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PLATFORM CONTROL SYSTEM (PCS) DESIGN FOR AN AUTONOMOUS ROBOT

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ABSTRACT

Although captive robots may be capable of impressive feats within their limited world, many applications require robots that can move in order to do multiple tasks, fetch, avoid obstacles, etc. In this paper, the status of an on-going project to design and implement a control system for the maneuvering of the WOMBAT robot platform is discussed.

The WOMBAT is a completely autonomous robot being built as a College of Engineering research project by a student engineering organization, C. M. Robotics at Louisiana Tech University. A background overview of the WOMBAT is given via a history of precursory robot projects and the WOMBAT objectives and requirements.

The WOMBAT platform control system (PCS) design task is discussed in terms of the procedures followed, the engineering trade-offs made, simulation and test stand results obtained. The current status of the design effort and future plans are described.

KEYWORDS: Robots, Control Systems, Design Project.

I. INTRODUCTION

Most robots are just mechanical arms sticking out of a table or mounted along an assembly line. Although the captive robots may be capable of impressive feats within their limited world, many applications need robots that can maneuver over much larger distances, fetch, run a maze, seek light, recharge themselves, all requiring the ability to move. A robot used to load a machine tool spends its time waiting for the machine tool to finish its operations. Ideally, a single robot could be positioned between two or more machine tools so it can be fully utilized. Ultimately the robot would have eyes, ears, and an arm, but the first step is to make it move.

Through artificial intelligence (A.I.) and robot mobility, a general purpose unit can be designed that will provide flawless work and minimal human intervention. Our unit "WOMBAT" which is presently being designed will eventually incorporate these features of AI and robot mobility. This paper will discuss the projected wheel sensor and motor selection and control design for the WOMBAT'S mobile base that will allow it to maneuver.

A. Precursory Robot Projects

The WOMBAT is an autonomous robot being built by C. M. Robotics, a student engineering organization at Louisiana Tech University. C. M. Robotics is a multi-disciplinary undergraduate student design organization with primary interest in robotics. During the 1980-81 academic year, C. M. Robotics (formerly Critical Mass) contracted with Ruston State Bank to build an Autoteller Demonstration System. Utilizing profits from the Autoteller project, the organization initiated a project to design and build an autonomous robot named the BANDICOOT. [3], [4]. The major goal for the BANDICOOT was to run through a maze and find the end of the maze. This robot was built and partially met its objectives in 1984. The BANDICOOT robot used a "Big Track" toy by Milton Bradley Company as its base. During the project, the robot's limitations due to its base became evident. Also during this same time frame, independent of the C. M. Robotics project, three electrical engineering students designed and built, as a senior design project, a heavier robot base for a radio-controlled robot platform. [16], [17], [28]. When C. M. Robotics began its current, more ambitious robot project, the development, design, construction of the WOMBAT robot, the radio-controlled robot platform was used as a proto-type for the WOMBAT base.

B. WOMBAT Description

The WOMBAT robot requirements include:

1. BASE
   - A. Total weight 100-150 lbs.
   - B. Width less than 27 1/2"
   - C. Must climb wheel chair ramps
   - D. Must maneuver in an uncluttered room
   - E. Must roll on indoor/outdoor carpet
   - F. Must clear small bumps (electric power cords, cracks in sidewalks, etc.)
2. SAFETY
   - A. Emergency drive motor off switch on all four sides
3. GENERAL
   - A. Simple arm
   - B. Programmed in a high-level language
   - C. Speech recognition & synthesizer
   - D. Sonar range sensor
   - E. Infrared proximity sensors

A functional block diagram of the WOMBAT is shown in Figure 1.

There are currently 35 undergraduate students representing eight different majors (primarily electrical and mechanical engineering and computer science) working on the WOMBAT project. The student management of the overall effort is well coordinated and task descriptions, team assignments, schedules and budgets have been developed. Major subsystems, in addition to the platform, include the arm, the sensors [10], speech recognition and synthesizer, on-board computer, external computer, radio link, power supply, sensor and control system software, artificial intelligence (A.I.) software for autonomous command and control.

The design of the robot base position and rate feedback sensors and motor control described herein was accomplished as partial fulfillment of electrical engineering student design requirements by co-authors

Mossy and Zerkus [26], [32]. In the following, motors, motor control, wheel position and rate feedback sensor design, initial test results, and status of the platform control system design are described.

