Report of DeMaMech Program

Osaka University

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2. Executive Summary

I went to the Netherlands from September 2004 to December 2005 and Denmark in January. My research topic at TU Delft is Ankle actuation for dynamic bipeds. We analyzed Passive Dynamic Walking and walking on a flat floor by using the model which has two legs connected to foot with ankle joint. It is described in section 4.

At TU Delft I took three lectures 'Control Theory', 'Optimization in System and Control' and 'Biomedical Engineering Design'. The lectures at TU Delft were very different from those of Osaka University. They were not only taking lectures but also some group assignment or making a presentation. The contents and style of these lectures is described in section 4.

At Technical university of Denmark, I studied about hexapod robot. This robot will be used for micro manipulation. So I summarized its limitation and possibility.

In section 5, I describe my actual life during studying abroad. I could do many kinds of experiences I could not do in Japan. One of these experiences is living with a Danish person. Because of this, I could get to know a lot of foreign students.

At last, I summarize what I could get and review throughout my foreign life in section 6.

3. Travel Schedule

From September to December 2004: Delft University of Technology

January　2005 : Technical University of Denmark

4. Research or Lectures

4.1 Delft University of Technology

4.1.1 Research：Ankle Actuation for Dynamic Biped

Introduction

Recently much research have been performed on robotic walking locomotion such as ASIMO (HONDA) or QRIO (SONY). These robots can walk with two legs. However, the locomotion that is realized by these researches need to be refined and further developed to achieve higher energy efficiency and more natural movement resembling human features. Passive Dynamic Walking has been used as a starting point of the walking theory. This theory is that a simple knee-less biped structure walks down a slightly inclined walkway with no external energy input, in other words, the swing phase is completely ballistic. Passive Dynamic Walking showed that a biped structure itself has a potential to operate locomotion although there is a restriction to a corresponding slope angle and initial angular velocities of each legs. Most recently, the biped robot has been developed based on Passive Dynamic Walking. It has knees, hips and an upper body. But, It doesn't have ankle. we think that it lose high energy at foot contact if it doesn't have ankle. So we propose the model that has legs and flat feet connected to legs with ankle joint. With the addition of ankles the energy efficiency and stability can be improved.

Model

In this section we will explain the model which we treat. The model consists of two rigid legs and two feet connected with ankle joint which is shown in Fig. 1 and Fig. 2. In order to simplify the simulation, we will study a two-dimensional model. We will make the following assumptions to keep the simulation manageable.

1. The legs and feet suffer no flexible deformation.
2. The contact between the foot and the floor are modeled as an instantaneous while the heel
strike impact and toe strike impact.
3. The heel strike impact and toe strike impact are fully inelastic impact where no slip and no bounce occur.
4. The floor is assumed to be a rigid and flat.

There is one problem due to oversimplification of the model. Contrary to humans who have knees, the legs of the model cannot extend or retract, which inevitably leads to foot scuffing at during the leg swinging. In the simulation, we will simply assume that there is no interference between the floor and the swing foot under certain conditions.

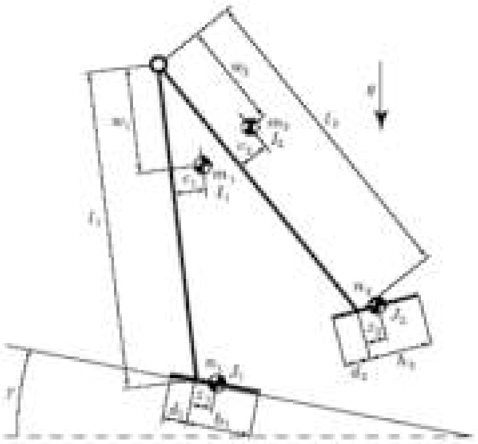

Fig. 1: Parameters of the simulation model

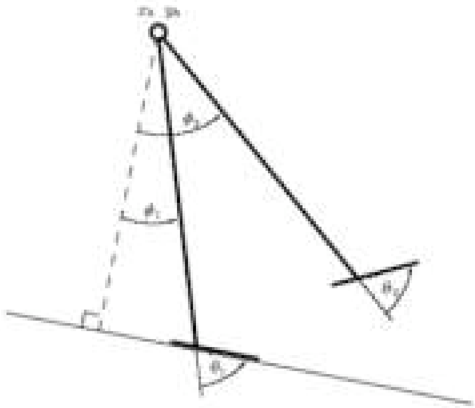

Fig. 2: Six degrees of freedom of the simulation model; the position of hip, the absolute leg angles and the relative foot angles.

