Collaboration Projects

Vibration Suppression Control of Light-Weight High-Speed Humanoid Robot Arm

We conducted research on design and control of humanoid robots to achieve human-like movement in order to achieve both quick motions and safety. With this research, we succeeded in making a light-weight robot arm move at high speed, performing the ribbon spinning movements seen in rhythmic gymnastics. This research was conducted jointly with the Uchiyama/Konno laboratory (Associate Professor Atsushi Konno), the Graduate School of Engineering, Tohoku University

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1. Introduction

Recently, quite vigorous research activities have been made in the field of autonomous humanoid robots, and it is considered that the future when robots with wireless communication functions diffuse into our common households is not so far away. Given this factor, we are looking one step ahead and are currently working on research aimed at using such robots as tools to enrich communication.

There are an idea to use robots as a type of real "media players" [1]. This allows a robot at a remote location to be used as an "avatar" (alter-ego) to communicate gestures and expressions of feeling to people at the target location [2]. Such robots can be used not only for bidirectional communication, but also for tangible playback of media contents. For instance, touch-video can be achieved by showing subjects at the target location wearing Head Mounted Displays (HMD) CG images of the communicating person superimposed on a robot using mixed reality technologies.

Photo 1 shows a time series of video images that might be shown to subjects. In this case, the only purpose of the robot is for the subjects to reach out and touch it, as it changes its posture according to the video.

A wide variations of video contents can be considered depending on the robot development, from contents that focus on conversation and involve little movement, to contents requiring advanced athletic abilities, such as playing music and performing sports activities.

Before the applications discussed above can be implemented in practice, however, various technical issues must be solved, such as implementation of high athletic capabilities and safety aspects of the robots. For this reason, it is necessary to improve the athletic performance while securing safety by weight reduction and develop a control system that suppresses vibrations during movements brought about by the reduced rigidity of the structural materials.

This article explains the results of our research on vibration suppression control of light-weight robot arms.

2. Robot Arm Control Method and Motion Experiment

2.1 Robot Arms

In space applications, long-reach robot arms are used for manipulating satellites and other objects that are far heavier than their own weights, and deflection of the structural parts

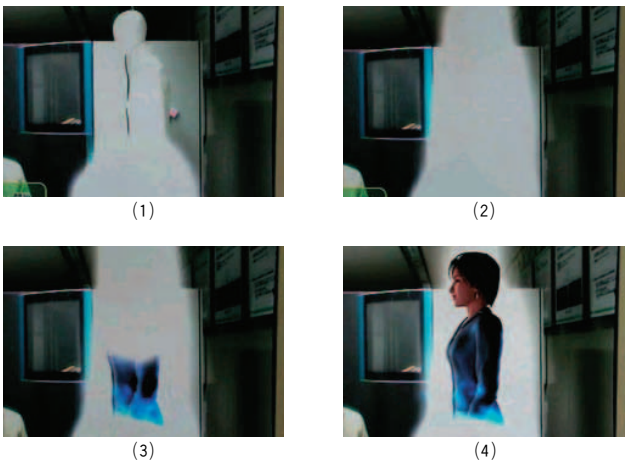

Photo 1 Time series of video images shown to subjects

must be taken into consideration when these arms are controlled. **Photo 2** shows a robot arm created for studies of robot arms in space applications, where highly flexible rods are used intentionally for the structural members. Strain gauges, which are sensors for measuring deflection, are fixed to the rods and the detected deflection of each rod is used as a feedback signal for control purposes. It should be noted that, under normal circumstances, members used for humanoid robots are typically modeled as rigid bodies, but in fact they do also deflect when the arms are moved at high speed. Thus, they should actually be modeled as flexible arms and controlled accordingly, in the same way as for space robots.

Photo 3 shows the robot arm used in this research. The thin wire-shaped objects in the enlarged photo (the circled areas) are the wiring of the strain gauges.

