論文 / 著書情報
Article / Book Information

Title	Big-hand: Fluid Powered Soft Hand to Hold a Human Body Aiming for Caregiver Body Lifting Action Support
Authors	Chiun Tai Loh, Hideyuki Tsukagoshi
Citation	The 12th International Symposium on Fluid Control, Measurement and Visualization(FLUCOME2013), , , pp. OS4-01-2
Pub. date	2013, 11

The 12th International Symposium on Fluid Control,
Measurement and Visualization
November18-23, 2013, Nara, Japan
FLUCOME2013

Big-hand: Fluid Powered Soft Hand to Hold a Human Body Aiming for Caregiver Body Lifting Action Support

CT. Loh[*]**, H. Tsukagoshi**
Department of Mechanical and Control Engineering, Tokyo Institute of Technology, Tokyo, Japan
*Corresponding author, E-mail: lohchiuntai@cm.ctrl.titech.ac.jp

ABSTRACT

The percentage of old age people around the world is increasing especially in Japan. With the increase number of old people in the community, the demand for caregiver will increase accordingly. This will then put more physical burden towards caregiver. Therefore, robotic assistance for caregiver is needed to reduce their work burden especially in physically challenged task such as human transport. In this paper, a new robotic system called Big-hand is being proposed. The Big-hand acts as a connecting mechanism that connects human body to the robotics system that will perform all sorts of supporting action. High compliance is required as it is dealing with delicate human body. Three different concepts has been proposed and there are some improvement on each of the concept compare to the previous one. Improvements and weakness of each of the concept are being discussed in this paper. All concepts are design based on pneumatic power as it is light weight and has high power output. Besides, having pneumatic powered actuator near a patient will not interfere with any electronics device that the patient is using which is a big advantage. Lastly, the paper states the future development of this research.

Keywords: *pneumatic, rehabilitation, caregiver, soft-robotics, nursing*

1. INTRODUCTION

The number of people with the age of 65 years old and above in Japan is increasing every year. This brings an issue of increase of caregiver demand as aging people tends to lose their physical ability to live independently. Furthermore, the workload of caregiver itself is physically challenging especially in human transfer task. When dealing with delicate object, human tends to exert more force than required and this increases the chance of injury towards themselves. Due to this fact, nursing personal and caregiver has been hoping to have robotics system to help them in moving and supporting patient. Knowing this problem, some big company has started to developing robots that aid in moving patient around such as the RIBA 1 and 2 [1,2,3], Panasonic Power Motion Assist [4], wheel chair convertible bed [5,6], and also the Toyota Care Assist Robot [7]. These development will aid nursing and caregiver in transferring patient but the robots are too big and heavy to be implemented in normal household especially in Japanese household.

All current development of healthcare support robots are actuated using electrical power. Due to this, the size and weight of the whole system are relatively big and heavy. Instead of using electrical power, the author selected pneumatic power due to high power to weight ratio and it does not interfere with any electronics device that the patient is using. With proper design, pneumatic actuator can be compliance which will aid in minimizing injury when transfer task is being performed. The final goal of the research is to design a robotic system that is light weight, cheap and easily being used by normal people.

The following of this paper will discuss on the proposed concept, each and every concept strength and weaknesses and also the possible improvement.

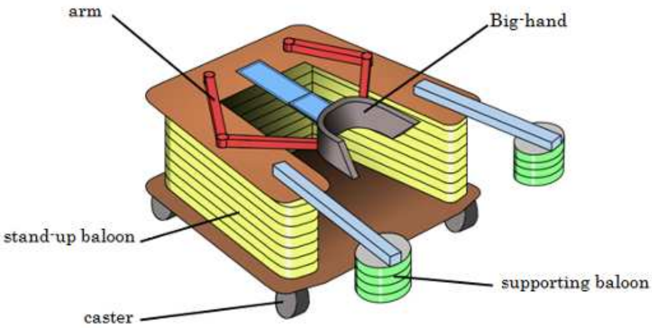

Figure 1: Structure of stand-up supporting system of Big-hand

2. BIG-HAND STAND-UP SUPPORTING SYSTEM BASIC STRUCTURE

Figure 1 shows the basic structure of standing up supporting system. It consists of several actuator and all of them are actuated by pneumatic which makes it lightweight. Big-hand in this system is to connect the human body with the supporting system. Behind the Big-hand, an extending arm using Λ-drive for actuation. For the main standing up supporting force, stand-up balloon is used. During the stand-up supporting action, the center of gravity of the system and human being is not stable as it is situated outside of the system and will tend to topple towards the patient direction. Therefore, a supporting balloon at the front of the system is placed to provide balancing support. Caster is fixed at the bottom of the system to allow easy maneuver by the user.

