Appendix A: Sample Laboratory Exercise

Lab for Building 100 Stiquito Kits

In 1903, an engineer named Henry Ford founded the Ford Motor Company in Detroit, Michigan. Through the pioneering use of standardization, mass production, and the assembly line he was able to produce reliable, low-cost cars and other motor vehicles. You are an enterprising engineer who wants to revolutionize Stiquito kit manufacturing using the same techniques developed by Henry Ford for automobiles. A dependable supply of standardized Stiquito kit components has already been secured. All that is needed now is for you to decide upon a plan for assembling them.

There are two basic strategies that can be applied. The first requires that each worker put together Stiquitos from start to finish. Every part of the construction process is performed on a Stiquito kit by the same worker. If it takes one worker one hour to put together one Stiquito kit, and you have 48 workers, how many Stiquito kits can you build in one week? Remember that the workers have to eat and sleep, and if they work over 40 hours a week, the Stiquito Kit Builder's Union requires you to pay them double overtime.

Your alternative is to adopt the assembly line method. Here, each worker does only one part of the construction process. By assigning one worker to do one production step, and having the worker pass the unfinished Stiquito kit to the next person in the assembly "line", several Stiquitos can be in various stages of completion at a time. The closer the Stiquito kit is to the end of the assembly line, the closer it is to completion.

What advantages and disadvantages are there to using to first method?
What are the advantages and disadvantages of the assembly line method?

Taking into account the advantages and disadvantages of both methods, choose one for your new Stiquito kit factory. Implement the design you have chosen and test its viability.

Quantity	Measure	RAW MATERIALS - Item
25	0.762m	Plastruct ST-4 570-704 3.175mm plastic styrene rod
1	30.480m	20 AWG copper wire
255	0.348m	K&S Eng No. 100 1/16" OD aluminum tube
128	0.914m	K&S Eng No. 499 0.020" steel music wire
100	9v	battery connector
1	59.000m	.004" 70 degree C Flexinol wire
2	30.480m	28 AWG wire wrap wire
1	1237.5m	34 AWG copper magnet wire
1	125/box	box of Ziploc^{TM} bags
20	6/sheet	packing list

Quantity	Measure	KIT CONTENTS - Item
3	60mm	Plastruct ST-4 570-704 3.175mm plastic styrene rod
1	60mm	20 AWG copper wire
3	100mm	K&S Eng No. 100 1/16" OD aluminum tube
5	100mm	K&S Eng No. 499 0.020" steel music wire
1	9v	battery connector
1	540mm	.004" 70 degree C Flexinol wire
1	600mm	28 AWG wire wrap wire
1	1500mm	34 AWG copper magnet wire
1		Ziploc^{TM} bag
1		packing list

A summer workshop is scheduled for July 1995. Arkansas teachers will spend three weeks learning about engineering and technology and will work on these lab exercises and many others which are currently being developed [1]. See the information below for access to these and other labs.

ADDITIONAL INFORMATION

Detail of the labs can be obtained by anonymous ftp to `engr.engr.uark.edu`, subdirectory `pub/engr_ed`. The file `lab_list.txt` contains the current list of lab exercises, and the subdirectory the exercises are located.

The Stiquito II technical report can be obtained via anonymous ftp from the same site, subdirectory `pub/engr_ed/stiquito` as `tr414.ps.Z`

Ordering information for Stiquito II kits was not available at publication time. Check the `stiquito` subdirectory listed above for the current available sources.

The authors of this paper are working on a book entitled, *Stiquito: Design and Implementation of Nitinol-Propelled Walking Robots.* IEEE Computer Society Press has expressed an interest in the book for publication in 1995.

REFERENCES

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[3] Mills, Jonathan W., "Stiquito: A Small, Simple, Inexpensive Hexapod Robot. Part 1: Locomotion and Hard-wired Control," Technical Report 363a, Computer Science Department, Indiana University, Bloomington, Indiana 47405, 1992.

[4] Mills, Jonathan W., "Stiquito II and Tensipede: Two Easy-to-Build Nitinol-Propelled Robots," Technical Report 414, Computer Science Department, Indiana University, Bloomington, IN, 47405, 1994.

[5] Mohan, Nanjundan, and James M. Conrad, "A M68HC11 Microcontroller-Based Stiquito Controller," Technical Report 1993-1, Computer Systems Engineering Department, University of Arkansas, Fayetteville, AR, 72701, May 29, 1993.

[6] "Math, Science, and Engineering Education : A National Need : Hearing before the Subcommittee on Postsecondary Education of the Committee on Education and Labor, House of Representatives, One Hundred First Congress, first session, hearing held in Kansas City, MO, May 1, 1989," U.S. G.P.O.: Washington, D.C., 1989.

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Engineering Design - Assembling Kits

Once the kits have been made, they need to be assembled. Alternatively, kits can be ordered from the sources listed at the end of the paper. Either Stiquito or Stiquito II can be assembled, although the previous lab creates Stiquito kits.

