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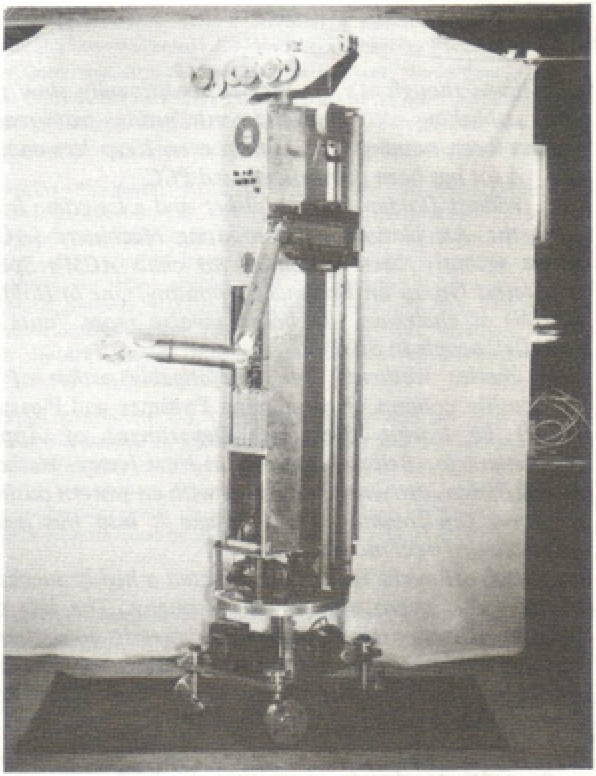
An Electromechanical Household Servant



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Delos Johnson Reynolds holds an E.E. Degree from the Cooperative University of Cincinnati. From 1939 until his retirement in 1968, Mr. Reynolds worked as a design engineer for Westinghouse. He has designed a variety of electrical, electronic and mechanical equipment.

Mr. Reynolds says that the design and building of a home robot is an attractive hobby because it does not require cooperation or permission, sometimes difficult to obtain. Robots are stand-alone items, and open-ended hobby projects; one needs to be very patient due to the great difficulty in building a robot.

INTRODUCTION

While modern household appliances really take the drudgery out of housework, they still require attention by the homemaker. Often the remaining part of a task requires more time-consuming attention and manual skills, which may make it very difficult to do several tasks simultaneously. A household servant in homes before World War II was the effective solution to this problem. Now available technology could be used to develop an electromechanical household servant, a "Home Robot." Homemaker activity surveys and studies have tended to show about five hours of actual housework per day done in the home for a family which includes at least one child under fifteen years of age. This excludes time devoted to child care and outside operations such as shopping.

A home robot should be able to perform these tasks:

Clothing Care: Load clothes in washer and dryer, sort clothing and put away
Room Care: Care of floors, dust furniture, make beds, clean bathroom and fixtures
Food Preparation and Cooking
Kitchen Clean-up
Special Tasks, such as housecleaning or walls, windows and drapes and other seldom-performed tasks.

It is apparent that a home robot will probably be a little slower than the typical housewife and may initially be unable to do all the listed tasks. It will likely operate at least five hours a day and will be very useful.

It will be a complex appliance and will probably have a price somewhat like that of an automobile. Present availability of 16 bit microprocessors and of large (4K or greater) static random access memory in DIP cases makes it now possible to build an adequate computer control system into the home robot. A large memory and a fast computer are necessary because of the number of programs which must be available and run on an apparently simultaneous basis to properly control motions. Programming for the home robot will become a very competitive activity.

Since the home robot will operate in already existing homes and new homes, this determines some of the design specifications of any home robot. For example, a height limit of 78 inches overall would allow robot to pass under a typical 6 feet 8 inch doorway with a threshold plate and rugs, and a width limit of perhaps 18 inches would be prudent for entering a typical 2 feet 8 inch wide doorway. Because of door-hinging, the actual opening width is only 30 inches. To avoid contact, the navigational errors would have to be held to ± 5½ inches. Another design specification decision would be on the question of whether to climb and descend stairs or steps. The writer's opinion is that operation on single level should be specified because there are many ranch-style single-level homes and in many others most of the housework is performed on one level. The big-city high rent apartments are mostly single-level. Adding stair-climbing would increase both development cost and risk and would also increase physical operational risks.

Development of the home robot now seems both possible and timely. Occasionally there are articles in the news of such efforts by small organizations or individual inventors. There appears to be no effort of the scope and size necessary to launch a home robot industry. Most knowledgeable observers will agree that the possible reward for a successful development is large. The deterrent: development risks, business risks and legal risks are substantial. Further, by the nature of the venture in the present legal environment, there is no way of assuring that the rewards for a successsful development will go to the developer to compensate the risk taken. Also, the risk is so large that failure would entail serious personal consequences for the individual who advocates the venture.

One approach which might overcome some of the above impeding factors would be to define the home robot with a provisional design specification. Additionally, one should separate a basic design into sub-assemblies and define the interfaces between them so that a cooperative effort could proceed by individuals or organizations. This would divide the costs and reduce the risk factors. Also, some of the sub-assemblies could be of value independent of the success of the complete project. The home robot, as here defined, would be a mobile unit, which could be moved to any home with minimal requirements at the home. The major changes would be in programming to accommodate changes from home to home by reloading the computer programs. This would facilitate development trials after a functional development model is available.

CONSIDERATIONS OF THE ROBOT IN THE HOME

The great benefit obtained is automatic performance of many home chores. A complete, seven-day cycle of programs would be performed every week. Desired omissions, alterations and additions would be entered into the main program as soon as the need for change is known. At the desired day and time, the necessary sub-program would be moved from the bulk memory, and any change would be made. Then it will begin to run. The homemaker would have a little directory listing the entry call up for the many programs in bulk storage. To get these benefits, the household would need to operate in a more standardized way, particularly in respect to storage of food, cooking utensils and tableware. Since the robot would restore many of these items after use, this precaution might be stated as "let the robot work and don't interfere." Safety "stop" switch bars should be on the robot so that any danger to humans can be limited.

Another consideration is that the home robot will not be as small nor as flexible as a human and will therefore required more space to operate. Therefore, some rearrangement of furniture may be necessary to obtain the advantages of an automatic housekeeper. Longer-than-human telescopic arms will allow for fewer paths to be used so that this problem is minimized.

A general design consideration should also be to limit the available force of the various moving parts so that a human could successfully resist any accidental entanglement while stopping the robot. In many respects, the home robot design seeks performance capability of about that of a 90-pound human. Estimates of design weight for an experimental model, for which some major portions have been built or purchased, run between 250 and 300 pounds. It appears likely that a production home robot might weigh around 200 pounds. With four 5-inch diameter by 1¼ inch wide wheels on shag rug, the force needed to start pulling the robot is about 0.25 of its weight or a design figure of 75 pounds. At a speed of one foot per second, this corresponds to 0.136 horsepower. This speed is selected because humans would need to be able to evade and avoid interfering with the robot. The wheels could have tires of woven material, such as the hard wool closed-loop pile stair runners. This should reduce tracking and give slip-free propulsion. All wheels should be powered so that any wheel will climb upon a throw rug lying on a polished floor and not just push the rug along. Another safety consideration in design is to avoid close-moving parts on exposed portions of the robot.