2.1 Big-hand stand-up supporting system supporting action.

This system main focus is to support a patient with weak lower extremities in standing up. In order to do so, the system need to go through three major steps in order to perform the whole supporting action. The whole supporting action is shown in figure 2.

The supporting action start off with alignment where the patient or helper align the system to make sure that the Big-hand is facing towards the patient chest. Once it is aligned, the Big-hand will be extended by the extending arm using the Λ-drive. Extending the arm allowing the Big-hand to fit to the patient chest and grip their body. This will connect the patient to the system and allow it to perform the supporting action. Before upward support is carried out, the system will first need to adjust the patient center of gravity. To do so, the system will simply pull back the Big-hand together with the patient body using the extending arm. Once at a stable center gravity position, the stand-up balloon and the supporting balloon will be inflated to provide upwards supporting motion. While this stand-up motion is occurring, Supporting balloon and stand-up balloon will adjust accordingly to ensure that the patient balance is at place so that there will not be any accident occurring.

Besides supporting standing-up motion, the system can be used for rehabilitation towards the patient lower extremities. Usually patient with weak leg does not has the strength to stand up and walk and will probably rely on wheel chair most of the time. This will cause the patient to lose his or her leg strength even more when time goes by. Using this system, it allows the patient to do squad action with some supporting so that they could retain their leg strength as much as possible without the need of rehabilitation personal.

