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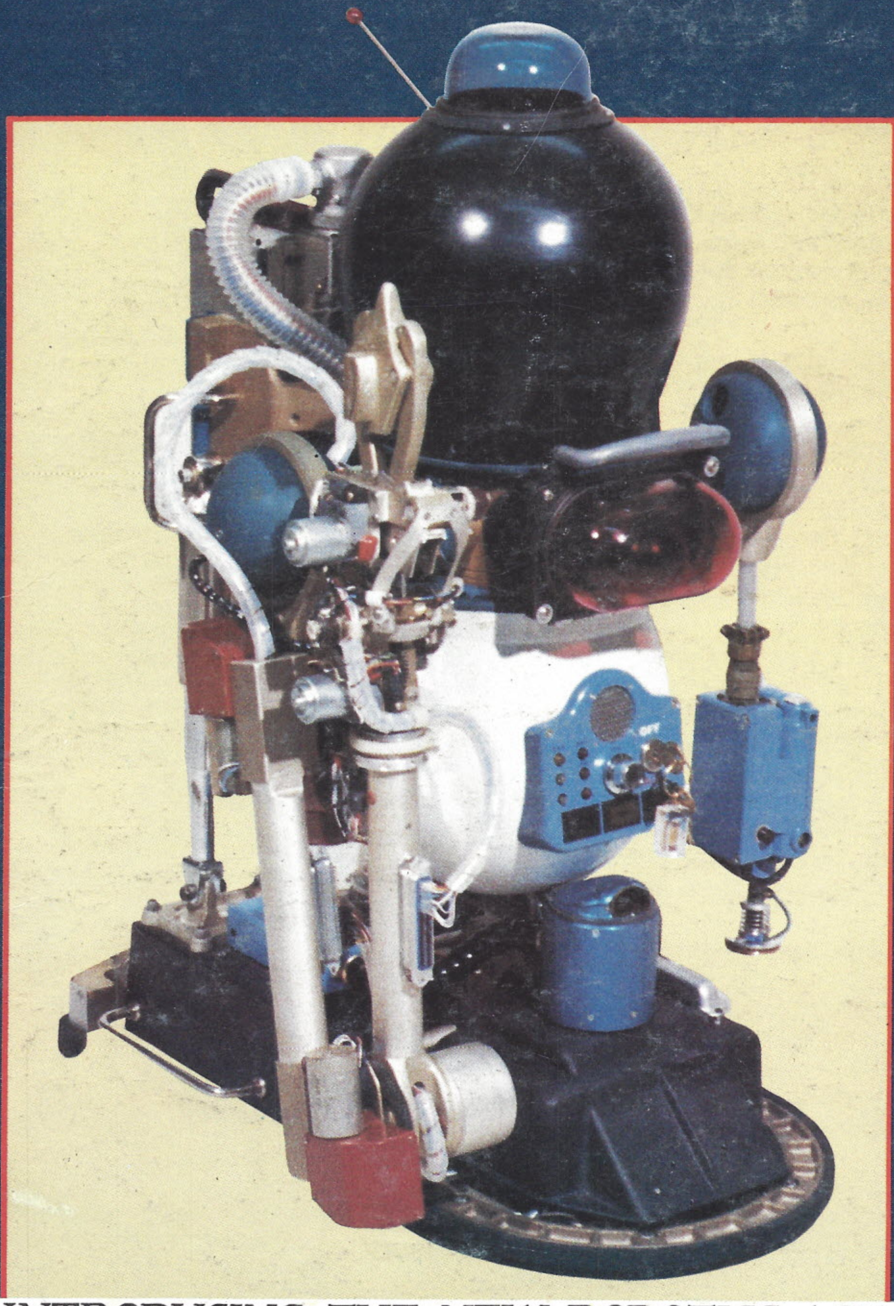
ROBOTICS AGE™



