Design and Evaluation of The Soft Hand WSH-1 For The Emotion Expression Humanoid Robot KOBIAN

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Abstract— **Personal robots and robot technology (RT)-based assistive devices are expected to play a major role in our elderly-dominated society, with an active participation to joint works and community life with humans, as partners and as friends. In particular, these robots are expected to be fundamental for helping and assisting elderly and disabled people during their activities of daily living (ADLs). Therefore we developed a new bipedal walking robot, named KOBIAN, capable of human-like movements and of human-like emotions. This robot is expected to be capable of interacting with surrounding people both physically and psychologically. A fundamental role for this interaction is played by the hand, which should both be capable of grasping and of gestures. To this purpose, the Waseda Soft-Hand 1 (WSH-1) was designed and realized. This paper presents the description of WSH-1 and its preliminary evaluation.**

The results clearly emphasize the importance of having a robotic hand with soft fingers for the interaction with other people.

I. Introduction

THE average age of most industrialized countries is rising fast due to an increased expectation of life and a contemporary reduced child birth rate [1, 2]. In particular, in Japan, while today there are about 2.8 workers per retiree, this figure is estimated to fall to 1.4 in 2050. Thus, there is considerable expectation that in the next years there will be a growing need for greater medical and nursing care services.

In particular, robots and robot technology (RT)-based assistive devices are expected to play a major role in this elderly society, with an active participation to joint works and community life with humans, as partners and as friends. These robots are expected to be fundamental for helping and assisting elderly and disabled people during their activities of daily living (ADLs), not only by working together with humans, but also by expressing human-like emotions and behaviors.

As a possible robotic assistant, in the last year we developed a new bipedal walking robot, named KOBIAN [3], whose body is based on the WABIAN-2R (WAseda BIpedal humANoid-No.2 Refined) robot [4]. Table 1 summarizes the characteristics of the new robot. Fig. 1(a) shows the main dimensions of KOBIAN; Fig. 1(b) shows the configuration of its degrees of freedom (DOFs); finally Fig. 1(c) shows the picture of the first prototype.

KOBIAN is capable of human-like movements and of human-like emotions. It is therefore expected to be capable of interacting with surrounding people both physically and psychologically.

KOBIAN		
Height	1400 mm	
Weight	58 kg	
DOFs	48, distributed as follows:	
	Head	7
	Neck	4
	Arm	7x2
	Hand	4x2
	Trunk	1
	Waist	2
	Leg	6x2
Sensors	6-Axis Force/Torque Sensors Photo Sensors Magnetic Encoders	
Actuators	DC Servo Motors	
Reduction Mechanism	Harmonic Drive Gears Timing-belt/Pulleys	
Batteries	Li-ion Battery	

Table 1: Main characteristics of KOBIAN.

A fundamental role during the interaction is of course played by the hand, which should both be capable of grasping and of gestures. To this purpose, we designed and realized the Waseda Soft-Hand 1 (WSH-1), based on [5]. This paper presents the description of WSH-1 and its preliminary evaluation.

