ning and services, advisory systems and management decision support, telecommunications, marketing, and consumer products—potentially large markets. While many such systems are being developed, few can be found in the current marketplace. Most existing commercial expert systems center around financial planning and automated decision aids.

Chapter 6 addresses professional applications, discussing AI in medicine, engineering, architecture, chemistry, education, law, publishing, agriculture, mathematics, and science. Of this wide range, medical applications have been particularly successful.

Chapter 7 describes AI applications in aerospace, ground transportation, and the military. For readers especially interested in military applications, programs being funded by DARPA's strategic computing program are discussed.

In addition to bibliographies and references, the book provides appendices listing addresses and telephone numbers of organizations mentioned in the text, an alphabetical index of expert systems and of companies and universities referenced, and a glossary. The level of expert system description detail varies, begging a more standard format to aid reader comparisons of system capabilities. In light of the anticipated increase in available systems, the authors will need to improve their next edition's format.

Briefly summarized, this book offers a good starting point for readers seeking an overview of expert systems and applications, but not requiring in-depth technical detail.

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Legged Robots that Balance

Marc H. Raibert (MIT Press; Cambridge, Mass., 1985, 233 pp., $30, hardcover)

Robotics research can be characterized as a loosely coupled array of related disciplines. Among these is intelligent mobile robotics research, a discipline including those fascinating mobile robots that move about on legs. So far, surprisingly little research literature has surfaced on this nascent science of legged robotic locomotion—a science aiming to build robots that not only move about on legs, but that do so with agility, speed, and balance.

What is the purpose of such machines? Principally, to travel where wheeled vehicles cannot. Key applications would be (1) unmanned activity on on other planets, (2) fighting forest and industrial fires, (3) assisting in rescue operations, (4) and applications in extreme climates. In contrast, military applications seem dubious since these costly robots are easily disabled by human adversaries.

Raibert's book, a welcome addition to our sparse literature on legged robots, is more a report than a survey. It deals with research Raibert and his associates have conducted at Carnegie Mellon University, providing a working theory of active balance on which machines can be built that run comfortably on legs and do so at different gaits. A 15-minute videotape called "Robots that Run," prepared by Raibert as an accompaniment to his book, is available from the MIT Press.

Although Odetics Corporation has produced a hexapod with hinge-jointed legs that climbs and descends stairs and other obstacles, Raibert focuses on jointless-legged robots capable of running—defined as the ability to engage in short ballistic flights or leaps where, at times, no "feet" touch the ground. Carnegie Mellon has developed two such research machines, both of which are single-legged robots designed to move by hopping. The first hops in only a single plane, while the second hops in any direction. Raibert focuses on the kinematics of various running gaits and the control algorithms needed to generate and balance those gaits. He doesn't discuss heuristic or symbolic-processing approaches.

These one-legged travelers move on legs consisting of double-acting air cylinders that employ pressurized air to

Robots that move on legs, and do so with agility, speed, and balance.

drive pistons providing the spring for hopping. The idea seems basic enough; indeed, Raibert records surprise at the simplicity of the three-part algorithm he discovered to control the planar, one-legged hopping machine. Raibert summarizes his theory in a single sentence: "We argue that the trotting quadruped is like a biped, that a biped is like a one-legged machine, and that control of one-legged machines is a solved problem." One might better term this hypothetical rather than theoretical since the claim has very little confirmatory evidence.

Raibert's main thesis, that controlling one-legged running robots is considerably simpler than one might have anticipated, appears convincing. However, AI history signals caution before such optimism. Raibert himself observes that, in multilegged systems, shortening the legs in various phases becomes an important factor. And he does not address the limitations of unjointed, inflexible legs nor the problem of balancing on inclines. An underlying dilemma faces legged locomotion: Rigid, stilt-like legs create precarious and unstable vehicles—whereas hinged, jointed legs are far more difficult to analyze dynamically and to balance. A principal question remaining is how far this approach can proceed before knowledge-based symbolic processing will be required to handle the complex situations that practical systems must solve to justify their price tags.

Unwarranted optimism aside, Raibert's useful book provides considerably more than a research-in-progress report. Its numerous appendices contain equations for legged locomotion's kinematics and dynamics. A complete bibliography presents the best research being done in this interesting discipline. Although Raibert may have oversimplified the problem and underestimated its difficulty, his simplification provides a model of clarity that throws many important considerations into relief; for example, that active balance techniques are essential for solving legged locomotion problems.

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