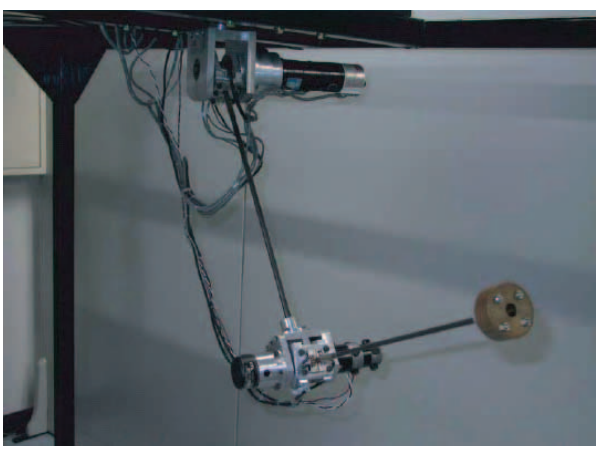

Photo 2 Example of space robot arm

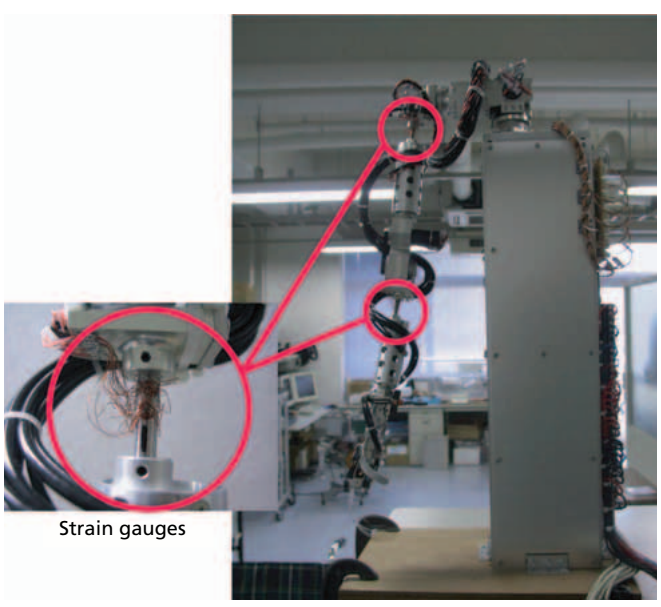

Photo 3 Robot arm used in this research

2.2 Comparison with Human Arms

The robot arm used in this research was built for the purpose of using the robot as a media player; it is thus necessary to reproduce human movements accurately. A human arm consists of three joints located at the shoulder, elbow and wrist, connected by the upper and lower arm, respectively. Among these, the only components that are difficult to simulate are the joints. As the flexibility of the human arm is increased, the contact area between the joint surfaces becomes smaller and the risk of bone dislocation increases proportionally. To accommodate this, the human flexible joints are configured with tendons and muscles connecting the bones and have a very complicated mechanism.

This complicated structure appears dominantly in the shoulder structure. The shoulder blade bones are separated from the ribcage and have several degrees of freedom; the center of rotation itself can be moved up/down as well as forward/backward.

The aim of this research is to achieve both a reproduction of human movements and safety. In order to achieve these, it is necessary to reproduce the complicated mechanism of human arms to the greatest extent possible while keeping the weight low. We thus adopted a design where the arm has more joints that can be operated independently (degrees of freedom) than a normal humanoid robot. Specifically, as shown in **Figure 1**, the robot arm has 10 degrees of freedom in total: two degrees of freedom at the area corresponding to the base of the collarbone, three degrees of freedom at the shoulder, one degree of freedom at the elbow, three degrees of freedom at the wrist and one degree of freedom at the hand. Moreover, each member is made as thin as possible so that they can be driven by compact motors.

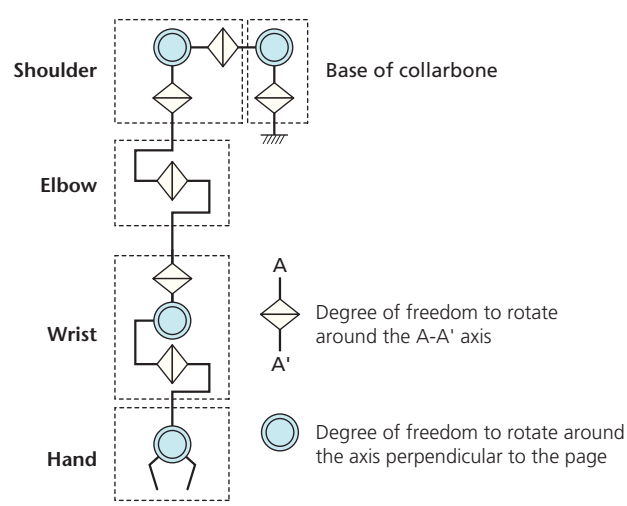

Figure 1 Configuration of degrees of freedom of robot arm joints

2.3 Modeling for Control Purposes

A robot arm is normally constructed by connecting links (bars) together using rotating joints. When analyzing such structures dynamically, each link is typically modeled as a rigid body (an object that cannot be bent) whose mass is concentrated at the center. In these models, the flexibility of the links is ignored and vibrations in the links due to high-speed movement hence cannot be analyzed. When the structures are flexible, however, it becomes necessary to formulate models that include spring factors in the structure and use these model equations to analyze the vibrations.

One method for conducting simple modeling while maintaining practical accuracy that has been proposed for some time is the concentrated spring mass modeling [3] [4]. In this modeling method, an arm is divided into multiple sections. The mass of each section is divided into two, which are assumed to be concentrated at both ends of each section. The intervals between each individual pair of concentrated masses (station) are regarded as a mass-less spring (field). **Figure 2** shows a concept of flexible arm.

