Rox-544v2—at an insect's pace

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Presented at the Science Fair in 2001

Project summary

In addition to constructing a robot and understanding the mechanisms that enable insects to evolve easily in many different types of terrain, the aim of this project is to develop rules for designing complex projects and tools that will enable amateurs or small businesses to reduce costs, eliminate errors, and save time.

Project report

"It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar which any bungler can be with two after a fashion." A.M. Wellington, 1887

Context:
Last year, I started constructing a robot using the American cockroach as my inspiration [14]. As my project progressed, I experienced more and more problems. In addition to constructing an entire robot and understanding the mechanisms that enable insects to evolve easily in many different types of terrain, the aim of this project is to develop rules for designing complex projects and tools that will enable amateurs or small businesses to reduce costs, eliminate errors, and save time.

1- Problem:
After working on the basic mechanical and electronic design of Rox-544 last year, the aim of this year's project was to design the robot's head, including high-level sensors that would enable the robot to move around and maintain its stability. In addition, a special effort was made to improve work procedures, reduce costs and eliminate errors.

2- Designing the head:
The head is designed to perform complex tasks that require a certain amount of processing time, but are not absolutely necessary to the functioning of the robot:

Objectives for constructing the head
Maintaining the stability of the robot's body:
- Rolling, pitching, yawing (thanks to two double-axis accelerometers)
- Optimal positioning of legs [2]

Long-term decision regarding trajectory [2]:
- Record of movement
- Orientation (combination of magnetic and solar compasses)
- Detection of obstacles (sonar)

Table 1: Tasks performed by the head
The solutions in parentheses were chosen after comparing all the possible options.

Magnetic vs. solar compass:
Knowledge of orientation dictates a need to find an optimal solution. A magnetic compass cannot be used in proximity to an electric motor. It is possible to calibrate this type of compass under specific conditions, but not in an environment with variable magnetic fields. Variations exceeding ±40° have been measured near motors. Another mechanism that is able to perform the functions in Table 2 must be designed.

Specifications for the new compass
- Unaffected by magnetic fields
- Accurate (uncertainty <5°)
- Ability to indicate a fixed orientation (not necessarily North). It is possible to calibrate a magnetic compass when motors are turned off.

Table 2: Design objectives

It has been shown that insects use the sun to orient themselves [13, 18]. In fact, they observe the polarization patterns in the sky resulting from the angle at which the light rays penetrate the atmosphere. These patterns remain perpendicular to the sun's meridian (line connecting the sun and the zenith). The meridian rotates around the zenith (approximately 15 degrees/hr.) as a result of the apparent movement of the sun [13]. It is therefore possible, thanks to the clock present in the robot's micro-controller and by using equation 1.1, to have a fixed point throughout the day.

$$\theta_{final} = \omega_{rotation}t + \theta_{initial} \qquad 1.1$$

A compass that measures the sky's polarization, RoxPOL-OP, was therefore constructed. It consists of two polarized filters (IMAX lenses) placed over photoresistive cells, all connected to a differential amplifier, thereby ensuring that the compass is unaffected by light variations. Only the variations in polarization play a role. The device uses a servomechanism to scan the sky.

Photoresistive cell
Photoresistive cell
Differential amplifier

The signal, unaffected by the light intensity, provides the orientation of the sun's meridian.

Figure 1: Diagram of the RoxPOLOP

Determining orientation involves finding the orientation of RoxPOL-OP that produces the maximum signal, applying equation 1.1 and using the robot's proprioceptive sensors to calculate the actual orientation. The initial results were unsatisfactory (±10°) because the rotational speed of the sun's meridian is not constant as a result of the sun's tilt, which varies according to season, latitude and time of day. This is where the magnetic compass comes into play. It is used to determine the solar time of day (sundial), to calibrate RoxPOL-OP to the North and to "learn" [11] the function represented by the variation of $\omega_{rotation}$ as a function of the time of day. Various learning mechanisms helped improve results from day to day. The results obtained are impressive: less than ±5° on average from initial tests (Fig. 2).

Moreover, the difference between the maximum and minimum polarization values give some indication of the validity of the results obtained.

Orientation as a function of the time of day
Orientation (degrees)
Time

Figure 2: Different orientations, in grey (minimum and maximum polarization values), indicated on the solar compass. The grey areas represent invalid data (when the polarization intensity, in black, is too weak).

