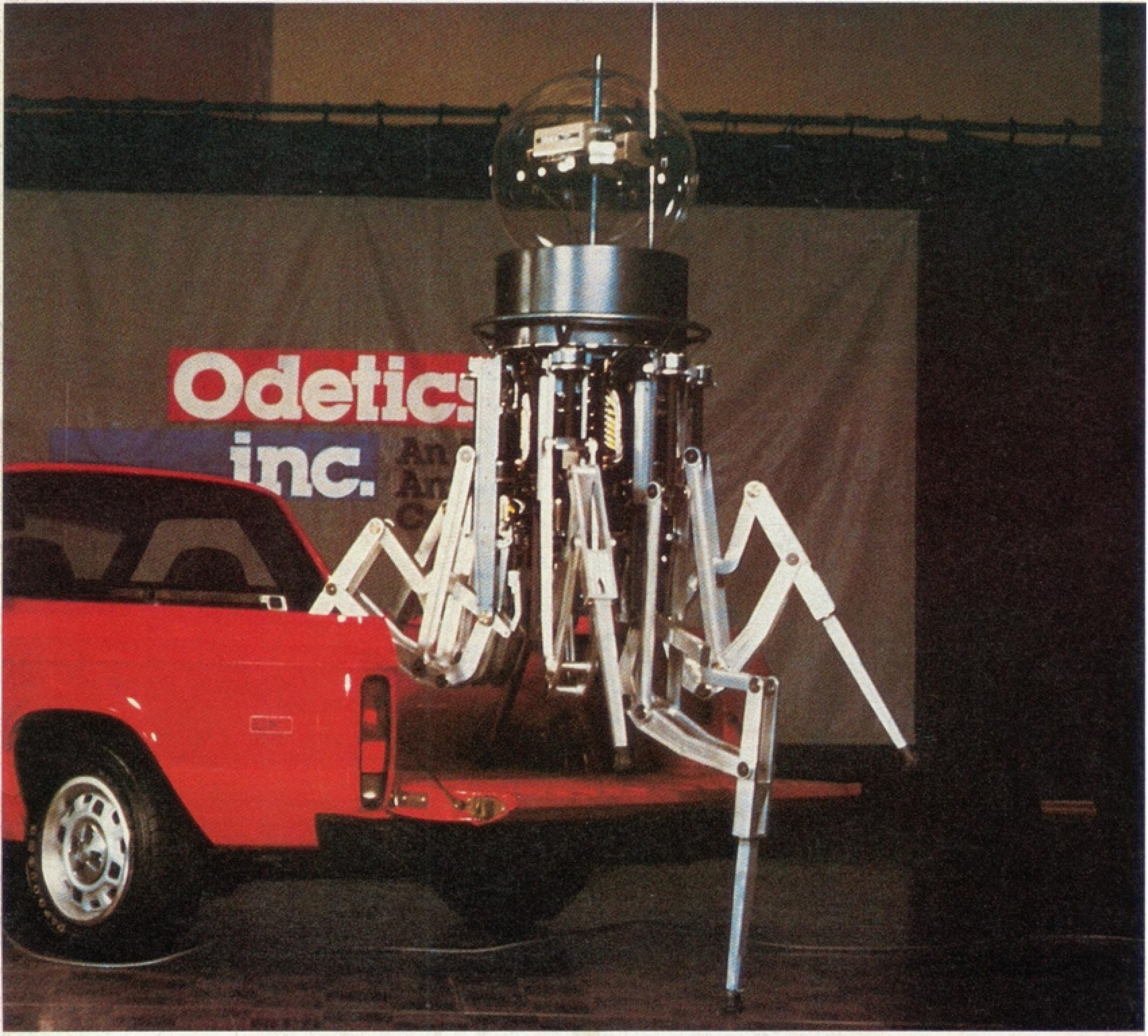
Odetics
inc.

ODEX I: THE FIRST FUNCTIONOID

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Functioniod is a term given to a machine for a new era in robotics, a word coined by an American company pioneering this era.

The first functionoid, unveiled in Los Angeles last March by its developers, Odetics, Inc., of Anaheim, California, is a capabilities model we dubbed ODEX I. It walks on six articulators, or legs, and weighs 370 pounds.

