“TIGERBOT”
(Autonomous Robot)

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Abstract - This paper demonstrates artificial intelligence through the construction of a simple robot developed by converting a toy vehicle. The circuitry of the toy vehicle was redesigned and incorporated with proximity sensors, thereby turning the vehicle into an autonomous self-contained robot (“Tigerbot”). This robot has the ability to roam, avoid obstacles without human intervention, and is speech capable. The authors demonstrate how machines can be designed to be aware of their surroundings and adapt accordingly. In the future, artificial intelligence concepts employed in this project may be applied in the design of other machines that would assist humans in performing common household chores. This article represents efforts by students implementing knowledge acquired in a Capstone Senior Project course.

Introduction

The basic electronic transistor has steadily become smaller with a corresponding increase in capability due to the advancement of technology in the world of electronics. It is now possible to embed millions of transistors onto a single microchip. Using a network of these transistor-embedded chips, innovators are now able to develop industrial machinery that exhibits “artificial intelligence.”

However, in consumer household machineries/equipment, there has been relatively slow progress in emulating this intelligence as compared to industrial settings. Only recently, this celebrated intelligence has been incorporated into a few household products, such as robotic lawnmowers and vacuum cleaners. Such products must, of necessity, have the ability to “sense” their environment through reading and interpreting data received through sensors, to enable the system to autonomously roam, avoid obstacles, and be speech capable. The objective is to produce a machine that can perform many common household chores with or without limited human interaction.

The changing environment of the average home (such as one-story, two-story, size, changing needs of individuals, etc.) is one of the major elements responsible for the slow emergence of intelligence-based household products. To overcome this obstacle, a new breed of versatile household products that would adapt to the unpredictable household environment would have to be designed and produced. This type of intelligence would merge home equipment and appliances to function as a single unit [1, 2, 3].

Overview

This article expresses the utilization of artificial intelligence through the design of a simple robot constructed from a toy vehicle dubbed herein as "Tigerbot," (Texas Southern University's mascot is the tiger). The toy vehicle was chosen as the only alternative for the design, as it is easily accessible to and affordable by students. The results were obtained through a joint effort by senior students enrolled in the "Senior Electronics Project" course that applies the years of integrated knowledge gained in an electronics engineering technology program, which includes principles of programming, circuitry design, and application of theory to the prototype.

The robot described herein is able to roam and avoid obstacles with no human interaction, and is also capable of preprogrammed speech playback. The successful construction of the "Tigerbot" demonstrates how machines can be made aware of their surroundings and adapt accordingly. It is hoped that future advances in robotics and artificial intelligence will expedite the design of equipment that will perform common household chores quickly and easily, and also may be adapted to assist people with special needs.

Selecting the vehicle to convert

There are a number of toy vehicle platforms that can be used to convert into a robot. However, it is advisable that a selection be made that will easily adapt to the environment in which the robot will be deployed. A regular wheel (tire) would suffice in most cases, however, if the robot will be operated in a rough terrain, a vehicle with tank-like treads would be appropriate. If it will be operated in off-road conditions, a vehicle with enough traction and ground clearance is desirable for this type of environment. For the "Tigerbot," a GI JOE® toy tank was utilized due to its treaded locomotion, which gave the traction required for a smooth, slippery terrain. This toy vehicle is quite close to the ground, but its environment is relatively flat and does not pose a problem.

Selecting and controlling the motors

The chosen vehicle must have a suitable motor for the desired task, not too powerful or too weak. An understanding of its electrical and mechanical characteristics is highly recommended, and is usually found in the service manual provided by the manufacturer of the vehicle. If no data sheet can be obtained, laboratory tests can be conducted to acquire the desired data. It is important to have knowledge of the type of motor in the vehicle (continuous, stepping, servo, etc), the operating voltage range, and the maximum current the motor can handle without suffering any damages.

In this undertaking, direct current (DC) continuous motors are used in the "Tigerbot." A DC motor will spin steadily in one direction when a battery is connected across the terminals. If the battery polarity is reversed, the motor will spin steadily in the opposite direction. The knowledge that a motor can be switched ON and OFF by connecting a battery in either way is not enough to make our robot functional. The robot must be able to move in any desired direction regardless of the polarity of the battery terminals. For this purpose, an independent ON-OFF switch is utilized.

Furthermore, some instances require the robot to cruise at full speed, or other times the robot might be required to slow down or come to a full halt when approaching an obstacle. A motor control circuit called the H-bridge or motor driver can control the speed and direction of the motors. The H-bridge circuit may be constructed or bought ready-made, either as a single chip or in a kit. Most motor driver chips come with added features that protect the motor and other circuits of the robot. Even the most basic ones provide the capability of controlling the motor with digital signals.

