

From the Human Hand to a Humanoid Hand: Biologically-Inspired Approach for the Development of RoboCasa Hand #1

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Abstract. In a society getting older year by year, Robot technology (RT) is expected to play an important role. In order to achieve this objective, the new generation of personal robots should be capable of a natural communication with humans by expressing human-like emotion. In this sense, the hands play a fundamental role in communication, because they have grasping, sensing and emotional expression ability. This paper presents the recent results of the collaboration between the Takanishi Lab of Waseda University, Tokyo, Japan, and the Arts Lab of Scuola Superiore Sant'Anna, Pisa, Italy, and RoboCasa in a biologically-inspired approach for the development of a new humanoid hand. In particular, the grasping and gestural capabilities of the novel anthropomorphic hand for humanoid robotics RCH-1 (RoboCasa Hand No.1) are presented.

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1 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 (NIPS (2003); OECD (2004)). 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. One possible solution to support this aging society could be given by the next-generation Robot Technology (RT). These new robots should be capable of a smooth and natural interaction and communication with the human society and its environment, in particular for home and personal assistance of elderly and/or handicapped persons (Takanishi (2004)). Next generation robots, then, should be able not only to work together with humans, but also to express human-like emotions.

In this sense, the aspect and the functionalities of the hand assume a major role. The hand, in fact, not only is a fundamental organ for exploration, manipulation and interaction with objects and other persons (Table 1; Chao (1989); Kapandji (1982)), but it is also a basic tool for communication and expression of emotions through gestures (Kendon (2004)).

This paper describes the realization of RoboCasa Hand No. 1 (RCH-1), recently developed at RoboCasa, the Italy-Japan Joint Research Laboratory on Humanoid & Personal Robotics between the Humanoid Research Institute of Waseda University, Tokyo, Japan, and the ARTS Lab of Scuola Superiore Sant'Anna, Pisa, Italy.

2 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 (Chao (1989); Kapandji (1982)). 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 1). Moreover, it is capable of expressing emotions and feelings through gesture. MacKenzie and Iberall (1994) list 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.

As a general criterion, artificial hands could be divided into two main categories:

1. prosthetic hands;
2. robotic hands.

Prosthetic devices are usually simple gripper (OttoBock (2001)) with one or two DOFs, with high reliability and robustness, but with poor grasping capabilities. Due to the lack of DOFs, such devices are characterized by a low grasping functionality, because they do not allow adequate encirclement of objects. Conversely, robotic hands could achieve better performance in mimicking human capabilities, but they are complex devices requiring large and bulky controllers (Bekey et al. (1990); Bicchi (2000); Borst

NATURAL HAND PERFORMANCE	
Number of DoFs	22
Wrist mobility	2+1 DoFs
Total volume	$\simeq 50$ 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	100° , depending on the joint
Max. duration of grasp	Var. with energy
Number of sensors	$\simeq 17'000$
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 flexions	Limited only by muscular fatigue

Table 1. Main characteristics of the human hand (adapted from Zecca (2003)).

	Size (norm.)	# of fingers	DoFs	Actuators (Type)	Control	# of sensors	Weight (gr)	Force (N)	Speed (sec)
Human hand	1	5	22	38 (I+E)	E	$\simeq 17'000$	$\simeq 400$	>300	0.25
Ottobock SUVA	1	3	1	1 (E)	I	2	600	$\simeq 100$	<1
MARCUS Hand	$\simeq 1.1$	3	2	2 (I)	I	3	–	–	–
Southampton hand	$\simeq 1$	5	6	6 (E)	E	–	400	38	$\simeq 5$
Hokkaido hand	>1	5	7	7 (E)	E	–	125	–	–
Karlsruhe	$\simeq 1$	5	17	17 (E)	E	–	$\simeq 120$	12	0.1
NTU Hand	$\simeq 1$	5	17	17 (E)	E	35	1570	–	–
Utah/MIT	$\simeq 2$	4	16	32 (E)	E	16	–	31.8	–
Belgrade/USC	$\simeq 1.1$	4	4	4 (E)	E	23+4	–	–	–
Stanford/JPL Hand	$\simeq 1.2$	3	9	12 (E)	E	–	1100	–45	–
DLR Hand II	$\simeq 1.5$	4	13	13 (E)	E	64	320	30	–
Robonaut Hand	$\simeq 1.5$	5	12 + 2	14 (E)	E	43 +	–	–	–
RoboCasa Hand #1	$\simeq 1$	5	16	6 (I+E)	E	24	350	$\simeq 40$	0.25

Table 2. Comparison among several types of artificial hands (modified after Zecca (2003)). The size of each hand is normalized respect to the adult human hand. In the Actuator type and in the Control rows, ‘*I*’ means ‘*internal*’, and ‘*E*’ means ‘*external*’. *Speed* indicates the time required for a full closing and opening.

et al. (2003); Jacobsen et al. (1984); Salisbury and Craig (1982)). Table 2 presents a comparison among several types of artificial hands.