A feature of the home robot that affects the travel requirements is the length of the arms. By having a long telescopic part to the arm, it will be able to program the robot to make a bed from one side or to set a table from one side. This is needed for small rooms. It also makes it possible to do much work in the kitchen area without traveling. Travel programs

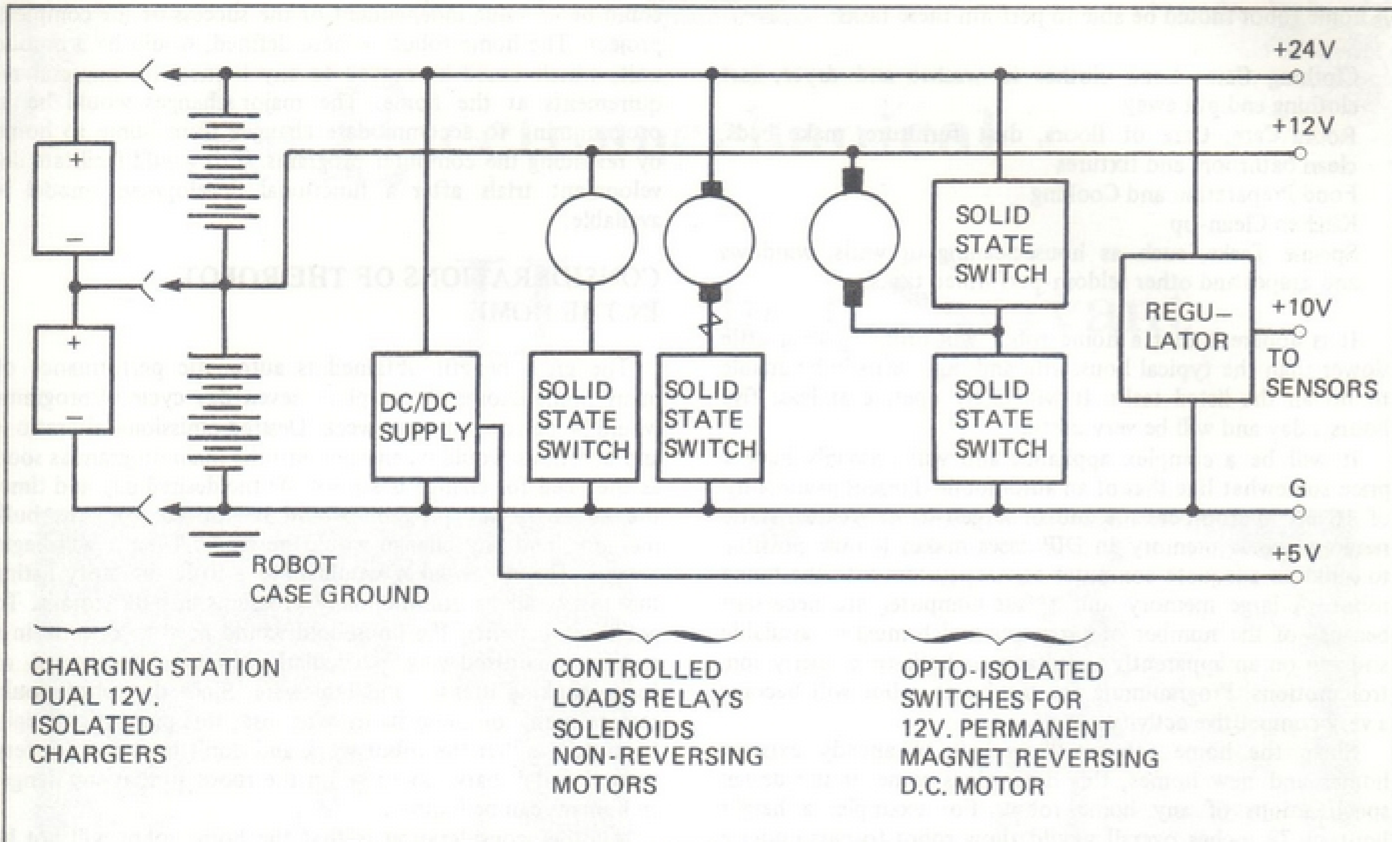


Figure 1. Typical power circuits for a 24 Volt D.C. home robot.

would control the robot from station to station in the house. The humans would soon learn to keep the robot paths clear of obstacles. Proximity sensors on the robot and additional programming would be needed to avoid or remove any remaining obstacles, when required.

Removable trays would be provided to facilitate carrying things and to reduce the number of trips required. Difficult-to-handle items, like silverware, might be handled and stored between use on a special tray.

POWER SUPPLY

The use of two 12-volt automobile batteries (or similar batteries designed for deep cycling) and available aircraft/automobile accessory motors and power semiconductors makes an attractive experimental power supply. The current drawn from the batteries would be 10 to 15 amperes when traveling and the batteries would be cycled to a fairly deep discharge once a day. Such usage would probably require yearly replacement.

If a battery-powered design is planned, space can be provided for Marine deep cycle designed batteries. A good size is 11 inches long by 6-3/4 inches wide by 9-3/8 high to top of terminals. These batteries weigh 45 pounds each and will furnish 25 amperes for 136 minutes (reserve capacity rating). Two of these 12-volt batteries will furnish about 1000 watt-hours with a good margin of capability. This would correspond to an average loading of 200 watts over a five-hour work period. These batteries ought to give a long service. Other batteries could be used on initial experimentation until the robot is to be put into service. There are also problems of safety with respect to the generation of hydrogen gas at high charge rates or overcharge and corrosive fumes from the electrolyte. Sealed cells may overcome these problems.

Most motors on the robot will require reversing. Permanent magnet small D.C. motors are available with good characteristics for most uses and save the energy normally needed for field excitation. A conventional forward-reverse relay circuit could be used with 24-volt motors. If a solid state control is desired, it should be possible to develop a circuit for control of 12-volt motors which use one battery for each direction of rotation. The propulsion motors would mostly be used in the forward travel direction. The motors on the left side could be wired so as to propel forward on the battery which the right side motors use for reverse travel and thus equalize battery drain. Such a circuit could use two power transistors and would require two opto-isolators for each motor. This scheme would also require dual-isolated charger circuits in the charger station. Figure 1 shows typical power circuits for a battery-powered home robot.

For a working home robot, 60 hertz power from the public utility should be more satisfactory.