The machine demonstrates a variety of attributes unique to mobile, nonfactory robotics, including unprecedented strength-to-weight ratios and agility. We at Odetics adopted the word "functionoid" to differentiate unmanned vehicle systems (UVS) like ODEX I from the single-function, fixed-platform robots used to automate assembly lines.

Odetics intended the first functionoid to be part of a dawning era in the robotics industry in which a multifunctional unit could literally walk away from the factory floor and perform virtually anywhere.

Later incarnations of the functionoid will perform a number of useful tasks in a wide range of applications, generally in environments dangerous for humans or inaccessible to conventional wheeled or tracked vehicles.

The Los Angeles demonstration, held less than 18 months after development of ODEX I officially

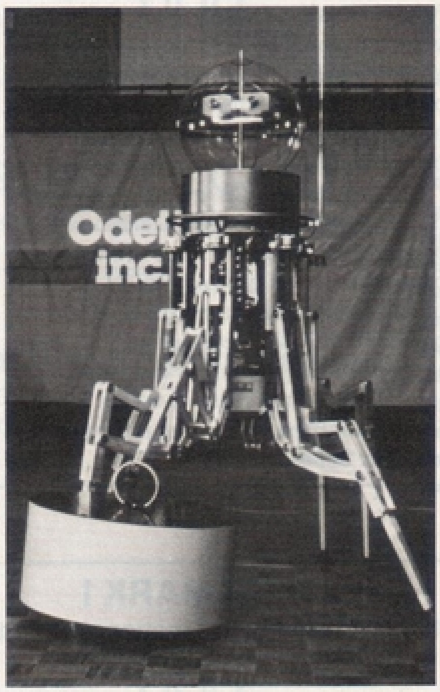


Photo 1. ODEX I executes a feat of agility and strength during the first functionoid's unveiling in Los Angeles last March. In this portion of the demonstration, the unit uses one of its articulators to adjust a swivel ring on top of a pedestal, puts the crutch tip through the ring, then lifts the pedestal. Each articulator can lift as much as 400 pounds.

began, caught many analysts and researchers by surprise, since Odetics is a new entry to the robotics industry. Founded in 1969, Odetics manufactures high-quality audio, digital, and video recording equipment for electronic information processing. The firm's Spaceborne Division has captured more than 70 percent of the world market for digital magnetic tape recorders for use in space vehicles.

Unlike most manufactured products, the functionoid project was not "customer driven;" ODEX I was built without specific applications or customer requirements. The project was the result of a company goal to identify and penetrate a large market to protect the company's long-term growth and competitiveness.

Odetics was the "customer" for the first functionoid and, as such, identified six highly desirable capabilities as ODEX I's design objectives. These included mobility/walking, profile changing, agility/maneuverability, strength, stability, and self-contained power.

A machine possessing these capabilities would serve as the base technology for future functionoids built to perform specialized tasks. This technology would lend itself to such tasks as mining and undersea exploration.

According to a report by SRI International, a Menlo Park, California market research organization, the mining industry needs a machine that includes ODEX I's capabilities in the areas of land and seafloor exploration, fire inspection, hauling, continuous coal mining, and roofbolting.

The nuclear power industry is another promising commercial market. SRI International reports potential applications for functionoids in nuclear power production in the general areas of plant surveillance and inspection, reactor maintenance, decontamination, accident recovery/emergency response, refurbishing/decommissioning, and waste storage.

