Bio-inspired Robotics Hands: A Work in Progress

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Abstract. Towards dexterous manipulation and human-like grasping capabilities, a new phase of robotics hands have been developed recently with biomimeticly oriented functionalities. This manuscript is an attempt to survey in details biomimetic based dexterous robotics hands. In particular, the article focuses on a number of developments that have been taking place over the last two decades, in recent development related to this biomimetic filed of research.

Keywords: Biomimetic, Dexterous Manipulation, Biomimetic Robotics.

1 Introduction

Over the past two decades, large number of dexterous robotics hands have been developed that explicitly emulate human like hand shape and movements. However, it was clear that biological functionalities could not be fully emulated due to luck of the right technologies. Over past few years, engineering such biomimetic intelligent creatures, such as robots, was hindered by physical and technological constraints and limitations. Literatures in this vital field have been focused since early 1990, when the Utah and JPL hand researchers published their research work in progress in 1984 (refer to Fig. 1., [1,2]). Biomimetic robot hands, as indicated by Yoseph B. [3], have been introduced lately over the last decade. This is due to a number of potential advantages over purely mechanical robot hands, as known here as the classical hand. Within this article, we shall survey a number of potential research frameworks that have been focused lately towards Biomimetic robot hands design and implementation.

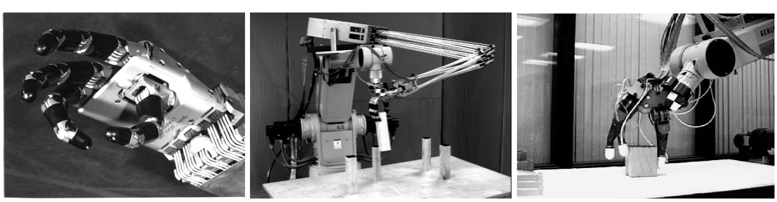

Fig. 1. The Utah and JPL hands, early attempts to emulate human grasps, [1,2]

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2 Bio-inspired Dexterous Robotics Hands

2.1 Hand Biomimetic Compliance Control Structures of Human Finger

In their paper, Byoung K. et, al. [4], for an object grasped by a robot hand to work in compliance control domain, they analyzed necessary condition for successful stiffness modulation in the operational space. They proposed a new compliance control method for robot hands which consist of two steps. RIFDS (Resolved Inter-Finger Decoupling Solver) is to decompose the desired compliance characteristic specified in the operational space into the compliance characteristic in the fingertip space without inter-finger coupling, and RIJDS (Resolved Inter-Joint Decoupling Solver) is to decompose the compliance characteristic in the fingertip space into the compliance characteristic in the joint space without inter-joint coupling. It was found, a finger structure should be biomimetic in the sense that either kinematic redundancy or force redundancy are required to implement the proposed compliance control scheme.

2.2 Control of A Multi-finer Prosthetic Hand

In [5], Craelius W. et. al. have developed a control of multi-finger prosthetic hand. The prosthetic hand is controlled by extrinsic flexor muscles and tendons of the metacarpal-phalangeal joints. The hand uses Tendon-Activated Pneumatic control and has provided most subjects, including amputees and those with congenital limb absence, control of multiple fingers of the hand. This is illustrated in Fig. 2.

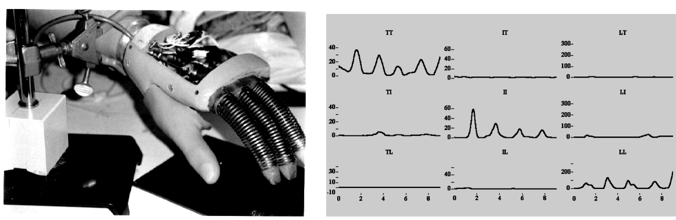

Fig. 2. (a) Linear actuators provided movement of 3 independent fingers. (b) Signals derived from TAP sensors, 9-sec. period of repetitive finger flexions, [5].