II. PLATFORM CONTROL SYSTEM OVERVIEW

The methods of controlling a motor in a robot can range from the most simple on/off power switch to the complex servo control circuits used in industrial manipulators. When more than one motor is used to drive the wheels as in the system discussed here, accurate speed control of each motor is critical. When commanded to walk a straight line, each motor must run at the proper speed or the robot will follow a crooked path. If the speed of each wheel is accurately known, then a robot with a microcomputer can also navigate by keeping track of its position relative to some initial starting point.

A closed feedback loop will be used to control dynamic qualities of speed, direction and position, subject to stability restrictions that can be determined by a mathematical analysis of the problem. In the generalized feedback loop of the WOMBAT system, the commanded value of the controlled parameter is set from the controller AI program. The commanded value is compared against the measured value of the parameter as determined by the feedback from the sensors; the error signal is then processed by the controller (control algorithm) in the dedicated on-board control computer; and the actuation command is used to drive the motors. A block diagram of the PCS is included in Figure 1 and the platform wheel layout in Figure 2.

III. MOTOR SELECTION

A. Initial Motors

The original motors on the WOMBAT proto-type base [17] were Delco 8-pole split-series window lift motors from a 1970 Chevy Corvett. These motors have a steady state no-load current of about 8.0 amps and a stall current of about 17.6 amps. There is a right and a left motor. Each of the two motors are identical save the gear train mounted on the end. The motors have a worm gear actually turned into the shaft, the work gear engages a toothed gear which transmits power to the wheel via a lovejoy flexible coupling. There is a 46:1 gear reduction between the motor and the wheel. The motors produce approximately 16 in-lbs of torque with a speed between 47 and 72 rpm.

During testing of the window lift motors it was discovered that the motors became very hot. The decision was made to call Delco and inquire about the heating problem. From Delco engineering it was learned that window lift motors were designed for intermittent duty and that Delco had stopped production on that type of window lift motor in 1971. The motors were designed to operate 8 seconds at a time with a maximum operating time of 10 minutes. Technical information was also received on all electric motors used in General Motors X-Body and J-Body cars.

The possibility of cooling the window lift motors was examined. The cooling systems examined included: 1) heatsinks with forced air cooling, 2) ventilation of the motor case with forced air cooling, and 3) pumping Freon gas through the motor case. After several motor cooling schemes had been evaluated, it was decided that a better and more reliable robot would result if the Delco window lift motors were not used as the main drive motors of the WOMBAT. Cooling the window lifts would add unnecessary complexity to the drive system, and would only prolong the inevitable burn-up of the window lift motors.

With the drive motors removed the initial platform becomes little more than a square of plywood. Adapting new motors to the existing mechanical drive system appeared more difficult than saving the previously done work. For these reasons, it was decided to start over at square one. Designing a new WOMBAT platform set the project back approximately one month, but, in the long run, a better robot will result.

B. Other Motors Evaluated

The decision to use new motors brought on new problems: (1) Cost - budget constraints dictated that a maximum of $50.00 could be spend on the motors. (2) Mechanical - a drive train to the wheels would have to be built.

Drill Motor. A variable speed reversible drill contains a DC motor with a separate field coil. These motors could be used, but a voltage higher than 12 volts must be used. In fact, a voltage of about 100v would be needed to get the rated horsepower from the drill motors. Rechargeable 100v batteries are not available within the budget constraints.

Pedal-Assist Motor. The pedal-assist motor is a permanent magnet DC motor. It is designed to be run on 12 VDC. No-load speed is 3600 RPM, no-load current is 3.5 amps, stall torque is 15 in-lbs, and stall current is 50 amps. The motor is rated at .194 horsepower at 3120 RPM. The pedal-assist motor cost about $10.00

Although the pedal-assist motor was attractive, it had one major drawback: a drive train would have had to be built. At the time the decision had to be made, C.M. Robotics did not have a mechanical engineer or machinist. No one in the club that at time had the necessary skill to produce such a drive train.

Wheel Motor. A wheel motor is basically a coaster with a permanent magnet DC motor and gear train. It is designed to be run on 12 VDC. The drive wheel is 4 3/4" in diameter. No-load speed is 200 RPM. No-load current is 2 amps. Stall current is 10 amps. They cost $29.50 each.