INTRODUCING THE NEW ROBOTICS AGE

AVATAR: A HOMEBUILT ROBOT

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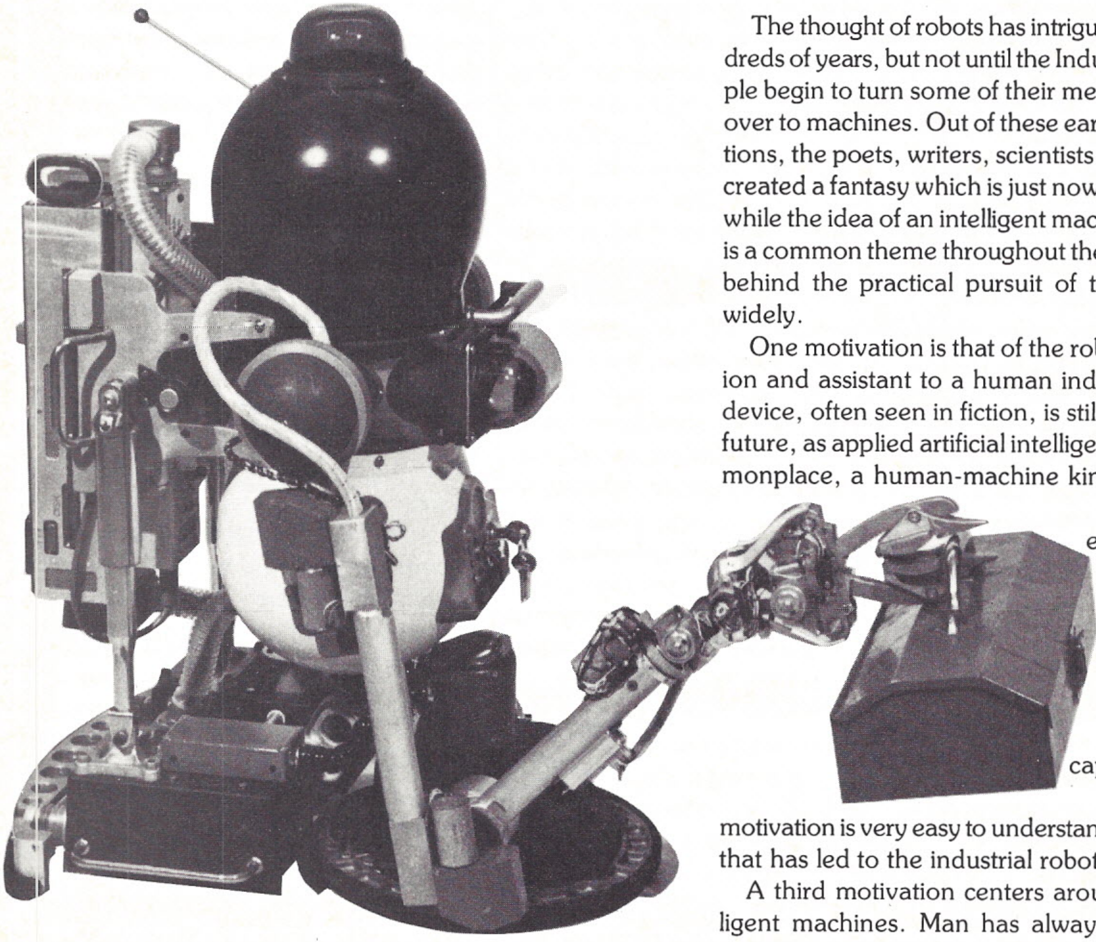
Last year, *Robotics Age* ran a "Homebuilt Robot Photo Contest" with the goal of drawing out photos — and articles — about the experimental robot systems many of our readers are building. Of the entries received by the October 1, 1981 deadline, Avatar by Charles Balmer Jr. was the clear winner by virtue of system concept, descriptive material in the form of this article, and excellent photographs, one of which, taken in color, provides the cover illustration for this issue. The cover photograph and all photos accompanying this article were taken by the author.

Photo 1. Carrying out the fantasy of the helpful personal companion, Avatar is shown delivering a tool box to his master.



Perspectives on Robots

The thought of robots has intrigued man for probably hundreds of years, but not until the Industrial Revolution did people begin to turn some of their mental and physical abilities over to machines. Out of these earliest mechanical contraptions, the poets, writers, scientists, and other men of vision created a fantasy which is just now becoming a reality. And while the idea of an intelligent machine companion or robot is a common theme throughout the fantasy, the motivations behind the practical pursuit of the robotics dream vary widely.

One motivation is that of the robot who is both companion and assistant to a human individual. The companion device, often seen in fiction, is still mostly a fantasy. In the future, as applied artificial intelligence becomes more commonplace, a human-machine kinship similar to that of a captain and his ship, or even of a human and his dog may develop.

A second motivation is the practical desire for a worker robot, one who will amplify our production capability with a minimum of human effort. This motivation is very easy to understand and it is the driving force that has led to the industrial robots existing today.

A third motivation centers around the building of intelligent machines. Man has always desired to understand his own intelligence, and that understanding would imply the ability to duplicate, change, and expand. Although the intelligence of today's machines is very low, some experimental machines in the artificial intelligence laboratories are beginning to show glimmers of intelligence that may blossom, guiding us to the next plateau in our understanding of both man and machine.

Many roboticists like myself tend to work in relative isolation, occasionally going public partly because of pride in our accomplishments. This urge is also due to a desire to share some of what we have learned, to learn what others are willing to share, and maybe even to inspire greater accomplishments. While our interest in robots separates us as a group, it is that same common interest which binds us together in the pursuit of a dream. Our job as experimenters or researchers is to take the robot fantasy and turn it into a robot reality.

Setting Some Goals

The robot designer and builder have some pretty tough decisions to make throughout the project, but the hardest ones must be faced at the start. What's it going to look like? How big is it going to be? How is it going to be powered? What computer is it going to use? *And*, the most difficult question, what is it going to do? It's interesting to note that whenever you mention to someone that you're building a robot, they inevitably ask the most difficult question first. Don't be afraid to say "I don't know yet."