The instructions for building these two robots and tools required are located in the sources listed below. This lab will take some time. Each robot takes four to eight hours to assemble. Since the robots can be built in several pieces and assembled at the end, several students can work concurrently on the pieces and reduce the time to two hours.

The objective of this lab is to examine the way the different parts work together. An assembled robot (or even a single leg) can be shown and movement of the leg demonstrated. The mechanical characteristics and the design process can be discussed as well.

Electronics - Control Circuits

Stiquito II must be controlled by a computer or other electronic or mechanical device. These robots have 12 actuators, too many to control manually. The Stiquito II Technical Report [4] contains information on how to build and use an interface to Stiquito II using the parallel port of an IBM PC or compatible computer. This interface allows students to control the actuators and experiment with different gaits.

The interface is simple, uses inexpensive parts, is optimized to produce a tripod gait in Stiquito II, and can be fabricated on a single-sided, robust printed circuit board. This laboratory exercise will introduce students to handling, soldering, and testing printed circuit boards. This may not be appropriate for younger students, since it involves soldering.

The cost of the interface materials is \$6.00 from the source listed at the end of this paper. The parts of this interface include:

- Two DS2001 Darling high-current driver chips (16 pins)
- Two 74LS373N Octal tri-state Flip-flop chips (10 pins)
- One G5102 5-element 1 K-ohm resistor network
- One 25-pin D-shell male connector
- 60 cm of 9-wire ribbon cable
- One printed circuit board, 5 cm by 5.7 cm

Required tools include:

- Needlenose pliers
- Wire cutters
- Small hobby knife (X-Acto^{TM} type)
- Soldering iron and solder
- Volt-ohmmeter
- 320 grit sandpaper

Many of these item are already available in school shop classrooms. Only a few sets of tools are needed for a class.

The technical report describes in detail the objectives, precautions, and procedures of this lab. Procedures include soldering skills, component soldering, wire soldering, and circuit testing. This lab exercise provides students with a small project that has a direct application for a future lab.

Computers - Programming Robots

The interface card created in the previous lab experiment will be used to control the walking gait of the Stiquito or Stiquito II robot. The technical report shows code written in BASIC, although any language can be used as long as data bytes can be written the parallel interface. It is suggested that an interpreted language be used, since the time needed to modify loop delay values, recompile, and run for a compiled language reduces the excitement of quick changes and testing.

In IBM PC and compatible computers there is a parallel printer interface that has a control port and a data port. Data from the most recent write to the data port is held inside the PC. In order hold two bytes simultaneously latches on the interface card must be used.

When the interface card is attached to the parallel printer port, the control port is used to choose whether the horizontal driver latch, the vertical driver latch, both latches, or neither latch will track or capture and hold data sent to the data port. Only three of the six control port bits and six of the eight data port bits are used by the interface card.

The code the students write consists of simple FOR/NEXT loops, OUT, PRINT, IF/THEN, and GOTO statements. The objective of this lab is to examine how the robot moves depending on the computer instructions. Students will learn (or re-examine) computer programming, computer control, and computer design. The teacher will have to determine how much help the students will need in the program design based on their ages and backgrounds.

The equipment needed for this lab is any IBM PC or compatible computer, even older 8088-based models, and a BASIC interpreter (standard with many older computers). The interface cards and Stiquito robots built earlier are also needed.

CONCLUSIONS

This paper presented several lab exercises which utilize the Stiquito and Stiquito II robots. The exercises are intended to introduce students to engineering concepts and the process of design. Students will have an opportunity to formulate questions as well as participate in hands-on activities.

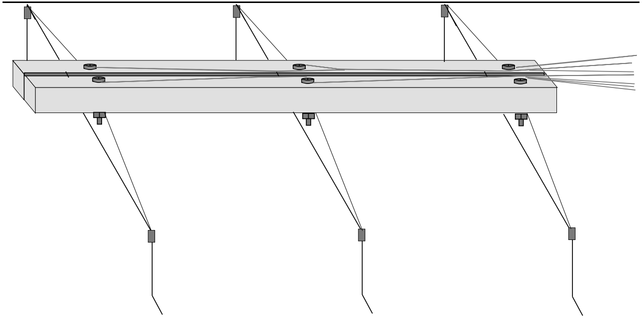

Fig. 1. The Stiquito Robot

Fig. 2. The Stiquito II Robot

results from changes in the crystalline structure of nitinol. When heated, the wire contracts about 10%, and when cooled with a recovery force applied, returns to its original length.

The original Stiquito (Figure 1) is 600 mm long by 70 mm wide by 25 mm high and weighs 10 grams. It can walk up to 10 cm per second and carry up to 50 grams. Research robots have been built which carry a microcontroller and support circuitry (but not the power source) [5]. When the nitinol wires contract, the body is thrust forward. When the wires cool, the legs drag forward due to the force of the piano wire which was bent by the nitinol. The power consumption of Stiquito is large; between 0.1 and 0.3 amperes of current are needed to activate the nitinol actuators.