2.3 A Biomimetic Controller for a Multifinger Prosthesis

In [6], Abboudi R. et. al. have presented a novel controller for a multifinger hand prosthesis, and developed it and tested to measure its accuracy and performance in transducing volitional signals for individual "phantom" fingers. Pneumatic sensors were fabricated from open-cell polymeric foam, and were interposed between the prosthetic socket and superficial extrinsic tendons associated with individual finger flexion. Test subjects were prompted to step individual fingers or combinations thereof to perform either taps or grasps. Sensor outputs were processed by a computer that controlled motions of individual fingers on a mechanical prosthesis. Trials on three upper-limb amputees illustrated that after brief training sessions, the TAP controller was effective at producing voluntary flexions of individual fingers and grasping motions.

2.4 Tendon and Muscle Force Requirements for Humanlike

In [7], Pollard N. And Richards G. have stated that adapting human examples to a robot manipulator is a complex problem, however, in part due to differences between human and robot hands. Force transmission mechanisms in robot fingers are generally symmetric about flexion / extension axes, but in human fingers they are focused toward flexion, Fig. 3. The reserach describes how a tendon driven robot finger can be optimized for force transmission capability equivalent to the human index finger. They have shown that two distinct tendon arrangements that are similar to those that have been used in robot hands can achieve the same range of forces as the human finger with minimal additional cost in total muscle force requirements.

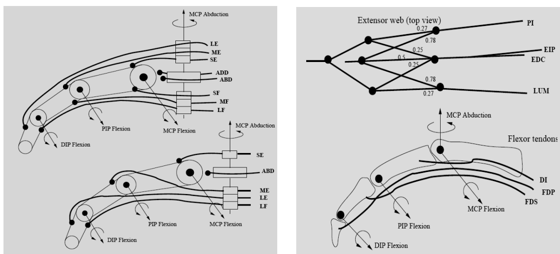

Fig. 3. (a) : 2N and N+1 tendon fingers. (b) : Flexor and extensor tendons of the index, [7].

2.5 Principal Components Analysis Based Prosthetic Hand

In [8], Matrone G. et. al. presented prosthetic hands and controlled by means of non-invasive interfaces based on electromyography (EMG). Driving a multi degrees of freedom (DoF) hand for achieving hand dexterity implies to selectively modulate many different EMG signals in order to make each joint move independently, and this could require significant cognitive effort to the user. A principal components analysis based algorithm is used to drive a 16 DoFs underactuated prosthetic hand prototype with a two dimensional control input, in order to perform the three prehensile forms mostly used in Activities of Daily Living (ADLs). Principal components set has been derived directly from the artificial hand by collecting its sensory data while performing 50 grasps, and subsequently used for control. This is shown in Fig. (8).

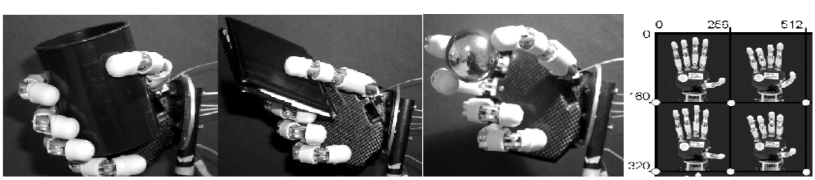

Fig. 4. Power, precision and lateral grasp, as in [8]

2.6 Biomimetic Tactile Sensor for Control of Grip

In [9], Wettels N. et. al. , are developing a novel, robust tactile sensor array that mimics the human fingertip and its distributed set of touch receptors. The mechanical components are similar to a fingertip, with a rigid foundation surrounded by a weakly conductive fluid contained within an elastomeric skin, Fig. 5. It uses the deformable properties of the finger pad as part of the transduction process. Multiple electrodes are mounted on the surface of the rigid core and connected to impedance measuring circuitry within the core. External forces deform the fluid path around the electrodes, resulting in a distributed prototype of impedance changes containing information about those forces and the objects that applied them.

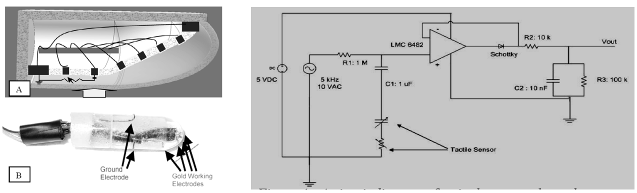

Fig. 5. eft : a) Drawing of biomimetic tactile sensor. b) Sensor prototype core with “skin” removed, Right : A circuit diagram for single sensor channel, [9].