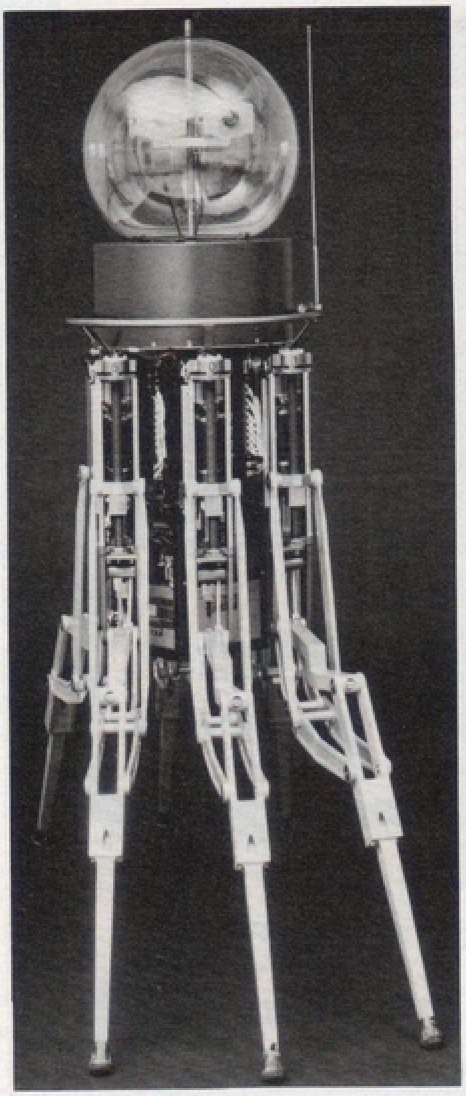
A functionoid has a number of likely applications in the armed forces. include agriculture, security, forestry, construction, utilities, and medicine.

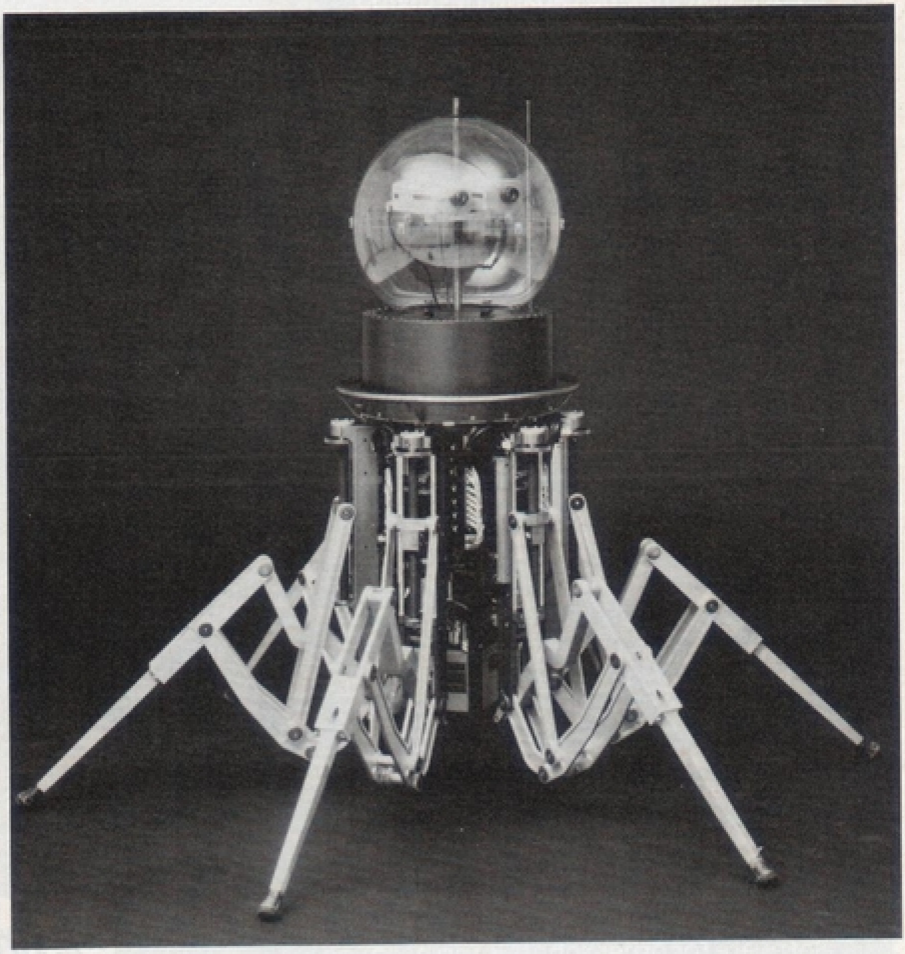
Maneuverability. The first and most difficult design objective to achieve was the mobility/walking capability. The advantages of a walking machine become quite clear, since wheeled or tracked vehicles can traverse only about half of the earth's land surface.

Odetics is not the first organization to recognize the potential of a walk-

Today, Ohio State University in Columbus and Carnegie-Mellon University in Pittsburgh are the two leading American educational institutions in the research of mobile robotics. The USSR's Moscow State University and a $140 million cooperative effort between Japanese government and business represent the most extensive overseas development efforts.