Although the wheel motors have less power than the pedal-assist motors, they have one big advantage -- a drive train. All that is necessary to get a motor drive train operational is to mount the wheel motor. In view of the above advantage, it was decided to buy two wheel motors and use them as the main drive for the WOMBAT.

IV. MOTOR CONTROL

To control the speed of a DC motor with a constant field, the average voltage across the armature must be varied. There are two ways to vary the average armature voltage: 1) by dropping the undesired voltage across some controlling device or 2) by turning the motor on and off at such a rate that the desired average voltage appears across the motor. A variable DC supply wastes power across the controlling device. This wasted power is converted into heat. Unnecessary heat generation should be avoided whenever possible as it adds to an already serious problem. Also, as the largest consumer of power in the robot, the motor drive system must be efficient.

A. Pulse Drives

Pulse drives use the concept of turning the motor on and off very quickly thus the average voltage across the motor armature is controlled.

There are two major types of pulse drives with many variations of each:

(1) Pulse Width Modulation and (2) Variable frequency. At the time of this writing, no decision has been made as to which system or variation of a system the WOMBAT will use. There are many advantages to each type of drive. The decision has been made to simulate and to test each type of pulse drive.

Pulse Width Modulation (PWM). Pulse width modulation involves turning the motor on and off to control the average voltage across the armature. This is accomplished by feeding the motor a square wave. The frequency of the square wave remains constant. The amplitude of the pulse remains constant. The duty cycle of the square wave is changed to vary the average voltage. [21], [22]. In order to be effective the on time of the pulse must be less than the mechanical time constant of the motor and drive system. The mechanical time constant of the motor and drive system is defined as the time it takes for the motor to reach 63% of its rated top speed.

Variable Frequency. Variable frequency motor control also involves turning the motor on and off to control the average armature voltage. With this method, the duty cycle is a function of a controlled frequency, with the pulse on-time constant while the repitition rate (period) changes. [11], [25].

A trade study was performed to determine the type of semiconductor device to use as switching devices to implement the pulse drive. Power transistors and SCR's were considered, but MOSFET's were selected . [32].

V. FEEDBACK SENSORS

To close the PCS loop, sensors are required for both position and rate information from both drive wheels.

A. Position Sensor

Initially, optical shaft encoding [13] was considered for wheel position sensing. However, the cost proved to be outside the budget constraints. Thus, a search for a simpler system was initiated.

Ideas for an induction sensing system were developed. The system will sense metal conductive strips spaced about the perimeter of the wheel and provide a calibration of distance relative to some initial starting point. The system consists of the induction unit, an operational amplifier driver, a retriggerable monostable multivibrator and the computer interface lines. The induction system is relatively inexpensive in comparison to an optical system. Flexibility is allowed through the advantage of being able to easily change the drive wheel system without any conflict. This system does not require the manufacture of special gears or a disk. All that is required is a ferrite loop coil mounted next to the wheel. This allows for an easy adjustment in distance calibration.

Mechanical stability on the WOMBAT must be accounted for because the wheels will be shock mounted and vibration isolated from the ferrite loop coil. Slight pulse width deviations would occur with mechanical jitter on a surface. The system accounts for this possible jitter by use of a retriggerable one shot. The retriggerable one shot only fires on the leading edge of the pulses, and its output constitutes a constant pulse width.

With this induction system only a limited number of conductive strips can be placed on the perimeter thereby limiting the resolution to that defined by the spacing of the conductive strips. A decision had to be made with respect to resolution that could be obtained with the induction pickup. This was done by what was called the "spacing test". [26]. A one inch spacing was selected as a result of the tests.

Schematics of the induction sensor unit are included in [26].

B. Velocity Sensor

The velocity sensor as currently conceived is essentially a digital tachometer. This design will provide the control computer with a frequency that is proportional to the sensed velocity. It consists of an electromechanical generator, a direction relay, a non-inverting op-amp, and a voltage to frequency (V/F) converter.

