The ROUS:
Gait Experiments with Quadruped Agents

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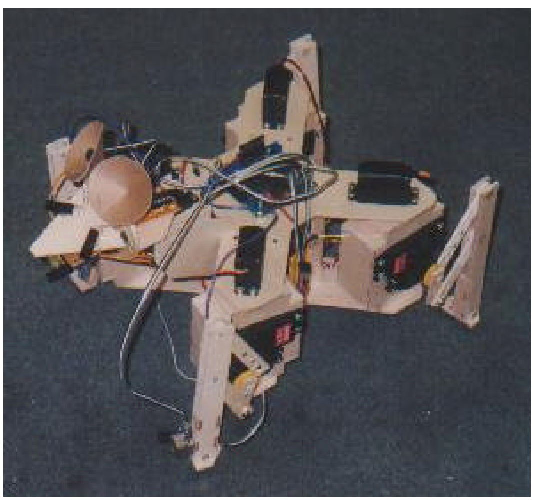
Abstract

The ROUS, or Rodent of Unusual Size[4], is an autonomous quadruped built on a cruciform body plan with three degrees of freedom per leg. This flexibility allows the agent to explore a variety of gaits, including the standard forward and reverse as well as a crab-like sidle to the left and right. Further gait variation could be achieved with experimentation.



Platform

The original ROUS platform was of a design not tried before in the three previous four-legged walkers built in the Machine Intelligence Lab. Instead of a two-layer X-shaped frame in which the shoulder boxes are sandwiched between the top and bottom layers, this original design was a single layer on which were mounted the circuit boards and z-axis servos. The shoulder boxes were mounted in brackets and their rotation actuated by means of push rods attached to the ends of the z-axis servo horns. However, testing revealed that this design was inherently unstable, as the weight was spread across the entire platform, causing it to tip over when it tried to lift one leg, even with the center of gravity shifted to the diagonally opposed leg. Further, the z-axis rotation was seriously limited, further restricting its range of motion.

The final ROUS platform is based on Steve Stancliff's design for "Bob" [3], a four-legged robot with three degrees of freedom, and is constructed using 1/8" birch model aircraft plywood. The X-shaped frame and two-layer construction provide greater freedom of motion for the legs as well as minimizing the area over which the weight is spread.

The main processor board is mounted on the top of the upper layer of the platform, and the secondary processor mounted on the other side.

The legs of the ROUS have three degrees of freedom: in-out (x-axis), up-down (y-axis), and rotation (z-axis). The x-axis and z-axis actuation is accomplished using 43 oz-in Dymond servos. However, in order to provide sufficient force to lift the platform, the y-axis actuation is accomplished via 180 oz-in servos from FMA Direct.

A five-bar mechanism was implemented to transform the angular velocity of the x- and y-axis servo rotations into linear velocity.
The TJ-Pro board is mounted on the top of the platform, permitting easy access; the single-chip board is mounted on the underside of the upper layer, which is set four inches above the bottom layer. This not only provides sufficient clearance for maintenance but also provides space for the twelve AA NiCad rechargeable batteries (in two packs of six).

Microprocessors

The combination of an MSCC11 single-chip board from Mekatronix with an MS68HC11E2 microprocessor and an MTJPRO11 expanded board with an MS68HC11E9 microprocessor, also from Mekatronix, was selected for its combined advantages of low cost, low weight, accessibility when mounted on the platform, and memory capacity. The TJ-Pro board has 32k of SRAM and expanded input and output ports, allowing greater flexibility with regard to sensors and programming.

The MSCC11 board has had a servo controller program burned into its 2k of EEPROM that permits the use of up to 16 servos on ports B and C, as well as an interface routine for communication between the two processors.

The TJ-Pro board houses the high-level programming and communicates with the MSCC11 through the serial interface.

Software

The MS68HC11E2 houses a serial-communication routine which interfaces with a servo-controller program capable of driving up to sixteen servos independently. The servo-control routine is accessed by the high-level code resident on the MS68HC11E9 which arbitrates behavior changes based on sensor input.

All software for this project was written and compiled under the ImageCraft 68HC11 C compiler and development environment (ICC11).

Sensors

All sensors are connected to the TJ-Pro board unless otherwise stated.

I. IR

The infrared detection suite consists of two Sharp GP1U58Y digital IR detectors and two collimated IR LEDs. The collimated IR emitters are hot-glued to the Sharp cases and the ensemble then mounted on the front legs, half an inch above the "foot."

The IR emitters are connected to port B on the TJ-Pro board and are powered off a 40 kHz signal generated by dividing the 68HC11's E-clock with a 74HC390 decade counter. The collimation is achieved by inserting the LED in a one-inch length of black shrink-wrap tubing, thereby focussing the infrared radiation toward the front instead of permitting 360^{o} radiation. This prevents the detector from being saturated by non-reflected IR when the LED is mounted to the side of the case.