2.4 Control Method

The difficulty in controlling flexible arms is that it is necessary to perform the intended task of achieving certain movements, while at the same time suppressing the vibrations generated during the movements by the control. That is, there are two parallel control objectives that must be taken into consideration at the same time: the controllability of the movements themselves, and the controllability of the vibration suppression.

Moreover, a flexible arm operating in three-dimensional space has the characteristic that the mechanical properties such as rigidity change significantly depending on the posture.

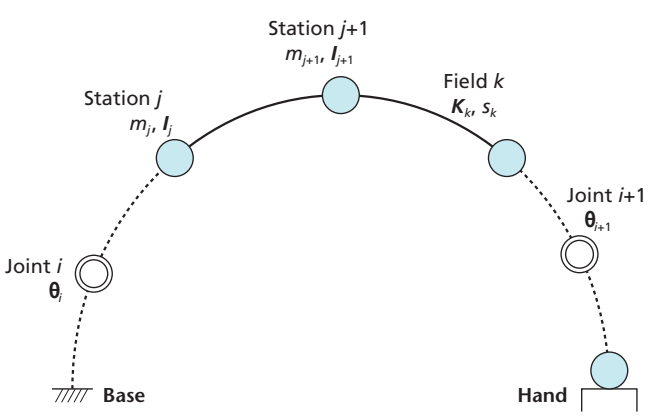

Figure 2 Concept of flexible arm [3]

Particularly since the controllability of elastic vibrations depends on the arm's posture, it is necessary to take this dependency on posture into consideration when developing the control law for suppressing the structural elastic vibrations.

To deal with this issue, the concept of mode accessibility, where the concept of accessibility proposed by Tosunoglu et al. is applied to elastic vibration modes at each level, has been proposed [5]-[8]. Through the introduction of this concept, it becomes possible to evaluate each actuator incorporated in the robot arm quantitatively in terms of degree of influence on each of the elastic vibration modes, indicating the levels at which each actuator is able to influence each vibration mode. This technique clarifies the relationship between the uncontrollable postures and inaccessible postures of elastic vibrations, allowing the control designer to find postures where the mechanical vibrations in the robot arms render the system uncontrollable in practice.

2.5 Motion Capture

As an example of movements to be performed by the robot, we measured the movements in a ribbon exercise performed by a rhythmic gymnast with experience of participating in the Olympics. The measurement/experiment was conducted in the Multimedia Laboratories; it was a highly complex task of measuring not only the overall body movements but also detailed movements of the fingers using 10 cameras.

2.6 Experiment

Based on the analysis and control design tasks described above, we conducted a motion control experiment using the robot arm introduced in Section 2.1.

We confirmed that the vibration suppression control law worked by stopping the arm suddenly during the motion experiment, and we succeeded in making the robot arm recreate the ribbon spinning movements of the human rhythmic gymnast observed in the recorded motion capture data, taking advantage of the arm's high-speed movement capabilities (**Photo 4**).

3. Conclusion

In order to achieve an effective arm design for quick and agile light-weight humanoid robots, we extended the design ideas of space robots, whose weights are being minimized as much as possible, while retaining controllability by taking the flexibility of the robot arms into consideration in the control

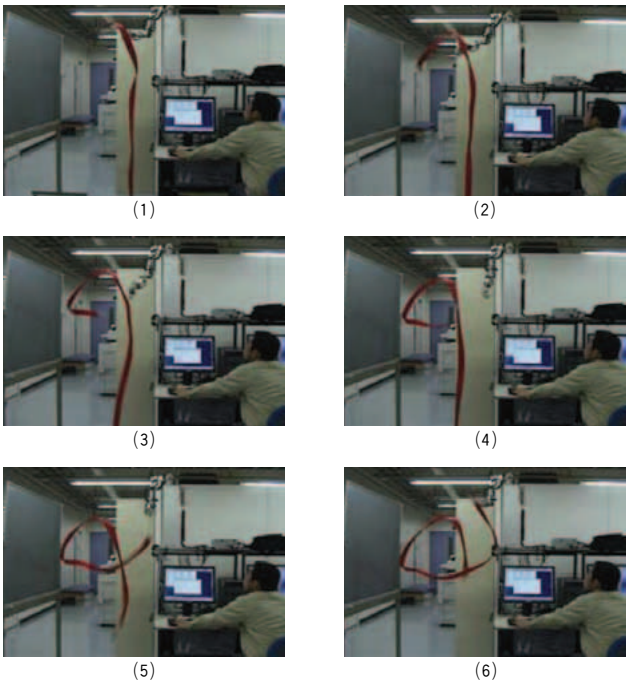

Photo 4 Ribbon rotation movement achieved by robot arm

design. Since the arm designed in this work is equipped with 10 degrees of freedom, it can move more human-like and smoothly than conventional robot arms. Using its special capabilities for quick and agile motion, it can be applied to humanoid robots for playing and enjoying dynamic contents. In the future, we intend to investigate ways to achieve even faster and more stable motion.

References

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Abbreviations

HMD: Head Mounted Display