Stability

In this section, we describe the stable walking of this model. Its stability is the most important characteristic in order to analyze the walking. As said before, walking should be regarded as a continuous passive fall with intermittent changes of foot contact. And the stable walking is that the stride pattern repeats itself. In other word, the end of a successful step is the start of a new one, and so some points in the graph map to some others. This is called 'Poincare mapping'. If we can find this function, the walking of this model become cyclic motion, which is called limit cycle. However, the Poincare mapping of this model is nonlinear. Therefore we made this function linear around fixed point. This equation is the following.

$$\boldsymbol{v}_{fp} + \Delta \boldsymbol{v}_{n+1} = \boldsymbol{S}(\boldsymbol{v}_{fp} + \Delta \boldsymbol{v}_n) \cong \boldsymbol{S}(\boldsymbol{v}_{fp}) + \boldsymbol{J}\Delta \boldsymbol{v}_n$$

If the eigenvalues of the Jacobian $\boldsymbol{J}$ are between –1 and 1, errors decrease step after step and the walker is stable. The eigenvalues of this model are 0.5799+0·152i, 0.5799-0·152i 0.359, 0.0000, so the model is linearly stable.

Results of simulation

First, we considered Passive Dynamic Walking of this model. Using a Newton-Raphson iteration we could find an initial condition to make the walking of this model a limit cycle. The result of this simulation is shown in Fig. 3.

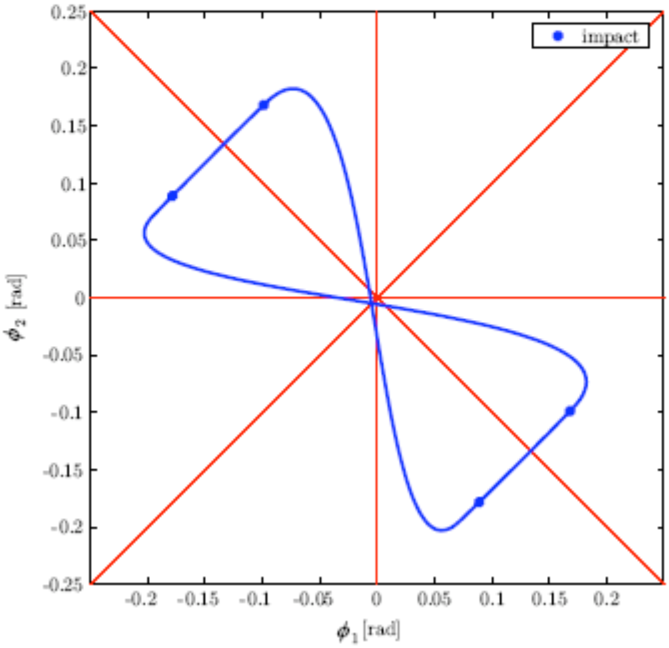

Fig3. The simulation of Passive Dynamic Walking

Next, we considered about the walking on the flat floor. When this model walks down a slope, there is no external input. That's because the energy lost by the impact is provided by the potential energy generated by the slope. However, when this model walks on the flat floor, the potential energy isn't generated. So it needs external input. So, we considered about ankle actuation as the external input such as

- Impulse input to ankle
- Change natural angle of ankle spring
- Change ankle stiffness

The method of changing natural angle is to change the natural angle of foot spring between toe strike and toe lift. The smaller the natural angle is, the larger energy the model is given. The method of changing ankle stiffness is also to change the stiffness of foot spring between heel strike and toe lift. The larger stiffness is, the larger energy the model is given. However, as a result of simulation, even if we made the input larger in any type of ankle actuation, it was impossible to keep the footstep. Therefore it is difficult to find a limit cycle in the walking with only ankle actuation. So we need more actuation in order to find limit cycle. This method is a hip actuation. So, finally, we considered about the walking on the flat floor by ankle actuation and hip actuation. We chose 'Change natural angle of ankle spring' as an ankle actuation. The hip actuation is to change natural angle of hip sprig. By using this method, this model can walk on a flat floor. The result of simulation is shown in Fig 4.

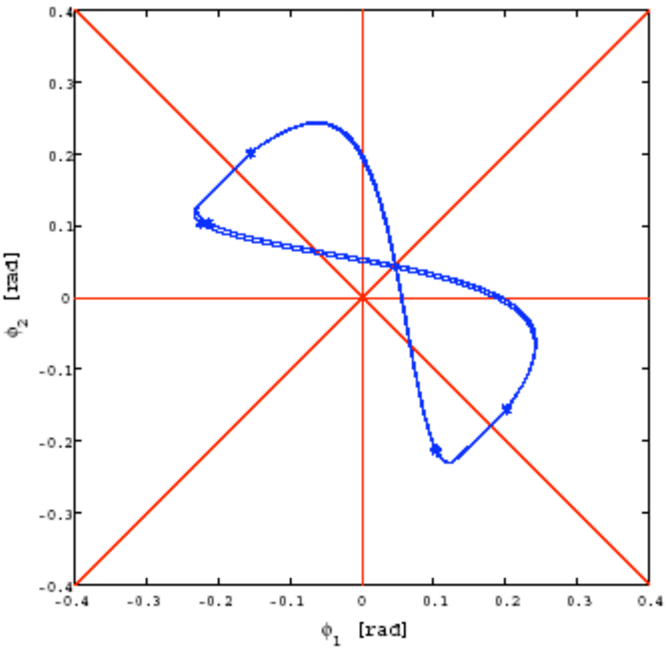

Fig 4. The simulation of Ankle and Hip actuation

4.1.2 Lectures

Control Theory

The topic of the lecture 'Control Theory' is the following.