The detectors have been hacked [1] from digital to analog, which results in a linear correlation between the value read by the analog port (here, PE1 and PE2) and the distance to the source of the IR. With the collimated IR emitters mounted directly beside the detectors, the value read by the analog port corresponds to the distance between the emitter and the obstacle off which the IR is reflecting.

II. CdS cells

The cadmium-sulfide photo-resistor is a device that changes its resistance value in response to the intensity of the light radiation to which it is exposed.

Figure 2 details the simple circuitry required to use the CdS cell for detection of ambient light. Two collimated CdS cells are mounted on the head of the ROUS at right angles to each other and 45^{o} off the long axis off the head, thereby covering approximately 180^{o} in front of the platform. The higher the value read by the analog port (PE3 and PE4), the brighter the light to which the CdS cells are exposed. The possible values range from 0 to 255.

III. Contact switches

Both front feet have a microswitch mounted on the bottom in order to detect when contact with the ground has been made. Figure shows the required circuitry; in this case, the analog port (PE5 and PE6) reads a value of 255 if the switch is off (i.e. the foot is not in contact with the ground) and a value of 0 once the switch has been depressed.

IV. Microphone

The condenser microphone used here (Figure 1) yields a signal in the 10 mV range, which needs to be amplified in order to be used. A two-stage amplifier was constructed using a LM324 op-amp – two inverting amplifiers in series with a total gain of 330 – the output of which is then passed to a LM339 comparator. The comparator output goes to the first input-capture pin (IC1) on PA2 of the TJ-Pro board.

The virtual ground (VGND) referred to in the circuit diagram is produced by voltage dividers which shift the "ground" value to 2.5 volts in order that the signal, when inverted by the amplifiers, is inverted with respect to 2.5 volts instead of shifted in its entirety about the 0 volt level.

The circuit diagrams provided by Radio Shack in the microphone packaging call for a 1k resistor and 1 to 10 uF capacitor. However, experimentation initially indicated that both capacitor values are too high to yield a signal. Ed Carstens' robot "Ziggy" [2] included a microphone circuit which used a 2.2k resistor and 0.001uF capacitor.

However, in order to improve the range from less than one centimeter, further experimentation was necessary. The best range was achieved with a 1k resistor and a 3.3 uF capacitor. These values allow the microphone to pick up a handclap from up to twelve feet away, provided that there is no other interference.

Unlike the other sensors, the microphone does not connect to the analog port (PEx) of the TJ-Pro board but instead is connected to the first input compare, IC1 (PA2). By using the interrupt system, the associated behavior can be triggered at any point during the ROUS's operation.

<u>Behaviors</u>

The ROUS exhibits five primary behaviors: walking, collision avoidance, light following, climbing, and remote deactivation.

The primary behavior, walking, actually includes several related behaviors. The ROUS can move forward, back, to either side in a crab-like motion, and can turn to the left or right. In order for a four-legged platform to walk, it is critical to keep three legs on the ground at all times in order to maintain its balance.

The light following behavior is triggered by the light level registered by the CdS cells. If the light level on one CdS cell is significantly higher than that on the other, the ROUS will crab-step sideways toward the light. An ambient light level below the set threshold (see code) will cause the robot to go into a hibernation mode, crouching down and waiting until the light level is once again above the preset threshold.

Collision avoidance is a function of the IR suite. Should the IR value registered by the detector on either front leg be above the preset threshold (see code), the robot will lift that leg in order to ascertain whether the obstacle is too high for it to surmount. If the obstacle is determined to be too high (in other words, if the IR value after lifting that leg is still above the threshold), the ROUS will turn and proceed in the other direction; otherwise, it will climb over the obstacle. If both IR values are simultaneously above the threshold, the ROUS will assume an attack posture, rising to the highest position permitted by its servos, then back off and proceed in another direction.

The remote deactivation is triggered by input from the microphone. Because this input is set up as an interrupt, the "kill switch" can be activated at any point during the ROUS's operation rather than at a set point in the sensor polling hierarchy. When the deactivation signal is received, the ROUS drops into a crouch. In order to end the deactivation routine, the main processor must be reset.