2.7 A Shape Memory Alloy-Based Tendon-Driven Actuation

According to Bundhoo V. et. al. [10], a new biomimetic tendon-driven actuation system for prosthetic and wearable robotic hand applications is presented. It is based on the combination of compliant tendon cables and one-way shape memory alloy (SMA) wires that form a set of agonist–antagonist artificial muscle pairs for the required flexion/extension or abduction/adduction of the finger joints, Fig. 6. The performance of the proposed actuation system is demonstrated using a 4 degree-of-freedom (three active and one passive) artificial finger test-bed, also developed based on a biomimetic design approach. A microcontroller-based pulse-width-modulated proportionalderivation (PWM-PD) feedback controller and a minimum jerk trajectory feedforward controller are implemented and tested in an ad hoc fashion to evaluate the performance of the finger system in emulating natural joint motions.

Fig. 6. Left : An artificial finger, [10]. Right : Examples of interactive grasp planning using input provided by an operator, [11].

2.8 Biomimetic Grasp Planning for Cortical Control of a Robotic Hand

In [11], Ciocarlie M. et. al., and in their paper, they outlined a grasp planning system designed to augment the cortical control of a prosthetic arm and hand. A key aspect of this task is the presence of on-line user input, Fig. 6., which will ultimately be obtained by identifying and extracting the relevant signals from brain activity. The grasping system can combine partial or noisy user input and autonomous planning to enable the robot to perform stable grasping tasks. They used principal component analysis applied to the observed kinematics of physiologic grasping to reduce the dimensionality of hand posture space and simplify the planning task for on-line use. The planner then accepts control input in this reduced-dimensionality space, and uses it as a seed for a hand posture optimization algorithm based on simulated annealing.

2.9 Grip Control Using Biomimetic Tactile Sensing Systems

Wettels N. et. al. in [12], have presented a proof-of-concept for controlling the grasp of an anthropomorphic mechatronic prosthetic hand by using a biomimetic tactile sensor, Bayesian inference and simple algorithms for estimation and control. The sensor takes advantage of its compliant mechanics to provide a tri-axial force sensing end-effector for grasp control, Fig.7. By calculating normal and shear forces at the fingertip, the prosthetic hand is able to maintain perturbed objects within the force cone to prevent slip. A Kalman filter is used as a noise-robust method to calculate tangential forces. Biologically-inspired algorithms and heuristics are presented that can be implemented on-line to support rapid, reflexive adjustments of grip.

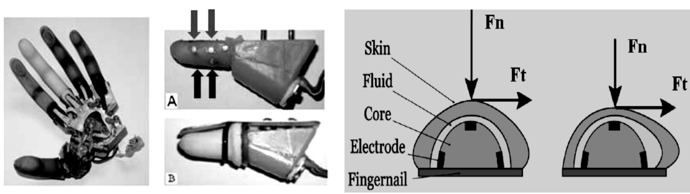

Fig. 7. Left: Otto Bock M2 Hand. Tac prototype sensor array Right: Effect of normal and tangential forces on different electrodes, [12].

2.10 Development of Bio-mimetic Robot Hand Using Parallel Mechanisms

In [13] Lee S. et. al., describe a development of bio-mimetic robot hands and its control scheme. Each robot hand has four under-actuated fingers, which are driven by two linear actuators coupled, Fig. 8. Each fingertip can reach toward objects by curved surface workspace in 3D-space. The robot hand was designed considering the dexterity and the size suited for human tools and has tactile sensors equipped on the fingertips of each finger. The robot hand has 4 fingers with totally nine DOFs including two linear actuators and linkage knuckles. In the former part of this paper, the design of the robot hand is presented. And in the latter part of the paper, computational simulations are described. The simulations show the performance of the robot hand to manipulate tools of various shapes.

