

Design, fabrication and preliminary results of a novel anthropomorphic hand for humanoid robotics: RCH-1

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Abstract— Among social infrastructure technologies, Robot technology (RT) is expected to play an important role in solving the problems of both decrease of birth rate and increase of elderly people in the 21st century, specially but not only in Japan.

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, human 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 this paper, the development of a novel anthropomorphic hand for humanoid robotics RCH-1 (ROBOCASA Hand No.1) and its integration into a humanoid robotic platform, named WE-4RII (Waseda Eye No.4 Refined II) is presented.

Humanoid robotics; personal robotics; artificial hand; human-robot communication.

I. INTRODUCTION

The average age of Japanese population is rising faster than any other nation in the world, and by the middle of the 21st century a third of the population is expected to be of age 65 or above. Simultaneously, the number of children born annually is dropping [1]. In this scenario, there is considerable expectation that, among all social infrastructure technologies, next-generation Robot Technology (RT) will be invaluable in supporting this aging society. As a result, next-generation robots must be able to coexist with the human living environment, functioning not merely as technology and tools but as partners [2].

In order to obtain a successful interaction between humans and humanoid robots, particularly for home and personal assistance of elderly and/or handicapped persons, it is important that the personal robot is able to adapt to its partners and environment, and moreover that it is able to communicate in a natural way with humans.

The work described in this paper is the recent result of the collaboration between 2 laboratories, the Takanishi Lab of Waseda University, Tokyo, Japan, and the Arts Lab of Scuola Superiore Sant'Anna, Pisa, Italy, that have created a joint laboratory in Tokyo for investigating the problems of human-robot interaction with an interdisciplinary approach. The joint laboratory is called ROBOCASA, and it is promoted by the Italian ministry of Foreign Affairs.

The first objective of the ROBOCASA team is to increase the expressional capabilities of the humanoid robot WE-4R (Waseda Eye #4 Refined), developed in Takanishi lab, by adding two hands, developed at ARTS lab. These hands have the ability of grasping, sensing and gesturing, in order to make the interaction between human and robot more natural.

II. THE FIRST JOINT HUMANOID PLATFORM AT ROBODEX2003

The first joint ARTS-HRI humanoid platform has been integrated in occasion of ROBODEX 2003, held in Yokohama, Japan, from April 3 to April 6, 2003. This humanoid robotic platform integrates the Emotion Expression Humanoid Robot WE-4R (Waseda Eye No.4 Refined) developed at the Takanishi Lab with the robotic hands developed at the ARTS Lab.

The arms are anthropomorphic manipulators with 9 degrees of freedom (DOFs) and the head has 29 DOFs (waist: 2, neck: 4, eyeballs: 3, eyelids: 6, eyebrows: 8, lips: 4, jaw: 1, lung: 1) and a multisensory system which serve as sense organs (visual, auditory, cutaneous and olfactory sensation) for extrinsic stimuli [3]. The system is able to react to the extrinsic stimuli assuming 7 facial expressions (happiness, anger, disgust, fear, sadness, surprise, and neutral) and moving the head, the body, and the arms [4].

However, the hands of this robot have a pure aesthetic function, and they cannot be used to express some gesture or to grasp objects or actively explore the environment. But the hand is a fundamental organ. The human hand, in fact, is a marvelous example of how a complex mechanism can be implemented, capable of realizing very complex and useful tasks using a very effective combination of

mechanisms, sensing, actuation and control functions [[5]. The human hand is not only an effective tool but also an ideal instrument to acquire information from the external environment. Moreover, it is capable of expressing emotions through gesture.

TABLE I. MAIN CHARACTERISTICS OF THE RTR2 HAND.

Number of fingers	3
Degrees of Freedom	9
Degrees of Motion	2 motors integrated into the palm
Underactuation level	7
Thumb ab/adduction	Yes
Weight	320 grams
Maximum grasping force	16N
Sensors	Current sensor Pressure sensor Tension sensor Position sensor

In order to overcome this limitation, the robotic hand RTR2 has been connected to WE-4R. This hand has three under-actuated fingers, with 9 DoFs in total, of which 2 are directly controllable. The adduction/abduction movements of the thumb enable the execution of several functional grasps [6]. The sensory system is integrated within the hand structure and it is composed of exteroceptive and proprioceptive sensors. The sensory signals are used to control grasping and manipulation of the hands, and to cooperate with the arms of the humanoid during the reaching movements before grasping [7]. The main characteristics of the RTR2 hand are summarized in TABLE I.