A ready-made H-bridge IC chip was used for the "Tigerbot" due to the limited time and funding available for the project. The key factors in selecting the H-bridge IC were as follows:

- The chip must be able to handle 1.1A stall current of the "Tigerbot's" motors; and
- The chip must allow for a wide range of motor power.

Selection of SN754410 H-Bridge IC as a motor driver

After intensive research, the Texas Instruments quadruple half-bridge driver chip (SN754410NE) [10] was selected, as it met the requirements stated above:

- Provides drive currents up to 1 A (up to 1.1A with proper heat sink);
- Operational motor voltage range of 4.5V-36V (+5V was used); and
- All inputs are compatible with TTL logic of a BX24 micro controller [5].

The SN754410NE chip not only meets but exceeds the requirements due to additional built-in features with advantages stated below:

1. One chip: Controls two motors which help save space on the "Tigerbot's" circuit board.

2. Built in clamping diodes: Since a motor is an inductive load, it tends to send the resisted current back to the source as Back Electromotive Force (Back EMF). This feature protects the chip from damage by preventing the Back EMF from returning to the chip. See diodes configuration in Figure 1 below (figure and data derived from data sheet provided by Texas Instruments [10]).

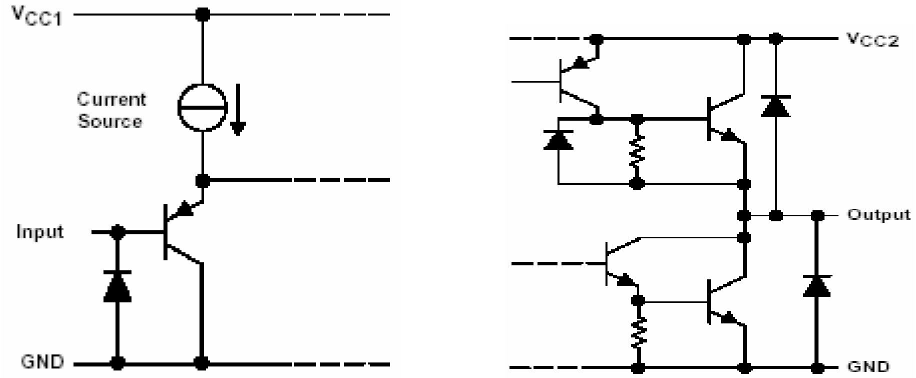

Figure 1. Diode Configuration

3. Thermal shutdown: In the event of a motor stall, generated heat may damage the chip. This feature automatically shuts the chip down when excessive heat is detected.

4. Input hysteretic: This feature makes the motors immune to interfering noise from other electronics in the circuit.

5. Sink /Source interlock: This ensures that there is no simultaneous conduction of the inputs and outputs, by accurately pinpointing the targeted gate.

6. No glitches during power up or power down: This allows for a smooth startup and shutdown sequence.

Operation of the SN754410NE

Figure 2 below is a simplified block diagram of the chip exhibiting its motor control setup [10].

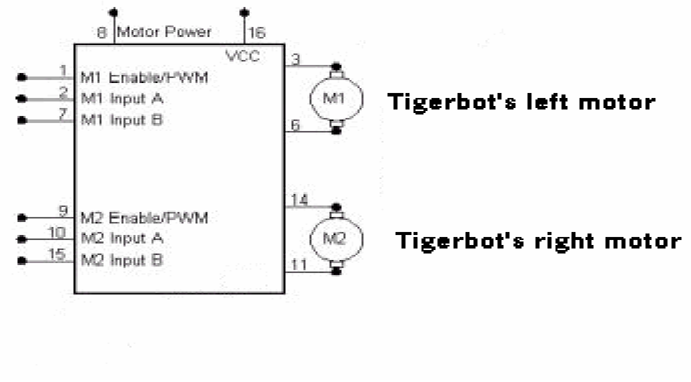

Figure 2. Motor Control Setup

- Setting the **M1 input A High** with **M1 output, A** goes to one side of left motor, and setting the **M1 input B Low** then the **M1 output B** is at ground. This will cause the left motor to spin in one direction.

- Setting the **M1 input A Low** causes the **M1 output A** to ground. With the **M1 input B High**, the left motor will spin in the opposite direction.

- If both the input pins are set the same, then both output pins are also set to ground or high, causing the motor to short and dynamic breaking may occur.