Odetics' functionoid's walking attribute is characterized by a tripod





Photos 2a, b. ODEX I can assume several different profiles to adapt to particular applications. In the narrow profile, ODEX I can walk through doorways, hallways, and other narrow openings, with a width of only 21 inches. The squat profile puts the distance between ODEX I's articulators at 72 inches. With the payload area only 36 inches off the ground, ODEX I can continue to walk. This profile also enables ODEX I to assume other profiles very quickly.

The first of these appears to be sentry duty. This is a natural for a machine, since human sentries quickly grow fatigued with this boring work, and it's very costly for the Department of Defense. Other industries to which a functionoid may one day be applied

ing machine. Patents for various types of walking devices date back more than 100 years. General Electric Corporation's four-legged "walking-truck" built for the U.S. Army in the late 1960s is one of the landmark achievements in this field.

gait. The system raises three articulators to advance. These articulators continuously alternate with three other articulators momentarily on the ground supporting the machine.

The three advancing articulators are called "translators," and the troductory demonstration when ODEX I climbed into and out of the back of a pickup truck. The task was achieved through a combination of teleoperator controls and automatic step climbing.

Operator Control. The teleoperator begins by positioning ODEX I in front of the truck's tailgate and activating a step-climbing addendum to the normal walking program using a joystick control unit. The teleoperator assists the functionoid in initially finding the exact location of the tailgate edge.

From that point, the functionoid walks up the step under complete teleoperator control for horizontal motion and under totally automatic control for negotiating vertical motion. The descent from the truck is performed in the same manner.

We "paper trained" the functionoid to verify the algorithms for this routine. That is, before we had it actually climb into a truck, we took a large piece of paper and made a drawing of the truck bed. Placing this model on the floor resulted in a successful rehearsal of the routine the first time we used the vehicle.

On each articulator is a decal with numbers 0 through 5 for ease of teleoperator identification. These numbers play a role in a further example of agility and maneuverability: we use one of the articulators to adjust a swivel ring on top of a pedestal, put its crutch tip through the ring, then lift the pedestal.

To accomplish this, the teleoperator selects the desired articulator and enters the number with a thumbwheel switch on the control unit. The operator chooses the algorithm for this "articulator mode," then simply uses the joystick to move the articulator horizontally, and then adjusts the stepping height knob for vertical movement.

ODEX I's ability to change directions in mid-stride and to rotate while moving required extensive research. Ironically, these feats of agility demand very little of the teleoperator. To rotate the system while it is walking, for instance, the teleoperator must only adjust the rotation rate knob on the joystick control unit to have the system gyrate to the left or right.

The functionoid's ease of operation is noteworthy. The teleoperator presently is concerned only with 10 switches and knobs and a joystick. Future functionoids will have simpler controls.

Strength. Our ability to add strength to the functionoid was a milestone. A walking machine must be very strong simply to lift its own weight. The machine is under tremendous stress when merely extending articulators to take a step.

The more weight placed on a machine like the functionoid, the more power is required, and some agility could be lost. We wanted to ensure that, when functionoids start supporting heavy payloads and performing heavy lifting tasks, agility will not be impaired.

The best example of the functionoid's strength was demonstrated last March when we put ODEX I in a squat profile behind a pickup truck rigged with a special lifting bracket. The functionoid raised itself on three legs and lifted the back end of the 2200-pound vehicle. It then proved itself equally strong in the normal profile as it walked across the floor, turning the truck's position 90 degrees.

ODEX I can carry a maximum load of nearly 2100 pounds (5.6 times its own weight) while in a stationary position with all six articulators on the ground and nearly 900 pounds at normal walking speed (2.3 times its own weight). The load capacity of any one articulator while the unit is operating is 400 pounds.

ODEX I is the first walking machine in which strength-to-weight ratios are thought of in multiples of unit weight. Its strength is maximized because ODEX I practices concepts a person would use to lift a heavy load.

ODEX I assumes a wider profile for stability while lifting, and the weight is centrally located on the primary structure for greatest capacity. During the truck-lifting demonstration, the teleoperator shortened the stride length for better weight distribution.