The RTR2 hand is controlled by a laptop (ACER Travelmate 6xx, Win 2000 Pro) with a National Instruments PCI-6025E, 12-Bit, 16 Analog Input Multifunction acquisition board and SCB-68 Connector. The control software is developed in LabView 6.1 [8]. The hand control software exchanges data with the main control computer through TCP/IP.

A picture of this joint humanoid platform is shown in Figure 1.



Figure 1. The first joint ARTS-HRI humanoid platform is grasping an apple during ROBODEX 2003.

The preliminary tests on this platform showed that the further development of the humanoid platform should have been the hand system.

III. DESCRIPTION OF THE NEW JOINT HUMANOID PLATFORM

In order to overcome the limitations of the first joint humanoid platform, the forearms and the hands of the humanoid platform has been re-designed. According to the requirements defined in the ROBOCASA laboratory, the two hands has been designed and fabricated at ARTS lab. In particular, the new hands has been designed and realized in order to be capable of:

Basic gesture, like pointing, waving (calling people), closed hand (fist), hand shake, closing mouth when yawn, goodbye, ok, good, peace sign, counting (from 0 to 5), and so on;

different grasping, like cylindrical grasping (i.e. small bottle), spherical grasping (i.e. apple), tip pinch (i.e. candy), and lateral grasping (i.e. key), to carry on some basic activities like single hand grasping of small objects (apple, banana, can, small bottle, small toys and puppets, etc.) or 2 hands grasping of large objects, up to 20cm (i.e.: ball, and big toys and puppets).

Moreover, the hands should be capable of:

Hardness measurement, like 2 hand measurement (by holding the object with the 2 hands), 1 hand measurement (by grasping the object), 1 finger measurement (by pressing the object against a hard surface);

Surface recognition.

However, these functionalities have not been yet exploited in the current prototype. A picture of the prototype of the new humanoid platform, named WE-4RII (Waseda Eye No.4 Refined II) with the two novel anthropomorphic hands, named RCH-1 (RoboCasa Hand #1), is showed in Figure 2.



Figure 2. A picture of the new humanoid platform WE-4RII with RCH-1.

A. Mechanical development

In order to obtain these functionality, the Hand System of the new humanoid platform should be composed by 2 symmetrical hands (left and right) with 5 fingers each. There should be 6 motors, one for opening/closing each finger plus one for abduction/adduction of the thumb. The thumb adduction/abduction motor could be located in the palm, while the other 5 motors should be located into the forearm.

The dimensions of this hand should be compatible with the standard Japanese male hand, i.e. weight lower than 500g and approximate size of 188x106mm, with length of the fingers of about 110mm and diameter of 20mm.

The speed of the fingers of the artificial hand should be comparable with the one of the human fingers, i.e. the maximum tapping frequency should be around 4.5 Hz and the maximum angular velocity should be around 2000 deg/s.

1) Description of the prototype

The new hand, named RCH-1, consists of 5 identical underactuated fingers with cylindrical phalanges in aluminum alloy. The design of the finger is based on the PALOMA Hand [10], which in turn is an evolution of the RTR2 hand [6]. The 3D model of the finger is shown in Figure 3, and a picture of the new hand is presented in Figure 4. A detailed description of the connection between the hand and the forearm is presented in [9].

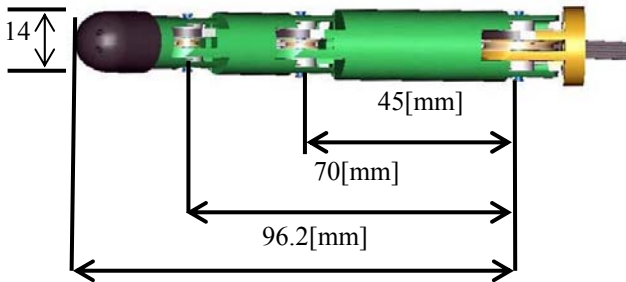


Figure 3. Dimension of the finger of RCH-1.

