Adaptive Motion of a Musculoskeletal Robot Arm utilizing Physical Constraint

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Abstract: Musculoskeletal robots have been developed to investigate how musculoskeletal systems contribute to intelligent behaviors in living things. In this research, we develop a musculoskeletal robot arm, which has a skeleton similar to human's arm and pneumatic muscles to drive the skeleton, in order to investigate how the design contributes to adaptive behavior under physical constraint. As an example of a physical constraint, we focus on a door-opening task in which the robot arm reaches and grasps a doorknob to open the door. In this paper, we show that the musculoskeletal robot arm can accomplish the door-opening task by using its characteristics even if the door slightly moves and rotates.

Keywords: Musculoskeletal robot arm, Adaptive behavior, Constrained environment

1. INTRODUCTION

Design of a robot bears a central role for the attainment of a given task because it determines how the given task is difficult for the robot. So far, in terms of engineering, it has been mentioned that the most important characteristic of the robot's design is how easily and accurately it can be modeled analytically. In contrast with this common sense of control engineering, in recent years, it is known that well-designed robot's body can make a huge contribution for task accomplishment even if the robot cannot be modeled sufficiently. The information processing, which provided by the well-designed robot's body, is called morphological computation[1]. In this research, we focus on the morphological computation of a musculoskeletal robot arm designed by referring human's musculoskeletal system.

So far, many researhes have focused on musculoskeletal system as a driving system for robot arms. However, these designs are not similar to human's nor other living organism's musculoskeletal system. In contrast with these researches, there are several researches which strongly focus and mimic a human's musculoskeletal system. Holland and Knight developed a humanoid robot called CRONOS[2], and Mizuuchi et al. also developed a humanoid robot called Kojiro[3]. These robots have a structure similar to human's one and they are not limited to an arm. However, the concrete advantage of their structure is still not quantitatively shown in these researches.

In this research, we develop a musculoskeletal robot arm based on a human's upper limb musculoskeleton in order to investigate how the design contributes adaptive behavior of human beings. As one of tasks which a human naturally does, we focus on a task in which the developed robot arm reaches and grasps a doorknob and opens the door. This door-opening task, where the robot arm has to physically contact with the doorknob, is known as one of most difficult task for traditional robots[4]. In this paper, we realize the door-opening task by using very simple control and evaluate how the design of the robot arm contributes for the task accomplishment quantitatively.

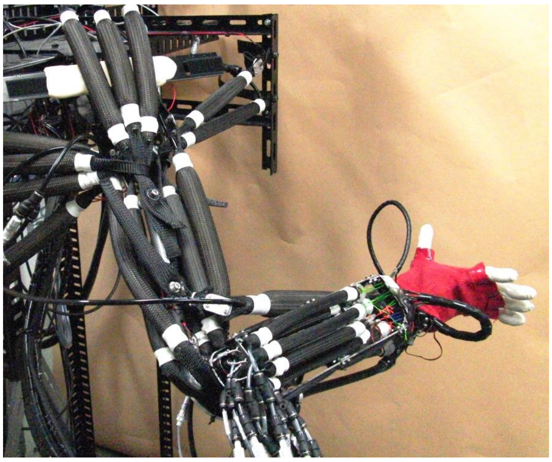


Fig. 1 The developed musculoskeletal robot arm.

2. MUSCULOSKELETAL ROBOT ARM

Fig.1 shows the overview of the developed musculoskeletal robot arm. In this design, there are several similarities with humans' structure. For example, the forearm consists in a radioulnar joint (two bones called ulna and radius set in a parallel configuration that allows for twisting) and the wrist joint employs an ellipsoidal joint[5]. In order to drive this structure, 17 McKibben pneumatic muscles are attached to the bones. The muscle's layout is also inspired by that of humans. For instance, there are not only monoarticular muscles but also biarticular muscles and almost of them are part of antagonistic pairs[5]. Additionally the robot hand mounted on the developed robot is also driven by pneumatic muscles. Each pneumatic muscle has a pressure sensor and its internal pressure is controlled by a PID control system.

Fig.2 shows the sequential snapshots of the realized door-opening task. The motions were generated by a very simple control which switches several desired pressures of each muscles because the flexibility of the muscles and the humanlike skeleton can allow physical interactions with the door in a careless way. At the same time,