Since we wanted a machine that could traverse rough terrain and perform other necessary tasks, we designed a functionoid that could maintain a very stable platform. ODEX I's stability is achieved primarily through use of a rigid leg structure with active suspension. Should it stop on the side of a hill, the system would lock the articulators and remain very stable.

Self-contained power, the final milestone we wanted to achieve with ODEX I, was completed early in the development cycle with the installation below the primary structure of a standard 24V, 25 amp-hour aircraft battery.

ODEX I runs on 450 watts and requires a recharge after about one hour of normal walking. When the system stops, the teleoperator can shut off all power except a "wake up" circuit. ODEX I draws only 2 watts when in this stand-by mode. We are currently looking at alternative power sources to extend the power ranges, but for the purposes of the capabilities model, we had all the power we needed.

Other attributes of ODEX I include ease of repair due to the use of modular parts. An entire articulator, for example, could be changed within an hour. The functionoid's circular design makes it omnidirectional. The design also provides complete articulator overlap capability. Each leg can enter another leg's zone of operation.

The articulators have a folding mechanical attribute as well. ODEX I can assume a tucked profile, because one section of an articulator can fold into the operating area of another section of that same articulator.

The circular design distinguishes the functionoid from other walking machines. Previously, most walkers featured articulators stemming from a long, rectangular primary structure.

As we were building a prototype of a very advanced technology, almost all of the mechanisms for ODEX I were custom-made. We created the design, and in most cases, even constructed these mechanisms ourselves.