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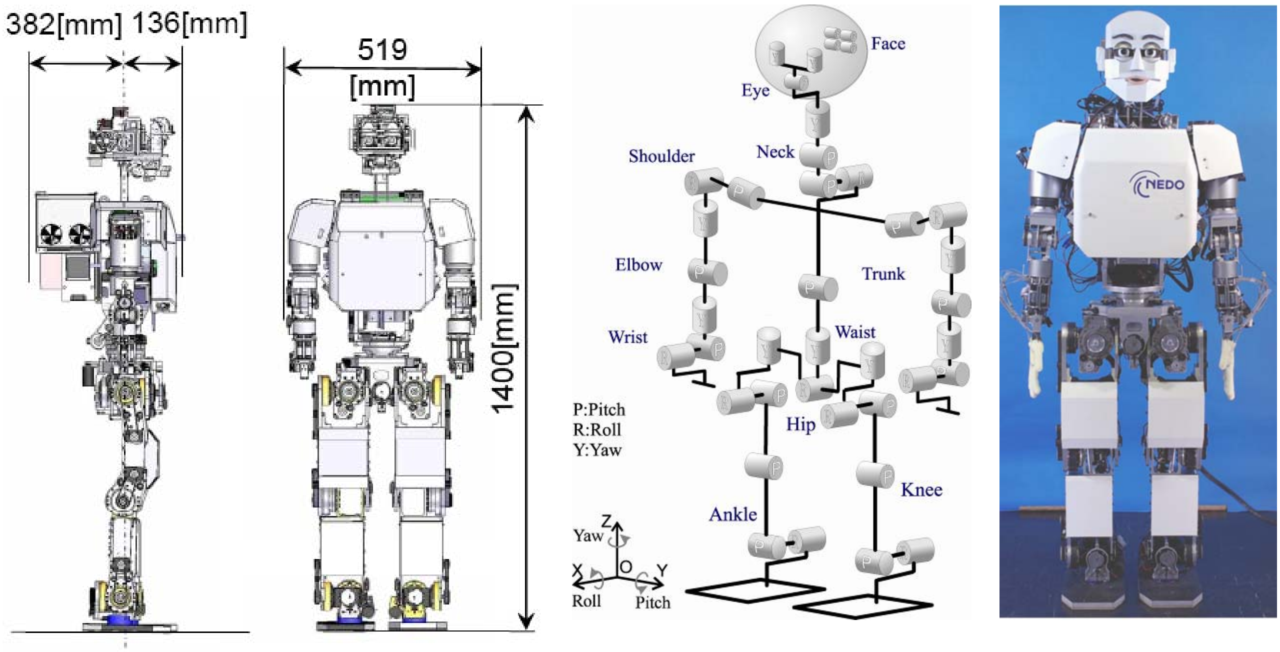


(A) Overview. (B) Distribution of the DOFs. (C) KOBIAN.

Fig. 1: Overview of the whole-body emotion expression humanoid robot KOBIAN: (left) main dimensions; (center) distribution of its DOFs; (right) picture of the first prototype.

II. DEVELOPMENT OF THE NEW ARTIFICIAL HAND

A. The model: the human hand

The model for the realization of an artificial hand is of course the human hand, which is a truly remarkable instrument capable of realizing very complex and useful tasks using an extremely efficient combination of mechanisms, sensing, actuation and control functions [6, 7]. The human hand is not only an effective tool but also an ideal instrument to acquire information from the external environment thanks to a huge number of sensors (Table 2). Moreover, it is capable of expressing emotions and feelings through gesture [8]. In [9] there is the list of about three hundred tasks that hands perform related to the activities of daily living. Therefore the replication of its mechanical capabilities and of its sensory–motor functionalities is a continuous challenge for scientists and engineers.

B. Requirements for the artificial hand

In literature there are several examples of artificial hands, ranging from the very simple 1-DOF pincher of the OttoBock prosthetic hand [10] to the 13 DOFs of the DLR hand [11], with several other variations in terms of size, speed, number of DOFs, anthropomorphism, etc (see [12] and related references for a more detailed discussion on artificial hands).

In case of WSH-1, grasping capabilities are required for a better interaction with humans and with the surrounding environment, especially considering a robot for home and personal assistance. At least the robot should be capable of cylindrical grasping (e.g. to grasp a can, or a small bottle, etc.) and spherical grasping (to grasp small balls, or fruits like orange, apple, and so on;).

Natural Hand performance	
Number of DoFs	22
Wrist mobility	2+1 DoFs
Total volume	50 cc
Weight	400 g
Type of Grasps	Power Grasps, Precision Grasps
Force of power grasp	>500 N (age 20–25); >300 N (age 70–75)
Two fingers force	>100 N
Tapping force	1–4 N
Max. tapping frequency	4.5/sec.
Range of flexion	~100º, depending on the joint
Max. duration of grasp	Variable with energy
Number of sensors	17’000~20’000
Proprioceptive sensing	Position; Movement; Force
Exteroceptive sensing	Acceleration; Force; Pain; Pressure; Temperature
Proportional Control	Ability to regulate force and velocity according to the type of grasp, the object, etc.
Stability	The grasp is stable against incipient slip or external load
Possible # of flexions	Limited only by muscular fatigue
Gestures & Emotional Expression	See [8] for several examples

Table 2: Performance of the human hand (adapted after [13]).

In addition to grasping, the following functions are required:

- Simple gesture (pointing, peace sign, etc);
- Emotion expression;
- Handshake;
- Gentle Touch.

