On the realization of a novel anthropomorphic hand for humanoid robotics: RoboCasa Hand #1

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Abstract —In Japan, the average age of the population is rising faster than other nations in the world, due to decrease of birth rate and increase of elderly people. A possible solution to this problem is a new generation of personal robots capable of a natural communication with humans. In this sense, human hands play a fundamental role in exploration, communication, and interaction with objects and other persons.
In this paper, the novel anthropomorphic hand for humanoid robotics, RCH-1 (RoboCasa Hand #1), and its integration into the humanoid robotic platform WE-4RII (Waseda Eye #4 Refined II) is presented.

Key Words: Humanoid robotics; personal robotics; artificial hand; human-robot communication.

1. Introduction

In Japan, the average age of the population is rising faster than other nations in the world, due to the increment of elderly people and to the contemporary reduction of the birth rate. The projections of the National Institute of Population and Social Security Research of Japan show that, by the middle of the 21st century, about one third of the population will be of age 65 or above [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. The next generation of personal robots must be able to coexist with humans in the human living environment, functioning not merely as technology and tools but as partners and companions [2].

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

The work described in 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. These laboratories have created in Tokyo a joint laboratory, named RoboCasa, for investigating the problems of human-robot interaction with an interdisciplinary approach.

The first objective of the RoboCasa team has been to increase the expressional capabilities of the humanoid robot WE-4R (Waseda Eye #4 Refined), developed in Takanishi lab [3], by adding two novel anthropomorphic hands, developed at ARTS lab.

2. Requirements for the hand system

In order to obtain a natural communication and interaction between human and robot, the hands should be capable of basic gesture, like pointing or waving (calling people), and different grasping, like cylindrical grasping or lateral grasping. Moreover, the hands should be capable of estimate the hardness of the object, and also to discriminate different surfaces according to their roughness. A more detailed description of these requirements is presented in TABLE I.

TABLE I. REQUIREMENTS FOR THE NEW HANDS

Basic gesture	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;
Single hand grasping	cylindrical grasping (i.e. small bottle), spherical grasping (i.e. apple), tip pinch (i.e. candy), lateral grasping (i.e. key),
Two hands grasping	Handling of large objects, up to 20cm (i.e.: ball, big toys, and puppets).
Hardness measurement	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	Discrimination of the roughness of the surface of the objects

The dimensions of this hand should be compatible with the male hand. It means that the weight should be lower than 500g, and the approximate size about 190x110mm, 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.

(a) Realization of the first prototype

The new hand, named RCH-1 (RoboCasa Hand #1), consists of 5 identical underactuated fingers with cylindrical phalanges in aluminum alloy. The design of the finger is based on the PALOMA Hand [4], which in turn is an evolution of the RTR2 hand [5].
RCH-1 has in total 16 Degrees of Freedom (DOF) or 6 Degrees of Motion (DOM): one DOM for the flexion and extension of each finger, plus one DOM for thumb adduction/abduction. The underactuation level UL, defined as UL=DOF-DOM, is equal to 10. One 2-DOFs trapezo-metacarpal joint at the base of the palm allows the thumb opposition movement towards the other 4 fingers.
The motor for thumb adduction/abduction is located inside the palm, while the motors for the movement of the underactuated fingers are all located inside the forearm, thus mimicking the structure of the human body.
The palm is composed by and 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 abduction/adduction 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. 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 Lenght	191 mm
Lenght of fingers	92.2 mm
Diameter of fingers	14 mm
Palm width	95 mm
Palm thickness	40 mm

(b) Description of the sensory system

RCH-1 is equipped with several sensors:

- 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
- 2 FSR sensors, on the dorsum of the hand.

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

1) Contact sensors

The contact sensory system should emulate the mechanoreceptors of the human hand. Johansson [6] 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.
So, the contact sensors for RCH-1 were constructed using flexible circuits and were fabricated with the standard photolithograpy procedures on kapton (polyimide sheets). The top and bottom kapton sheet (Dupont Pyralux film LF9150R, DuPont de Nemours, Germany) are 127μm thick having a single-sided copper cladding of 305g/m^2 Cu with approximately 35μm 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, in order to avoid the severe hysteresis that was observed in the first prototypes. The foams function as springs to make the top kapton layer return to its initial state upon the termination of contact with an object. Furthermore, this “unnecessary contact” becomes more evident when the layers are wrapped around the robot’s fingers.