An overhead cable of light-weight construction is suggested. This cable would hang above the level of floor lamps and below the level of ceiling-hung lamps. It would be above the level of seated persons but could interfere with the taller walking persons. Its jacket would be white or other highly visible color. It would be held taut or taken up by torque motor, and care would be taken to assure longest possible life for this flexible cable. The cable would operate from a 230-

volt 15-ampere outlet and would be about 75 feet long to reach any place in the working area. The cable would slide upon little hook-like supports placed in doorways or the corners of passageways where the cable would need support. For the A.C. powered robot, A.C. motors would be used to drive major loads. Rectified power supplied would be used for small D.C. motors and solenoids. Suitable separate power supplies would be used for electronics. With a 115/230-volt power supply at the robot, it would also be convenient to supply needed portable appliances from a receptacle on the robot. The overhead cable would also be useful as an aid to navigation.

NAVIGATION

Fixed stations may be selected as starting places for the robot to travel to for portions of each task. Many tasks may be completed with little movement of the robot, provided the arms are telescopic. In a typical 8-room home, 48 stations may be sufficient. Navigation has to take the robot through doorways and avoid obstacles such as fixed furniture. A proposed method is to use one sensor for the length of the cable, a second sensor for reading the horizontal angle of the cable to the earth's field, and a third sensor for reading compass direction of the wheeled carriage as determined by the horizontal angle of the earth's field to the carriage directional axis.

The propulsion and steering of the wheeled carriage would be designed so as to perform with good repeatability. The arrangement shown in Figure 2 provides for ten modes of movement:

1. Forward
2. Backward
3. Sideways to the right
4. Sideways to the left
5. Forward right turn
6. Backward right turn
7. Forward left turn
8. Backward left turn
9. Rotate carriage right about center of base
10. Rotate carriage left about center of base

(Centers for all turns are 21 inches to right or left from the center of the carriage).

Preferable definite stops on all steering mechanisms would aid repeatability. The command to start or finish a turn could be executed any time except when moving in modes 3,4, and 9. The time required for steering the wheels would accommodate many kinds of program control, such as making small offsets from a desired path, using time of application as the control of steering. The first four modes allow for travel into very restricted places. For modes 3 and 4, the steering mechanism positions the wheels so that the effective width of the robot on the floor is smaller. This reduces the stability, and programming would need to consider this in positioning and loading the arms. The restriction of turns to a 21-inch radius in conjunction with a maximum velocity of one foot per second would result in a centripetal acceleration of the center of mass of the robot of 0.57 feet per second. This would result in an outward sliding force at the wheels of about 5.33 pounds, which is quite tolerable. If the center of the mass were 50 inches above the floor, the tipping moment would be such that it would take an additional force of about 47 pounds applied at the 50-inch level to start upsetting the

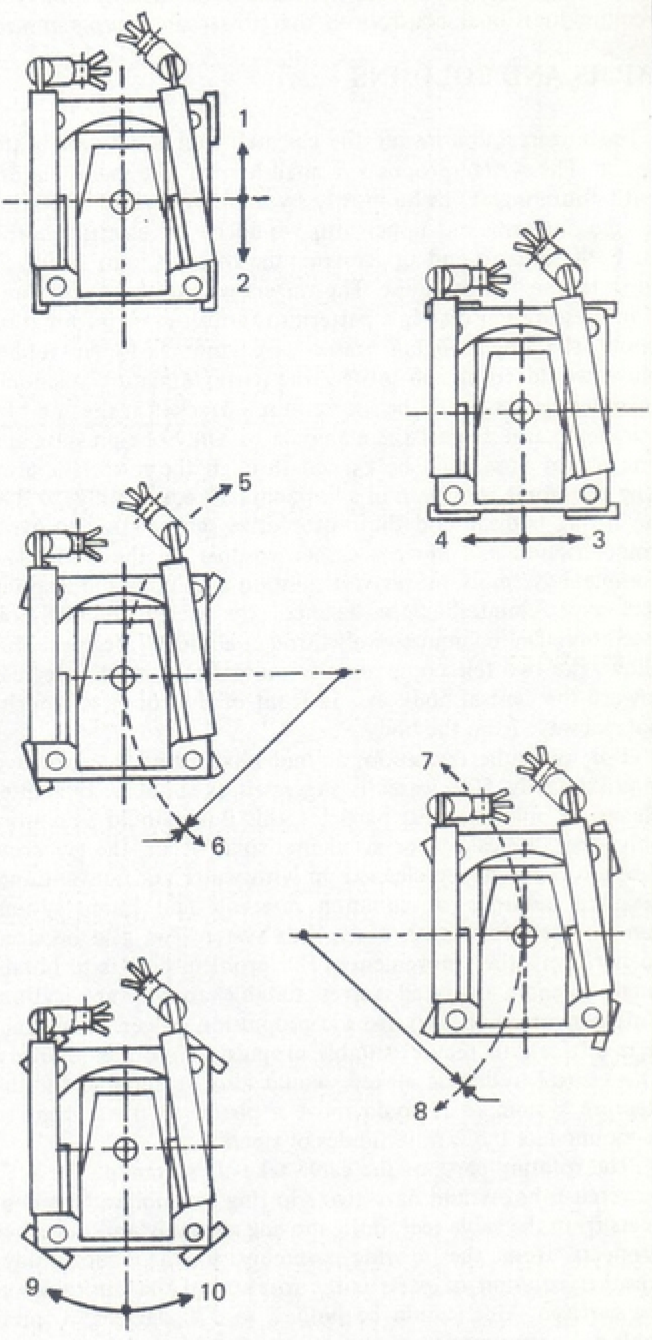


Figure 2. Modes of motion have definite steering positions.

robot, provided arms and their loads are symmetrically located to the the robot body. The physical limitations on speed and radius of turn protect against this kind of upset due to machine or program errors.

The steering pivot is offset from the center of the tire width by 1¾ inches. When any change in steering mode is programmed while the robot is not in motion, weak forces can be applied to the propulsion motors in suitable direction for each wheel to cause the wheel to rotate as the steering power moves the contact point with the floor in a 1¾ inch radius circle. This arrangement reduces scuffing of rugs or marking of hard floors. The wheel motors, whether hydraulic or electrically-powered, require individual controls so that this can be programmed.

ARMS AND COLUMNS

The fingers and arms are the essential functional part of the robot. The writer proposes a small human-like manipulator[1] with four fingers, to be mostly hydraulic-operated. Rotation in the forearm and upper arm would be by electric motor. In both forearm and upper arm, the rotating joint would be next to the elbow joint. The fingers would have paint[2] and film pressure sensors[3] in a pattern to furnish some information about the object being grasped. A gum elastomer rubber glove would cover and protect the parts. Miniature solenoid-operated valves would be located on a bracket at the end of a telescopic arm nearest the manipulator. Only one pressure and one return hose need be carried through the telescopic arm. The telescopic motion is in a horizontal direction only, so that no lifting is done and the motor drive can be sized to overcome friction and move a carpet sweeper on the floor. The complete assembly moves vertically on a column and a spring reel type counterbalance balances the weight of the arm assembly. The column swivels through about 97 degrees. This allows the two telescopic arms to move from about 7 degrees toward the central body axis in front of the robot to straight out sideways from the body.