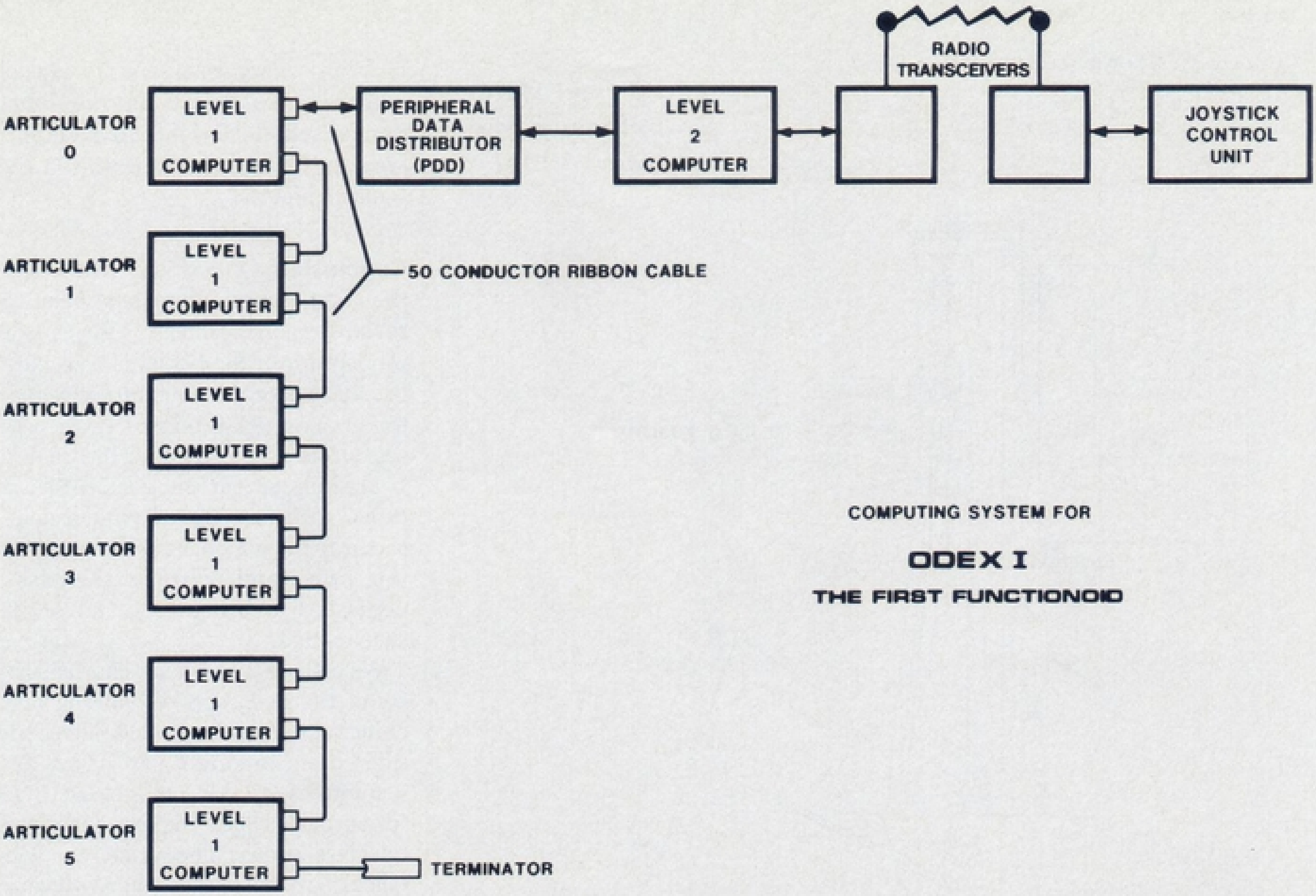


Figure 1. ODEX I has six computers referred to as "level 1" computers—one for each articulator. A peripheral data distributor (PDD) communicates to these computers via a 50-conductor ribbon cable, daisy-chained and terminated at the last articulator. The PDD conducts the data flow to an on-board "level 2" computer through an interface. This level 2 computing system accepts commands from the joystick control unit and computes the required articulator motion using algorithms developed in-house. The joystick control unit communicates with ODEX I's computing system through a radio link.

Control Computers. Odetics also designed the functionoid's computing system. ODEX I has six level 1 computers, one for each articulator. Each computer features three circuit boards.

One circuit board provides status reports for the higher computer level and accepts and interprets commands for actuating the articulator motors. The other two are servocontroller boards, which accept instructions from the first circuit board and exert direct control over the articulator.

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We were able to develop and test the level 1 computing system, the actual servocontrol, before the higher level software was completed. The entire software package was completed in 10 months.

This software uses extensive assembly language and some high-level language to incorporate the algorithms we developed for mobility. We also created the computer hardware system, using off-the-shelf microprocessors and integrated circuits.

Development. Although all the actual work required to build the first operational functionoid was done in less than 18 months, the idea for this walking machine was first conceived more than 10 years ago. The funds needed to proceed with development, however, were not available until Odetics became a publicly-held company in July 1981. A few months later, the board of directors authorized the first phase of ODEX I's development.

We put together our research and development team of mechanical and electrical engineering and computer science experts and leased space for an operations center. By June 1982, we had successfully tested an operating articulator.

By September, we had created a teleoperated machine with an umbilical cord that served as the communications link between the remote higher level computing system and the lower level computers on-board ODEX I's primary structure. We also achieved self-contained system power.