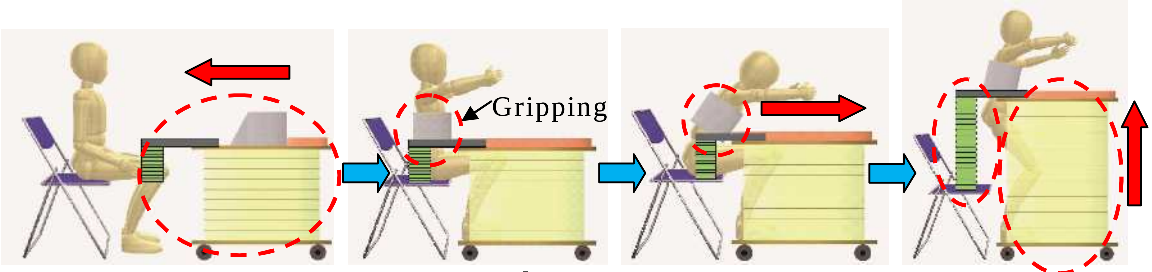

Figure 2: Stand-up Supporting Steps

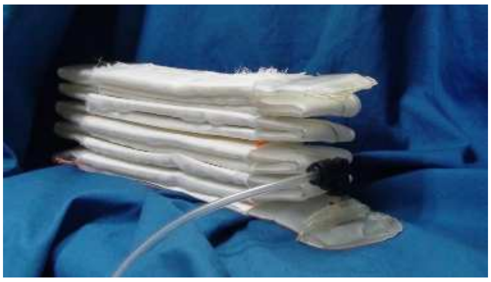

Figure 3: ZTA with cloth binding

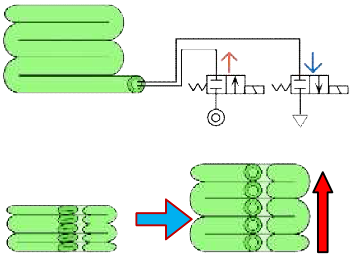

Figure 4: Zig-zag tube operating principle

3. STAND-UP BALLOON DETAIL

Stand-up balloon is the main upward pushing force actuator. It is form from flatten urethane tube in a zig-zag manner as shown in figure 3 which is called zig-zag tube actuator (ZTA). As this tube has the tendency to lose its folding arrangement when pressure is being supplied, a cloth binding is being put on the entire tube which will constrain its sideways movement. The whole ZTA is very light in weight and the output power is high enough to support the human body weight. For testing, the system is built for a human with the height of 130cm. To support human of this size, ZTA with a width of 50mm, length of 300mm and 28 times of folding of the tube is needed. Each layer of the tube has a thickness of 2mm and its height is 112mm without pressure supply. When 0.2MPa pressure being supplied, the ZTA is able to produce more than 80kg force which is more than enough to support human of this size. The expansion illustration is shown in figure 4. At supplied pressure, ZTA is able to expand to 400mm height which is more than enough for supporting a stand-up motion. If actual adult size ZTA is build according to this ratio it should be able to support adult size human without any problem.

4. SUPPORTING BALLOON DETAIL

The main purpose of the supporting balloon is to prevent the toppling of the whole stand-up supporting system. The working principle is almost the same as ZTA but there is a slight difference in their tube arrangement. As mentioned in the previous section, ZTA is formed from stack up folding of flat tube. As for this supporting balloon, the tube is stack up in a wound up configuration which gives the name of Wound Tube Actuator (WTA). Figure 5 shows the actual WTA and figure 6 shows the working principle of WTA.

5. EXTENDING ARM

Big-hand need to be extended out of the supporting system in order to grab on to patient body. To do so, the extending arm in plays the role in providing this extending force and retraction force. Extending force and retraction force of this arm is produce through Λ-drive which is shown in figure 7. There is a tube in a Λ-drive but it is separated into two different section. Supplying pressure into either one of this section will produce either pulling or pushing force.

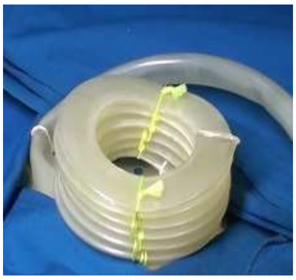

Figure 5: WTA

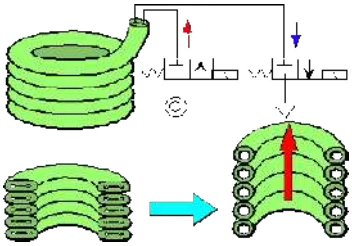

Figure 6: Operating principle of WTA

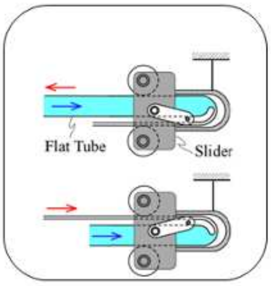

Figure 7: Λ-drive

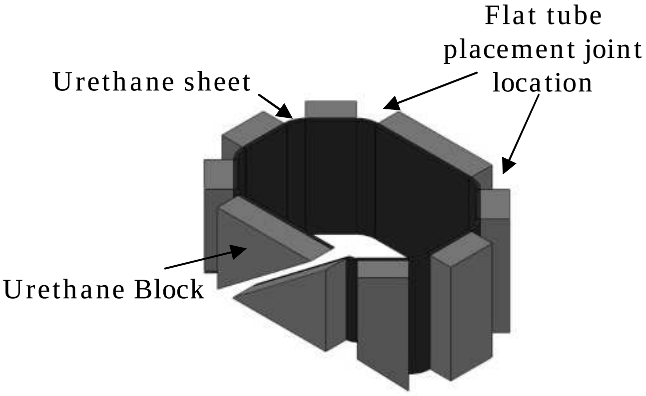

Figure 8: Polyurethane concept design

Figure 9: Polyurethane concept prototype

6. BIG-HAND WITH FLAT TUBE JOINT USING FOAM POLYURETHANE

The first concept was proposed with the main objective of having a soft robots that is gentle towards human being while performing the task. To achieve this gentleness, foam polyurethane is being used as the building block. Figure 8 shows the design of the first concept of Big-hand and figure 9 is the prototype of the first concept. As seen in figure 8, the hand is entirely build from foam polyurethane with flat tube being placed in its joint. By inflating the flat tube urethane at the joint, inflation of the tubes create a pushing force which will then bend the hand into gripping action.