RCH-1 aims at filling the gap between these two main classes of artificial hands, by realizing a device as close as possible to the human hands in terms of dimensions and performance without increasing too much the complexity of the system.

3 RoboCasa Hand #1 (RCH-1)

RCH-1 should mimic as close as possible the performance of the natural hand summarized in Table 1. In addition, further requirements on the specifications for grasping and gesture should be fulfilled.

Grasping capabilities 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 following grasping types are needed:

- **cylindrical grasping:** e.g. to grasp a can, or a small bottle, etc.;
- **spherical grasping:** to grasp small balls, or fruits like orange, apple, and so on;
- **tip pinch:** (thumb and index, or thumb and middle finger) for small objects like candies, pens, etc.;
- **lateral grasping:** for keys, paper, name cards, credit cards, and so on.

Besides the single hand grasping of small objects, the robot should also be capable of two hands grasping of large objects (i.e.: ball, big toys, puppets, etc). Additional functionalities could be the measurement of the hardness of the grasped object, and the recognition of different surfaces.

Gestural capabilities A "gesture" is a form of non-verbal communication made with a part of the body and in particular with the hand, and used instead of verbal communication (or in combination with it). The language of gesture is rich in ways for individuals to express contempt, hostility, or approval towards others. Most people use gestures and body language in addition to words when they speak; some ethnic groups and languages use them more than others do, and the amount of such gesturing that is considered culturally acceptable varies from one location to the next. Thus, the robot should be able to point at objects, waving (calling people), close the hand (fist), shake the hand with its partners, closing mouth when yawn, and some other simple signs like goodbye, ok, good, peace sign, counting, and so on. The robot should also be capable to adapt to change in the working environment, as the same gesture can be interpreted in a different way according to the person and the context. More details and examples on world-wide known gestures can be found in Kendon (2004).

3.1 Realization of the first prototype

According to the above mentioned requirements, two new hands (left and right) have been designed and fabricated at ARTS lab. These new hands have then been integrated into the Emotion Expression Humanoid Robot WE-4R (Waseda Eye #4 Refined: Miwa et al. (2002, 2003)). The result of the integration, named WE-4RII, is shown in Figure 1(a).

Each new hand has in total 16 Degrees of Freedom (DOF) or 6 Degrees of Motion (DOM): 1 DOM/3DOFs for flexion/ extension of each finger, plus one 1DOM/1DOF for thumb adduction/abduction. Each finger is underactuated (Figure 1(b)), and its movement is driven by a single cable actuated by a motor placed in the forearm (Maxon RE-max17 4.5W 216012), thus mimicking the human muscular structure (Figure 2). The

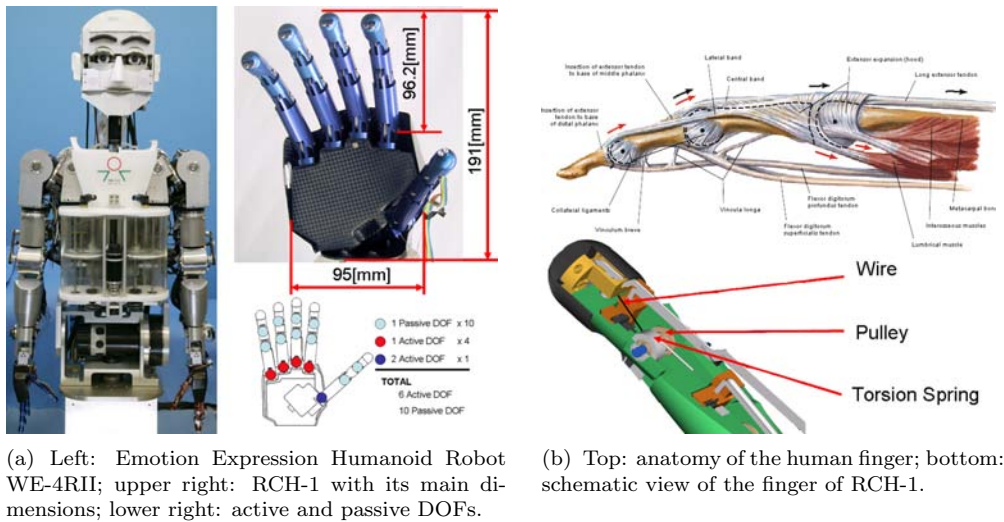


Figure 1. Overview of RCH-1 and details of the finger design.

flexion of the three phalanxes is provided by a single cable connected to the actuator in the forearm, while the extension is obtained through torsion springs. The motor for thumb ad/abduction is integrated into the palm (Faulhaber 1016M006G) and it is placed in a homologous position as the *abductor pollicis* in the human hand (Figure 3).