Accelerometer (inclinometer):
Rox-544 uses two ADX202 accelerometers to measure the static acceleration resulting from gravity in order to determine the rolling, pitching and yawing of its body and to orient the RoxPOL-OP toward the zenith. Since a tilt sensor recognizes only frequencies below 20 Hz [33], a low pass filter (RC) with a cut-off frequency (when $V_{exit} = \frac{V_{signal}}{\sqrt{2}}$) of 20 Hz was designed. Equations 1.2 and 1.3 make it possible to find the correct values for resistance (R) and capacity (C) [9].

$$X_c = \frac{1}{2\pi fC} \qquad 1.2$$

$$V_{exit} = \frac{X_c}{\sqrt{R^2 + X_c^{\ 2}}} \qquad 1.3$$

Sonar:
An ultrasonic module is currently being tested. Initial results are conclusive. The sonar has a sweep angle of 30° and an effective distance of [0.15, 3.2] m. Each sweep takes approximately 0.150 sec. When walking at a speed of 0.35m/sec., the robot has enough time to detect the potential obstacles in its path.

3- Motors:
Several Rox-544 motor parameters were quantified this year. For example, the relationships between "force exerted vs. current circulated through the motor" and "position vs. value of the internal potentiometer" have now been identified (through experimental results). The maximum speed and acceleration, as well as the motor's inertia, have also been measured. A sound knowledge of these relationships made it possible to design new sensors for measuring force, position, speed and acceleration more quickly, at a lower cost and with a better success rate.

The infrastructure currently in place makes it possible to develop methods of controlling the motors. At the control base, a proportional-derivative (PD) loop was added to give the robot a certain degree of adaptability, enabling it to interact more effectively with its environment by improving its "contact stability" [5]. At a higher level, networks of mutually inhibited neurons [15, 16, 22, 29, 30, 31, 34] are currently simulated with the use of MATLAB software. These networks will "let the physics do the calculations" [34, 26]. Their role is not to force any artificial movement, but to support the creation of a movement that is consistent with the natural dynamics of the legs.

4- Software:

Once again, a strong basis for support was needed. As a result, RoxBIOS was developed. This software, burned into the HC11 EEPROM, performs the operations outlined in Table 3 following a "reset"

RoxBIOS functions following a "reset"

1. Deactivates the motors.
2. Loads a program, if necessary.
   - Executes the program, if necessary.
3. Uses the interruption vectors.
4. Executes the default program.

Table 3: RoxBIOS functions

The RoxBIOS program is not executed only following a "reset". It also takes programming errors ("illegal opcode"), as well as other possible fatal errors, into account. As a result, a given leg will never go "crazy" and will never affect the others. In the worst case scenario, the motors will be deactivated.

The second step involves creating virtual sensors on which the rest of the program is based [8].

5- Infrastructure:

A data acquisition card was developed to do experiments on the robot. The card acquires the data and transmits it to a computer at a speed of approximately 70 bits of data/sec., which corresponds to the robot's maximum data processing speed. The computer then uses the METLAB software to process the data. This technique makes it possible to verify hypotheses much more quickly, easily and accurately. According to the logbook, five times less time is needed to conduct the experiments.

A technique for soldering surface-mounted components inside a stove has now been developed to minimize the damage caused by heat, limit the number of improper connections and decrease manufacturing time.

6- Rules for designing a complex system

The importance of having a strong basis for support, strictly adhering to a procedure, drawing diagrams prior to construction and quantifying the system parameters in order to conduct simulations was highlighted throughout the project (see booth).

According to the logbook record, the use of diagrams prior to construction reduced programming and assembly errors by 66%.

Conclusion:

Although Rox-544 is not yet completed, several sensors have been successfully added: the solar compass improves the navigational system's accuracy, the inclinometer helps keep the body position stable and the sonar effectively detects obstacles located [0.15, 3.2] m from the robot.

The parameters used to describe the behaviour of the motors are now known and the intelligence monitoring stage has begun. RoxBIOS is responsible for detecting and resolving software errors, and will deactivate the motors that power a given leg in order to ensure that the others are not affected.

The use of simulations and the acquisition of data were more than useful in understanding the phenomena involved, even for the design of simple components. This engineering protocol, as well as the infrastructure in place, can easily be applied to other completely different projects.

Moreover, this robot faithfully fulfils its platform function, facilitating the understanding of mechanisms present in insects. This research will undoubtedly help improve the mobility of autonomous robots, enabling them to integrate more easily into a human environment.