Stiquito is somewhat difficult to build for young people and is not easy to adjust or repair once assembled. Stiquito II [4] was developed to provide a larger and more robust platform for research and yet be easy enough to build that it could be used educationally. Stiquito II (Figure 2) is much larger than Stiquito. It can be built with an articulated body or rigid body, is 160 mm long, 110 mm wide, and 40 mm high. Its six legs have two ranges of motion (up-down and forward-back), so it does not drag its legs, but rather steps. Stiquito II is so new that its capabilities have not been fully exercised, but it is expected to travel about twice as fast and carry twice as much weight as Stiquito.

Educational use of Stiquitos depends on their low cost. The original Stiquito cost approximately $4 in quantities of 100, with nitinol wire accounting for 75% of the robot's price. Stiquito II costs approximately $7 in quantities of 500, with nitinol wire accounting for 85% of the robot's price. Extra materials (especially nitinol) are suggested to allow for mistakes and will raise the robot's price by about 40%.

LAB EXERCISES

Assembly Lines - Stiquito Kits

Before the Stiquito robots can be built, individual kits must be made from the "raw materials." The materials for the kits are bought in bulk, and the kits are made by cutting and packing the pieces in plastic bags with one bag holding enough material to build one Stiquito Robot. Later, the bags are distributed and the kits assembled.

Appendix A provides an example of the information which can be used for a lab. Although this lab has materials for 100 robots, smaller quantities can be used. The materials cost $400 for 100 robots. Tools required include several wire cutters, small hobby saws, scissors, tape, meter sticks, and hobby knives (X-Acto^{TM}-type).

This lab will have students think about assembly lines, plan a line, and test their line. Competing groups using the two different assembly methods can be formed to measure the effectiveness of each method.

Inexpensive Technology Lab Exercises for Grades 6-9

James M. Conrad and Jonathan W. Mills

INTRODUCTION

The need for technology education in primary and secondary schools is well documented. What is needed is a way to infuse the excitement of technology and engineering into the middle and high school curriculum. This must be done at a low cost, since most school districts work with limited funding.

One vehicle for introducing technology and engineering will be the Stiquito and Stiquito II robots. Stiquito is a small, simple, inexpensive ($4) hexapod robot developed by the Computer Science Department of Indiana University at Bloomington. Stiquito II is a larger, slightly more expensive ($7) hexapod robot which is easier to build than Stiquito. Even though these robots were originally designed to be used in research, they are used worldwide for educational purposes. These devices employ several concepts from electrical, mechanical, and chemical engineering. Applications of the robots would encompass computer and industrial engineering concepts as well.

This paper contains motivations for introducing engineering to middle, junior high, and high school students, an introduction to the Stiquito robots, and details on lab exercises. Instructions at the end of the paper direct users to the location of these lab exercises on the Internet.

MOTIVATION AND GOALS FOR LABS

Many scholars have written of the need for technology education in primary and secondary schools. At a hearing before the Subcommittee on Postsecondary Education of the Committee on Education and Labor, U. S. Congress House of Representatives, educators, businessmen, and politicians discussed the importance of science and technology to the future of the United States [6]. One startling statistic is that, in a study of 1986-87 college graduates, only 23% were interested in science and engineering disciplines as high school seniors. As high school sophomores, only 24% of these students were interested in science and engineering. If students see applications of the science and math they learn in school, perhaps they will become more interested in these disciplines. Engineering and technology provide examples of application of the science and math they learn in school.

Therefore, what is needed is a way to infuse the excitement of engineering into the secondary school curriculum. Few teachers have the expertise and resources to introduce engineering into curricula, yet many students suggest they learn about these subjects in middle, junior high, and high school. A survey of more than 400 engineering students at the University of Arkansas was administered in the Fall of 1994. Students repeatedly wrote that the ideal age to learn about engineering was in the 6th though the 9th grades.

In order to provide this opportunity to learn about engineering, faculty at the University of Arkansas have been preparing lab experiments. The main goals for these labs are to provide students with an opportunity to examine the design and building of a product. The product they build is Stiquito and its controller. While working on these labs they investigate Industrial, Electrical, and Computer Engineering. The labs allow students a chance to choose and control their actions and learn from mistakes they may make, without expending much cost or time.

STIQUITO AND STIQUITO II

Legged robots are typically large, complex, and expensive. These factors have limited their use in research and education. Few universities could afford to construct robot centipedes, or 100 six-legged robots to study emergent cooperative behavior. Even fewer universities could give each student in a robotics class his or her own walking robot.

The introduction of Stiquito in 1992 changed that. Stiquito was developed from a larger and more complex robot called "Sticky" because it looked like an insect commonly called a "walking stick."

Stiquito is a small, simple, and inexpensive six-legged robot that has been used as a research platform to study computational sensors, subsumption architectures, neural gait controllers, emergent behavior, cooperative behavior, and machine vision [3]. Stiquito has also been used to teach science in primary, secondary, and high school curricula. As of mid-1994, 2500 Stiquitos have been distributed from Indiana University and several hundred more from other universities as well as private companies.

Stiquito is small and simple because it uses nitinol actuator wires. The nitinol wire translates the heat induced by an electric current into mechanical motion, replacing stepping motors, screws, and other components otherwise needed to make a leg move. The mechanical motion