There are also several constraints needed to preserve the mobility of the robot:

- Max # of active DOFs: 4;
- Max weight of the hand: 200 gr;
- Max weight of grasped object: 300 gr;
- Max size: proportional to the height of the robot.

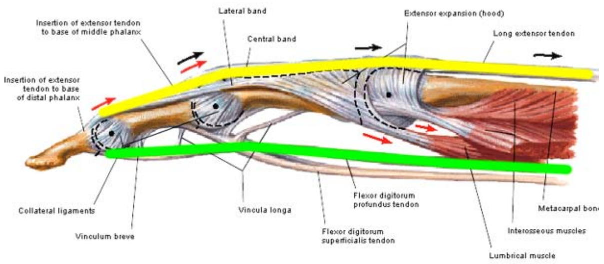
To achieve these results, we decided to use soft materials for both the structure of the hand and its covering (see details in the following sections). Moreover, we used underactuation to increase the number of DOFs while keeping the maximum number of DOMs (degrees of motion) [5, 14]. To keep the cable safe during grasping, we decided to use hollow pipes inside the palm of the hand, thus mimicking the metacarpal bones of the human hand.

The next sections describe in details the development of the fingers and the hand.

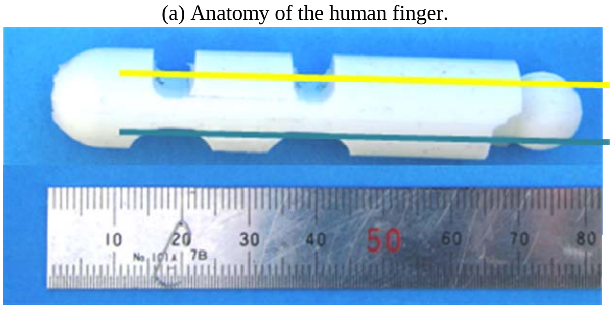
C. *Structure of each finger*

Each finger is realized as a single piece of silicon, with hollows in correspondence with the metacarpo-phalangeal joints (MCP), proximal interphalangeal joints (PIP), and distal interphalangeal joints (DIP). The actuation is provided by two wires connected to the same motor but acting in opposite directions, as shown in Fig. 2.

An additional passive DOF is added at the MCP joint by using an oval ball socket made by Teflon (Fig. 3). This allows the mechanical compliance to the torsion of the fingers, thus absorbing shocks and vibrations. Moreover, it makes it possible to quickly exchange the fingers, as there is no screw fixing them to the palm.



(a) Anatomy of the human finger.



(b) Prototype of the finger with highlighted driving wires.

Fig. 2: Anatomy of the human finger (top) compared with the structure of the artificial on (bottom). Extensor tendon and flexor tendon are highlighted in yellow and green, respectively.

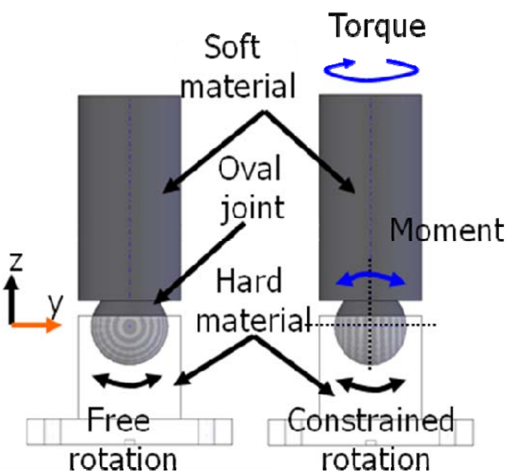


Fig. 3: Schematic drawing of the oval ball joint.

D. *Assembly of the hand*

A CAD image of the assembly is shown in Fig. 4. While keeping a similar structure, each finger has a different size and a different mounting point, thus mimicking the natural hand. A picture of the first prototype of WSH-1 is shown in Fig. 5.

