BASIC EXPERIMENT TO COMPARE THE PERFORMANCE OF MULTI-ARTICULATED 3-DIGIT MYOELECTRIC HAND

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ABSTRACT

The anthropomorphic hands with multi-articulated digit are appealing compared to conventional 1-Degree-of-Freedom hands with 3-digits 3-joints. The coordinated movable joints ease to grasp objects with variety of shape and size while reducing compensative joint movements of the residual limb and torso. Therefore, the developers state their design superiority based on the number of capable prehensile forms, which are important index to describe the static function of holding object(s) within the hand. However, to conduct tasks, the response and efficiency grasping motion are nevertheless important. Further understanding the effect of multi-articulated digit design on the static and dynamic functions, in relation with myoelectric control is a notable topic. In this research, we conducted a comparative experiment between 3-digit hands: 3-joint conventional, Ottobock DMC hand, and 7-joint multi-articulated fingered THK TRX hand. Gripping time of pick-and-place task on large and small diameter cylinders were measured. 3 non-amputee subjects participated in the test using hand mounted on a quasi-prosthesis socket. As result, the large diameter cylinder's average gripping time of 7-joint hand was 0.77 seconds, larger than that of the 3-joint hand, 0.42 seconds. For the small diameter cylinder, the gripping time for 7-joint hand was shorter than the 3-joint hand.

INTRODUCTION

The anthropomorphic prosthetic hands with multi-articulated digit are appealing compared to conventional 1-Degree-of-Freedom (DoF) hands with 3-digits 3-joints structure. The coordinated movable joints of anthropomorphic hands ease to grasp objects with variety of shape and size while reducing compensative joint movements of the residual limb and torso. Therefore, the developers state their design superiority based on the number of capable prehensile forms [1, 2], which are important index to describe the static function of holding object(s) within the hand. However, to conduct manipulation tasks, the dynamic functions, i.e. response and efficiency gripping motion, are nevertheless important. Fukuda et al. [3] reports difference between the proportional speed and the constant speed myoelectric control of a hand on the screen. The trajectory of approaching the hand to the target and the gripping time operating the virtual hand on a monitor showed different timing of closing the hand. Bouwsema et al. [4] reports on their investigation of two grasping tasks and a reciprocal pointing task of a myoelectric transradial prosthesis in comparison to intact hand. Decoupling of reach and grasp were reported with other characteristic of kinematics of grasping. Experiment to analyze the trajectory and motion time of conducting tasks with myoelectric hand with multi-articulated digit should indicate design solution to improve static and dynamic functions of the hand mechanism. In this paper, a basic experiment is reported comparing the performance of 3-digit myoelectric hand with multi-articulated and traditional digits.

METHODS

Two 3-digit 1-DoF hand is compared. As a conventional prosthetic hand, Ottobock 8E38=6 DMC plus (referred to as DMC hand) is applied. The MP joint in the digits are coupled and driven. As Multi-articulated digit hand, THK TRX hand prototype (referred to as TRX hand) is applied. The index and middle fingers are designed with link-coupled 3-joint mechanism. The PIP joint of the finger flexes in relation to the MP joint, and a coil spring in the DIP joint operates to adapt the joint angle to settle the contact. The thumb's MP joint is driven in relation to the finger's

MP joint with a linear actuator. The TRX hand is operated by two microcomputers: THK SEED-MS3A (referred to as MS3A) and SEED-BL1A (referred to as BL1A), as in Figure 2. The MS3A acquires and process the myoelectric sensor signals and BL1A operates the linear actuator speed for opening and closing the hand.

To experiment the effect of articulated finger on the reach-gasp-pick-place-release task, subjects' operations of the hands were measured and the gripping time are compared. Motion capture and analysis system (Nobby Tech, VENUS 3D), with 4 cameras (Optitrack Flex 13, 1280x1024, Sampling:120 Hz) are arranged on the desk and 6 markers (Diameter:6.6 mm) were attached to the hands in relation to compute the joint angles of the digits and hand position and posture (Figure 3). The experiment was approved by the TDU IRB (#28-97, 29-83, 30-65, 31-094). Three able-bodied subjects (average 23.3 SD0.4 years-of-age, all male and right handed) participated donning a quasi-transradial socket with hands connected distal to the sound hand, after giving a written consent (Figure 3). Two objects, a large diameter cylinder (D:48 mm, H:100 mm, 112 g) and a small diameter cylinder (D:30 mm, H:100 mm, 42 g), were to be grasped at the lateral side. The large diameter cylinder was requested to hold with power grip form, and small diameter cylinder with precision grip form at the distal phalanges. The right direction was set as positive of X axis, the depth direction as positive Z axis, and the vertical up direction as Y axis (Figure 4). The initial position of the hand was set on the edge of the desk. The object initial position was set on the desk (H:780 mm) at the position Z:300 mm, X:-100 mm and released at position Z:300 mm X:100 mm. The subject was seated at H:440 mm, Z:-300m, in front of the desktop workspace. The experimental was proceeded as follows:

1) Adjust the width between the thumb and finger to 50 mm by grasping a wooden rectangular parallelepiped (50x50x100mm) before measurement.
2) Place the hand in the initial position.
3) Reach, gasp, pick, move the object to the right 200 mm and release.
4) Returned the hand to the initial position.

The experiment was conducted with the small diameter cylinder first and the large diameter cylinder latter for both hands. Subjects practiced 5 times before measurement. Total of 120 trials (10 trials for 2-objects, 2-hands, 3-subjects) were recorded and the latter 5 trials in each condition were used for evaluation.