For hydraulic operation, a fluid mixture of glycerine and approximately 50% water is suggested as suitable. If a filter cleans out metallic wear particles, this fluid should be reasonably clear. If leakage or accidental spills occur, the glycerine mixture is able to be cleaned up with water and conventional cleaning methods. A common reservoir and pump system can be used for both arms. This system can also be sized to perform other movements. The problem here is to obtain small solenoid-operated valves suitable to this application. This system could also provide propulsion power. Here again it is difficult to secure suitable propulsion hydraulic motors. The central hydraulic system would also be suitable for the steering system as it could move a piston to fixed stops to accommodate the various modes of steering.

The rotating parts of the cable take-up system on the A.C. powered robot would have two slip ring assemblies. One connects from the cable reel to the moving assembly and the other connects from the moving assembly to the robot body. Another rotation of parts is the rotation of the turntable on the carriage. This should be limited to 370 degrees; a spiral cable can accommodate that motion.

Similar limitation can be placed upon the rotation of the upper arm and forearm rotations. Cable retraction to accommodate the column vertical motion and telescopic arm motion can be accommodated inside the body (see Figure 9). The cable would contain two small hydraulic plastic tubes and electrical wires required from small motors, solenoid valves and sensors. The cable for each arm would be taken up in the narrow space alongside the main electronics package.

THE ROBOT EYE

This is a general purpose light-activated sensor and associated computer system. Much research is in progress on the general problem of recognition and control. The input to the information processing and decision process is usually a digitized output from a television-like rectangular scan. Apparently a large capacity memory and a very fast computer is needed by this method. Since the home robot will operate in a known environment and does not require capability to operate to close limits, a less complex input would enable a very useful robot to operate. Linear arrays of 32 or 64 elements are available. These could be used with an electromechanical shift from a vertical to horizontal position. Another method would be to build a special array arranged to detect clear openings, corners or linear features. Such an array might consist of sixteen photodiodes, as shown in Figure 3. These diodes are in TO-18 cases and present a plastic lens to concentrate the light from the camera lens upon a one-millimeter- square sensitive area. A hole in the mounting plate of 0.104 inches diameter over the diode is the effective size of the element. The small number of elements would facilitate standardization of outputs and would permit a high rate of computer processing needed for real time control. Working distance of 20 inches to 60 inches could be obtained by two lenses and a solenoid-operated mirror. Resolution would range from four-tenths inches at 20 inches distance in the center of the array to about 8 inches at 60 inches distance at side of scene.

Color separation filters should be available by electromechanical means to enable sorting of clothes by color and to increase contrast when necessary. The robot could also identify the room it is in by wall color or other unique visual features.

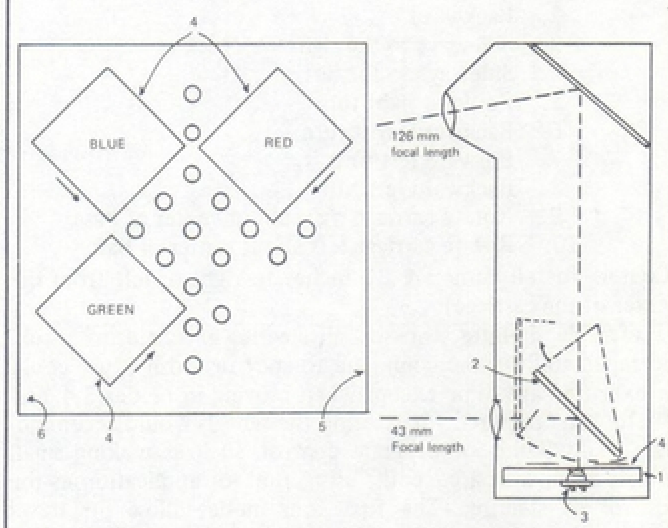


Figure 3. Robot eye.

1. Array mounting plate
2. Swinging mirror
3. Typical photo-diode
4. Color separation filters for 9 central photo diodes
   Two filters may be adequate
   minus blue and minus red
   (Wratten No.12 and 43)
5. Top of scene
6. Bottom of scene