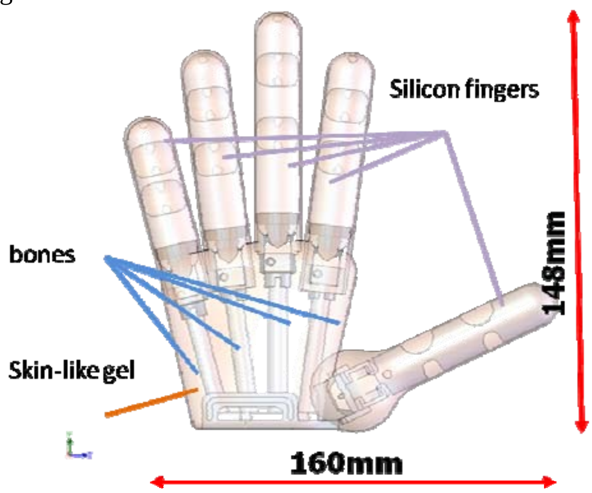


Fig. 4: CAD image of the assembly of the hand, showing the overall size.

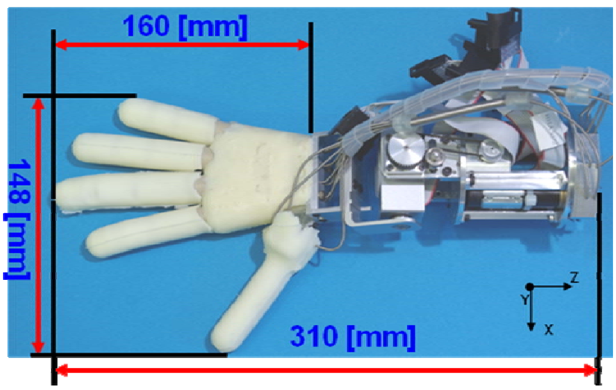


Fig. 5: Picture of the prototype of the hand, showing also the placement of the motors in the forearm.

WHS-1 has 4 motors to control 5 underactuated fingers by using antagonist wires for flexion and extension (flexion/extension of a) index; b) middle; and c) thumb, ring finger and pinkie; thumb ab–/adduction;). The hand weights 180[gr], or 950[gr] including the forearm. These four groups are shown in Fig. 6, and the motors chosen for each of them are presented in Table 3.

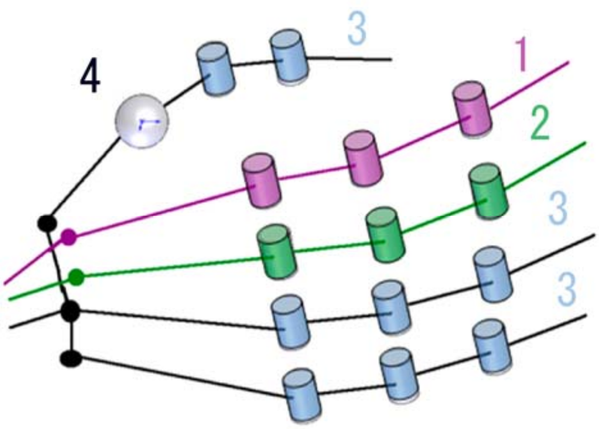


Fig. 6: Structure of the DOFs and DOMs of the hand, with the 4 actuation groups in evidence.

Section		Motor	Gear Ratio
1	Index finger	RE-max17	84:1
2	Middle finger	RE-max17	84:1
3	Thumb/Ring/Pink fingers	RE-max17	157:1
4	Thumb ad/abduction	RE-max17	157:1

Table 3: Selection of the motors for the hand. Section number refers to the sections shown in Fig. 6.

III. Evaluation

To evaluate the acceptability of WSH-1, three different prototypes of hand were built:

a) **hard type** (all the hand is made by rapid prototyping);
b) **soft type** (the palm is made by Septon with inserts in rapid prototyping; soft fingers are made by silicon, with Septon cover);
c) **mixed type** (hard palm in rapid prototyping, soft fingers made by silicon with a Septon cover).

These three hands are shown in Fig. 8.

