-education required is enormous [5]. Automation through the application of computers has impacted on every area of life. Already people and robots are working side by side on production lines. This new technology can be used for the good of mankind but in the process may put people out of work. Fundamental questions about work and the purpose of industry have to be answered. Does industry exist to make profits or to employ people?

Currently robots are being employed in highly repetitive and dangerous jobs including spray painting and forging. As technology advances, management will introduce them into many other occupations because robots are more productive than people allowing a company to make higher profits or compete with cheap imports.

Robots are - reliable, uncreative, consistent, unimaginative, never sleep, can't solve problems, never take a sicky, don't care for anyone, never question what you say, made in the Image of Man and Machine.

People are - unreliable, creative, inconsistent, imaginative, need sleep, can solve problems, get sick, care for others, question what you say, created in the image of God.

My own research involves developing a robotics environment in which learning robotics is natural and fun, an environment designed to help children learn about robotics so that they can be involved in the development of robots and be equipped to make social decisions for the good of mankind. This has involved applying basic learning principles to a new field and investigating the robotics capability of LOGO and turtle robots. Roboticsland includes a modular robot which can be constructed, modified and rebuilt with ease. Sensors and manipulators can be added and then manipulated as objects using a computer language.

## 3. Robotics Language

LOGO has limitations in the area of robotics [6] because it lacks concurrency. Due to LOGO's sequential nature a program can not test the sensors while the turtle is moving. Thus when finding or following a wall the program must alternate between movement and sensing resulting in jerky motion. Program constructs of the type -

motion UNTIL touch, and
motion WHILE touch

are required for realistic, real-time robotics experiments.

Robotics experiments require the addition of a variety of sensors and manipulators. Current versions of LOGO do not allow addition of extra hardware related commands. A robotics language would allow additional commands and labels (for example FLIGHT being front light sensor) to be added by the user.

In LOGO a curve is drawn as a combination of straight line segments and angles, resulting in jerky motion of the robot. The robot repeats the sequence of forward motion and turn until the curve is complete. The smaller the segment the more realistic the curve. In the main circles and arcs are drawn, but the use of Bezier functions [7] allow complex curves to be drawn. Bezier curves are used in the design of car body panels and aeroplane airframes where a smooth transition is required from one complex curve to another.

A Bezier curve is specified by designating the start and end points of the curve and one or more control points. The control points do not lie on the curve but control the shape of the resultant curve. Modifying a control point changes the shape of the curve. Calculation of the Bezier function produces a number of points on the curve. These can then be used to calculate vectors (direction and distance) for the turtle to move along. Taylor series expansions are required to perform trigonometric functions. The low precision of sixteen bit integer arithmetic results in a course curve.

