Foreword

Powering Mobility for All: Development of Robotic Legs

Xiaojun Sun*

1. Introduction

It is a great honor for me to have the opportunity to write this foreword for KYB Technical Review No.69. We, BionicM Inc., are a venture company engaged in the research and development of robotic legs. Since 2023, we have been engaged in joint research with the Basic Technology R&D Center, Engineering Div., KYB Corporation. In this article, I would like to introduce our company as well as briefly introduce robotic legs and their development, as many of you reading this foreword may not know much about prostheses.

2. Mission of BionicM Inc.

I was inspired to develop prosthetic legs in the future because my life was profoundly changed when I first encountered a prosthetic leg. Originally, I was born into a farming family in Guizhou Province, China, as an able-bodied person. But when I was nine years old, my right leg was amputated at the knee due to osteosarcoma. After the amputation, I started living with axillary crutches, which completely changed my life. For example, when I walked to school in the rain, I often slipped and fell. Another difficulty was that I could not do by myself what I could do in my daily life before, because my hands were tied by the crutches, which was very inconvenient. After living with crutches for 15 years in China, I first encountered prostheses when I was a graduate student in Japan. I will never forget the joy I felt when I walked on the street for the first time with my prosthetic leg after almost a year of rehabilitation. I could walk out in the rain with an umbrella in my hand and carry a tray in the cafeteria by myself. My hands were off crutches for the first time in 15 years. It was literally a life-changing moment.

While the word mobility may remind many of you of cars, trains, and other means of transportation, I believe that "feet" are the fundamental means of transportation or mobility for human beings. Our society has required mobility to move people and things quickly, even over long distances, in our economic activities. With the development of the machine industry, cars, trains, and other means of mobility have been developed to meet this demand. These are hardly affected by weather, terrain, and other environmental factors and allow for efficient time management, thus contributing greatly to economic development. On the other hand, foot-based mobility, which relies on physical strength, is not suitable for fast, long-distance travel due to its limited travel distance and speed. Able-bodied people, for whom bipedal walking is the norm, tend to focus on the disadvantages of their feet. However, feet can adapt to narrow streets, slopes, and other different environments sequentially according to their very fine motion control. Although the contribution of feet to economic development may be small compared to other means of mobility, I am sure from my experience that bipedal walking implemented by feet is a fundamental human movement and can greatly contribute not only to physical health, which is the foundation of human activity, but also to mental health. I want to provide technology that can help people to walk where they want to go with their own feet. This is how I see our company's mission of "Powering Mobility for All" being fulfilled.

3. Prosthetic Legs and their Development

As you know, a prosthetic leg is a device that replaces the missing part of an amputee's lower limb. Prosthetic legs are mainly divided into transfemoral prostheses (for above-knee amputees)

* Xiaojun Sun, CEO, BionicM Inc.

Fig. 1 Transfemoral prosthetic leg

and transtibial prostheses (for below-knee amputees). A transfemoral prosthesis generally consists of three components: a socket, a knee joint, and a foot, as shown in Fig. 1. The robotic knee joint Bio Leg® we have developed corresponds to and provides the function of the knee joint.

Many knee joints on the market use their springs, hydraulic dampers, and other mechanical elements to support knee flexion and extension during walking[1]. These mechanical elements are passive components that contribute to the user's gait primarily as a braking device. This means that the user must "walk" as if swinging the prosthetic leg (including its knee joint) by moving their trunk and hip joints. Such compensatory movements during walking are known to contribute to lower-back pain[2]. It has been confirmed that compensatory motions in other movements also place a physical burden on the user[3) 4]. This is one of the major problems for transfemoral prosthesis users.

Research institutes including universities have been trying to solve problems with conventional commercial knee joints by developing a powered knee joint with a built-in electric motor. Our Big Leg®, which is also a powered knee joint, came out of my research in the second half of my Ph.D. Powered knee joints are now also used as drivers by incorporating active components such as electric motors. (Physiologically, centripetal contraction is now possible in addition to centrifugal and isometric contraction, which may mean that the basic functions of the human body's muscles have finally been added to the knee joint). As a result, a powered knee joint can now assist the user in climbing stairs and performing other movements that were difficult with conventional knee joints. Recent joint research has shown through an experiment that a powered knee joint can support the user's knee extension movement when standing up from a chair, thereby improving the symmetry of the bipedal load on the user's legs[5]. In this way, a powered knee joint has the potential to reduce the user's physical burden. I believe that in the future, amputees will be able to regain lower limb function to almost the same level as able-bodied people.