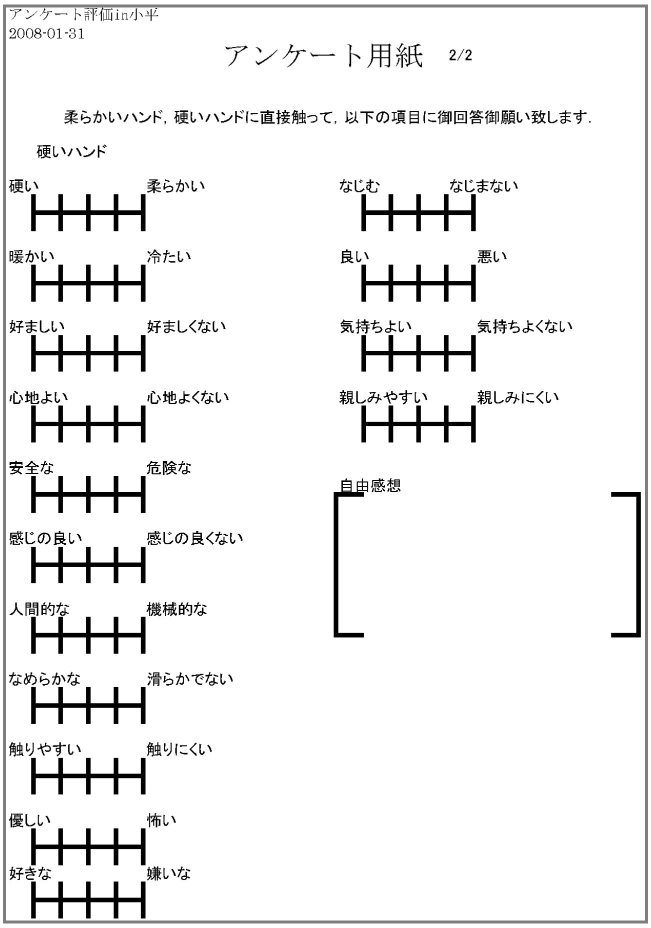
#	Semantic Differential Pairs	
A	Soft	Hard
B	Warm	Cold
C	Desirable	Undesirable
D	Pleasant	Unpleasant
E	Safe	Dangerous
F	Positive feeling	Negative feeling
G	Humanlike	Machinelike
H	Smooth	Rough
I	Enjoyable to touch	Painful to touch
J	Gentle	Frightening
K	Like	Dislike
L	Familiar	Unfamiliar
M	Positive	Negative
N	Positive sensation	Negative sensation
O	Friendly	Unfriendly

Table 4: Semantic differential questions used in the experiments. Please note that the English terms used in this paper might not be 100% correct due to the translations. In case of doubt, please refer to the original Japanese text.

Two groups of users participated to the preliminary evaluation after providing the informed consent:

- Group #1 – 12 young subjects, all students in Waseda University; age 24±1.7 – compared Hand A and Hand B;
- Group #2 – 12 elderly subjects, all guests of the health care center “Care-town Kodaira”; age 76±9.9 – compared Hand B with Hand C. A picture taken during this evaluation is shown in Fig. 9.

15 semantic differential questions were used, as shown in Table 4. A 5 points scale from -2 to +2 was used, with 0 meaning the neutral response. Fig. 7 shows the snapshot of the evaluation sheets used in the experiments. Please note that the English terms used in this paper might not be 100% correct due to the translations. In case of doubt, please refer to the original Japanese text.


アンケート評価in小平
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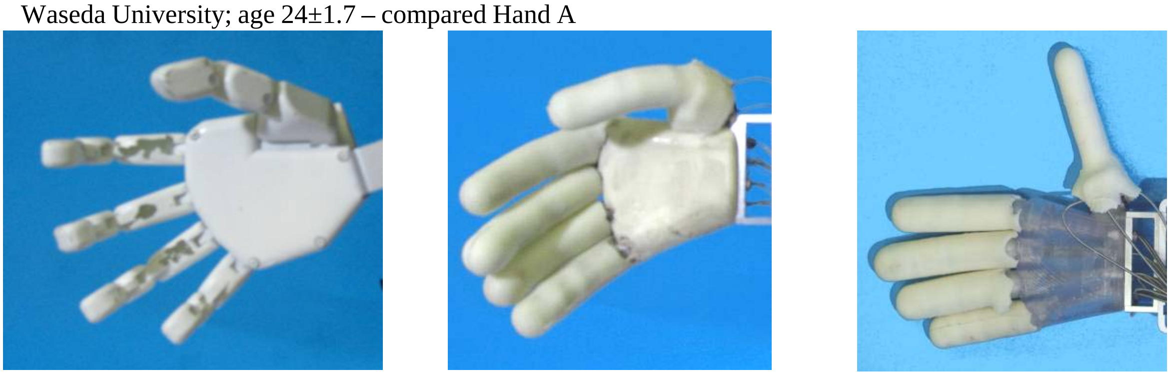
アンケート用紙 2/2
柔らかいハンド，硬いハンドに直接触って，以下の項目に御回答御願い致します．
硬いハンド
硬い 柔らかい
暖かい 冷たい
好ましい 好ましくない
心地よい 心地よくない
安全な 危険な
感じの良い 感じの良くない
人間的な 機械的な
なめらかな 滑らかでない
触りやすい 触りにくい
優しい 怖い
好きな 嫌いな
なじむ なじまない
良い 悪い
気持ちよい 気持ちよくない
親しみやすい 親しみにくい
自由感想