While many of the detailed questions are going to depend on the individual project, here are several suggestions that will help guide the initial planning.

General Purpose Modular Designs Are Attractive

Very few homebuilt robots are going to be designed to perform only one task. At some point in the future you will want to add or change something. This means that flexibility and modularity should be prime considerations in your design. In short, the design should have a general-purpose flavor.

Think of your robot as a testbed or a laboratory in which you are going to conduct both practical and entertaining experiments. You may want to try different navigation programs or add a new type of sensor to make its hand sensitive to touch. These and other additions can be accommodated if the robot laboratory environment is preserved.

Another general guideline is to design a fully integrated robot system. Since the robot is going to be computer controlled, the real flexibility is in the software, so provisions must be made for programming the robot directly or loading the program into the robot after it has been generated on another machine. Both approaches have advantages and disadvantages, but the important thing to remember is that you are building a *system*. This means designing well-defined and segmented modules and, most important, well defined and easy-to-use mechanical and electrical interfaces between modules. The basic components of an integrated system are a computer, a mass storage device for program storage, a terminal or console, and a printer for hardcopy generation. Provisions should also be made so that your programs can be run and debugged in the robot's computer system. With all of these things "designed-in" from the start your robot lab will be usable as soon as you can turn on the computer.

Cautions

There are two cautions I would like to mention. First, don't attempt a design that is too ambitious — if your robot lab is designed properly, you will be able to expand its capabilities as time goes on. Remember there are a number of limitations you must contend with throughout the project. The most damaging are the lack of money, time, technology, and your own abilities. Any one of these deficiencies can doom a project before it is started.

The second caution may not seem major, but what you decide will greatly influence what you can expect from the project. If you choose the robot lab approach, you will be all set to experiment with many different areas of robotics. The

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other approach is to build a system which does some very limited or practical task. In this case you will probably dedicate your robot with no intention of modifying what it does. Take a hard look at what you want to accomplish and choose the approach that fits your needs.

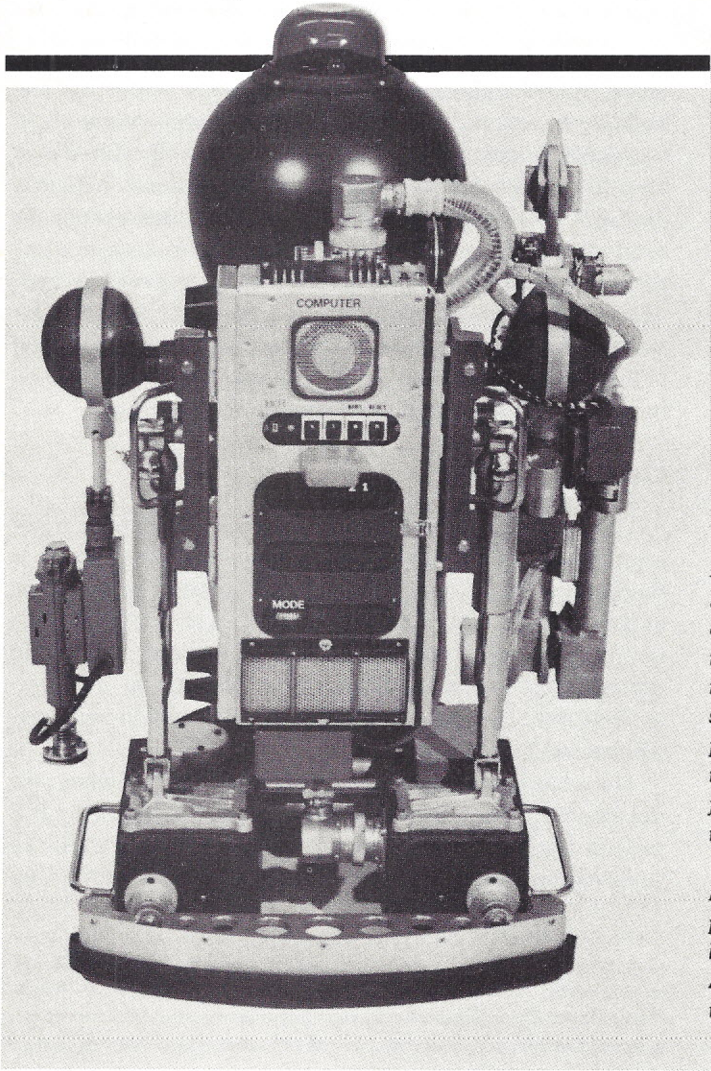
The final comment concerns the actual construction, and is strictly a personal observation. A robot is a three dimensional, functional, but imaginative sculpture. One of the great pleasures in designing and building a robot is to let your imagination run wild (not amuck). You quickly learn to balance practicality and form to produce something that not only does the job but also satisfies the craftsman's sense of perfection and the artist's sense of shape. The form need not be humanoid although people will treat it with more understanding if they can identify some human structural or functional qualities.