A sample step routine for forward locomotion would proceed as follows:

1) all servos set to their zero (centered) positions
2) weight shifted to back right; left front lifted, extended, lowered
3) weight shifted to left front; right rear lifted, retracted, lowered
4) body shifted forward
5) weight shifted to back left; right front lifted, extended, lowered
6) weight shifted to right front; left rear lifted, extended, lowered
7) body shifted forward
8) platform should now be centered

VI. Test Plan

While theoretically the platform has the capability to climb over an obstacle up to four inches high (based on the length of the vertical leg members), a maximum height of two inches was set in order to avoid placing excessive strain on the servos as well as in consideration of the issue of balance. As mentioned in the "Behaviors" section, the climbing routine involves the ROUS lifting the leg in front of which an obstacle has been detected and, if the IR readings indicate that there is no obstacle at that height, stepping onto the obstacle. Due to the angle of approach and position of the other servos, the ROUS often "sees" an obstacle as being too high to climb, even if this is not the case. Tests with barriers of 0.5, 0.75, 1, and 1.5 inches in height indicate that the highest barrier the robot will traverse with any regularity is 0.75 inches high. It has been tested with success on barriers 1 inch high, but its success in these cases is determined by the angle at which it approaches the barrier. Since the fundamental concept in this case is the creation of an autonomous agent which can be left to its own devices to navigate randomly around a room, the angle at which it will approach an obstacle cannot be predetermined. Therefore, for all intents and purposes, the maximum height of a traversable obstacle will be set at 0.75 inches.

The ROUS has been operated continuously to the end of its useful battery life during testing, which usually averages between fifteen minutes and half an hour, depending on how long the batteries have been charged beforehand.

The range of the remote deactivation feature was tested by first connecting the output of the circuit to an oscilloscope and noting the response to loud noises at a succession of ranges, and then by integrating the sensor's interrupt routine into the main program and repeating the procedure. Test results indicate an optimum range between six and nine feet; a range greater than six feet tends to produce erratic responses. It is also important to note that, unfortunately, the noise and vibration caused by the platform's twelve servos will frequently trigger the remote deactivation, as the vibration translates through the frame and into the microphone. Putting the microphone on a standoff (e.g. a wire or other flexible object which would absorb most of the vibration rather than transmitting it) would solve this problem.

Summary

The ROUS – Robot (or Rodent) of Unusual Size – is an autonomous four-legged walking robot capable of maneuvering over obstacles less than two inches (and preferably less than one inch) in height. With a suite of on-board sensors including IR detectors, CdS photo-resistors, and a microphone, it can demonstrate such behaviors as obstacle avoidance, light following, and remote deactivation, as well as walking forward, back, to either side in a crab-like motion, or turning to the right or left.

References

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[4] Goldman, William S. *The Princess Bride.* Balantine 1975

Acknowledgements

The ROUS is a direct descendant of Steve Stancliff's IMDL project, "Bob," in terms of overall mechanical design. I would like to thank him for explaining the gait patterns and fundamental concepts used in "Bob."

In addition, I owe thanks to Charles William Eno for his invaluable assistance with the design of the original platform, AutoCAD tutorials, and his help with the serial interface and servo control code, as well as the helpful suggestions and feedback in general.

Thanks also need to go to Eric Anderson for his input and suggestions, Scott Jantz and Aamir Qaiyumi for their help debugging hardware and other assistance, and the rest of the Machine Intelligence Lab for their assistance and support.

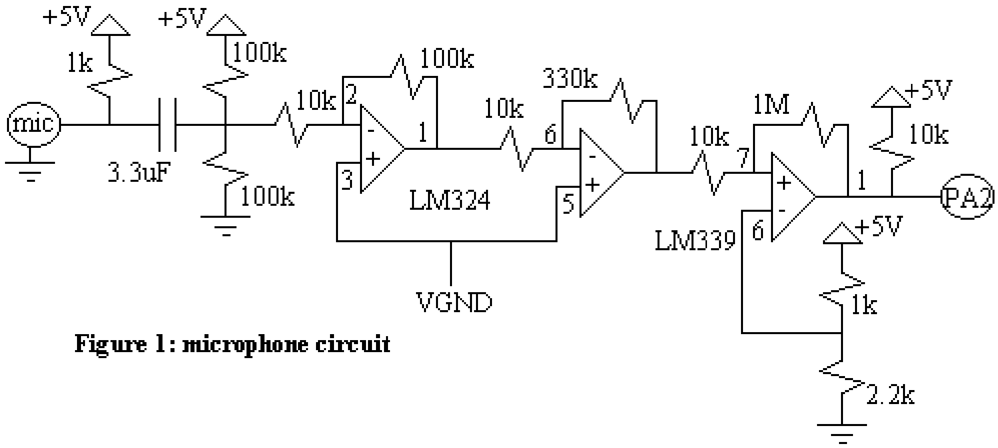

Figure 1: microphone circuit

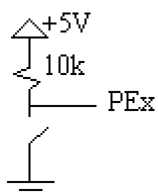

Figure 2: contact switch ckt

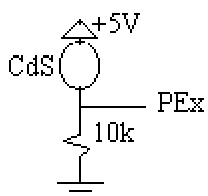

Figure 3: CdS circuit