Robotics and Autonomous Systems 74 (2015) 267–282

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

Underactuated anthropomorphic hands: Actuation strategies for a better functionality

Mahmoud Tavakoli *, Baptiste Enes, Joana Santos, Lino Marques, Anibal T. de Almeida

Institute for Systems and Robotics, Department of Electrical and Computer Engineering, University of Coimbra, Portugal

HIGHLIGHTS

- Actuation Strategies for Under-actuated Anthropomorphic Hands.
- Sixteen actuation strategies in five groups (1–5 actuators).
- 2 benchmarks for grasp diversity and grasp functionality.
- 2 comprehensive analyses for each criteria.
- Suggestions for design of efficient under-actuated hands with minimum actuators.

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
20 August 2015
Accepted 28 August 2015
Available online 7 September 2015

Keywords:
Underactuated hands
Anthropomorphic hands
Grasping
Actuation
DOF
DOA
Robotics
Prosthetic hand

ABSTRACT

This paper aims to analyze the number of actuators as well as the actuation strategy for underactuated prosthetic hands. Two comprehensive analyses were performed for this purpose. 16 possible actuation strategies in five categories of one to five actuators were defined. Based on these 16 strategies two analyses were performed: grasp diversity and grasp functionality. In the first analysis, we defined a performance metric based on all possible grasps by the human hand, while in the second analysis only the top grasps with the highest frequency of usage were considered. By comparing the performance of these strategies we obtained some interesting results regarding the best actuation strategies for the under-actuated anthropomorphic hands. Such study can be useful for designers in the early stages of designing a prosthetic terminal, for deciding the number of actuators and how such actuators are allocated to the DOFs of the hand. In other words, this study shows which joints of the hands should be coupled together and driven by a single actuator, in order to get the best performance with minimum number of actuators. This is important for developing hands, which have a small number of actuators (i.e. less than 5 actuators), and thus benefit from a simple electromechanical structure.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Anthropomorphic robotic hands that have been developed so far for industrial and prosthetic purposes can be roughly categorized as fully actuated hands [1–4] and highly underactuated [5–8].

The former group has many actuators, placed on the forearm or in the hand itself, by the sacrifice of the weight and the size of the hand and the actuation power. These hands can grasp and manipulate a wide range of objects by applying a complex control strategy. Yet, due to their electromechanical and control architecture complexity, they are not the best option for many applications that demand simplicity, lightness and low cost.

The underactuated hands usually contain 1–6 actuators (compared to the 34 muscles that control human hand). They offer the following advantages [9] over the former group:

- Simpler electromechanical structure.
- Lower weight, size and price.
- Simpler control architecture.

The human hand has an average weight of 400 g [10]. However, prosthetic terminal devices of similar weight have been described as being too heavy by users [11]. With the current technologies it is not possible to construct a fully actuated hand lighter than 400 g. For this reason fully actuated prosthetic hands are not being commercialized for prosthetic applications. Here we present some of the underactuated hands, which are either a prototype in a research center or commercialized product, and categorize them based on their number of actuators. For a simpler description of

* Corresponding author.
E-mail address: mahmoud@isr.uc.pt (M. Tavakoli).

http://dx.doi.org/10.1016/j.robot.2015.08.011
0921-8890/© 2015 Elsevier B.V. All rights reserved.

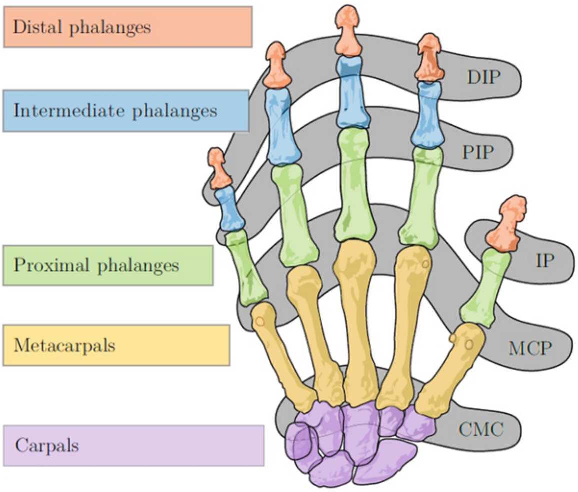

Fig. 1. Bones and joints of the human hand. DIP—Distal Interphalangeal joint; PIP—Proximal Interphalangeal joint; IP—Interphalangeal joint; MCP—Metacarpophalangeal joint; CMC—Carpo-Metacarpal joint [12].

these prototypes, we depicted the name of the bones and joints of the human hand. In the following paragraphs DOF indicates "Degrees-Of-Freedom" and DOA stands for "Degree-Of-Actuation" or in other words Number-Of-independent-Actuators.