Tachometer Generator. This is a small dc motor used as a generator and precision calibrated for linearity. A rubber runner wheel has been attached to the shaft and the tach generator will be mounted on a bracket on the drive wheel on the bottom of the WOMBAT platform. This tach generator will ride on the drive wheel and produce a linear curve from 1 to 2 volts. The WOMBAT unit will have the capability to travel reverse, meaning that the tach generator would produce a negative voltage if the leads were not reversed. This is accomplished by using the same four pole relay that the solid state motor control circuitry uses to reverse direction of the drive motors.

Op-Amp. The next stage is a unity gain operational amplifier which serves to time average the linear voltage response of the tach generator. This is necessary due to mechanical jitter and vibrations which could possible cause the response to vary instantaneously.

V/F. The last stage is a voltage to frequency converter which will take the linear input voltage from the unity gain amplifier and transform it into a proportional frequency. A 9400 chip will be used and for the voltage to frequency relationship of concern will give us a proportional frequency range of 2KHz to 4KHz. This is a lot wider range (more precision) than could be obtained by an A/D converter with only 256 levels. The microprofessor clock time circuit (CTC) will be used to sample this frequency, and an error constant will be derived from it to compare to the commanded speed value.

VI. CONTROL COMPUTER/CONTROLLER

At the beginning of the WOMBAT project, a Microprofessor (MPF-1) was selected as the dedicated drive (control) computer. The function of the control computer is to take in commands from the off-board computer (the computer that contains and runs the artificial intelligence program) and decode them and implement them to properly controll the motors. The control computer will also take in bump sensor data and relay that data to the off-board computer after cutting power to the drive motors.

A. Hardware - Software Trade-Offs

A computer gives a system versatility. A computer gives a system the ability to be reconfigured or reconfigure itself to meet current conditions. A problem arises when a large demand is placed on real-time software. Motor control is such an application.

In the WOMBAT motor drive system there are a number of signals that must exist. These signals must be generated by and read by the computer at regular time intervals and the control algorithm solved. These signals are 1) left and right motor drive signals, 2) left and right drive motor feedback, and 3) left and right drive motor actuation signals. Coupled with these tasks are taking in serial data from the off-board computer, decoding commands, sending data back to the off-board computer, and processing bump sensor data. The timing demand on software can be cut down by using interrupts. Using interrupts for such things as bump sensors and data requests from the intelligent computer will insure that no time is wasted polling these ports.

The point to be made here is that it is possible to have so many time dependent tasks that the computer simply cannot function effectively in the system, i.e., require more than 100% CPU. Thus a totally software implemented system using I/O lines from peripheral interface adapters (PIA) to generate and take in signals is not effective.

The flip side of the coin from a totally software implemented system is a near totally hardware implemented system. In such a system the computer is not responsible for exact timing. The computer simply changes constants in the hardware that generates time functions. If system speeds are high this is the best method. However, the WOMBAT system is slow by comparison. Unnecessary external hardware wastes power and causes inefficient use of the computer.

A hybrid between the two approaches provides a reasonable solution. This hybrid approach comes in the form of multi-purpose support chips. One such support is the Z-80 clock time circuit (CTC). The CTC can provide pulses at regular intervals. The CTC can also provide interrupts to the CPU, so that software events can take place at regular intervals. However, the CTC cannot output a variable duty cycle pulse. Frequency can be varied but pulse width cannot. A scheme using a flip-flop to develop a variable duty cycle pulse was derived. [32]. It involves using two CTC channels with two different time constants. The output of each channel would be wired to a flip-flop. Channel 1 would reset the flip-flop. Channel 0 would set the flip-flop. By changing the time constants in both channels, variable duty cycle and variable frequency/variable duty cycle pulse trains can be produced.

B. Controller Design and Simulation

An initial simple proportional control law with position and rate feedback from both drive wheels is being considered. A digital simulation with simplified motor models is being programmed in BASIC and will be used to evaluate the proportional controller.

VII. MOTOR AND SENSOR TESTING

Because the new WOMBAT base was not finished, it was decided to build a motor test stand. The motor test stand has a motor similar to the one used in the wheel motors. The motor has a gear train and a wheel attached. The test stand has a pipe stand to mount sensors, relays to control the direction of the motor, a diode for dynamic braking (with a dropout switch), and bread board for assembling circuits. The test stand is built in such a way that it can be reconfigured easily. An illustration of the motor test stand is given in Figure 3.