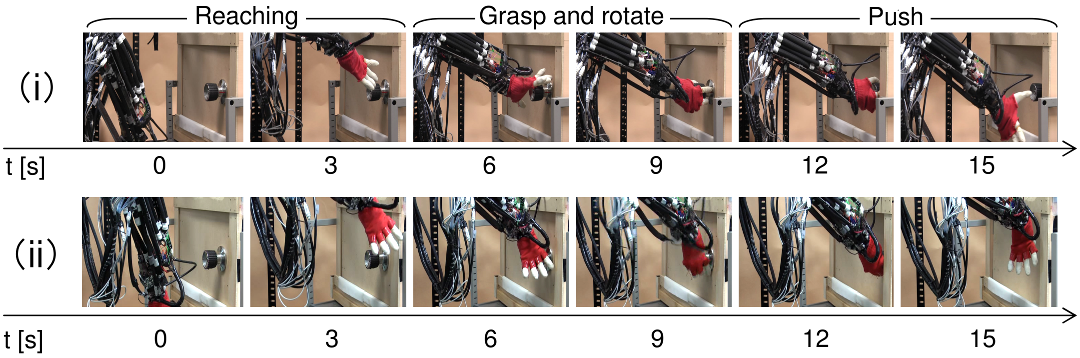


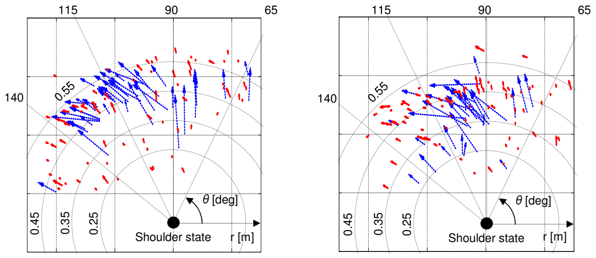
Fig. 2 Door opening movements by the developed robot arm. (i)Precision grip, and (ii)power grip were executed.

the muscle flexibility and humanlike skeleton would provide high robustness when the relative attitude between the door and the arm is changed. The desired pressures were configured by a trial-and-error process and it was not very difficult. In fact, if the robot can keep grasping the doorknob, randomly generated motions are still sufficient to rotate the doorknob and open the door.

3. EXPERIMENT AND RESULT

In this section, we evaluate the robustness of the both motions employing precision grip and power grip which require different postures of the forearm to grasp the doorknob. Fig.3 shows the result of the evaluation of the door-opening robustness. In this experiment, the same sets of desired pressure were used for different relative attitude between the door and the arm. Note that, however, the reaching phase was skipped by fixing the robot hand on the doorknob. In this figure, the blue and red arrows indicate successful and failed directions of the door-opening, respectively, obtained for different attitudes In this result, it is shown that both kinds of motions can open the door by using same sets of desired pressure even if the relative attitude between the door and the arm was changed. This would show the advantage of the flexibility of the developed robot arm because the flexible muscles can store and emit elastic energy to adapt the environmental change. Additionally, difference of the grip can be seen as difference in the directions for which the robot can successfully open the door. This indicates that the flexibility of the arm robot can adapt the changing of the external physical constraints.

Table.1 shows the result of quantitative evaluation of the robustness. From this table, it can be seen that the design of the developed robot arm contribute to improve the robustness of attainment of the door-opening task quantitatively. Additionally, it is also clarified that the difference in the grip provides different property of robustness. In order to increase the success rate, adopting sensory feedback control or machine learning technique will be an important future work.



(i) Precision grip (ii) Power grip

Fig. 3 Result of the robustness analysis.

Table 1 Success rates of door opening

r[m]	Success rate[%](trials)	
	(i) Precision grip	(ii) Power grip
$r < 0.25$	0 (5)	60.0 (10)
$0.25 \leq r < 0.35$	26.7 (15)	57.1 (21)
$0.35 \leq r < 0.45$	64.5 (31)	43.2 (44)
$0.45 \leq r < 0.55$	40.0 (50)	24.2 (33)
$0.55 \leq r$	7.1 (14)	0 (2)

θ[deg]	Success rate[%](trials)	
	(i) Precision grip	(ii) Power grip
$\theta < 65$	33.3 (6)	14.3 (7)
$65 \leq \theta < 90$	26.9 (26)	42.9 (28)
$90 \leq \theta < 115$	53.1 (32)	52.4 (42)
$115 \leq \theta < 140$	50.0 (36)	27.6 (29)
$140 \leq \theta$	6.7 (15)	50.0 (4)

REFERENCES

[1] R.Pfeifer and J.Bongard. *how the body shapes the way we think. a new view of intelligence*. MIT Press, 2006.

[2] O.Holland and R.Knight. The anthropomimetic principle. *Proceedings of the AISB06 Symposium on Biologically Inspired Robotics*, 2006.

[3] I. Mizuuchi, Y. Nakanishi, Y. Sodeyama, Y. Namiki, T. Nishino, N. Muramatsu, J. Urata, K. Hongo, T. Yoshikai, and M. Inaba. An advanced musculoskeletal humanoid kojiro. pages 294 –299, nov. 2007.

[4] W. Chung, C. Rhee, Y. Shim, H. Lee, and S. Park. Door-opening control of a service robot using the multifingered robot hand. *Industrial Electronics, IEEE Transactions on*, 56(10):3975 –3984, oct. 2009.

[5] D.A. Neumann and D.L. Wong. *Kinesiology of the musculoskeletal system: foundations for physical rehabilitation*. Mosby St Louis, MO, 2002.