6.1 Flat tube joint using foam polyurethane

Force is generated from inflation of flat tube at the joints. Flat tube itself is light in weight but has limited bending angle and the output force is not linear with respect to angle. Bending angle can be increased by increase the number of tubes placed in a single joint. On the other hand, the force profile of flat tube is influenced by the change of tube geometry when the bending angle changes. This non linearity cannot be change as long as tube is being used. As patient comfort is very important to gain their confidence in the device, torque control on every individual joint is required to achieve even force distribution when gripping. Therefore, it is crucial to understand the torque profile of flat tube joint.

Force output from the tube has direct relation with the mating area of the tube. The mating area can be calculated from the geometry changes of the tube. From the cross sectional area of the tube, when joint angle is zero, the tube geometry consists of two semi circles at both ends of a rectangle. The geometry of the tube will then change in to a shape shown in figure 10. It is assume that changes of the tube circumference is negligible thus it remains constant regardless the change in pressure and angle. In figure 10, length l is the portion where the pressure is being converted into torque for that joint. Length l is decreasing as the joint angle increases. Foam polyurethane has been used as a connecting joint between linkages and this causes the joint does not has a fixed rotating point. This furthers complicates the geometry equation because the rotating point is changing with respect to the bending angle.

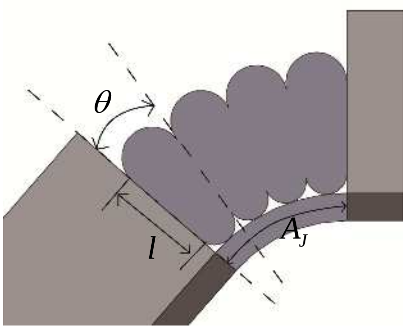

Figure 10: Flat tube joint model

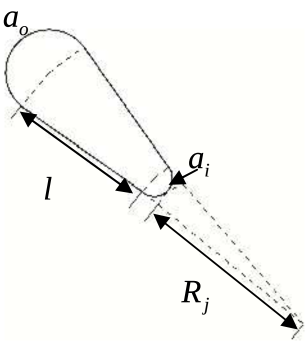

Figure 11: Single Flat tube model

As shown in figure 11, the tube circumference, C, is the summation of two mating area, inner arch length, a_i, and outer arch length, a_o. To find the length of inner arch and outer arch, position of rotating point must be found. Finding the arch radius of polyurethane, R_j, using Eq. (1) will gives the position of the rotating joint.

$$R_j = \frac{A_j(180)}{\theta\pi} \tag{1}$$

$$2l + a_i + a_o = C \tag{2}$$

$$l = \frac{\dfrac{R_t\pi}{2} - \dfrac{\sin\left(\dfrac{\theta}{2}\right)(R_j + d_j/n)\pi}{2(1-\sin(\theta/2)180} - \dfrac{(180+\theta)\pi}{360}\left(\dfrac{\sin(\frac{\theta}{2}(R_j + d_j/n)}{(1-\sin(\theta/2)}\right)}{\left(1 + \dfrac{(180+\theta)\pi\tan(\theta/2)}{360}\right)} \tag{3}$$

In Eq. (3) R_t is the radius of the tube used while d_j is the distance between two consecutive linkage when the bending angle is zero. This equation is derived from Eq. (2) and it will gives the mating area of the tube for all bending angles. The equation itself shows that the mating area is decreasing with respect to the bending angle.

6.2 Human weight support strength

Polyurethane is light in weight but the down side is that the material is not able to sustain high load. The material tends to deform when high load is being applied to it. For the first concept, the entire structure is made of foam polyurethane including the joint. In order to allow the joint to bend freely without much resistance, the thickness used are small and could not sustain much load. Big-hand is lifting up the patient by supporting body weight through armpit and some gripping force. The weight supporting through armpit is relatively big compare to gripping. When human load is being applied on Big-hand, the structure deformed. This shows that the material itself could not sustain much load. Despite the weak material structure, the concept of using flat tube at the joint is being retain and carry on with the next concept.