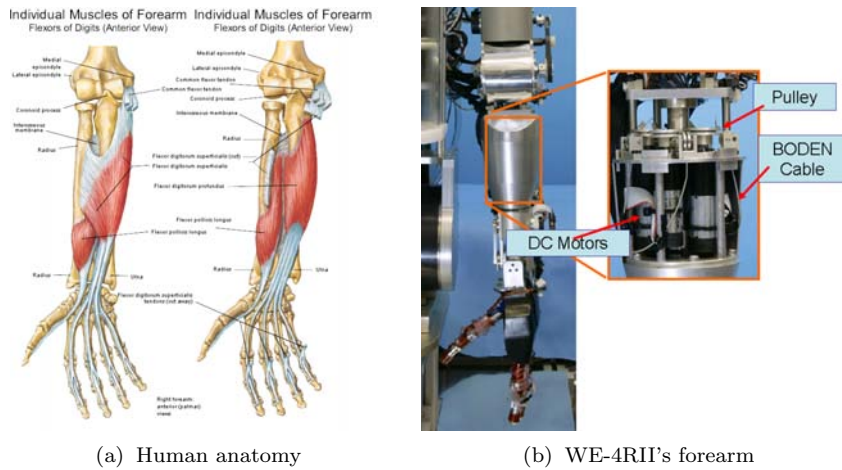


Figure 2. Left: superficial and deep muscles in the human forearm; Right: view of the forearm of WE-4RII, and detailed view of the finger motor block.

RCH-1 has the same dimensions of an average adult. Each finger is 92.2 mm long,

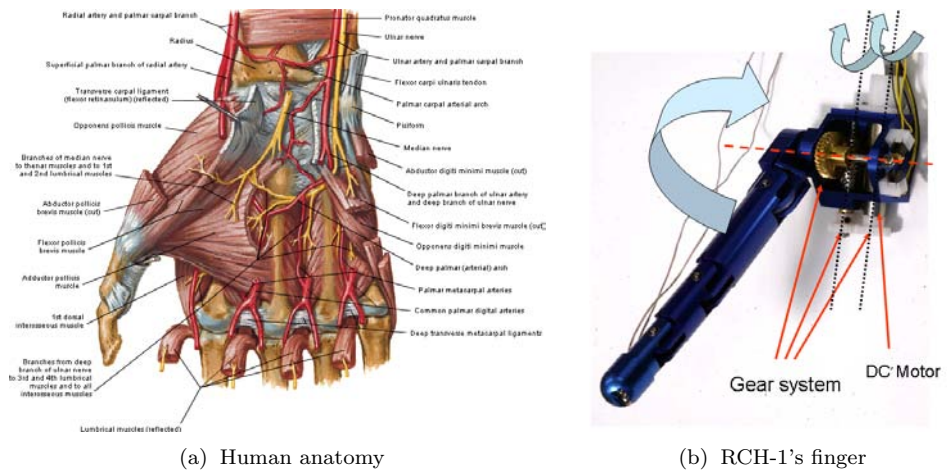


Figure 3. Left: palmar view of the human hand; Right: details of the abduction-adduction mechanism of RCH-1. The motor is placed in the same position as the *abductor pollicis*.

with a diameter of 14 mm; the palm is 95 mm in width and 45 mm in thickness; the overall length of the hand is 192.2 mm; the total weight of the hand is about 320 gr without silicon cover. A more detailed description of the RCH-1 and its integration into the WE-4RII can be found in Zecca et al. (2004).

4 Advanced behaviors for WE-4RII

The ability of WE-4R to show emotions have been tested in several occasions. However, it lacked the capability to interact with objects and people. Thanks to RCH-1, instead, WE-4RII is capable of several additional behaviors. Some examples are shown in Figure 4 (handshake; victory), Figure 5 (dumbbell; maracas), and Figure 6 (throwing; bye-bye).