Robots are not restricted to traversing curved paths consisting of a series of discontinuous segments. By varying the speed of one motor relative to the other the turtle robot will follow a continuous curve. If the speed ratio is varied during motion the curvature of the path is changed. This opens up an area of robot control that can easily become highly complex. A simple LOGO style command for curve following, given a robot in which motor speed can be varied, is:

```
CURVE RIGHT/LEFT(xcoord,ycoord,finalangle)
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The parameters specify the final position and heading of the turtle robot assuming current position and heading to be of zero value in the coordinate system. A program would then calculate a path, and speeds for the motors, and send the robot on its way. The robot could either turn and then follow a simple curve with the motor speeds in a fixed ratio or a complex curve could be calculated and traced.

## 4. Design of Turtle Robots

A variety of turtle robots are available. Each has two motors for movement, a pen control mechanism, lights, a speaker, touch sensors located around the perimeter and control electronics. To turn, a turtle robot rotates around its centre, one motor turning forward, the other turning backward.

Trugon * ( figure 1) is fabricated from Fischertechnik model construction components allowing a greater flexibility in experimentation than is possible with commercial Turtle Robots. A high school student can construct Trugon, gaining an understanding of robotics, mechanics and electronics in the process. The current model was designed to perform all the functions of a standard turtle robot. It can be controlled from a micro-computer or from a hand-held push-button box. Children down to the age of two enjoy operating Trugon with the push-button box. To extend Trugon for use in a robotics environment more sophisticated electronics, including an on board micro-computer is being designed.

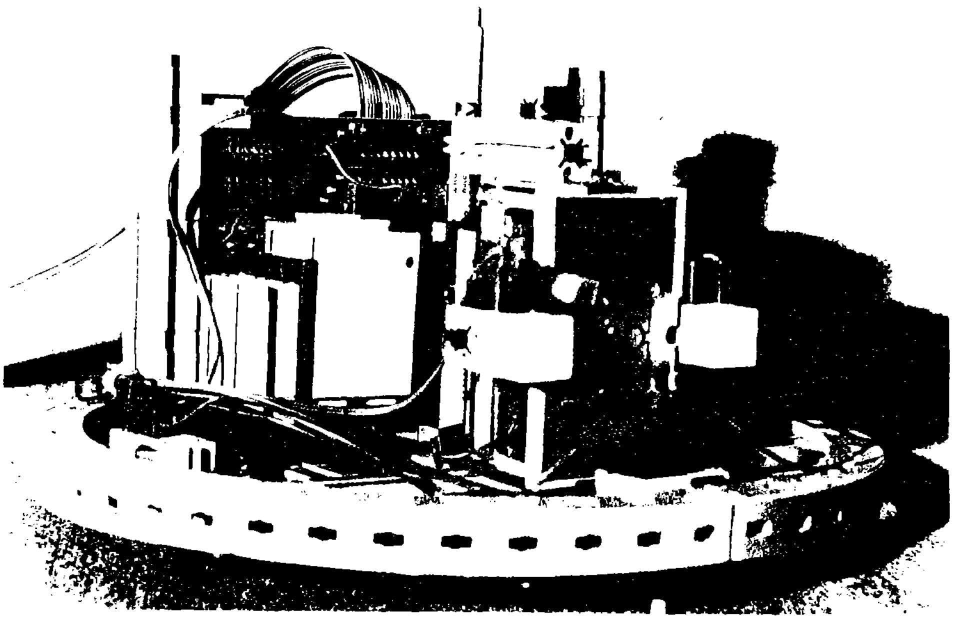

Figure 1. Trugon a turtle robot fabricated out of Fischertechnik.

Through the design of Trugon and discussion with educationalists, who use turtle robots, a number of basic design principles have emerged. The first reaction of people who see a turtle

* ancient Greek word for "turtle-dove"

is: why don't you get rid of the umbilical cord? Technologically a radio or infra red link is possible, provided the Turtle carries its own battery power, but then the turtle is no longer physically tied to the computer adding an element of magic to the process. When the turtle is obviously connected to the computer a child readily accepts that the command she typed on the keyboard caused the turtle to move.

Thus a physical connection is needed but it should be reduced to three wires (transmit, receive and ground), by serialising the data, to minimise the problems caused by the cord dragging on the floor and twisting. This has the additional advantage that a standard video display unit interface card (RS232C) can be used eliminating the need to purchase a parallel interface card just to operate the turtle robot [8]. If standard interface signals are used then the signal wires can not be used to carry power to the robot. On-board rechargeable batteries solve this problem. Also they allow experiments involving finding and connecting into a battery charger to be carried out [3].

One of the most important criteria from an educational point of view is the ability to see the pen. It is desirable not only to see the pen raise and lower but also to see it draw. One robot [9] has a clear base and many components relocated to an external control box to allow a clear view of the pen. A variety of pen lowering mechanisms and pens are used. Felt-tipped quick drying pens are best as they leave a thick, clear, smudge-free trace and can accommodate small variations in paper height. To compensate for large variations in paper height a spring loaded pen is required. The pen needs to be held firmly so that it does not wobble, and must be easy to replace, adjust and cap.

The accuracy required of the turtle robot varies with the application and the user. A turtle used in robotics experiments where sensors are used to provide feedback to correct its path need not be as accurate as one used for drawing squares where students learning geometry may be mislead if the square doesn't close. Two types of motors are in common use, direct-current motors and stepper motors. A stepper motor has a number of stator windings to which pulses are applied. The frequency of the pulse trains determines the speed of the motor and their phase relationship determines the direction. The motor turns an exact amount for each pulse. Thus the distance the turtle robot moves is directly proportional to the number of pulses sent to the motor, provided the motor doesn't slip due to a high torque load. Turtle robots that use stepper motors are reasonably accurate.

Special integrated circuits [10] are available to convert a pulse train and direction signal into motor drive signals. One disadvantage of the stepper motor is the amount of electrical noise produced by switching the current pulses. It is desirable to have an integral number of steps per degree of rotation of the turtle when turning (for example 2 steps to each motor per degree). This simplifies calculations and improves accuracy.