Control engineering: basic theory. State space description of linear dynamic systems. Realization of transfer function models by state space models. Controllability, observability, minimal order. Parallel and series connection, pole-zero cancellation, relationship with controllability and observability. Controllability and observability canonical forms. Jordan canonical form. Stability theory, frequency domain analysis. Dynamic response, relationship with pole and zero locations in the complex domain. Loop shaping for dynamic response, robustness indicators. Multi-input and multi-output systems. Pole assignment, design of state feedback. Linear observers, Kalman filter. Design of observer. Control design and separation principle. LQ regulator and LQG theory. Algebraic Riccati equation, choice of performance criteria. Asymptotic analysis, LQ control system design, dynamic compensation. Disturbances and reference signals, modelling of exogenous variables. Internal model principle, design of tracking control systems, servomechanism design.

And there is an assignment for real system by using Matlab. In this assignment, we apply the contents of lectures to real system.

Optimization in Systems and Control

Essentially, almost all engineering problems are optimization problems. If a civil engineer designs a bridge, then one of the main objectives is to obtain the cheapest design or the design that can be implemented most rapidly, where of course several specifications and constraints such as size, strength, safety, etc. have to be taken into account. When developing a new type of engine, we look for the most economical design, the cheapest design, or the design with the highest performance. A process engineer wants a production unit to deliver a final product of maximal quality, with minimal expenditure of energy or with maximal output flow. When composing a portfolio, a financial engineer tries to maximize the expected profits, subject to the given risk constraints. So we encounter optimization problems in almost every engineering field. How can we solve such an optimization problem? That is the topic that will be addressed in this course. We will consider both the transformation of real-world design problems into a more mathematical formulation, and the selection of the most efficient numerical algorithms to solve the resulting optimization problem. The examples and case studies of this course are primarily oriented towards systems and control. In preceding courses you have already studied modeling, identification and control of systems. However, the examples in these courses were usually limited to simple or small systems, and more complex systems were often dealt with by saying that they can be tackled using optimization. And that is what we will do in this course: you will not only learn how you can identify models and design controllers for complex systems using numerical optimization, but also how this can be done in the most efficient way. This course is divided into two parts:

1. optimization techniques
2. applications in systems and control

In the first part we study several classes of optimization problems and we discuss which algorithms are the best suited for each particular problem. In the second part we show how a controller design problem can be recast as an optimization problem and we use the results of the first part to efficiently design the controllers using numerical optimization.

Biomedical Engineering Design

Various types of prosthesis are currently on the market for the patients who lost a part of their body such as elbow. However, there are some problems such as functionality or controllability to be solved in order to meet requirements of patients. We receive the explanation about various type of prosthesis or its inner mechanism. After lectures, we discuss a new mechanism of prosthesis in a small group and make presentations at last as an assignment.

4.2 Technical University of Denmark

Research : Robotic Manipulation of Micro Parts

Because of technological achievements many products are continuously becoming smaller and smaller. This trend is especially clear in a broad range of manufacturing industries such as for instance the hearing aid industry. Many components used in high-tech products have reached a size where handling and assembly is becoming the main limitation in the utilization of new technologies.

When we process micro components, it is important to get a relative positioning accuracy between tools and part. For that purpose, it is important not only to improve the accuracy of mechanism between tools and components but also to stabilize the frame of manipulators statically and dynamically. However, the mechanism and the frame change shape by various causes such as disturbances and loads of process. Therefore a relative positioning accuracy between tools and components become worse. In order to avoid these deformation, an accuracy of mechanism had been improved by increasing cross-sectional or and second moment area. However, if the volumes of components become large then we cannot ignore the deformation by its weight.

In order to resolve these problems, a parallel mechanism has been used. A parallel mechanism is a mechanism that actuators are disposed in parallel with end-effectors. Contrary to serial mechanisms the inverse kinematics of parallel mechanisms is usually rather straightforward. Furthermore, the larger the degree of freedom of tools becomes, the easier it is to process components. In 3-dimensional space it needs 6 degrees of freedom. And if the tools are connected with cable, the tools are affected by cable. So, the summaries of requirements for manipulator of micro components are the following.