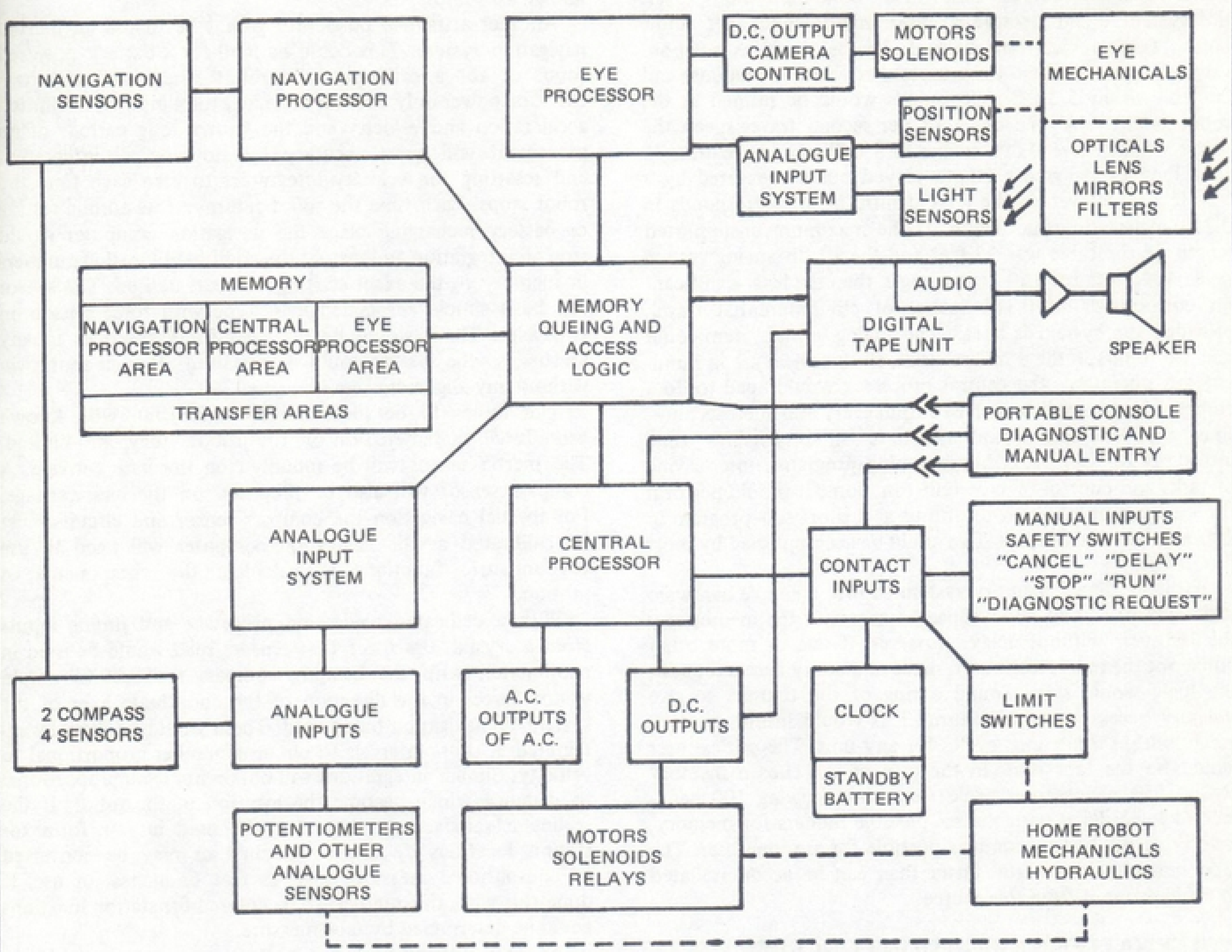


Figure 4. Computer control

Figure 4 is a block diagram showing the computer control of either the overhead cable-powered model or the battery-powered model having an inertial navigation system. A large working memory is shown which may be accessed by various peripheral units. These are analog input unit, eye processor, navigation processor (if inertial), tape unit and portable manual-input diagnostic unit. Since the analog unit will furnish 12 bits, the central processor should be of 12 bit capability or more, but a 16 bit microprocessor would be desirable for reasons of large direct addressing capability and availability of extra bits for setting flag bits along with data. The eye processor could be an 8 bit microprocessor. The navigation processor, if included, should be a 16 bit or longer word length microprocessor.

The analog input system, the eye and navigation processors should have available restricted address areas of memory which are common with part of the central processor and are used for transfer of information either to or from the central processor. The tape unit should have access to the entire memory and have a provision for 'read from' as well as 'write into' the memory. Typically, it would only write into memory whenever a new sub-program is called up. The read from memory (and write a tape) mode of operation would be used for diagnostic and program development. Each processor would also have a large area of memory for its sole operating use (except for tape unit access). Although it is not possible to forecast program requirements, a tentative choice of memory would be 8 K 16 bit words of core memory. The chosen memory had 650 nanosecond cycle time with 300 nanosecond access time and has facility to retain data when power is lost. A similar size semiconductor memory with suitable battery to retain memory would be acceptable and somewhat faster. There should be a separate digital clock circuit with a dedicated battery. Access to its reading would be via the contact input system. This true time clock in conjunction with the retention of data by the memory would permit programs which would effect recovery from power outages or other interruptions to the normal running programs.

The 12 bit analog-to-digital convertor of the analog input system requires 200 microseconds to digitize. Allowing for setting time and address times in the solid state multiplexer, the system could operate at 400 microseconds per input point. Typical electromechanical devices, such as solenoid valves, relays and small drive motors are slow in response and control within 5 to 8 milliseconds would be refined as the robot justifies. At the one foot per second travel speed the robot would move 0.096 inches in 8 milliseconds. With a 75 foot long cable, whose length played out is measured by a 12 bit A/D converter, the least significant bit corresponds to 0.219 inches of cable length. If the maximum unsupported length of the cable was 35 feet and the 12 bit analog system reads 4096 bits for 180 degree angle, then the least significant bit corresponds to 0.161 inches of circumferential travel, provided the system is linear. The analog input system could read 20 inputs in the 8 milliseconds. If 20 devices are in simultaneous operation, the central processor would need to do a compare and possible branch to output every 400 microseconds. since the processor would also have other programs, time interrupts for call back, housekeeping programs, interleaving of tasks and control of tape unit functions, it should perform the compare and branch to output as a short sub-program in 200 microseconds or less. This could be accomplished by most processors.

With the shared memory system shown, a simple hardware logic system should allow repeated access to the memory by the last user without delay. However, if one or more other units, not the most recent user, made a memory access request, the logic would step around a ring of the 6 users to give memory access to each in turn. This would insure memory access within 6 memory cycles for any unit. The critical user would be the tape unit. In the case of the chosen memory having 650 nanosecond cycle time and allowing 100 nanosecond logic delay with the six possible bidders for memory, a delay of 4.5 microseconds is possible for any one user. The tape unit should not run faster than can be accommodated to avoid dropout from this source.

ALTERNATIVE NAVIGATION CONCEPTS

The compass system consists of a compass affixed to the base carriage unit. This indicates direction of travel. A second compass is affixed to the cable takeup arm. This indicates the direction of the cable. Its readout would need to be interpreted by reference to what room of the house the robot is in. The hardware of each compass could be two Hall generators positioned at 90 degrees to each other. Another type of hardware would be a conventional floated magnetic compass whose card is a gray scale with no discontinuities. This would vary from white to black in 180 degrees and return to white in the next 180 degrees. Optical readouts would be stationed 90 degrees apart and their amplified outputs would be connected to two inputs of the analog input system. For either type hardware, the program being run would select the preferred sensor whose output is neither going through zero or through maximum at the angle of decision.

It would not be necessary to exactly calibrate or have a linear output to angle rate on the compasses. Stability and repeatibility are the desired attributes. They would be used mainly in reference to the particular house floor plan. Once all the needed robot stations have been placed in memory, the robot memory need only keep available the room number (or area number in case of L-shaped rooms) to be able to restart its navigation anyplace in the working area without human assistance.

Another attractive possibility would be to use an inertial navigation system. This could be used for a battery-powered robot or for a cable-powered robot where the cable was used for power only and not as a navigation input. The limited acceleration and velocity and the known long periods of no movement will assist accuracy by stopping all integration and resetting the velocity integrators to zero each time the robot stops. Each time the robot returns to its normal resting or battery recharging place the navigation computer would stop all integration and restore the computed location numbers in memory to the exact starting numbers desired. The sensor can be a simple suspended mass type with force sensors in two axes. There would be no need for gyroscopes in any sensors, so the system could be restarted after an shutdown without any alignment requirements.

The forces to be measured are small but, with known propulsion characteristics of the robot, they are limited. The inertia sensor will be mounted on the base carriage. A compass sensor will also be mounted on the base carriage. For inertial navigation the compass sensor and circuits must be calibrated as the navigation computer will need to use trigonometric functions to calculate the components of motion.

With a dedicated navigation processor and timing inputs from a crystal, the force that sensors read would be used in conjunction with the heading compass readouts to obtain vector forces in the direction of the coordinate axes of the system of navigation being used. These would be digitally integrated at short intervals to obtain a number proportional to velocity. Similar integrations will obtain numbers proportional to distance which become the location of the robot. If the scaling is satisfactory, these may be used in raw form for station locations by the programmer or may be converted to conventional measure, such as feet or inches for use. If done this way, the numbers to be entered for station locations could be determined by tape measure.

Another possibility for a navigation system suitable especially for a battery-powered home robot is to use a rotating beacon and receiver sensor on top center of the robot body. This is the space provided for the cable take-up system in the AC powered concepts. The system might use ultrasonics or sound waves or light. It might employ targets placed on the walls in some useful pattern with the least noticeable intrusion to the room appearance. With a height limit of 78 inches the beam could be parallel with the floor in a range of 72 to 78 inches. This would avoid interruptions except by persons standing more than six feet tall.