The robot's shape will be greatly influenced by the task, sensor capability, center of gravity, terrain, environment, etc. Some people find the exposed electronics and mechanics intriguing, while others prefer everything to be enclosed. In any case, the appearance of the robot is going to affect everyone differently, but the quality of the workmanship should always leave a good impression. Remember, your robot is you.

The Naming of a Robot: *Avatar*

A robot is somewhat like a child. It requires a great deal of patience, time and energy to construct, and then as it limps and crashes and smokes its way to adulthood, we as mothers and fathers learn something about being a robot while hopefully our robot learns a little bit about being a human. It seems only natural then that it should have a name, if for no other reason than to have something to yell during a fit of frustration or anger. I chose Avatar, the name of a mythical character in the movie *Wizards*, over several other equally "meaningful" names simply because it was phonetically richer. This is important because the robot has a voice input command system which I will discuss later in more detail.

Before elaborating on the specific capabilities of Avatar it should be noted that some are not yet fully designed or im-



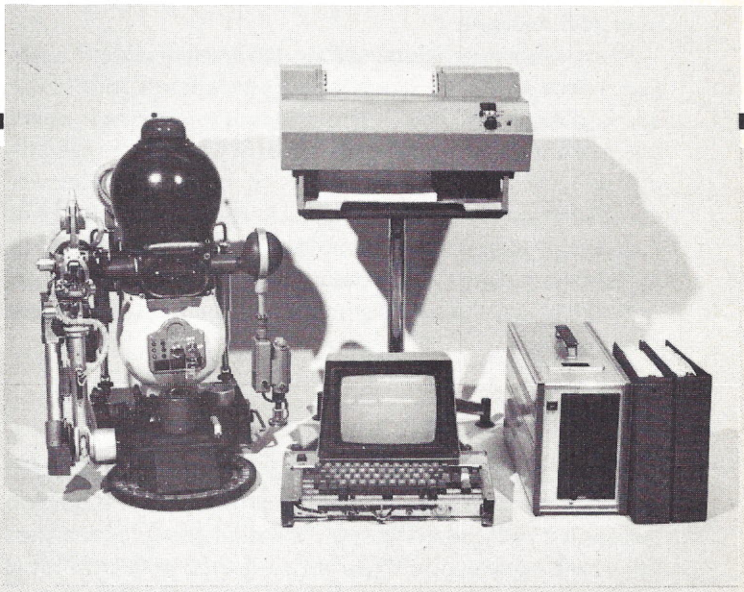


Photo 2. In the rear view, at left, the manipulator arm is on the right and the battery recharging Oasis access is on the left. The rear panel consists of the on-board computer's indicators behind a red plastic filter and switches for boot load and system reset.

Photo 3. Above, the complete Avatar development laboratory. As a robot, Avatar is an autonomous mobile device. But its on-board 64K byte 8085 processor needs much more in order to be used as a CP/M-based single-board computer (SBC) development system. Extra hardware includes a line printer (center, top), a home built video terminal (center, bottom), and a floppy disk drive. When used as a development system, Avatar's on-board computer is connected to these other system components and all drive power is removed to prevent accidents.

plemented. This is to be expected since Avatar is a laboratory and may never be totally finished.

My initial goals for the testbed design were, in the order of their priority:

1. To have a fully integrated system.
   a. Robot computer doubles as a software development system.
   b. Computer peripherals include two 8-inch single density disk drives, a video terminal and an 80-column dot matrix printer.
   c. All system software can be debugged in the robot using a system monitor program and a tether cable to the video terminal.
2. System will respond to voice input commands and possess a minimal voice output capability.
3. Robot will be able to navigate in a flat environment.
4. Robot will be able to locate and connect to a battery recharge station called an "oasis."

Currently, goals 1 and 2 are complete while 3 and 4 are only partially done.

In addition to this list of formal goals, an arm with six degrees of freedom was built, mostly for the fun of it, and some primitive software has been designed which will provide macro instruction capability for doing real-time coordinated movements. (As of this writing, the arm hasn't been tested because of lack of time.)

Goal 1, while complex, was achieved in a relatively straightforward manner. It took about one and a half years to build the three computer boards and the enclosure, the video terminal, the disk system, and the printer. Once these were finished and the operating system installed, I was able to begin software development. My initial tasks were to build a real-time executive and a command interpreter. As things progressed it was easy to add new software modules as I finished them.