Fig. 7: Snapshot of the evaluation sheet for the WSH-1 hand.



A) hard type. B) soft type. C) mixed type.

Fig. 8: The three different prototypes used for this preliminary evaluation: A) hard type (all the hand is made by rapid prototyping); B) soft type (the palm is made by Septon with inserts in rapid prototyping; soft fingers are made by silicon, with Septon cover); C) mixed type (hard palm in rapid prototyping, soft fingers made by silicon with a Septon cover).

Fig. 9: The guests of the health care center "Care-town Kodaira" playing with the RCH-1 hands assisted by the researchers of Waseda University and the staff of the Care Center.

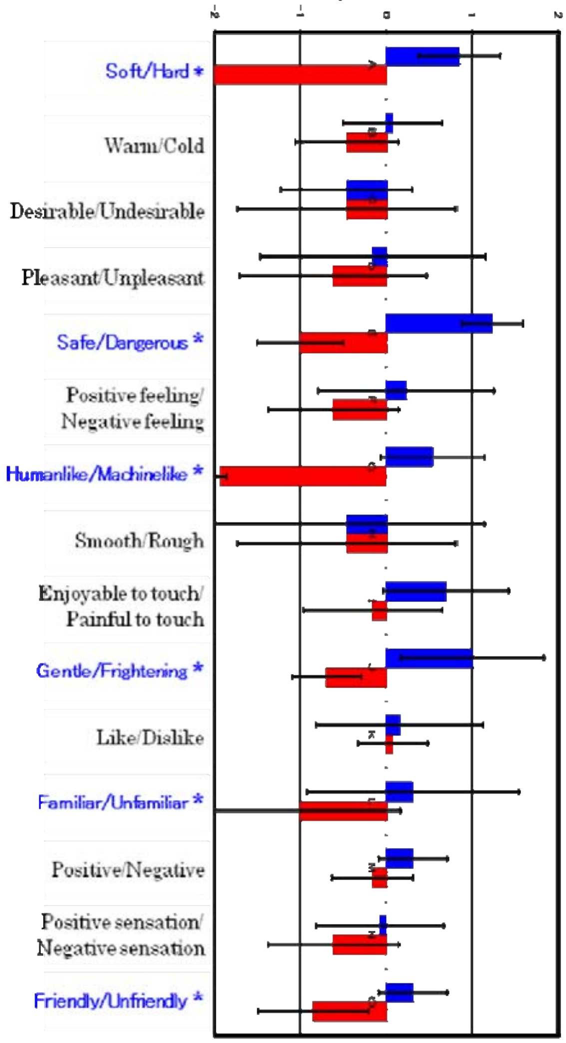


Fig. 10: Result of the evaluation Hard hand (red) vs. Soft Hand (blue) according to the students in Waseda University (Group #1) The blue * indicates a significant difference (p<0.01) between the results of the two hands.