To get usable data for the central processor, the navigation processor for the case of three targets in each room could measure the angle between targets and the compass north reference. With a constant rotational speed of the beacon, these angles could be read out by gating a suitable frequency oscillator into a counter. Depending upon the travel path being used, the angle which is changing most rapidly would be used as the address at which stopping or some steering function is initiated.

If ultrasonic pulses are used with only the walls of the room as targets, counting up to arrival of the reflection would measure the distance to the wall. The minimum distance would be perpendicular to the wall. By selection the wall perpendicular which is changing most rapidly, the raw distance data could be used as the arrival address to stop or initiate some other function. Such an ultrasonic system would be more accurate if the beacon is not rotating but is maintained generally perpendicular to the wall of interest. This could be done by a digital program which maintained a minimum count by testing small plus and minus increments of rotation of the beacon to hold minimum value. This would maintain the beacon perpendicular to the wall whose distance is being used for the navigation. The particular wall would be selected and changed according to need by the main navigation program.

PROGRAMMING

The proposed robot could be controlled by various program concepts, and development could proceed by various routes. The following is offered as a possible simple approach to getting started.

Based upon the house floor plan and locations of semi-fixed furniture, such as tables, beds, divans and fixed bath and kitchen equipment, a selection of robot operating stations would be chosen. The robot parking place when not in use and its cable attachment to the cable protective unit are also chosen. If the robot is battery-operated, this should be the location of the charging station.

A list would then be prepared of all needed travel sub-routines. These navigation programs would operate by sensing the cable length paid out and compass angles. The robot should arrive at a station with only a few inches error (about three inches). For a battery-operated robot, inertial navigation with suitable programs, as discussed under navigation, might bring the robot on the desired station with even smaller error. At the conclusion of the trip the eye sensor would look at the known scene on the fixed furniture (for example, a corner of a table) and correct its position by eye sensor.

The robot then would go to the task at hand program, and other sensors would be used as needed. It would be necessary for the robot figures to have sense of touch sensors as some things would be located by touch, and these would also be needed to avoid damage to fragile objects.

Many of the tasks would require the developmentof standard programs, which could be used in any home, for example, making a bed or place-setting a table. Where possible, the general sensors on the robot should be used in these task programs with minimal variation from the present human situation and methods. Specialized assistance can be provided where needed. For example, a right, head end, corner marker might be put on sheets and other bedclothing. The marker might be visual for the eye sensor to detect or could be magnetic for use with a magnetic detector. Another example would be to provide a reader for the point of sale Universal Product Code on grocery packaged goods to aid in storing and verification before use of frozen foods and other supplies.

For floor cleaning, the robot could travel to stations located in such a manner that outward sweeps of the cleaning tool from one location would clean the space covered by the robot at another location. A specialized cleaning tool having a proximity sensor on a very pliable nozzle and/or brush could sweep outward until stopping by limit stops on telescopic arm or by proximity sensor. The arm would then be retracted. The robot body could then swivel a program controlled angle from ten to about twenty-five degrees and sweep again so that the sweeps overlap. It would be most convenient to power the vacuum cleaner from the receptacle on a cable-powered robot. This floor cleaning concept can facilitate cleaning under tables and beds with suitable cleaning tools.

Programs for meal preparation are probably the area of programming of greatest variety and which are most essential to the success of the home robot. Homemaker activity studies have shown daily elapsed time spent cooking from 3 ½ hours down to about 45 minutes. Actual working time probably averages 1-½ hours, but the process of going back to the task from time to time is the measure of inconvenience to the homemaker. Programs could be as simple as that to remove a "TV" dinner from the freezer and put it into a microwave oven. More elaborate programs could provide for nearly any menu by calling up the individual item programs from bulk memory. The starting time of these programs would then be calculated so that all dishes on the menu are ready to serve at the desired meal time. These programs would then be merged; if any time conflicts exist, they would be resolved by minor adjustments in starting time or temperatures used. The resulting running program would be specific for the menu and number of place-settings of the day.

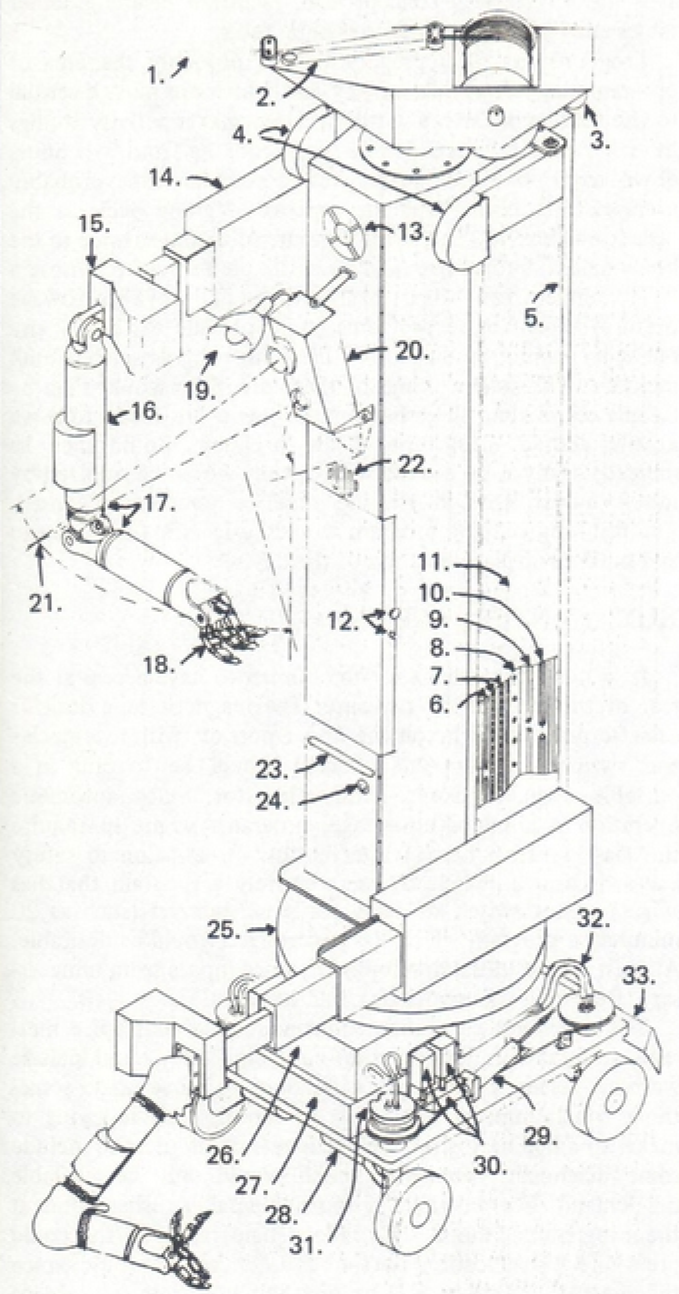
HUMAN INTERFACE

It is most convenient for the human to have access at the rear of the electronics enclosure. The magnetic tape deck or cassette units could be on the upper portion with receptacles and switches below. One concept would be to plug in a portable console, like a hand calculator. Since automatic operation is a major advantage, programs ought to require the least possible human intervention. In addition to safety bar switches, a switch to omit entirely a program that has started and a switch to delay for some interval (such as 20 minutes) a program which has just started would be desirable. At least in the initial development, voice inputs seem unnecessary. Recorded voice outputs could be useful.