1.1. Six actuators

Vincent hand is a 6-DOF (Degrees-of-Freedom), 6-DOA (Number-of-Actuators) commercial prosthetic hand. It has 1 actuator for each finger except from the thumb that is double actuated, one for the thumb abduction/adduction movement and another one for the thumb flexion (total 6 actuators) [13]. The metacarpophalangeal joint flexion is moved directly by gears. The metacarpophalangeal joint of the thumb, for flexion and abduction/adduction, is moved using two separate actuators. The hand prosthesis has 10 movable joints, which can be actively moved in the direction of flexion and extension [14]. The joints of the human hand can be seen in Fig. 1.

1.2. Five actuators

iLIMB is a 6-DOF, 5-DOA commercial prosthetic hand. It includes 1 actuator per each finger (total 5 actuators) which directly actuates the respective metacarpophalangeal joint flexion. The thumb abduction/adduction movement is not motorized and is performed manually. The abduction/adduction movement is actually limited to two possible positions at approximately 90 around an axis parallel to the wrist axis. At these positions a locking mechanism locks the thumb position. To alternate this position an external force is applied by the other hand, so that the thumb rotates around the mentioned axis until it locks in the second position [14,15].

BeBionic is a 6-DOF, 5-DOA commercial prosthetic hand. It includes 1 actuator per each finger (total 5 actuators) but in contrast to iLIMB hand the motors are placed in the mid-hand (metacarpus). The thumb abduction/adduction is manual. [14,16].

Meka H2 is a 12-DOF, 5-DOA compliant four finger hand (the little finger is eliminated). There is 1 actuator per each finger and another one for the thumb abduction/adduction movement (total 5 actuators) [17,18].

1.3. Four actuators

Smarthand is a 16-DOF, 4-DOA underactuated anthropomorphic hand. It includes 4 actuators all located inside the palm structure. The first actuator drives the thumb flexion/extension, the second one drives the index flexion/extension, the third one actuates the middle, ring and little finger flexion/extension and the fourth one actuated the thumb abduction/adduction [19]. The flexion/extension metacarpophalangeal joint is directly connected onto an extension of the brushed DC motor shaft; a certain degree of non-back-drivability is achieved by means of a high reduction, this actually, allows slight adaptation of the thumb axis while it is closed against the other fingers in a precision grasp [20,21].

1.4. Three actuators

Kazuki Mitsui et al. developed a 3-DOA underactuated anthropomorphic hand. It includes 3 actuators and one solenoid. One actuator for the thumb flexion, one for the index flexion and another one for the other three fingers. Yet through an innovative design a solenoid is embedded into the thumb axis, which enables the ab/ad of the thumb when necessary [22].

MANUS hand is a 3-DOF, 3-DOA research anthropomorphic prosthetic hand. It includes 3 actuators and one Geneva wheel. One actuator for the thumb, one for the other four fingers and one for the wrist. A different design purpose was tested using a Geneva-wheel based mechanism which enables the thumb to move into 2 planes with only one motor actuating it, the thumb has a coupled flexion and abduction/adduction [6].

1.5. Two actuators

Michelangelo is a 2-DOF, 2-DOA commercial anthropomorphic prosthetic hand. It includes 2 actuators, one for closing all the fingers and another one for changing the angle of the thumb. A small motor changes the path that the thumb will take when the main motor actuates to close the hand either in a palmer or lateral grasp [23,24].

KNU hand is a research prosthetic hand with 16-DOF and 2-DOA. It includes 2 actuators, one for the thumb flexion, another actuator for the other 4 fingers and one Geneva wheel. The approach used for the ab/ad of the thumb is the same as in the MANUS hand, but as the interphalangeal joint is coupled with the carpometacarpal joint a complex driven path is required to transmit the motor's power. Thus to achieve this feature an external Geneva and crank-slider mechanism is used [25].

1.6. One actuator

Single actuator hands are especially interesting because they are usually light-weight and simple to control. In such hands usually researchers try to use innovative mechanisms in order to increase the hand's adaptivity to a wide range of objects.

Sensorhand is a 1-DOF, 1-DOA commercial prosthetic hand. It includes only 1 actuator that actuates the flexion of the thumb, index and middle finger. The other two fingers have only an aesthetic purpose [26].

TUAT hand is a 21-DOF, 1-DOA research prosthetic hand. The thumb's rotation axis is placed at 6.5° from the wrist axis. The thumb only operates to fix the object position as a fulcrum [27].

Researchers have also analyzed kinematic and dynamical behavior of the finger flexion in order to design optimal adaptive mechanisms that can grasp different objects with a single actuator [28–30]. In some cases in addition to the adaptive flexion mechanism, researchers integrated a friction-based proximal joint on the thumb, that can be manually actuated by the other hand.

In the case of the Pisa-IIT hand [31], boundary surfaces are used in order to block some of the fingers from bending and to form the desired postures on the hand for grasping objects with different geometries. Baril et al. incorporated a mechanical blocking system

Download English Version:

https://daneshyari.com/en/article/10326946

Download Persian Version:

https://daneshyari.com/article/10326946

Daneshyari.com