Goal 2 was partially realized by purchasing a commercial speech synthesizer and interfacing it to the computer. A little driver software and I had voice output with a vocabulary of about 400 words in less than a month. The speech recognition portion of goal 2 was not accomplished so easily. The hardware design was not too difficult, taking only a few months. The speech recognition software development has

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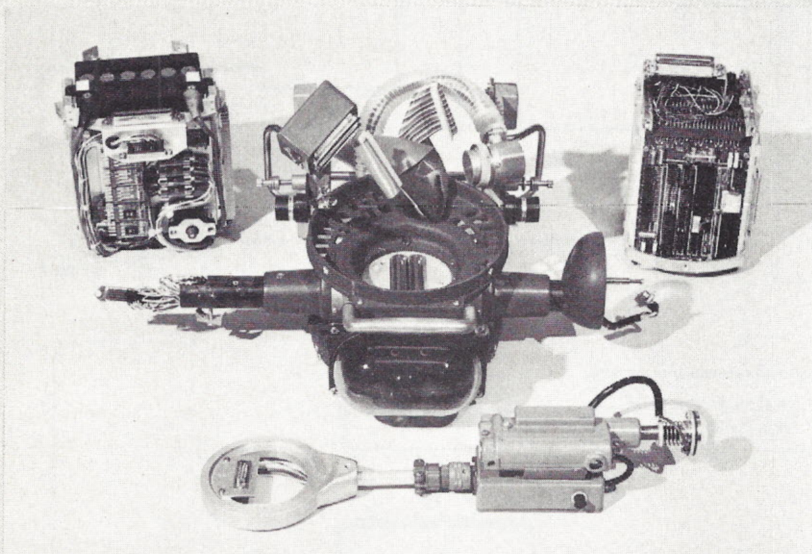

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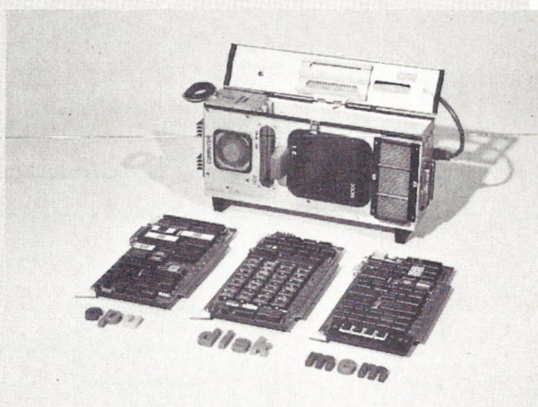

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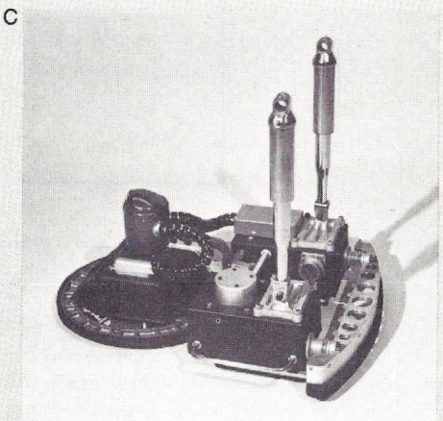

Photo 4. In this sequence of photos we show several views of Avatar in various stages of disassembly. At (a) we show the central body parts of Avatar including the power chassis (left), trunk structure (middle) and upper chassis (right). The computer chassis assembly (b) mounts in back of the trunk structure of Avatar. The base of the robot is a tractor assembly consisting of a powered steering wheel and two unpowered wheels (c). Note that the entire structure is designed for quick assembly and disassembly, a must for ease of service.