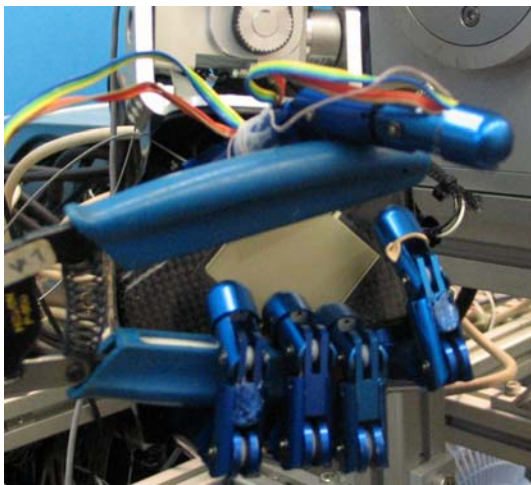


Figure 4. Picture of RCH-1 grasping an irregular object.

RCH-1 has in total 16 Degrees of Freedom (DOF)/6 Degrees of Motion (DOM), one DOM for each finger (flexion/extension) plus one DOM for thumb positioning (adduction/abduction). One 2 DOFs trapezo-metacarpal joint at the base of the palm allows the thumb opposition movement towards the other 2 fingers (Figure 5).

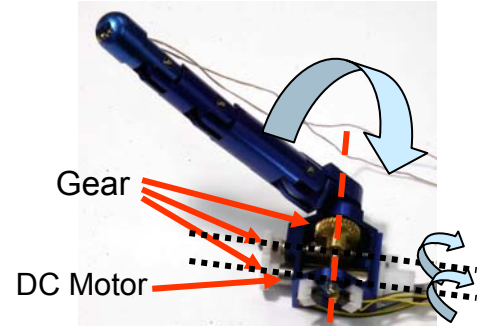


Figure 5. Details of the thumb adduction/abduction mechanism.

Each finger is underactuated, and its movement is driven by a single cable actuated by a motor. The motor for thumb adduction/abduction is located inside the palm, while the motors for the movement of the fingers are all located inside the forearm, thus mimicking the structure of the human body.

The palm is composed by an outside shell, made in carbon fiber, divided into dorsal part and palmar part, and an inside frame, which holds the fingers and contains the thumb adduction/abduction transmission chain. Optionally, a soft padding made by silicon rubber can be mounted on the palm in order to increase the compliance of the grasping. The total weight of the hand is about 320 grams, excluding the motors in the forearm and the cosmetic covering of the palm.

TABLE II. MECHANICAL CHARACTERISTICS OF RCH-1

Number of fingers	5
Degrees of Freedom	16
Degrees of Motion	6 (1 motor integrated into the palm, the other 5 integrated into the forearm)
Underactuation level	10
Thumb ab/adduction	Yes
Maximum grasping force	30N (expected)
Weight	320 grams
Dimensions:	
Total Length	191 mm
Length of fingers	92.2 mm
Diameter of fingers	14 mm
Palm width	95 mm
Palm thickness	40 mm

B. Sensory system

The RCH-1 hand is equipped with several sensors. In particular, it has:

16 contact sensors (on/off sensors), on the palm (2) and on all the phalanges;

2 3D force sensors, integrated into the fingertip of the thumb and of the index finger

1 FSR sensor, on the dorsum of the hand.

In addition, each motor has its own encoder for position control of the movement of the fingers. The description of these sensors is presented in the following paragraphs.

1) Contact sensors

Contact sensors provide information to the tactile sensing system that adequate contact or release information has been established for further manipulative actions. The contact sensors for the RCH-1 were constructed using flexible circuits and were fabricated with the standard photolithography procedures on kapton (polyimide sheets). The top and bottom kapton sheet (Dupont Pyralux film LF9150R) are 127 μ m thick having a single-sided copper cladding of 305g/m² Cu with approximately 35 μ m thickness.

Each of the distal, middle and proximal phalanges has large copper areas for contact. Once assembled, the top and bottom layers touch each other when a sufficient force is applied. Strips of polyurethane foam with an approximate thickness of 1mm are positioned on the bottom layer. The foams function as springs to make the top kapton layer return to its initial state upon the termination of contact with an object. Without these foam strips, severe hysteresis was observed. Furthermore, this “unnecessary contact” becomes more evident when the layers are wrapped around the robot’s fingers.

Efforts were made to make these sensors more sensitive to contact to emulate the mechanoreceptors of the human hand. Johansson [11] estimated that 90% of the Slowly Adapting I (SAI) and Fast Adapting I (FAI) mechanoreceptors get excited to a stimulus of 5 mN and all of these react to an indentation of 1mm. The SAI mechanoreceptors, which have small receptive fields and adapt slowly to a stimulus, can be analogous to on-off contact switches in an engineering implementation.