7. TEST OF STAND-UP SUPPORTING SYSTEM OF 130CM MANNEQUIN

Test has been done on 130cm mannequin. The mannequin leg has been remake so that it will not provide any support during the entire stand-up motion. As shown in figure 12 below, the entire supporting process is divided into 4 major steps. First is alignment of the system where the user make sure that the gripper is align in front of the patient chest. Once it is aligned, Big-hand will be actuated to grip the patient. It will then pull the patient back to the center of the system before actuating the supporting balloon.

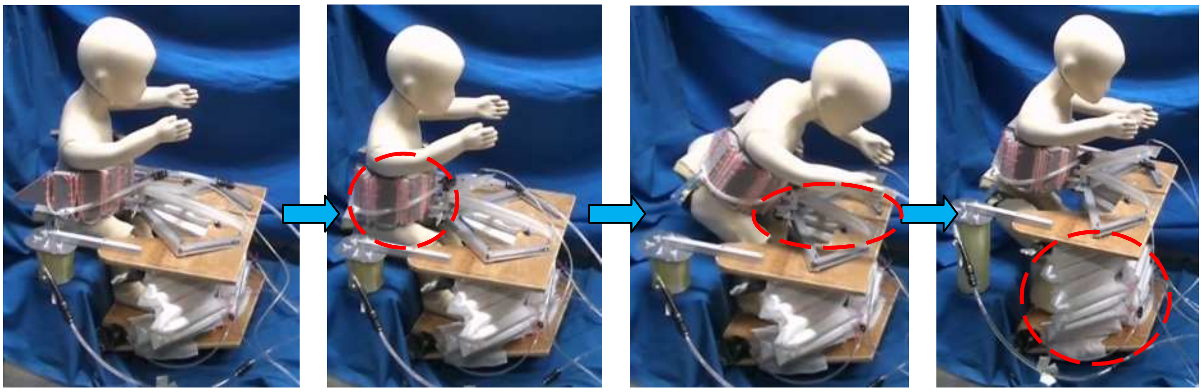

Figure 12: Test of stand-up supporting system on mannequin

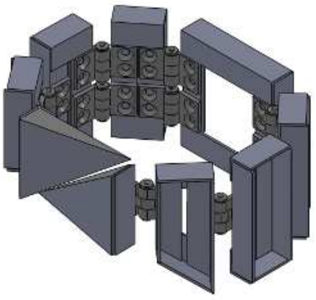

Figure 13: Aluminum Structure Big-Hand

8. ALUMINUM STRUCTURE BIG-HAND WITH FLAT TUBE JOINT

Due to the need of Big-hand to sustain the weight of a human being, it is desired to use a material with strong material strength that could sustain the load without any deformation. Use of material is carefully selected to ensure that it will not add on too much weight on the device. To do so, parts that sustain high stress will be using aluminum while the rest will be using light weight engineering plastic so that the final product will not be too heavy to carry around. The design for this concept is shown in figure 13.

8.1 Flat tube on aluminum hinge joint

For this second concept, the joint no longer has moving rotating axis as hinge at the joint is fixing the rotating axis. This changes the flat tube geometry behavior when the angle of the joint changes. Mathematical model for flat tube on aluminum hinge joint has been modeled with the assumption of no elongation of the tube material when it is being pressurized. R_j for the urethane joint has been replaced by dH and dC where dH is the distance between the hinge rotation axis and the base of the joint. On the other hand, dC is the distance from the hinge rotating axis to the crossing point of the two adjacent linkage face just as shown in figure 14. Eq. (5) shows how dC changes with respect to angle. The distance between the two adjacent linkages at zero degree bending angle is d_j. The radius of the inner arch is labelled as r and the calculation for that radius is shown in Eq. (6). Using Eq. (5) and Eq. (6), the mating area of the flat tube can be calculated using Eq. (7).

$$dC = \frac{d_j}{\tan(\theta/2)} \tag{5}$$

$$r = \frac{(dH + dC)\tan(\theta/2n)}{1 - \tan(\theta/2n)} \tag{6}$$

$$l = \frac{C - r(\pi - \theta/n) - (r + dH + dC)\tan(\theta/2n)(\pi + \theta/n)}{2 + \tan(\theta/2n)(\pi + \theta/n)} \tag{7}$$