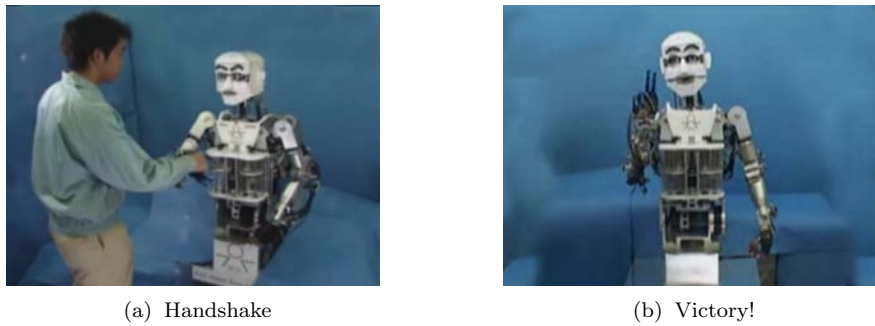


Figure 4. Advanced behaviors for WE-4RII - Part I.

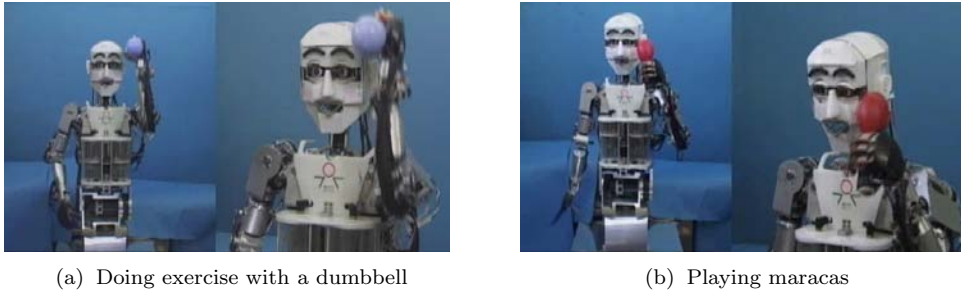


Figure 5. Advanced behaviors for WE-4RII - Part II.

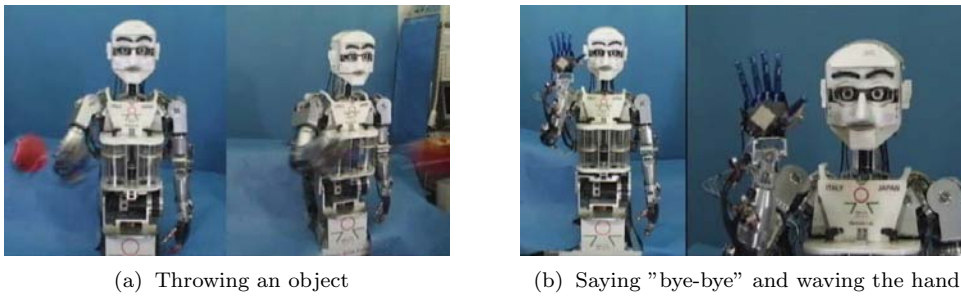


Figure 6. Advanced behaviors for WE-4RII - Part III.

5 Results and Discussion

In a society that is getting older year by year, there is a considerable expectations that robot technology could provide a substantial help to the population. However, in order to achieve a smooth and natural integration of the robots, emotions play 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 RCH-1, has been presented. The flexion of the five finger is in fact obtained with the replication of the architecture of the *flexor digitorum superficialis* and of the *flexor digitorum profundus*, by integrating 5 DC motors in the forearm (Figure 2). The extension of the fingers, however, is obtained by using torsion springs integrated into the structures of the phalanxes (Figure 1(a)). The abduction-adduction mechanism of the thumb replicates the function of *abductor pollicis*, *adductor pollicis longus* and *brevis* (Figure 3). However in RCH-1 these functions are obtained with one motor only.

RCH-1 has been successfully integrated into the Emotional Expression Humanoid Robot WE-4RII developed in Takanishi-lab of Waseda University in the framework of the RoboCasa project, co-designing also the forearm and the control system. The effec-

tiveness of the new hands for the interaction with the environment and with the users has been proved through several experiments. With RCH-1, moreover, several additional behaviors became possible.

Although RCH-1 represents a significant advancement of the state of the art, it still has several drawbacks. For example, the structure of the fingers is slightly too fragile, and sometimes the mechanical stops (which should prevent the phalanxes to bend backwards) break. Another limitation is the absence of a human-like skin, in terms of both compliance and sensory system. Furthermore, the current shape of the palm (i.e. flat) slightly reduces the grasping capabilities. The current activities in RoboCasa aim at solving these problems.

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