The tape unit capability could include several voice messages selectable under computer control. These would include warnings issued when a robot is about to move or do something which humans may wish to cancel, such as trying to make up a bed having human occupants. It should also include some diagnostic comments which would only be available on demand. For example, if the homemaker rushes home at the programmed hour and finds a bare table, he/she could press the "Diagnostic" button and the robot would voice the message, "Dinner will be one-half hour late because of power outage."

CONCEPT SUMMATION

The home robot becomes a group of several active systems acting cooperatively. Looking toward a practical, useful working robot, it becomes evident that many systems and programs are necessary to obtain the "quantum leap" in benefits of a robot in the home. Simplification is desirable, but the robot is necessarily a complex machine. It would be well to avoid any "science fiction" aspects. Although speech inputs to the robot are a technical possibility, the chance for human errors increases risks with no large benefit. A remotely controlled automaton or tele-operator would not be a great benefit, as the principal advantage of a robot in the home is that it should not require human attention. Referring to Figure 4, at least three microprocessors can be used, and 'read only'



1. Power Cable
2. Level Wind Mechanism
3. Torque Motor and Brake
4. Spring Counterbalance for Arms
5. Column Assembly
6. Counterbalance Cable
7. Chain Drive for Vertical Motion of Telescopic Arm
8. Hardened Steel Track
9. Electrical and Hydraulic Cable to Arm
10. Square Drive Shaft for Telescopic Motion
11. Protective Shutter Curtain
12. Attachment Point for Trays
13. Ventilation Fan
14. Telescopic Arm
15. Solenoid Valve Package
16. Upper Arm
17. Rotary Motion Joints
18. Fingers
19. Lamp
20. Eye Assembly
21. Crossover Point For Lenses
22. Speaker
23. Emergency Stop Bar Switch
24. Power Outlet
25. Turntable
26. Solenoid Valve Package
27. Hydraulic Reservoir
28. Hydraulic Motor
29. Steering Cylinder
30. Streer Select Solenoids
31. Steer Position Lock System
32. Hoses to Propulsion Motor
33. Proximity Sensor as Required

Figure 5. A.C. powered home robot.

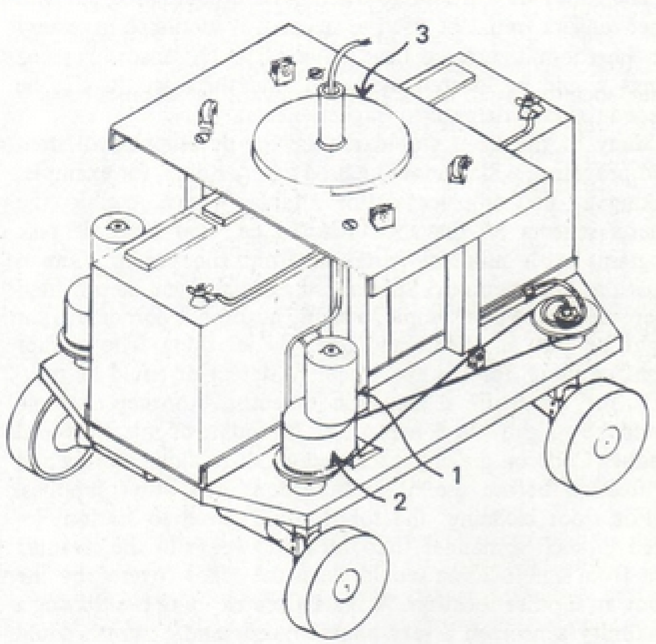


Figure 6. Carriage for D.C. powered robot.
1. Steering Motor
2. Mechanical Stops and Switch Unit
3. Bull Gear

memory may be used to good advantage for some of the memory block shown. For example, two buffer registers might be used, one in each direction at each interface, to provide isolation between the I/O busses of the eye, navigation and central microprocessors. This could serve to limit the effects of a failure and, by temporarily holding information, would result in less time delays in the processor programs. It would be desirable to have some isolation of the various systems to aid recovery after some failures. The desired goal is to be fail-safe but also to have programs to effect recovery in the largest possible categories of failure.

A complete robot of the AC-powered type is shown in Figure 5. The carriage covers are removed to show the hydraulic steering concept. A separate steering unit is provided for the wheels on each side of the robot. The carriage unit for the DC-powered type robot is shown in Figure 6. The turntable, which rotates with the electronics enclosure, is approximately three inches higher than its position in the AC version. Because of the higher speed of small DC motors, they are lighter than AC motors. That fact plus the need from some DC power supplies and the cable reel on the AC version results in about equal weights of the two versions despite the battery weight. The beacon for the navigation sensing on the DC-powered robot can project a shorter distance above the electronics enclosure than the power cable reel assembly, so that the overall height of the DC version will be the same as the AC version.

The writer has worked on this general concept to build an operational model and has sufficient construction finished to be a mock-up of the robot, as shown in Figure 7.

The writer has been limited to design and building a home robot of the general concept presented here. Other concepts and designs need investigation. As a criterion of success, completeness of approach appears most important to a good demonstration. Hardware and software methods of handling failures are very important, as the home robot's most valued contribution to life will be performed when no human backup is available. Mechanically, a light-weight design of moving parts, especially any long arms, is most essential. Necessary heavy components, such as batteries, transformers, hydraulic reservoirs, and large motors should be located low and centrally to help stability of robot.

CONCLUSION

A home robot is now practical with the use of available technology. There is a large potential field of use for the robot. The design, production, and programming of home robots could become a sizeable industry of importance to the computer society. Much mechanical hardware development needs to be done to get started.

Present microcomputer hardware development, as regards to microprocessors and analog input systems, is adequate. This article has outlined a basic concept, which has sub-assemblies that could be individual developments. All sub-assemblies are listed in detail in the Appendix. Tentative interface definition would make practical the consideration of alternate designs of the sub-assemblies. Since the microsystems group brings together the various subsystems for real time acquisition of data and control, they would be the logical choice as lead group on this project.

A cooperative effort by individuals or institutions could accomplish the mechanical developments adequate to get started. The home robot should prove to be a very broad field for additional developments and improvements of interest to mechanical and computer engineers.

As a new field, program developers can develop from the very beginning program basic concepts and strategy, which borrow from the present mature business and scientific programming knowledge without needing to conform to prior art.