- Lower Inertia
- Better Dynamic Behavior
- Smaller Package Size
- Higher Stiffness
- No Accumulation of Position Errors
- Reduced Runout Errors

- No Moving Cables:　Better Repeatability and Reliability

In order to satisfy these requirements as many as possible, a hexapod robot was proposed. Because of its structure, it has high rigidity and 6 degrees of freedom movement of the tool.

To enable precise control of robots, encoders are usually embedded in the actuators, but due to the small size of the hexapods such encoders are not used in this case. Instead, two custom made sensory systems are deployed to ensure proper functionality. In the surroundings of the hexapods, a number of optical sensors are placed. Visual servoing is a technique used for servoing a robot on the basis of image data from one or more cameras observing work cell, and thus relevant for the control of the hexapod.

However, in order to put these types of hexapod robots to practical use more, there are a lot of things to improve. In the respect of actuators, step motors are used so that we can control a hexapod easily. Therefore we cannot control the angular momentum. So it is difficult to perform tasks such as assembly. A DC servomotor enables us to control a hexapod dynamically.

The hexapod robot has six degrees of freedom. However its motion is limited to narrow range because of its structure. So if we process complex components, we need more hexapod robot. In micro scale a steady state error or an overshoot is not more negligible than in macro scale

The measuring method of absolute coordinates of current hexapod robot is a camera which is fixed outside. However if we can calculate the position of tool geometrically by loading sensors into each actuator, we can make the robot smaller. And, for example, we can use it for some medical operation.

5. Exchange student life

I stayed in the Netherlands for four months from September to December. Because studying abroad in this project was first experience of living overseas for me I was worried about not only communications with foreigners in English but also gaps in culture and custom between Japan and Europe at first. Moreover I had an accommodation with a Danish person. That's why I was more concerned about my life in the Netherlands than I expected for. However, because I would go to Denmark after staying in the Netherlands, I thought that it was very good chance to get some information about Denmark. I thought I could improve my communication skill by conducting daily conversation with him in English. And while I was living with him, I didn't have a problem so much about communication with him thanks to his concern about my being poor at English conversation.

Because he had many friends from other countries, he usually invited some of his friends to our house and drank with them weekend. So I joined it and conversed with them much in order to improve my English communication skill. Moreover, we had a party in my house once a month and Japanese group cooked some Japanese typical food and Danish group cooked Danish traditional food. So my life with him was very useful and enjoyable.

First, what I spent most time in the Netherlands were lectures and my research in TU Delft. The lectures at TU Delft were very different from those of Osaka University. They were not only taking lectures but also some group assignment or making a presentation. That' s why I could understand their contents in detail. In respect to my research I think I gained very valuable experience. That's because TU Delft is very famous for researches of a walking machine, which I am studying in Japan, and I have wanted to watch some robots there and to get some useful information for the walking machine which is being constructed in Japan before. In fact, I was surprised that the robots could walk I have seen with the video on the flat floor more easily than our robot. And I thought that I could not fail to try to study the technical know-how of a walking robot. However, I could not make my research a breeze more than I had expected because of lack of communication skill. When I went to meet my supervisor in the Netherlands, I had to explain my research in Japan. But I had difficulty in telling it exactly because of lack of technical terms. And I had a meeting once a week in order to report the result and to get detailed advice from my supervisor. First I could not understand what he said exactly for a short time. So I had him draw some pictures. But I could understand what he said and say my thought gradually at last. So I think I brought trouble to my supervisor much. However, I could get a result of my research because of his careful explanation. That's why I am very satisfied with my research in TU Delft. So I want to refer to this result for the research in Japan.

In actual life, when I passed a holiday I was struck by the cultural differences. Some shops are closed on weekend differently from Japan. So I cannot enjoy shopping on weekend. And I felt inconvenienced because of no convenience store open for 24 hours. However, after one month, I got used to these customs. And I could find my daily rhythm, so I didn't feel uncomfortable.

Because I could do various experiences not only in my university life but also in my daily life as mentioned above, this project was very meaningful for me

6. Suggestions to the Project

Countries in Europe are on the border with next countries differently from Japan. So we can see people coming from various countries. However, because of lack of my communication skill, I could not get across my thought to them exactly. Communication skill is one of the most important things in this project the purpose of which is intercultural communication. I think it is necessary to practice English communication in order not to be struck during conversation.

7. Summary

I think that I gained very valuable experience abroad because I could study and take some lectures abroad and get to know people from foreign countries as mentioned above, which is the experiment I cannot gain in Japan. Because of this experiment, I could know various concepts of value and look at Japan from a different point of view. So I could see myself again before getting a job. I want to make use of these experiences not only for my university life and also for my job.