Chapter 10
Human-Centered Metal Hydride Actuator Systems for Rehabilitation and Assistive Technology

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ABSTRACT

Metal hydride materials can store a huge amount of hydrogen and can convert energy due to enthalpy change through a hydride reaction. Artificial actuation systems that employ this special physicochemical property are named metal hydride actuators. The actuators utilize the mechanical energy formed from hydrogen equilibrium pressure through thermal energy given to the metal hydride alloys as output. Metal hydride actuators have a simple structure and a number of features that make them attractive for use in rehabilitation engineering and assistive technology. They provide a high power-to-weight ratio, high strain actuation, human-compatible softness and noiselessness, and they are environmentally benign. The behavior of metal hydride actuators is also useful for overall human-machine interface applications. This article reviews the motivation for the development of some of the leading artificial muscle-like actuators, outlines the metal hydride actuators and describes its applications in quality-of-life technology.

INTRODUCTION

In an aging society with a falling birthrate, there is an increased need for home-based rehabilitation systems and human-centered robots for healthcare services (Gardner-Bonneau & Gosbee, 1997). In particular, elderly patients who are required to lie in a reclined position due to stroke or bone fracture may suffer from disuse syndromes, such as bedsores, joint contracture and muscular

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atrophy (Bortz, 1984). It is difficult for these elderly patients to actively exercise for preventive rehabilitation. Thus, to manage these disuse syndromes, rehabilitation equipment and assistive devices, such as bedside apparatuses for continuous exercise of joints, power assistance devices for standing and transfer hoists must be developed. These equipment demands powerful and soft actuators, as well as human muscles.

Currently, however, no commercially available actuators with the desired characteristics, which are human-compatible, softness for safety, noiseless and having a high power-to-weight ratio exist (Burdea, 1996). These technical requirements present a challenge to the development of rehabilitation and personal autonomy systems. To solve this challenge, various types of artificial muscle-like actuators, such as pneumatic muscle actuators (Caldwell et al., 2000), shape memory alloy actuators (Huang, 2002) and polymer actuators (Shankar, 2007) have been actively studied by material scientists and biomedical engineers. However, a satisfactory result for artificial muscle technologies for rehabilitation or healthcare devices has not been achieved yet.

In order to fulfill the above demands for the design of a human-centered actuator, we originally developed some actuator systems using metal hydride materials as a flexible mechanical power source (Wakisaka et al., 1997). Metal hydride actuators (MH actuators) can produce a powerful and soft force, even if it is a small and light package, because the metal hydride materials can store a large amount of hydrogen gas by controlling heat energy; this energy is about a thousand times larger than the volume of the metal hydride alloy itself. Moreover, MH actuators have human-compatible softness and noiseless motion, which derived from a reversible thermochemical reaction of metal hydrides. An additional potential merit is that hydrogen is a clean energy carrier candidate because it does not have adverse effects on the environment (Sakintuna et al., 2007).

The purpose of this chapter is threefold: first, to overview soft artificial muscle-like actuators to support personal physical activity; second, to describe the properties of metal hydride materials, the structure and motion control technique of the MH actuator and the performance upgrade with installed soft bellows made of a multilayer laminate film; third, to show some applications of the MH actuators in rehabilitation and assistive technologies, which require a continuous passive motion machine for joint rehabilitation and a power assistance system for people with restricted mobility.

Finally, we present future works related to further improvements of the MH actuators for more suitable devices in rehabilitation engineering and assistive technology.

BACKGROUND

Current Actuator Technologies of Artificial Muscles

For many industrial machines and robots, actuators are very important elements (Alciatore & Histand, 2003). The actuators convert energy from an electrical, hydraulic or pneumatic power source to mechanical energy for rotational or linear motion. The main types of actuators are hydraulic, pneumatic and electrical motors. Muscles are actuators in the body. Electric motors have good controllability and high-energy efficiency, so they are in widespread use for practical applications, such as various industrial machinery and household electrical appliances. However, in the ratio of torque to mass in motors is low compared to that of muscle, making them bulky for medical and biomimetic robot applications (Smela, 2003).

Moreover, no commercial actuators fit together well for human motion assistance and rehabilitation in daily life. Rehabilitation equipment and assistive devices that patients directly wear on their body strongly require softness, quiet functioning,