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 three main axes, and other three strain gauges are used for temperature compensation. The performances of this sensor are summarized in TABLE III.

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 (Interlink Electronics, Camarillo, CA, USA) have been put in stack on the dorsum of each hand. Despite of their poor accuracy, which ranges from approximately ± 5% to ± 25%, FSRs can be used to detect 'stroke', 'hit', and 'push' [7].

(c) Software and acquisition hardware

The control system of the WE-4RII is composed by several personal computers, connected by Ethernet. In particular, 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 several acquisition boards. In particular:

- 2 boards for the acquisition of the data from encoders (PCI 6205C, Interface Corporation, Tokyo, Japan)
- 1 analog output board (DA12-16 (PCI) , CONTEC) for the control of the movements of the hand;
- 2 Analog acquisition boards (AD12-16 (PCI)E, CONTEC, CONTEC Co. Ltd, Tokyo) to acquire the signals from FSR and 3D force sensors;
- 1 digital I/O board (PIO 32/32T, CONTEC) for the acquisition of the information from the contact sensors.

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 are TITech Driver Ver.2 (TiTech, Tokyo, Japan).

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

A picture of the first prototype of RCH-1, with the sensory system in evidence, is showed in Figure 1.

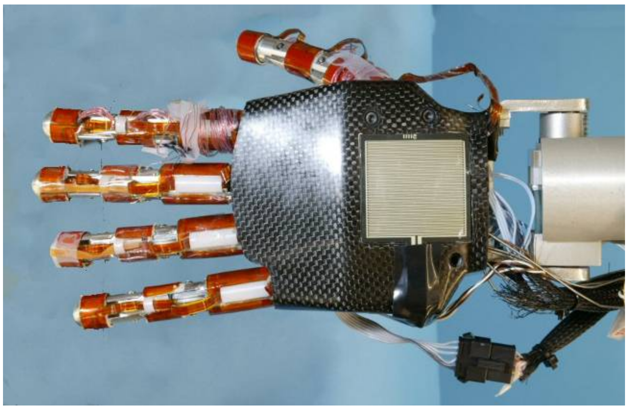


Figure 1. A picture of RoboCasa Hand #1 (left hand) with the FSR and contact sensors in evidence.

3. Integration of RCH-1 into the humanoid robotic platform WE-4RII

In order to integrate RCH-1 into WE-4R, the actuation system for extension and flexion of RCH-1 has been mounted inside the forearm of WE-4RII, thus mimicking the position of *flexor digitorum* and *extensor digitorum* in the human forearm. The motors are connected with the motors by using thin wires with Bowden cables.

The wrist gear system of WE-4R has also been changed to small harmonic drive systems in order to reduce the backlash and miniaturize the wrist mechanism.

A more detailed description of this platform is presented in [8] and [9].

4. Evaluation of the performance of the hand

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

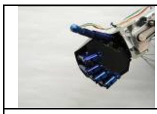
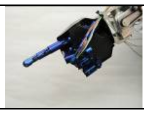
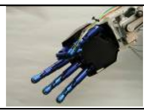
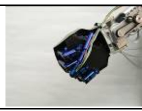
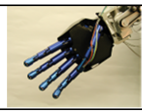
- assessment of the expressiveness of gesture.
- measurement of the speed of the movement of the phalanges;

(a) Experiment# 1: assessment of the expressiveness of gesture

A preliminary 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 interpretations has been recorded. The results of these experiments are summarized in TABLE IV.

Each gestural expression of RCH-1 can be interpreted in a different way according to the situation and according to the personal experience/condition of the observer.

TABLE IV. 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

(b) Experiment #2: 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 has been recorded by using Photron PCI Fastcam high-speed video camera system (250 frames/sec, 512x480 pixels). The variation of the angular position vs. time is measured using Photron Motion Tools™ software (Photron Ltd, Tokyo, Japan).

The results are summarized in TABLE V. The maximum speed of the phalanxes is comparable with the maximum speed measured for the human hand with the same experimental framework.

TABLE V. 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

5. Discussion and Conclusions

The next generation of personal robots should be able to adapt to its partners and environment, and to communicate in a natural way with humans, in particular for home and personal assistance of elderly and/or handicapped people.

In order to obtain these results, a novel humanoid platform has been realized. For this humanoid platform, named WE-4RII (Waseda Eye #4 Refined II), 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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