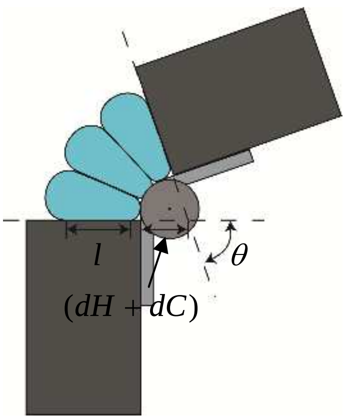

Figure 14: Flat tube model with hinge

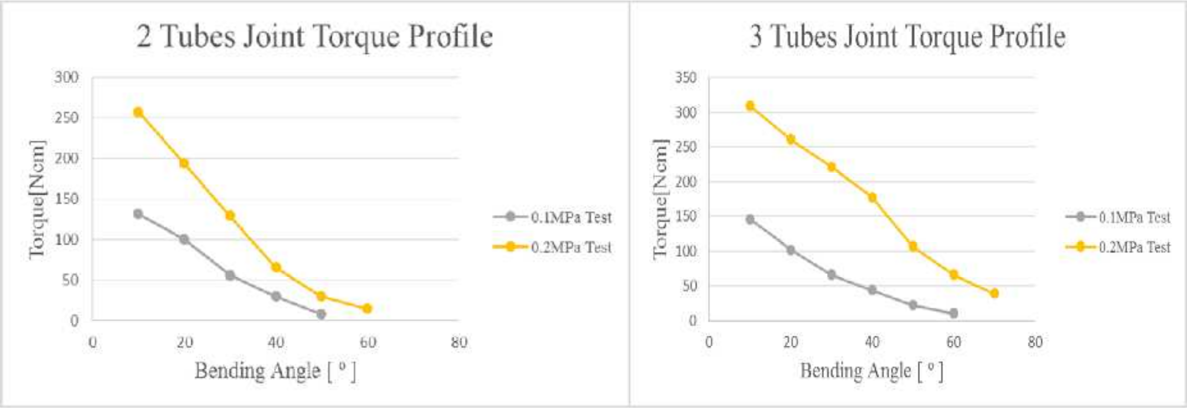

Figure 15: Test result for flat tube with hinge joint

8.1.1 Flat tube test result

Some test has been done to build the torque profile of this flat tube joint and the result is shown in figure 15. It if found that the torque of decreases drastically even when the supplied pressure remain constant. This kind of torque behaviour is not desirable in this second concept design. The desired torque profile would be a constant torque regardless of the bending angle. This test results leads to the need to change and improve the joint design which will be discussed in the next section.

8.2 Custom shaped air bladder with linen reinforced joint.

As mentioned before that mating area of a pneumatic pressure bag is determining the amount for output force. If the mating area is kept constant even the angle of the joint is changing, it would be able to keep the output torque to be constant on the same pressure supply. To achieve this, an air bladder with custom shape that fits into the joint perfectly at maximum bending angle is built. Polyurethane material is being used to fabricate the inner bladder. As the material strength is not able to withstand high pressure input, it will burst or changes it shape when supplied pressure goes over 0.1MPa. Therefore, it is desired to have another layer of linen covered over this polyurethane bladder so that the linen could limit the elongation length and sustain most of the pressure stress. Polyester linen is being used and a prototype shown in figure 16 has been build. The prototype is able to take up 0.4MPa pressure and leakage starts to occur once supplied pressure exceed 0.4MPa. The strength can be improved by having polyurethane bladder fit nicely with the linen shape so that no elongation on the material would occur. Torque for this joint has been measured as well and the result is shown in figure 17. It shows that the output torque is higher than flat tube joint. This custom shape bladder also be able to retain its constant force output at low bending angle but the torque start to drop when angle increases. This is due to the fabricated bladder shape does not fit the joint void perfectly at all angle. The drastic drop after a certain angle is mainly caused by the shape limitation where the fabricated shape of the bladder limits the maximum bending angle. This limitation can be lifted by fabricate a shape at a larger bending angle of the desired maximum bending angle.