A. Test Results

The motor test stand has been utilized to perform stall current and dynamic brake tests on the motors, MOSFET drive tests, PWM and V/F motor control tests; and will be used to test the feedback sensor systems.

Stall Current Test. The motor was brought up to speed; then an increasing load was applied to the motor until it stalled. The stall current was 10.5 Amps.

Dynamic Brake Test. Dynamic braking is a technique used to slow down a motor. Basically it involves cutting the power to the motor and shorting the motor leads. In our system, this is accomplished with a diode. The diode also serves as a "free wheeling" diode in the motor control system. In theory the free wheeling diode makes the motor more responsive to pulse drive techniques, and dynamic braking should stop the motor quickly. We found that the motor performed and controlled the same with or without the diode. The use of dynamic braking and free wheeling diode is probable more effective on larger motors.

MOSFET Test. The MOSFETs used were made by International Rectifier Corporation. They re IRF511. It was found that one IRF511 could drive the motor, but it got very hot. (The device was heatsinked). Two IRF511s were paralleled. They were able to drive the motor with very little heating.

The major problem found with the IRF511s was that they would not cut off unless the gate was grounded. A 1 kilo-ohm pull-down resistor was added but proved ineffective. A 50 ohm pull-down resistor worked better but not completely. It is believed that the gate may have to have negative biasing to function properly.

Pulse Width Modulation Test. The output of a WAVETEK function generator was connected to an oscilloscope and the gate input of the MOSFETs. Varied pulse widths at different frequencies were tested. This test proved that the motor speed does in fact vary with pulse width. It was found that frequencies lower than 1000 Hz were not good to use because apparently pulse width was longer than the motor mechanical time constant; thus, the motor oscillated in speed. Frequencies above 10,000 Hz were altogether ineffective. At 1000 Hz, the speed could be varied well by varying the pulse width. However, the motor would not turn off, even at very small pulse widths. This is possibly due to the gate pull-down resistor problem and not the control method.

Variable Frequency Test. It was found that motor speed could be controlled. However the frequency range necessary was surprising. The control range was from about 400 Hz to 1000 Hz. Below 400 Hz control lost effect and the motor speed began to oscillate but could be slowed somewhat. Above 1000 Hz the motor assumed full speed. Between 400 Hz and 1000 Hz motor speed could be controlled. Much of the difficulty with variable frequency control can be attributed to the function generator/test set-up and the gate pull-down resistor problem. However, variable frequency control did not appear to have a range of control necessary for the WOMBAT. Additional tests and simulation are planned to evaluate variable frequency control.

VIII. SUMMARY/CONCLUSION

The WOMBAT robot platform control system (PCS) concept has been formalized. The dedicated on-board PCS control computer, motors, and motor drive components have been selected. The feedback sensor system has gone through preliminary

design, and two motor control schemes and one control law have received preliminary evaluation.

Future plans include

- selecting control scheme from PWM and V/F
- finalizing and programming a control law
- completing simulation and utilizing it in fine tuning the control system
- building the actual subsystems
- testing the subsystems and the interconnections on the test stand
- interconnecting the subsystems in final layout on the platform
- testing and fine-tuning the final PCS

Although further analysis and simulation, final subsystem implementations, and final subsystem interconnection are certain to surface new problems, the objective of completing the WOMBAT PCS by March 1986 continues to appear feasible.