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Appendix: Development, Sub-Assemblies and Interfaces

The home robot may be readily divided into several logical sub-assemblies, within which considerable independence of design and latitude for innovation would be possible. These sub-assemblies are:

1. Wheeled Carriage
   - Propulsion, brakes, steering systems
   - Batteries, if battery-powered
   - Heavy power supplies
   - Hydraulic power units
   - Bull gear and central hollow shaft
   - Bearings for turntable
2. Turntable Base and Electronics Enclosure
   - Turntable assembly
   - Motor and drive and pinion for turntable rotation
   - Means for turning columns and position sensors
     - Motors and gear trains
     - Hydraulic cylinders and system
3. Right and Left Columns and Arms and Manipulators

   These need not be mirror-image designs. It may be determined that some differences will be advantageous. Since the effective output of the entire home robot occurs at the fingers, their capability and dexterity as enhanced by the fore and upper arms should be given priority over other sub-assemblies. These sub-assemblies contain:
   - Vertical column, consisting of:
     - Upper pivot journal pin
     - Column enclosure and structure
     - Column track and rollers
     - Retraction pulleys and system to manage electric/hydraulic cable from electronic enclosure to upper arm
     - Spring counterbalance to reduce load on raise/lower arm assembly system
     - Gear motor and roller chain or other system to raise and lower arm assembly
     - Gear motor and power train or other system to operate telescopic motion of arm
     - Application of position sensors to vertical and telescopic motions
     - Protective metal curtain and parts to allow vertical motion
     - Lower pivot journal pin
   - Telescopic arm
     - Power train and cables to extend and retract arm

Provision for cable to upper arm and hydraulics
Safety covers
Provision for attachment of upper arm
Provision for attachment of hydraulic package

Manipulator consisting of:
Hydraulic package of solenoid valves
Upper arm
Forearm—wrist finger assembly
Position sensors
Finger touch sensors
Enclosures—elastomer dust protectors and gloves

4. Power Cable Reel Assembly for AC Power Version
   - Torque motor and gear train with brake
   - Level wind mechanism and provision to sense length paid out
   - Two slip ring assemblies
   - Provision for mounting compass (directional sensor)
   - Enclosures
5. Battery Tray and Ventilation Facilities for Battery-powered Version
6. Personnel Protective Unit for A.C.-Powered Version
   - This is not on robot and is mounted at starting location of cable. It connects between cable and building electrical system.
7. Charging Station for Battery-operated Version
   - Two isolated 12-volt battery chargers
   - Protective equipment
   - Connectors and cable suitable for the robot to plug itself into charging station
8. Electronics and Controls
   - This group would coordinate the entire development and would design or select all electrical circuits in cooperation with programming considerations and mechanical possibilities.
   - Electronics
     - Central processor
     - Eye processor
     - Navigation processor
     - Tape unit or units
     - Input and output systems
     - Sensors
       - Eye unit
       - Navigation (as required)
         - Compass direction sensors
         - Inertial sensor
         - Zero speed sensor
         - Beacon sensor
         - Proximity units
         - Pressure and displacement sensors
     - Diagnostic and manual entry systems

The End

Continued from pg. 18

```
514        FOR J=1 TO LEN(X$)
516          W$=SST(X$,J,1)
518          CHANGE W$ TO W
520          IF W(1)<128 THEN 524
522          W$=Q$(W(1)-128+1)
524          IF J>1 THEN 530
526          S$=W$
528          GO TO 532
530          S$=S$&W$
532        NEXT J
534        GOSUB 900
536        PRINT #2, S$
538        GO TO 510
540        REM
542        PRINT "DECOMPRESSION COMPLETED; OUTPUT IS ON FILE ";F2$;"."
544        STOP
600 REM    ** LINE DECOMPOSITION ROUTINE **
602 REM    .. DECOMPOSES S$ INTO STRINGS Q$(1)..Q$(Q) ..
604 REM    A STRING IS DEFINED AS A CONTIGUOUS GROUP OF ALPHANUMERIC AND/OR
606 REM    PERIOD CHARACTERS, INCLUDING ANY APPROPRIATE SINGLE TRAILING
608 REM    DELIMITER. A CONTIGUOUS GROUP OF TWO OR MORE IDENTICAL DELIMITERS
610 REM    IS ALSO REGARDED AS A STRING. IN THIS SUBROUTINE, THE ENTRY STRING S$
612 REM    IS PROGRESSIVELY ERODED AS EXECUTION PROCEEDS.
614 REM
616 Q=0
618 L1=LEN(S$)
620 FOR L2=1 TO L1
622   W$=SST(S$,L2,1)
624   IF W$="."       THEN 640
626   IF W$<"0"       THEN 648
628   IF W$<="9"      THEN 640
630   IF W$<"A"       THEN 648
632   IF W$>="("      THEN 648
634   IF W$<="Z"      THEN 640
636   IF W$> "*"      THEN 640
638   GO TO 648
640 NEXT L2
642 S$=S$&" "
644 L1=L1+1
646 L2=L1
648 X$=SST(S$,1,L2)
650 IF Q<1 THEN 660
652 W$=SST(Q$(Q),1,1)
654 IF X$<>W$ THEN 660
656 Q$(Q)=Q$(Q)&X$
658 GO TO 664
660 Q=Q+1
662 Q$(Q)=X$
664 IF L1-L2<1 THEN 670
666 S$=SST(S$,L2+1,L1-L2)
668 GO TO 618
670 RETURN
672 REM
674 REM
700 REM    ** STRING INSERT ROUTINE **
702 REM    INSERTS STRING S$ INTO THE STRING TABLE OR AMENDS COUNT OF ITS
704 REM    OCCURRENCES TO DATE.
706 IF T1<1 THEN 718
708 FOR T3=1 TO T1
710   IF S$<>T$(T3) THEN 716
712   T(T3)=T(T3)+1
714   GO TO 724
716 NEXT T3
718 T1=T1+1
720 T$(T1)=S$
722 T(T1)=1
724 RETURN
726 REM
728 REM
800 REM    ** STRING TABLE SORT ROUTINE **
802 REM    STRING TABLE IS SORTED ACCORDING TO THE CURRENT SAVINGS-POTENTIAL
804 REM    FUNCTION FOR EACH ELEMENT THERE-IN.
806 REM
808 IF T1<2 THEN 838
810 T2=T1
812 F2=0
814 T2=T2-1
816 FOR T3=1 TO T2
818   IF FNS(T3) > FNS(T3+1) THEN 834
820   T4=T(T3)
822   W$=T$(T3)
824   T(T3)=T(T3+1)
826   T$(T3)=T$(T3+1)
828   T(T3+1)=T4
830   T$(T3+1)=W$
832   F2=1
834 NEXT T3
836 IF F2 > .5 THEN 812
838 RETURN
840 REM
842 REM
900 REM    ** TRAILING BLANK SUPPRESSION ROUTINE **
902 REM    .. PROGRESSIVELY DELETES ANY DETECTED TRAILING BLANKS FROM S$
904 REM    (ENSURING THAT ZERO LENGTH LINE IS NOT PRODUCED) ..
906 W$=SST(S$,LEN(S$),1)
908 IF W$<>" " THEN 916
910 IF LEN(S$)<2 THEN 916
912 S$=SST(S$,1,LEN(S$)-1)
914 GO TO 906
916 RETURN
918 END
```