At this point, the functionoid looked

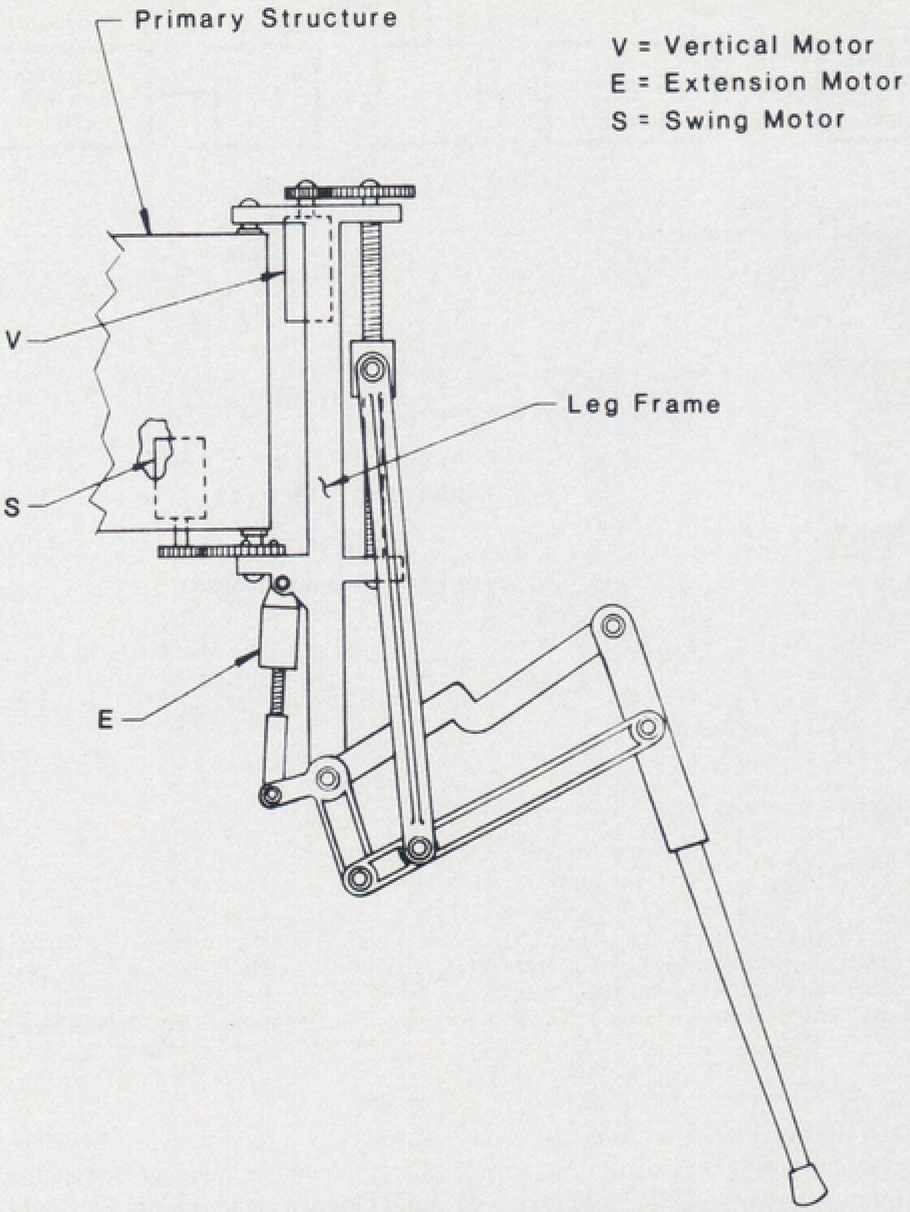

Figure 2. There are 18 motors on board ODEX I, three associated with each articulator. The largest of the three dictates vertical movement. The other two are identical, controlling extension and swing.

like the capabilities model we demonstrated at the March unveiling, except for the umbilical cord and an empty 10-inch span on top of the primary structure. The electronics package was eventually placed here. During phase 2 of ODEX I's development cycle, we completed the difficult goals of removing the umbilical cord and placing the level 2 computing system onboard the first functionoid.

ODEX I and a twin unit, ODEX II, were designed specifically to demonstrate the capabilities discussed in this article. The next generation functionoid will have other attributes designed to study its feasibility in different environments. Vital mechanisms and electronics will be sealed against the elements to prepare ODEX III for environmental testing.

We eventually want ODEX III to be autonomous, receiving only very general orders. We would like ODEX III to be able to proceed to an ordered position by picking and negotiating its own route.

Both autonomous and teleoperated functionoids will require accurate vision systems, not only for indoor applications such as nuclear power plants and security, but also for the exploration of different planets.

A future vision system might include stereo television with optical-ranging and ultrasonics to help determine dimensions and distances and perceive objects in the functionoid's line of sight. In addition, we hope to develop tactile sensors for the articulators.

Conclusion. Our decision to develop the first functionoid has been a rewarding one. James M. Beggs, administrator of the National Aeronautics and Space Administration, a customer of our Spaceborne tape recorders, wrote us shortly after the ODEX I announcement that, "NASA is proud to be associated with private sector firms which are willing to pay the price and to take the risks necessary to bring about advances such as this."

We believe that when historians recount the evolution of walking machines, Odetics' research will be considered an important part of the development of this technology. The functionoid also makes excellent business sense. The price we will place on future functionoids will vary with the embodiment, form, and applications they will be used for, as well as with the quantity ordered. Odetics expects to market functionoids directly and use joint venture licensing agreements.

We will bring to the market a tool that will allow humans to go places and do things that until now have been unsafe or impossible. This machine will help us achieve what we originally intended to do: help our company enjoy continued growth and competitiveness. □

About the Author: Marvin Russell, Jr. is director of engineering at Odetics, Inc.

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