- The above will occur if the Motor Enable pin is high. If it is low, both output pins will be in a tri-state condition.

Sensory of the robot

Some of the exceptional features of the robot are its awareness of its surroundings and its ability to make adjustments as necessary through the utilization of appropriate sensors. Many types of relatively inexpensive sensors are commercially available, such as proximity, water, light, sound, motion, temperature, and tilt. Also, a pinhole camera is a type of image sensor. A proximity detection sensor was used in the case of the "Tigerbot" to detect and avoid obstacles.

After intensive research, the Sharp GP2D15 infrared proximity detector was selected. The interface is 3-wire with power, ground, and output voltage that requires a Japan Solderless Terminal (JST) connector [8, 12].

Operation of the GP2D15

The GP2D15 sensors (utilize a method referred to as "triangulation") and a photodiode array (emitter and receiver) all in one package detect the presence of objects in the field of view. The emitter radiates a pulse of infra-red (IR) light that travels out and either hits an object or not. If the emitted light hits an object, it reflects back to the detector and senses the presence of an obstacle. If the light hits no object, it is not reflected and the reading shows no object (Figure 3) [8, 12].

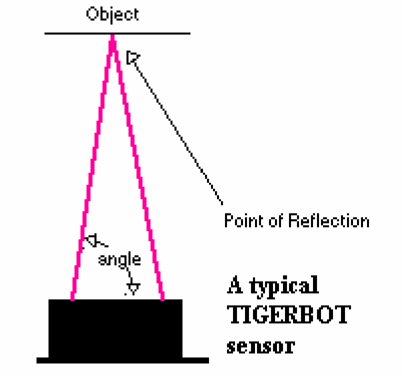

Figure 3. Tigerbot Sensor

Table 1 GP2D15 Detector Specification [8, 12]

Detector	Output Type	Range	Enable Method	On Current	Off Current
GP2D15	Digital (0 or 1) output	Factory preset to 24cm	Continuous readings ~38ms per reading	~25 mA	-

Interfacing

The sensor has an open collector output, which means the logic HIGH is only about +0.3V. However, it is not enough to interface with a digital logic setup, which requires +3.3V - +5V to obtain logic HIGH.

To solve this problem, a **10KΩ** pull-up resistor is used on every sensor of the "Tigerbot. The resistors are connected between the Vcc and the output of each sensor [13], so that the logic of the sensors becomes 0V(LOW) and +5V (HIGH).

Advantages of using the GP2D15

- The color of reflected objects has little influence;
- Simple logic interface;
- Detecting range preset to 24 cm;
- External control circuit unnecessary; and
- Low cost.
- Since the detector fires continuously, no clocking is necessary to initiate a reading.
- Since the output is digital, the outputs of two or more sensors can be combined to minimize usage of input/output pins on the micro controller.

Disadvantage of the GP2D15

- The sensors stay on even when not in use, thereby dissipating power.
- Each sensor constantly consumes approximately 25mA of battery current.
- If an object is closer than 10cm to the sensor, the output of the sensor goes low as the sensor is unable to detect the object (Figure 4) [8, 12].

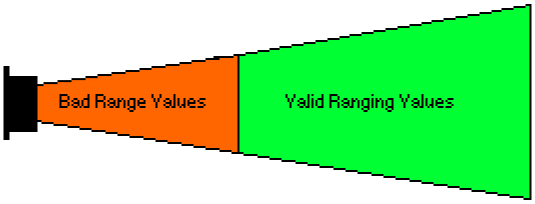

Figure 4. Angle of Sensor's Detection

The last disadvantage listed above was used as an advantage in designing the "Tigerbot." One sensor was set up under the "Tigerbot" as a ledge detector to prevent "Tigerbot" from falling over a ledge. This was accomplished by setting the sensor close to ground level for its logic level to read 0V (LOW); therefore, as soon as there is a drop of up to 24cm the logic of the sensor goes HIGH (+5V) indicating a ledge.

Setting up the "Tigerbot" sensors

The infrared beam of the GP2D15 is roughly football shaped with the widest portion in the middle being about 16 cm wide (Figure 5) [8, 12].

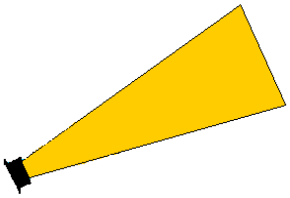

Figure 5. Infrared Beam of the GP2D15

The beam pattern is reasonably narrow, and for this reason the "Tigerbot" has a redundant setup of four sensors in front of it (Figure 6).