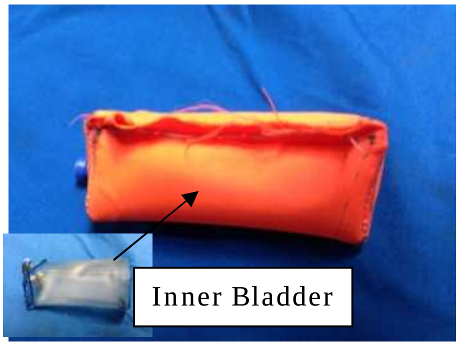

Figure 16: Custom shape air bladder with linen reinforce

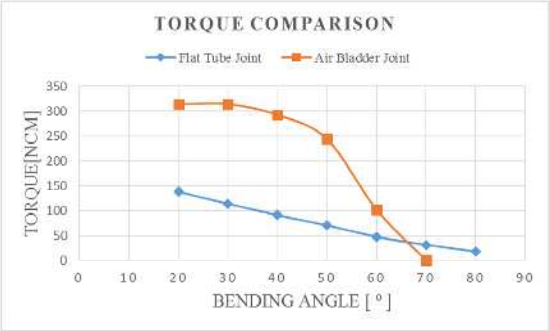

Figure 17: Torque comparison graph

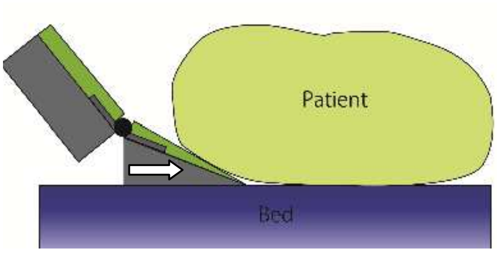

Figure 18: Required slip in action

9. GRIPPER TIP SLIP IN REQUIREMENT

When gripping is being performed, there are situation where the patient is leaning against something or lying on bed. This makes normal gripper not be able to reach in to the back of the patient. As shown in figure 18, a kind of slip in action is required in order to allow the gripper to fully engulf the patient body. When slip in occurs, friction is happening between the Big-hand tip and the patient as well as the bed or any object the patient is leaning against. Due to this, force is required to slip the tip of the gripper behind the patient. The required slip in force has been measured using actual human with different body weight. It is found that the maximum required slip in force is 143N on the patient bottom. On other area, the required slip in force is much lower which is around 100N. If the gripper could generate 150N force, the slip in action can be fulfilled. But it will be desirable if the required slip in force is reduce much further by reducing the friction between the patient and gripper.

10. FUTURE WORK

In the future, ways to reduce the required slip in force as well as the friction between the patient and gripper will be focused on. Other than that, even force distribution of Big-hand when performing the gripping action will be look into as well.

REFERENCES

[1] T. Mukai, S. Hirano, H. Nakashima, Y. Sakaida, Realization of Patient-Transfer Tasks Using Nursing-Care Assistant Robot RIBA and Its Safety Measures, *Proc. 2010 JSME Conference on Robotics and Mechatronics*, Asahikawa, Japan, 2010

[2] T. Mukai, S. Hirano, H. Nakashima, Y. Kato, Y. Sakaida, S. Guo, S. Hosoe, Development of a Nursing-care Assistant Robot RIBA That Can Lift a Human in Its Arm, *International Conference on Intelligent Robot and Systems*, Taipei, pp. 5996-6001, 2010

[3] T. Mukai, S. Hirano, M. Yoshida, H. Nakashima, S. Guo, Y. Hayakawa, Tactile-Based Motion Adjustment for the Nursing-Care Assistant Robot RIBA, *IEEE International Conference on Robotics and Automation*, Shanghai, pp. 5435-5441, 2011

[4] Y. Kume, H. Kawakami, Development of Power-Motion Assist Technology for Transfer Assist Robot, *Matsushita Technical Journal Vol 54,*pp. 50-52, 2008

[5] A. Ye, W. Zou, K. Yuan, Z. Xu, Y. Ren, A Reconfigurable Wheelchair/Bed System for the elderly and handicapped, *Proc. IEEE International Conference on Mechatronics and Automation*, Chengdu, pp. 1627-1632, 2012.

[6] Panasonic Bed-Shapped Robot, http://panasonic.co.jp/corp/news/official.data/data.dir/en090918-2/en090918-2.html, June 2012

[7] Toyota Care Assist Robot, http://www.toyota-global.com/innovation/partner_robot/family_2.html, June 2012.