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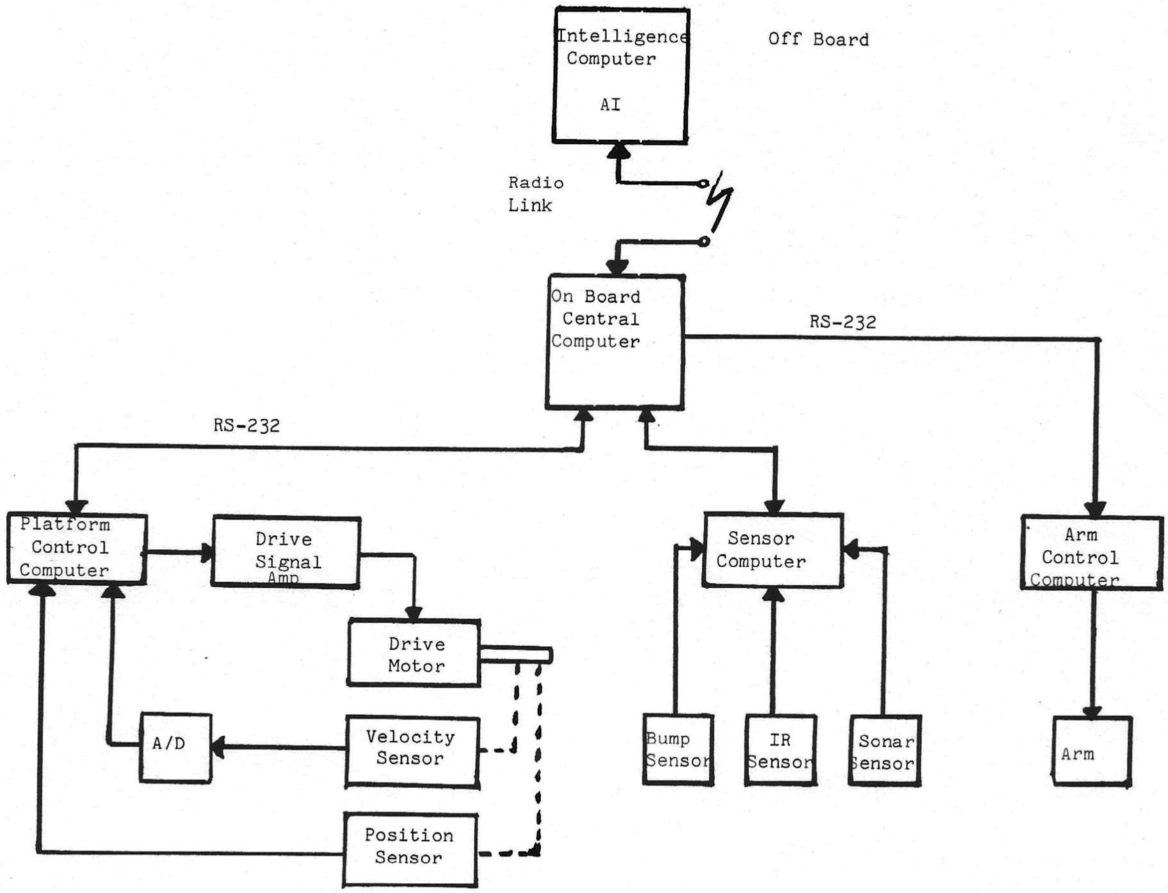

Figure 1. Functional Block Diagram

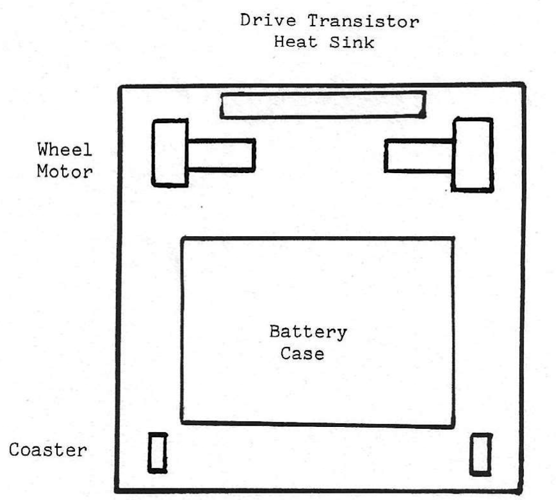

Figure 2. Underside of WOMBAT Platform

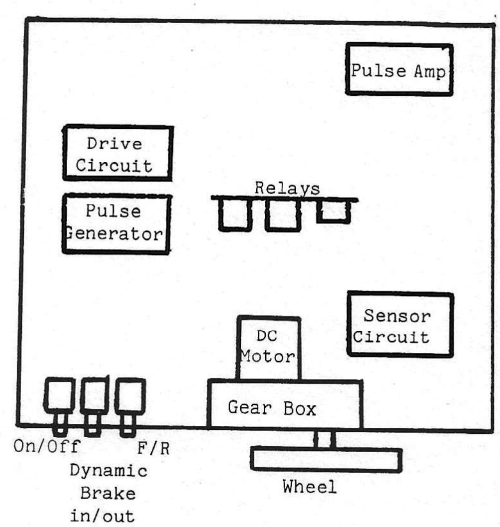

Figure 3. Motor Test Stand