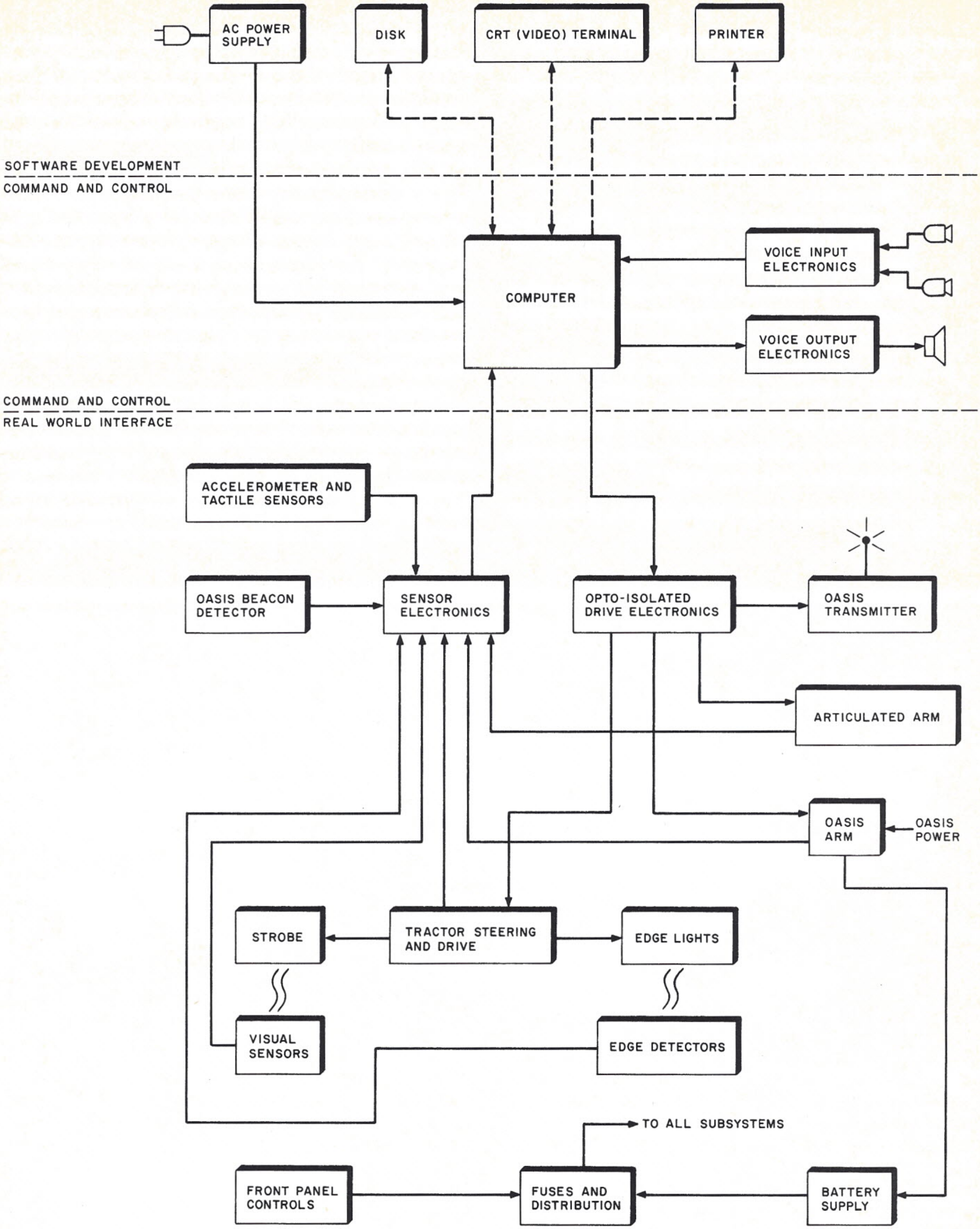

Figure 1. The Avatar robotics experimental system can be viewed as three major portions. At the bottom of this drawing we see the real-world interfaces, comprising the bulk of the diagram. In the middle we see command and control portions, principally, a computer with voice input and output. Finally, there is auxiliary software development hardware and software including a disk system, printer, terminal, and software tools.

taken about a year, but it has been worth it. Though the vocabulary is limited to about 30 words, this is quite adequate for most anticipated uses. The system is basically a speaker-dependent, isolated-word recognizer, but it can be easily trained to several speakers and even identify which one is talking.

Goal 3 is currently in progress. Most of the mechanical system is complete and functional. Some additional work must be done on the data acquisition section which brings all of the analog and digital signals from the sensors into the computer. While the basic motor drive software has been designed, it has not been fully tested. Motor speed and direction control is provided on a real-time basis directly from the computer using pulse width modulated speed control to the motors. Because it is all digital, the drive transistors dissipate a minimal amount of power.

A robot must be able to resolve its environment at least to within its own dimensions if it is going to successfully navigate. The ability to resolve is a function of the sensory systems and their ability to detect objects, walls, doors, steps down, etc. If you watch a very small insect navigate on a flat surface with obstacles in its way, you will notice that the old "crash and turn" method of navigation is an effective mechanism for getting about. For robots, however, which can weigh tens or hundreds of pounds, this method should be used as a last resort, unless you like damaged furniture and bruises.

Some method of non-contact object detection is a must. I chose to use the reflected light from the flash of a strobe. With four detectors mounted in a proper relationship to the strobe it is possible to build a crude but effective object sensor that will avoid collisions with large objects. As a backup however, the tractor is equipped with bump sensors and a four quadrant accelerometer to detect bumps on parts of the structure with no sensors. Another group of detectors sense holes or steps in the floor. This prevents the robot from sneaking through an open door and careening down the basement stairs. The drop-off sensors are also reflective and mounted ahead of and behind the wheels to sense when there is a sudden change in floor height. All of these sensors plus a navigation program capable of remembering its environment will, I hope, prove effective. The basic robot hardware block diagram is shown in Figure 1. Table 1 summarizes the system in more complete detail.