Figure 1: DMC (top) and TRX (bottom) hand's full open/close state

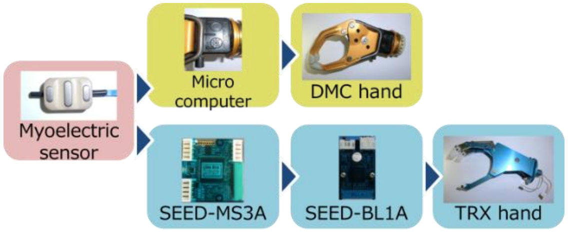

Figure 2: DMC hand and TRX hand's controller components

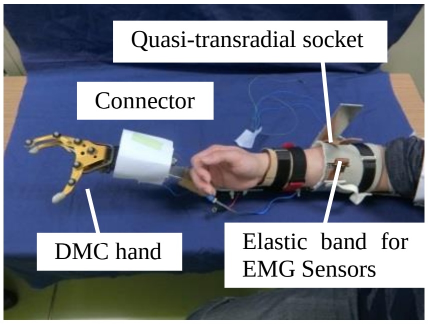

Figure 3: Experimental setup of the DMC hand on quasi-transradial socket

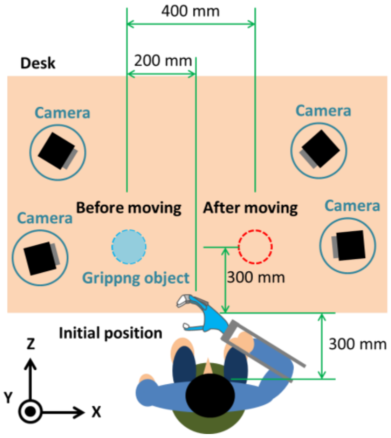

Figure 4: Experimental setup for measurement of pick-and-place task of small and large diameter cylinder.

RESULT & DISCUSSION

The gripping time, which consist of time during the reach and grasp motion, of the hands were calculated from the joint angle valuation of the index finger. The results showed that 3-joint DMC hand took approximately twice longer time to grip the small diameter cylinder, average 0.73 s, than the 7-joint TRX hand, 0.38 s, and on the contrary, DMC hand took approximately half to grip the large diameter cylinder, 0.42 s, than the TRX hand, 0.77 s (Figure 5). T-test showed that the differences were significant: the small diameter cylinder (t=2.22, df=28, $p<0.05$), and the large diameter cylinder (t=-2.38, df=28, $p<0.05$).

The changer over between the cylinder diameter size is further inspected. Light et al. reported, that the mean norm task time of power grasping objects, heavy- and light-weight, is longer than that of precision (tip and tripod) grip in their result analysis experiment with the SHAP test with intact upper limb subjects [5]. The 7-joint hand shows a resembling result to the SHAP test, however the time for small diameter cylinder is shorter. This is due to the initial “hand open” finger position to make the fingertip travel smaller. The articulated mechanism allows the fingertip to be moved faster making the 3-joint hand slower to grip. On the large diameter cylinder, the 3-joint hand became faster with the hand gripping the object with the proximal part of the hand. The assumption of the cause of this was that digit shape of the 3-joint hand makes the Form Closure of the grip [6] easier and with less movement to enable short gripping time. To confirm this assumption, the time to the contact of the cylinder and the hand were computed (Figure 6). The 7-joint hand contact was 0.17 s and shorter than that of 3-joint hand. The T-test between the hands showed the difference was significant ($t = 2.68$, $df = 15$, $p > 0.05$). This showed that 7-joint hand required additional time to have the distal phalanges to contact the object for Form Closure to stabilize the force to proceed to pick the object. The time surrounded by the dotted line on the bar of TRX_large can be considered as the drawback of mimetic mechanism of the human digit. Furthermore, this lag can be the disappointment of the DMC hand user to feel that multi-articulated hands to be cumbersome.

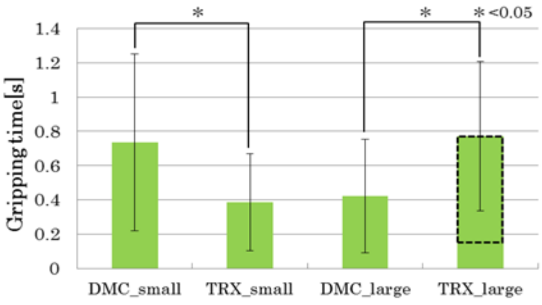

Figure 5. The gripping time in each condition

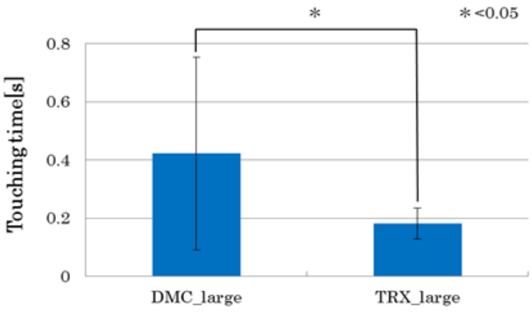

Figure 6. Average time till contacting the object with the hand

CONCLUSION

The effect of the multi-articulated finger control to perform pick-and-place task was discussed by comparing the gripping time of small and large diameter cylinders. A 7-joint THK TRX hand and the 3-joint Ottobock DMC hand are operated by non-amputee subject and motion capture system is used to evaluate and compare the result. The results showed that 3-joint DMC hand took approximately twice longer time to grip the small diameter cylinder, average 0.73 s, than the 7-joint TRX hand, 0.38 s, and on the contrary, DMC hand took approximately half to grip the large diameter cylinder, 0.42 s, than the TRX hand, 0.77 s. Further inspection described that the time for Form Closure of the 7-joint hand causes addition time to power grasp compared to the 3-joint hand. Further analysis of the motion captured data and modified experimental design is required to investigate the design factors of prosthetic hand mechanism and myoelectric control and their ponderability to the performance of object manipulation.

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