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The OmniTread OT-4 Serpentine Robot

by

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ABSTRACT

Serpentine robots are slender, multi-segmented vehicles designed to provide greater mobility than conventional wheeled or tracked robots. Serpentine robots are thus ideally suited for urban search and rescue, mine rescue, military intelligence gathering, and for surveillance and inspection tasks in hazardous and hard-to-reach environments. One such serpentine robot, developed at the University of Michigan, is the "OmniTread OT-4" [Borenstein et al., 2007]. The OT-4, shown in Figure 1, can climb over obstacles that are much higher than the robot itself, propel itself inside pipes of different diameters, and traverse even the most difficult terrain, such as rocks or the rubble of a collapsed structure.

Figure 1: The OmniTread OT-4 serpentine robot climbing over a pile of rocks.

The most unique design characteristic of the OT-4 is the use of pneumatic bellows to actuate the joints. These bellows allow simultaneous control of position and stiffness for each joint. Controllable stiffness is of crucial importance in serpentine robots, which require stiff joints to cross gaps and compliant joints to conform to rough terrain for effective propulsion. Another unique feature of the OmniTread design is the maximal coverage of all four sides with driven tracks. This design makes the robot indifferent to roll-overs, which happen frequently when the slender bodies of serpentine robots travel over rugged terrain. A less apparent unique feature is the single electric drive motor in the center segment that provides rotary power to each segment through a so-called "drive shaft spine" that runs through the whole length of the robot. We believe this design to be more weight and power efficient than individual motors in each segment. The penalty with this design is some inefficiency when articulating the joints. All of these features are shared by the OmniTread OT-4 and its predecessor, the OmniTread OT-8, shown in Figure 2 . The OT-8 is so designated because it can fit through a hole 8 inches in diameter [Granosik and Borenstein, 2005], while the OT-4 can fit through a hole 4 inches in diameter.

Figure 2: Our earlier-developed and larger OmniTread OT-8 can fit through an 8-inch diameter hole. Here it is driving up an inclined sand pit.

The main difference between the OT-4 and the OT-8 is that the OT-4 can operate without tether. To this end, it holds two onboard air compressors (in Segments #2 and #6 – see Figure **3**) that produce pneumatic power, Li-Polymer batteries (in Segments #3 and #5), and a wireless control system. Segments #1 and #7 can hold some payload such as cameras, microphones, and speakers, or they can be equipped with flipper tracks (see video). The segment in the center is called "Motor Segment" because it houses the single drive motor. All other segments are called "Actuation Segments" because they house, among others, the control components for the pneumatic joint actuators. The seven segments are connected by six pneumatically actuated 2-DOF joints, and each joint is actuated by four pneumatic bellows. Table I lists some of the OT-4's key specifications.

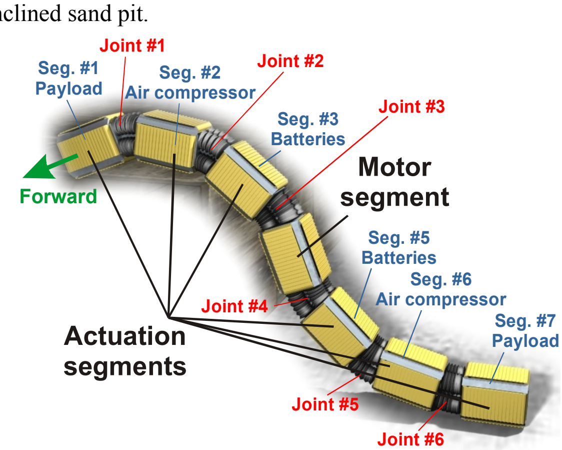

Figure 3: The OmniTread Model OT-4: Nomenclature for segments and joints.

In terms of performance, the tetherless OT-4 can perform much more challenging tasks than the OT-8, such as the vertical pipe climb and climbing through holes high above ground. The OT-8, on the other hand, performs much better on sand and in underbrush. That is because the larger diameter of the OT-8's grousers is less susceptible to jamming by ingested sand and small twigs. A comparison between the OT-4 and other serpentine robots is beyond the scope of this abstract but can be found in [Borenstein et al., 2007].

Table I: Specifications for the OmniTread OT-4.

Structure:	7 segments, six 2-DOF rotary joints
Dimensions: L×W×H: Weight: Motor Seg. length: Actuator Seg. length: Joint length:	 94 cm (37") x 8.2 cm (3.2") x 8.2 cm (3.2") 4.0 Kg (9.0 lbs) 10.9 cm (4.3") 10.3 cm (4.0") 3.6 cm (1.4")
Performance: Diameter: Lifting power: Flexibility: Turning radius: Speed:	 Can pass through a 10-cm (4.0") dia. hole When stretched out horizontally, OT-4 can lift three segments off the ground. Joints bend at least ±33° in any direction but ±41° in principal directions. Outside: 22.9 (9") Inside: 15.2 cm (6") 15 cm/sec (6 in/sec)
Control:	Off-board PC, connected through wireless data link. Full proportional control over angular position of joints, stiffness, and forward/backward drive speed. Currently, 3 operators are needed to operate six joysticks for the six 2-DOF joints.
Design features that enable tetherless operation	
Pneumatic power:	Obtained from two onboard compressors.
Electric power:	Obtained from onboard batteries. Sufficient for up to 75 minutes of operation.
Micro-clutches:	Any track can be individually engaged or disengaged under computer control, resulting in significant power savings.
Wireless control:	Wireless system for sending commands and receiving sensor and telemetry data.

CONTROL AND TELE-OPERATION

The OT-4's six pneumatic 2-DOF joints allow the operators to specify two joint angles as well as the stiffness for each DOF. This amounts to 24 controllable joint parameters, in addition to the single drive speed parameter. It is impossible for one human operator to control this many parameters in real-time. Indeed, it is difficult for the OT-4's crew of three well practiced human operators to control the OT-4 effectively in real-time. These difficulties become apparent in the seemingly hesitant motion of the OT-4 during the traverse of many of the obstacles and challenges shown briefly in our video segment. A large selection of detailed video clips, each documenting a complete traversal of an obstacle, is available at
http://www.engin.umich.edu/research/mrl/OmniTread_Video.html

In practice, each of the three tele-operators holds a conventional game pad, each equipped with two thumb-operated analog 2-D joysticks. Each of these joysticks controls the two DOF of one joint. Additional buttons on the game controllers allow the operator to change joint stiffness. None of these tasks is coordinated by the off-board control computer. Developing a higher-level computer control system that allows the number of operators to be reduced to only one is very difficult. However, this task was pursued with promising results by a team of AI researchers [Hutchison et al, 2007].

REFERENCES TO PUBLICATIONS ON THE OMNITREAD SERPENTINE ROBOTS

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