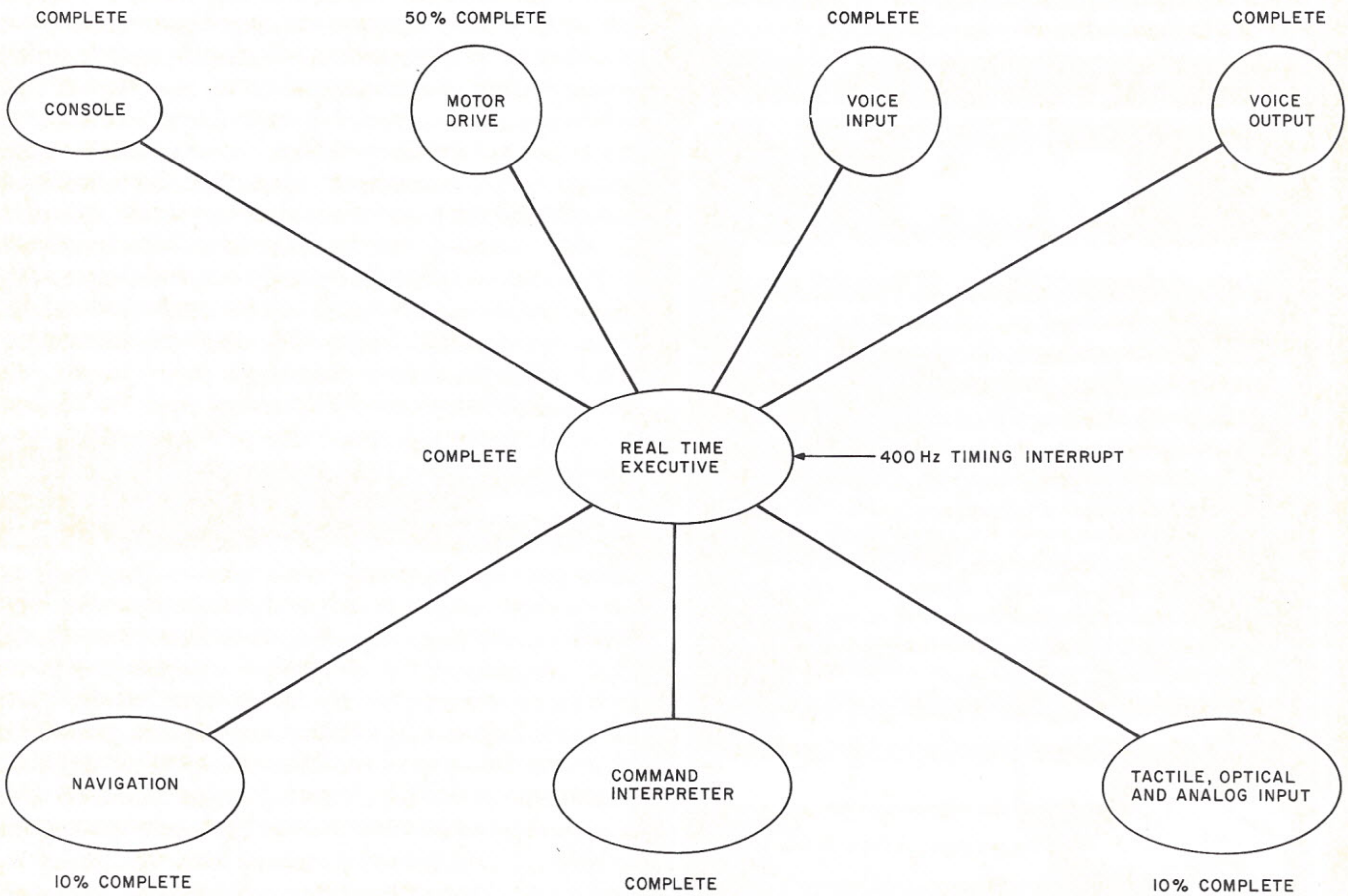

Figure 2. Avatar is controlled by a real-time software system running in its on-board 8085 computer module with 64K bytes of memory. This real-time software executes from a 400 Hz (2.5 ms period) interrupt clock. Software development tools including the CP/M disk operating system and compilers are not shown here.

Goal 4 addresses the problem of recharging the batteries as the robot wanders about. I suppose the robot could be designed to plug itself into a wall outlet, but I wouldn't be too comfortable knowing that it was wandering around trying to plug itself into a 120 V AC outlet. And I'd sleep better if I knew that its source of power had built-in safeguards to prevent or protect against shorts, sparks, overcharging, etc.

This concern led me to adopt the "oasis" concept. An oasis is a low voltage charging station with a beacon that can be activated by the robot when its batteries get low. The robot will have to remember how to get back to the oasis, but once there it can activate the beacon and maneuver itself into the proper position. The main beacon and another smaller beacon guide the robot into the charging station where it merely plugs itself into a special self-aligning socket and starts a recharge cycle. Once the recharge is complete, it will be free to move again.

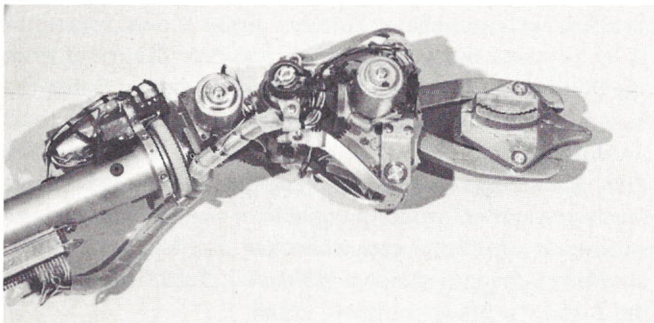

Photo 5. The hand of Avatar. This view details the end of Avatar's manipulator arm and its hand. The hand and arm has six degrees of freedom for complete controll over its position in 3-space.