4. Development of a Powered Knee Joint

Although the user benefits of powered knee joints have been proposed, they are still very different from human knee joints. There are still several challenges to overcome in the design and development of powered knee joints. One example is their weight. While in the human body the femur and tibia are firmly connected by various ligaments, the prosthetic femur is connected to the user's stump (the end of the amputated lower leg) by maintaining negative pressure inside the socket. The user must support the weight of the knee joint on the stump. Therefore, the knee joint should be as light as possible. On the other hand, a powered knee joint requires a relatively high power output around the knee joint. It needs to provide enough joint torque to support the user's body weight in the stance phase (when the prosthesis is loaded), while at the same time providing propulsion at a relatively high joint angular velocity sufficient for fast walking in the lift phase (when the prosthesis is unloaded). I have never seen a commercial knee joint driven by a combination of an electric motor and a reduction gear that meets both the weight and power requirements. To improve the weight to power ratio, I was involved in the research and development of a variable reduction gear specifically designed for knee joints as part of my Ph.D. research[6]. However, I believe there is still room for improvement. While feeling the wonder of the human body such as the muscles and joint mechanisms, it is interesting to pursue how I can develop a powered knee joint as close to the human body as possible. I find this work very rewarding.

5. Expectations for Corporate Collaboration

As mentioned above, the design of a powered knee joint requires a comprehensive understanding of various fields including mechatronics (mechanical and electrical engineering) and biomechanics. Based on my past experience, I believe that the strength of a venture company is its flexibility in product development. Then, based on the belief that a variety of perspectives are essential in product development, our company has promoted design and development with advice from engineers as well as prosthetists, physical therapists, and other medical professionals. After about five years of trial and error (about eight years including the research period), the product is finally ready for the market.

Looking back from a management perspective, I think the long product development time is an issue that needs to be addressed in future. In recent years, universities and companies have been announcing new knee joints one after another. As I feel that the competition for knee joints has become more intense than before, the product development period should be shortened. On the other hand, because knee joints are classified as medical devices in Europe and the United States and they are used every day, safety is more important than performance. I look forward to corporate collaboration as a means of resolving the trade-off between shortened development time and high safety. During the development of Bio Leg®, we were aware that users place a high value on the sensation of knee-joint movement. This is a subjective feeling, such as whether the user can feel that the knee joint is following where they want it to go when walking, or whether they have a good feeling when using it. We have come to understand that this type of sensation is very similar to the driving comfort of automobiles. I understand that Japan is a major exporter of automobiles as an industrial product that requires superior safety. The knowledge of technology and safety accumulated in automotive manufacturing could be applied to another "mobility", bipedal walking. If this is achieved, an even safer, more secure, and more sophisticated knee joint can be developed in a shorter period of time.

The terms "startup" and "venture" have become familiar, in part, because the Japanese government established the Startup Development Five-year Plan in 2022 to create a second startup boom. In order to explore new mobility markets without letting the boom fizzle out, I believe it is necessary to combine the flexibility of ventures that can adapt to the market with the robust hardware technology of large companies. Under our mission of "Powering Mobility for All", we are committed to doing our best to explore new mobility markets. We look forward to your continued cooperation.

Finally, I would like to thank Mr./Ms. Kaneishi, Mr./Ms. Komuta, and the entire engineering staff of BionicM Inc. for their great cooperation.

References

1) OKUDA Masahiko: "Historical changes and future tasks in prosthetic knee joint", Bulletin of the Japanese Society of Prosthetics and Orthotics, 27(1), 2011.

2) Devan H., *et al.*: "Physical activity and lower-back pain in persons with traumatic transfemoral amputation: a national cross-sectional survey", *The Journal of Rehabilitation Research and Development*, 49 (10), pp. 1457-1466, 2012.

3) Highsmith M.J., *et al.*: "Kinetic asymmetry in transfemoral amputees while performing sit to stand and stand to sit movements", *Gait & Posture,* 34 (1), pp. 86-91, 2011.

4) Wolf E.J., *et al.*: "Comparison of the Power Knee and C-Leg during step-up and sit-to-stand tasks", *Gait & Posture*, 38 (3), pp. 397-402, 2013.

5) Hobara H., *et al.*: "Improved Loading Asymmetry During Sit-To-Stand Movement In Unilateral Transfemoral Amputees Using Powered-prosthetic Knees", *American Academy of Orthotists and Prosthetists (AAOP)* 50*th Annual Meeting and Scientific Symposium*, Chicago, Illinois, USA, 2024.

6) Sun X., *et al.*: "Variable Transmission Series Elastic Actuator for Robotic Prosthesis", *IEEE International Conference on Robotics and Automation (ICRA)*, Brisbane, QLD, Australia, 2018, pp. 2796-2803.