A picture of the RCH-1 with the contact sensors is showed in Figure 6 (left).



Figure 6. RCH-1 with the contact sensors (left) and the FSR (right) in evidence.

2) 3D Force sensors

The first version of the 3D force sensor is based on flexible structure with a cross disposition of the strain-

gauges located at the base of the fingertip so as to make the whole fingertip a 3-component force sensor. Three strain gauges are used in order to sense the force on the 3 main axes, and other 3 strain gauges are used for temperature compensation. The performances of this sensor are summarized in TABLE III.

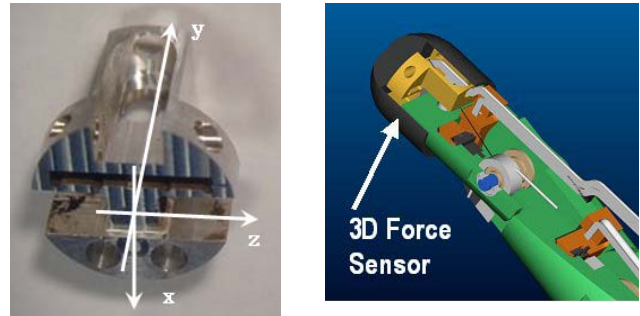


Figure 7. (left) a picture of the 3D force sensor with the force reference frame; (right) 3D model of the 3sensor mounted in the fingertip

TABLE III. PERFORMANCE OF THE 3D FORCE SENSOR.

Maximum Force (N)		Sensitivity (mV/N)	
Fx max	4.62	Sens x	0.68
Fy max	5.96	Sens y	1.2
Fzmax	4.62	Sens z	0.66

3) FSR on the dorsum of RCH-1

Two FSRs (Force Sensing Resistors) model 406 [12] have been put in stack on the dorsum of each hand. Despite of their poor accuracy, which ranges from approximately $\pm 5\%$ to $\pm 25\%$, FSRs can be used to detect ‘stroke’, ‘hit’, and ‘push’ [13]. A picture of the hand with the FSR in evidence is shown in Figure 6 (right).

C. Software & acquisition hardware

The personal computer used as control computer for the hand system is an Intel PIII 1GHz with 512Mb RAM, Win 2000. This computer is connected by Ethernet to PC1 (Pentium IV 3GHz, Windows XP) used for image processing and PC2 (Pentium IV 2.6GHz, Windows XP) for sensory processing and motor control.

The exchange of data between the computer and the two hands is carried out by the following acquisition boards:

2 Analog acquisition boards (AD12-16 (PCI)E, CONTEC [15])

1 digital I/O board (PIO 32/32T, CONTEC)

1 analog output board (DA12-16 (PCI) , CONTEC)

2 boards for the acquisition of the data from encoders (PCI 6205C, Interface Corporation [16])

Each hand has 6 motors in total, 5 for the opening/closing of the fingers and 1 for the thumb

abduction/adduction. The motor drivers used are TITech Driver Ver.2 [17].

The motors for opening and closing the fingers are Maxon RE-max17 4.5W 216012, with Gear GP16A 110323 and Digital MR Encoder 201940 [18]. The motor for the thumb ab-adduction is a Faulhaber 1016M006G, with planetary gearheads 10-1 64:1 and Encoder 30B19 [19]. The control software is developed in Borland Visual C++6.

IV. EVALUATION OF THE PERFORMANCE OF THE HAND

In order to assess the characteristic of the hand, two sets of experiments have been carried out:

1. measurement of the speed of the movement of the phalanges;
2. assessment of the expressiveness of gesture.

A. Exp 1: measurement of the speed of the movement of the phalanges

The movement of the finger from the full extended position to the full flexed position (Figure 8) has been recorded by using Photron PCI Fastcam high-speed video camera system (250 frames/sec, 512x480 pixel) [20]. The variation of the angular position vs. time (showed in Figure 9) is measured using Photron Motion Tools™ software, and the instant angular speed is showed in. Figure 10.

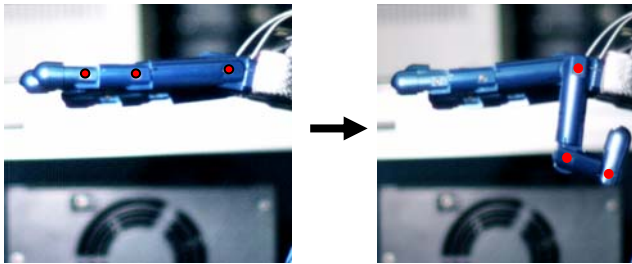


Figure 8. Evaluation of the speed of the phalanges.