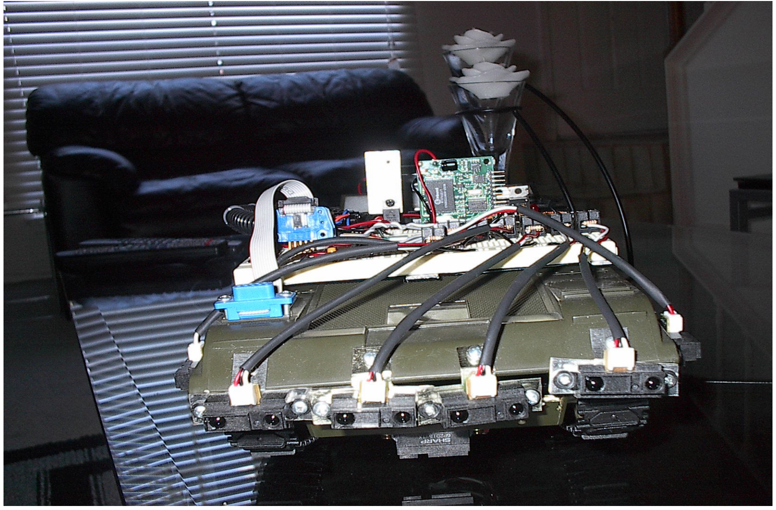

Figure 6. Tigerbot

Brain of the "Tigerbot"

Without a brain, the robot would be a hi-tech looking piece of junk. The robot must have the ability to read and interpret data received from its sensors, to enable it to make the required adjustments to its motors to avoid an obstacle. An autonomous robot must have the capability to automatically make such decisions and not require human interference after deployment.

To be able to behave as stated above, the robot requires an on-board computer that may be a single chip (called a micro controller) or a network of multiple integrated circuit (IC) chips, depending on the complexity of the decision-making process. Then, a computer program must be written that instructs the robot how to behave in all predictable situations. The program may employ a sequential method or fuzzy logic to execute instructions. Once the program has been written and finalized, it must then be loaded into the robot's on-board computer via a cable or infrared means. After the program is loaded into the on-board computer, the robot will be able to control itself upon deployment. Also, an advanced program can enable the robot to learn from its mistakes [4].

The BX24 micro controller, programmed in BasicX computer language (a subset of Visual Basic), serves as the computer brain of the “Tigerbot” [7, 14]. This versatile chip, made by Netmedia, has features that are essential for the design herein. The BasicX processor is the heart of the BX24 computer, and is based on an Atmel AT90S8535 chip. A high-speed 5-volt serial port is provided for connection to PC terminals. The serial port uses 3 wires, RxData, TxData, and DTR. The DTR line is used only for downloading programs.

Speech Capability of the Robot

Speech production may be quite complex for an elementary robot builder, and may require interfacing a computer sound card to process sound codes. Presently, however, with the development of easy-to-use speech processors, robot builders are able to produce speech without the complications of the past. These new processors, developed by companies such as ISD, Devantech, and Winbond, exhibit outstanding performances, and can be judged by their prices.

The “Tigerbot” uses a speech synthesizer module, the SP03 by Devantech [11]. The module includes an audio amplifier, a 3-volt regulator with level conversion to 5 volts, a PIC processor to provide easy communication with the BX24, and a Winbond WTS701 speech chip.

Loading speech onto the SP03

A PC program SP03.EXE is used to load 30 predefined phrases onto the SP03 through the RS232 serial port (PL1 pins) which requires three connections (ground, Rx, Tx) to the PC, and a 5V power supply.

The module’s Rx pin should be connected to the PC’s Tx line (pin 3 on the DB9 socket). The SP03 RS232 Tx pin should be connected to the PC’s Rx line (pin 2 on the DB9 socket). Finally, the SP03 Ground line is connected to pin 5 on the DB9 socket.

Speech playback

The phrases can be played back in sequence by sending the corresponding 5-bit binary combination to pins SEL0 - SEL4 using a parallel interface connected to the PL2 pins. Table 2 below shows the 30 phrases loaded onto the “Tigerbot’s” speech synthesizer, and the corresponding binary combinations required to playback each individual phrase.