A Word About Software Development

The computer software includes a disk operating system for managing the information stored on the disks, an assembler and an editor. High level languages which will run on the system include Basic, Fortran, Pascal and others. These along with many utility programs provide all the software development power that is needed. The system software for the robot itself is composed on several functional modules, all run under the supervision of a realtime executive. A simplified task diagram is shown in Figure 2. This diagram also shows a summary of progress to date.

A Word About The Structure Of Avatar

The mechanical structure is made from both surplus and specially designed and fabricated parts. The body domes are spun steel covers from an old x-ray unit, while most of the internal structure was constructed from aluminum bar stock. The computer supports are specially designed aluminum castings made in my foundry. The tractor assembly contains nine specially designed castings, while the arm contains eight more. Most of the gear reducers were surplus; however, the gear reducer and chain drive to the front wheel were completely fabricated. The computer enclosure was built from aluminum sheet metal and was designed to be easily removed from the robot chassis for service or stand alone use. Overall I have spent about 30% of my time designing and building the mechanical structure and 30% of my time designing and building the electronics. The software design time accounted for the balance of 40%.

Conclusion

The Avatar project has already stretched over four years and it is still going strong. I hope that within another year I will have achieved my four initial goals and will be able to choose some new ones. I have learned more from this project than I ever expected. I think I still have a lot left to learn. The most satisfying part of the project has been the voice recognition system since it had the most unknowns associated with it. After reading many books and experimenting with different techniques, I was able to make it work.

I would not recommend starting a robot construction project of this size unless your dream is strong, because without that emotional motivation you will not have enough momentum to overcome some of the obstacles. But if you can stay with it, it will probably be one of the most satisfying things you ever do. ■

Specifications of Avatar

Computer Hardware and Electronics

Processor Board

8085A	*Processor*
8251	*Console Serial Port 50-9600 BPS*
8255A	*24 Line Buffered Parallel I/O Port*
8259A	*8 Level Interrupt Controller*

Disk Board

8080A	*Disk Interface Controller*
8271	*Floppy Disk Controller*
8255A	*24 Line Parallel I/O Port*
8231	*High Speed Match Processor*
8257	*Direct Memory Access (DMA)*

Memory Board

8202	*Dynamic Memory Controller*
4116	*32 Dynamic Memory Parts (64K Bytes)*
2K	*Monitor and Bootstrap Program*

DC Power Supply
Push-Pull Transistor Inverter
Input: 10 to 14 Volts DC at 4.5 Amps
Outputs:
+5 Volts at 5 Amps
+12 Volts at 2 Amps
−5 Volts at 0.5 Amps
−12 Volts at 0.5 Amps
Cooling: Forced Convection

AC Power Supply
Push-Pull Transistor Inverter
Input: 110-130 Volts AC 50-400 Hz. at 0.7 Amps
Output: 10-14 Volts DC at 6 Amps
Cooling: Forced Convection

Computer Software

Operating System: Various Standard

Programming Languages
Assembly
Pascal
BASIC
FORTRAN

Computer Peripherals

Video (CRT) Terminal
Line Printer
Two 8″ Single Density Disk Drives
Robot Interface

Robot Hardware and Electronics

Upper Torso Card Cage
Voice Input Electronics
Voice Output Electronics
Analog and Digital Data Acquisition
Opto-Isolated Motor and Relay Drive
Visual and Edge Sense Electronics
Oasis Transmitter and Antenna

Trunk
Red Glass on Trunk Covers the 4 Sector
Visual Non-Contact Obstacle Detector Using
Light From Forward Looking Strobe Mounted
In Steering Pod On Tractor

Lower Torso
Battery
Fuses and Circuit Breakers
Edge Light Flasher
Power Distribution and Control Relays
Front Panel Controls
1) *3 Position Keylock*
   A) *Off*
   B) *Computer Only*
   C) *Computer and Auxiliary Systems*
2) *Red Button Controls Power To Tractor*
3) *Yellow Button Controls Power To Arm*
4) *Green Button Is a Spare*
5) *Yellow LED Indicates Power Supplied From Computer AC Supply*
6) *Top Red LED Indicates Battery Charged*
7) *Next Red LED Indicates Keyswitch Is On*
8) *Other 3 LEDs Are Spares*
9) *Volume Control Is For Voice Output*
10) *Grill Covers Voice Output Speaker*

Left (Power Recharge) Arm
Fixed Position
Extension To Plug Into Oasis Recharge Station

Right Manipulator Arm
6 Degrees of Freedom
3 Lbs. Max Load Fully Extended To 24″
Gripper Style Hand
Analog Position Feedback

Tractor
Tricycle Front Wheel Power and Steering With Bumper Ring Sensor
Reflective Edge Sensors
Strobe Power Supply and Light
4 Quadrant Bump Sensor

Physical Characteristics
Weight 85 Lbs. (39 kg)
Height 30″ (76cm)
Width 21″ (53 cm)
Depth (Arm Retracted) 22″ (56 cm)
Max Run Time On Battery 1.5 Hours

Table 1. Specifications of Avatar. The robot is a complex system of many interrelated subsystems. Part numbers are shown for computer hardware components where applicable.