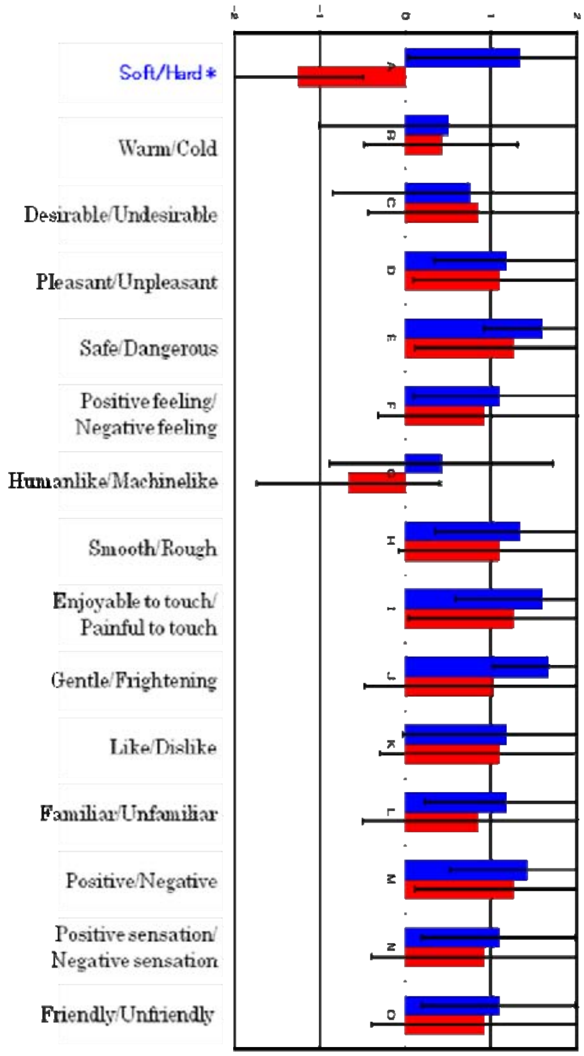


Fig. 11: Result of the evaluation Hard hand (red) vs. Soft Hand (blue) according to the guests of Care-town Kodaira (Group #2). The blue * indicates a significant difference (p<0.01) between the results of the two hands.

IV. Results

The results of this preliminary evaluation are presented in Fig. 10 and Fig. 11. Group #1, composed by 12 young subjects (age 24±1.7), all students in Waseda University, compared Hand A (Hard type) with Hand B (Soft type). The results (Fig. 10) clearly show a significant difference between the two hands, with an overall preference for the soft one (Hand B). In particular, Hand B was considered to be softer, more humanlike, more gentle, more familiar, and more friendly respect to Hand A.

Group #2, composed by 12 elderly subjects (age 76±9.9), all guests of the health care center “Care-town Kodaira”, compared Hand B (soft type) with Hand C (mixed type). In this case (Fig. 11) both hands are well rated. Moreover – although there are clearly huge variations for each parameter – only the hard/soft comparison brings some significant difference. Among the other parameters, only a few (namely: warm/cold, humanlike/machinelike, and desirable/undesirable) obtained a relatively negative evaluation. All the others, instead, are quite positive for both hands.

These results emphasize the importance of having a robotic hand with soft fingers for the interaction with other people.

It is also interesting to notice that Group #2 (elderly subjects) gave a much more enthusiastic response compared to Group #1 (young subjects).

V. Conclusions and Future Work

In a society that is getting older year by year, there is a considerable expectation that robot technology could provide a substantial help to the ageing population. In order to achieve a smooth and natural integration of the robots, emotion expression plays a major role. A key aspect in successfully emotion expression is the presence of a human-like hand, capable not only of grasping but also of signs and gestures.

In this paper, a biologically inspired approach to the development of a new anthropomorphic hand for humanoid robots, named WSH-1, has been presented. The flexion/extension of the five fingers is in fact obtained with the replication of the architecture of the flexor/extensor digitorum superficialis and of the flexor/ extensor digitorum profundus, and the actuation is provided by 4 DC motors integrated in the forearm.

As a preliminary evaluation, three different versions of the hand were built: A) hard type, B) soft type, and C) mixed type. These three hands were evaluated by using 15 semantic differential questions to understand the subjective perception of these hands. Two groups of subjects (Group #1 – 12 young subjects; Group #2 – 12 elderly subjects) participated to the experiments after providing informed consent.

The preliminary results show a clear preference for the soft hand, which is considered to be softer, more humanlike, more gentle, more familiar, and more friendly respect to hard hand. Both the soft hand and the mixed hand received a similar evaluation, with a slightly preference for the soft one, thus emphasizing the importance of having a robotic hand with soft fingers for the interaction with other people.

Despite of the positive acceptance, WHS-1 still has several drawbacks, which will be addressed in the near future. In particular, some touch or force sensors are needed in the hand, to provide some feedback about the grasped object, and to control the grasp.

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KOBIAN has been designed by 3D CAD software "SolidWorks". Special thanks to SolidWorks Japan K.K. for the software contribution, and KURARAY Co., Ltd. for the SEPTON contribution.

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