Table 2. Phrases and Binary Combinations for “Tigerbot’s” Speech Playback

Sel 0	Sel 1	Sel 2	Sel 3	Sel 4	Pins on SP03 Speech Synthesizer (PL2)	
Bx 24 pin #5	Bx 24 pin #6	Bx 24 pin #7	Bx 24 pin #8	Bx 24 pin #9	Corresponding pins on BX24 Microcontroller	
2^0 (1)	2^1 (2)	2^2 (4)	2^3 (8)	2^4 (16)	***Binary to Decimal Conversion***	
					Phrase #	***Speech***
1	0	0	0	0	**1**	(Empty on purpose)
0	1	0	0	0	**2**	Welcome, to Texas Southern University. The College of Science and Technology.
1	1	0	0	0	**3**	I'm the **TIGERBOT**, a senior project for the spring 2003 class.
0	0	1	0	0	**4**	My designers are, group leader Oyekunmi Fakunle and group members,
0	0	1	0	0	**5**	Samson Olewe, Courtney Smith, Hilda Gomez, Tony Prince, and Eric Davis.
0	1	1	0	0	**6**	The Department of Electronics Engineering offers degrees in, Civil and
1	1	1	0	0	**7**	Electronics Engineering technologies. For other technology degrees offered,
0	0	0	1	0	**8**	Please contact 713-313-7009,or visit us at room 3 19. For more information.
1	0	0	1	0	**9**	We hope, that you consider getting your degree with us at TSU.
0	1	0	1	0	**10**	The home of the, “Fighting Tiger”
1	1	0	1	0	**11**	Please Wait! System test, in progress.
0	0	1	1	0	**12**	Sensors Check, complete
0	0	1	1	0	**13**	Motors Check, complete.
0	1	1	1	0	**14**	All systems are ready.
1	1	1	1	0	**15**	Object detected by right sensor
0	0	0	0	1	**16**	Object detected on left sensor
1	0	0	0	1	**17**	Object detected by front sensors
0	1	0	0	1	**18**	Ledge detected
1	1	0	0	1	**19**	Texas southern university is accredited by the commission of the southern
0	0	1	0	1	**20**	Association of colleges to award the bachelors, masters, and doctorate degrees.
1	0	1	0	1	**21**	In case of emergency please call 713-313-7000
0	1	1	0	1	**22**	In case of fire, please use the stairs. Unless otherwise instructed.
1	1	1	0	1	**23**	Please be advised that, this institution is a drug and weapon free environment.
0	0	0	1	1	**24**	Violation of any school policy is punishable by, state laws.
0	1	0	1	1	**25**	Thank you and have a nice time.
1	1	0	1	1	**26**	Smile! You are on Tiger Camera.
0	0	1	1	1	**27**	
1	0	1	1	1	**28**	
0	1	1	1	1	**29**	

Powering your robot

Motors, when in operation, tend to generate electrical noise in power lines. Furthermore, they draw more current upon startup or when changing directions, that results in sag or spike in the flow of power throughout the circuitry of the robot. These problems may interrupt the execution of the on-board computer program, causing the robot to behave erratically. Therefore, it is necessary to divide the power supplies to the three sections described below to minimize the sagging and voltage spikes. The "Tigerbot" requires 36 volts of DC power divided into three separate sections as follows [6]:

1. ***Motor Power*** is provided by a pack of six AA batteries (+1.5V each) connected in series (Figure 7) to give a total power of approximately +9V @ 7A. However, this is regulated down to +5V by a 7805 (T-220 package style) voltage regulator to safely power the motors [9].

Figure 7. Power Package

2. ***+5V Rail*** is powered by a single 9V battery regulated down to +5V with a 7805 (T-220 package style) voltage regulator. The rail is used to power the following:
    - All the proximity sensors @ 175mA;
    - The 7386 OR gate chip; and
    - The 7754100NE motor driver chip.

3. ***+18V Rail*** is powered by two +9V batteries connected in series. This rail is used to supply power to the following components:
    - +5V @75mA to the BX micro controller via a 7805 (T-220 package style) voltage regulator; and
    - +5V @75mA to the SP03 speech synthesizer via a 7805 (T-220 package style) voltage regulator.

Testing the Final Product

Upon completion of the "Tigerbot," its capabilities were tested for exploration and surveillance purposes. For example, in a building, it was activated for search and rescue purposes utilizing its wireless camera, and it navigated a mall while employed as a vehicle to advertise products.

Conclusion

The artificial intelligence herein described was designed and implemented by students in a Capstone Senior Project course. In this endeavor, the circuitry of a simple toy vehicle was redesigned and converted to a robot that has the capability to autonomously roam, avoid obstacles, and is speech capable. The intention herein is to introduce an intelligent machine that can perform, with or without limited human interaction, many common household chores. It was successfully demonstrated that the "Tigerbot" met all the requirements of the project. Using this basic concept, more complicated systems can be developed in the future to eliminate the human element from performing certain dangerous or cumbersome tasks.

Acknowledgment

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