Some turtles allow the distance between the wheels to be adjusted so that this can be achieved.

Some robots use direct-current motors and apply a fixed voltage to the motors. As the load on the motor varies (for example friction in the drive axle) the speed changes. The voltage can be adjusted to match forward and reverse speeds of both motors but the frictional load varies with temperature and the calibration tends to drift. This problem can be overcome by connecting pulse-generators to the drive shafts. These consist of a small slotted disc which cuts a light beam to produce a train of electronic pulses with frequency proportional to speed and the number of pulses proportional to distance moved. These signals are used to provide feedback of the speed, position and direction of motion of the turtle robot for closed loop control. Reasonably sophisticated electronics (often a microcomputer) is used to control the motor speed accurately [9].

Most turtle robots have only two speeds; stopped and flat out. During the transition between the two the robot will lurch, due to inertial forces, particularly if the running speed is high. Students tend to get frustrated with low speeds. On-board micro-computer control allows the speed to be ramped up and down smoothly maintaining a stable platform without losing accuracy.

As the turtle has only two drive wheels, which are located on a diagonal through the centre, third and fourth wheels are needed to maintain balance. These are located on a diagonal at right angles to that through the drive wheels. Most turtles use feet or skids made out of curved pieces of plastic. These drag on the floor and catch on the edge of the paper. A much better solution is a spherical castor. One can be made quite easily from a roll-on deodorant bottle.

Turtles are circular in shape in contrast to Grey Walter's tortoise which was oval. This shape enables a bumper bar or dome, which operates four touch sensors, to detect an object which touches the periphery of the turtle. A disadvantage of the dome is that when pressing against a wall it drags on the wall, as the robot turns, holding the sensor switch closed longer than necessary. Domes are also used to protect the turtle robots inner workings from inquisitive fingers.

## 5. Building a Turtle Robot

Available turtle robots differ considerably from one another. Designers have both overlooked some of the problems and chosen different solutions. None of the designs conforms completely to the design principles described in the previous section.

A person who desires to build their own turtle robot can either buy a commercial one in kit form or design and build their own model. Building a commercial robot has the advantages that all the components and instructions are supplied and the final product is known to work [11,12]. All that is required are simple mechanical skills, experience in soldering and a knowledge of basic fault finding techniques. However there is the disadvantage that the robot may not be easy to modify to meet one's personal requirements.

Designing and building your own robot requires a knowledge of mechanics and electronics [10,13]. Hunting for usable components can be time consuming. Model aeroplane suppliers, electronics hobby shops and disposal stores are a good place to start. Richard Maddevar [10] has described a very simple turtle robot built from readily available components. His robot uses stepper motors for motion and an old telephone relay for pen control.

Trugon differs from other turtle robots in that almost all the electrical and mechanical components are from a model construction system. The electronics, pen and castors are not. The basic layout has been redesigned several times to both reduce component count and to meet new requirements. Currently it performs all the tasks of a normal turtle. Extensions under investigation include:

i. music, sound effects and voice output,

ii. audio input,

iii. replacing the pen with an optical system for detecting and following lines,

iv. a digital compass for determining absolute direction,

v. variable motor speed control for curved path traversal,

vi. automatic battery charging for feeding experiments,

vii. ultra-sonic range finding,

viii. light detection, and

ix. a manipulator arm.

Using Fischertechnik components restricts the design to things that can be accomplished with the available modules. For example the diameter of the robot is determined by the curvature of the components used in the bumper bar. The only motors available, at present, are direct-current motors requiring the use of closed loop control in order to obtain accuracy.

## 6. Conclusion

Most commercial turtle robots are available either as kits or fully constructed. They are designed specifically to perform the turtle functions supported by LOGO and are not easy to modify. A turtle robot fabricated from Fischertechnik is modular in construction, making it easy to modify and extend. The cost is low and a high school student can build it learning about robotics, mechanics and electronics in the process.

The LOGO language has proved itself in teaching mathematics, computer awareness and computer programming. However it is found to be lacking when used in robotics. Further development is required before a robotics environment is available for use in teaching.

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