The maximum speed of the phalanges is comparable with the maximum speed measured for the human hand with the same experimental framework, in particular if we consider the maximum speed during the normal gesture activities. These data are summarized in TABLE V.

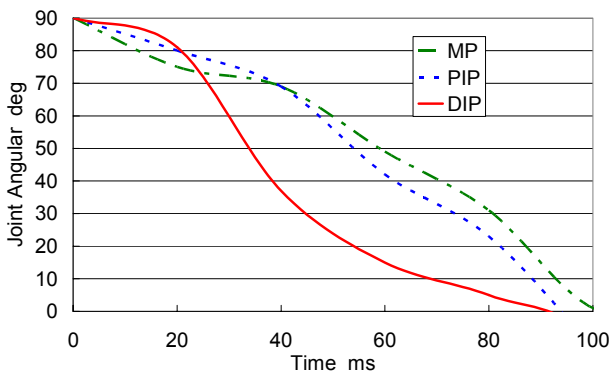


Figure 9. Angular position of each phalanx of the index finger during a full closure.

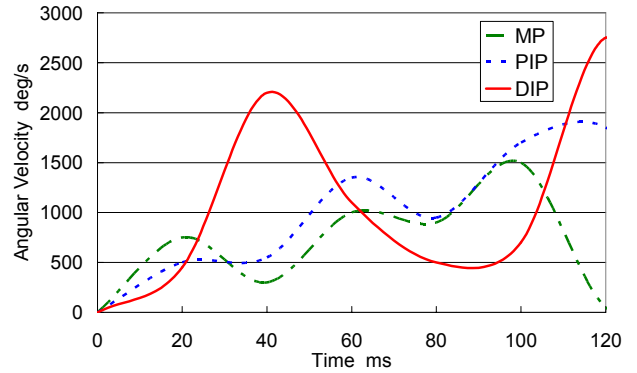


Figure 10. Angular speed of each phalanx of the index finger during a full closure.



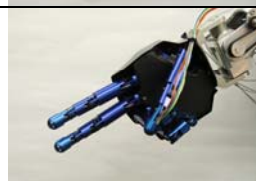
TABLE IV. MAXIMUM ANGULAR SPEED (DEG/S) IN RCH-1 AND IN HUMAN HAND.

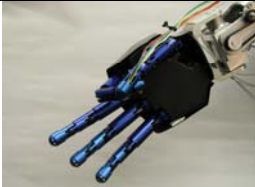


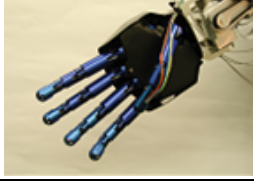
	Human (deg/s)	Human (deg/s) during emotion expression	RCH-1 (deg/s)
MP	2000	1000	1500
PIP	3750	1620	1850
DIP	3750	1750	2750

B. Exp 2: assessment of the expressiveness of gesture

A second test has been carried out in order to assess the gesture capabilities of RCH-1. A set of pictures of the hand has been shown to a group of 14 students of Takanishi lab (average age: 21; sex: male), and their answers has been recorded. Their response is shown in TABLE V.

TABLE V. SOME GESTURE BY RCH-1 AND THEIR INTERPRETATION BY A GROUP OF 14 STUDENTS..

	Ok: 14
	Number one: 7 To point: 7
	Peace sign: 9 Number two: 2 Victory: 2 To smoke: 1

	OK: 9 Money: 3 Number three: 2
	Lovers: 7 Engagement: 7
	Janken (“rock-paper-scissors” game): 13 Aggressiveness: 1
	Number four: 10 To cut: 3 Karate: 1

V. DISCUSSION AND CONCLUSIONS

In order to enhance the communication between robot and humans, two novel humanoid platforms has been realized. The first one, exhibited during ROBODEX2003 in April 2003, integrated the humanoid platform WE-4R, developed in Takanishi Lab of Waseda University, with the RTR2 Hand, developed by ARTS lab of Scuola Superiore Sant’Anna in collaboration with INAIL RTR Center.

For the second humanoid platform, named WE-4RII, two news artificial hands, named RCH-1 (RoboCasa hand #1), has been designed and realized with a joint effort of the ARTS Lab, Takanishi Lab and ROBOCASA. In this paper the first experimental results has been presented.

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