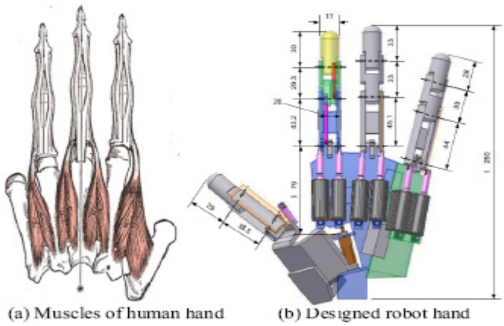

Fig. 8. Features of parallel actuated robot hand, [13]

2.11 Biomimetic Sensing for Robotics Manipulation

In [14], Petroff N. stated that in manipulation tasks, humans have the advantage over machines due to an unparalleled ability to process information from various inputs, including touch. A set of four robot end-effectors was equipped with force sensors to provide haptic feedback to aid in performing the manipulation tasks of rotating a sphere and a cube. The algorithm gives rise to new vector fields called Lie brackets that allow the fingers to be reconfigured without releasing the object, effectively increasing the workspace of the manipulation system. Experiments were conducted with fixed-point manipulation to produce a baseline for comparing reconfigurable manipulation experiments. Both open loop and closed loop, reconfigurable manipulation experiments were conducted on a spherical object.

2.12 Bio-inspired Sensorization of a Biomechatronic Robot Hand

In [15] Edinc B. et. al., have concluded from numerous neurophysiological studies, that humans rely on detecting discrete mechanical events that occur when grasping, lifting and replacing an object, i.e., during a prototypical manipulation task. Such events represent transitions between phases of the evolving manipulation task such as object contact, lift-off, etc., and appear to provide critical information required for the sequential control of the task as well as for corrections and parameterization of the task. They have sensorized a biomechatronic anthropomorphic hand with the goal to detect such mechanical transients. The developed sensors were designed to specifically provide the information about task-relevant discrete events rather than to mimic their biological counterparts. To accomplish this they have developed (1) a contact sensor that can be applied to the surface of the robotic fingers and that show a sensitivity to indentation and a spatial resolution comparable to that of the human glabrous skin, and (2) a sensitive low-noise three-axial force sensor that was embedded in the robotic fingertips and showed a frequency response covering the range observed in biological tactile sensors.

2.13 Design and Control of a Shape Memory Alloy Based Dexterous Hand

In [16], Price A. et. al., modern externally powered upper-body prostheses are conventionally actuated by electric servomotors. Although these motors achieve reasonable kinematic performance, they are voluminous and heavy. Deterring factors such as these lead to a substantial proportion of upper extremity amputees avoiding the use of their prostheses. It was found, it is apparent that there exists a need for functional prosthetic devices that are compact and lightweight. The realization of such a device requires an alternative actuation technology, and biological inspiration suggests that tendon based systems are advantageous. Shape memory alloys are a type of smart material that exhibit an actuation mechanism resembling the biological equivalent.

2.14 Bio-inspired Grasp Control In A Robotic Hand (Massive Sensorial Input)

In [17] Ascari L. et. al., found that no robotic tools able to perform an advanced control of the grasp as, for instance, the human hand does, have been demonstrated to date. In their paper a bio-inspired approach to tactile data processing has been followed in order to design and test a hardware–software robotic architecture that works on the parallel processing of a large amount of tactile sensing signals. The working principle of the architecture bases on the cellular nonlinear/neural network (CNN) paradigm, while using both hand shape and spatial–temporal features obtained from an array of microfabricated force sensors, in order to control the sensory-motor coordination of the robotic system. Prototypical grasping tasks were selected to measure the system performances applied to a computer-interfaced robotic hand.

2.15 Adaptive Grasping by Multi Fingered Hand

In [18] Takahashi T. et. al., proposed a new robust force and position control method for property-unknown objects grasping. The proposed control method is capable of selecting the force control or position control, and smooth and quick switching according to the amount of the external force. The proposed method was applied to adaptive grasping by three-fingered hand which has 12 DOF, and the experimental results revealed that the smooth collision process and the stable grasping is realized even if the precise surface position, the mass and the stiffness are unknown. This is shown in Fig. 9.

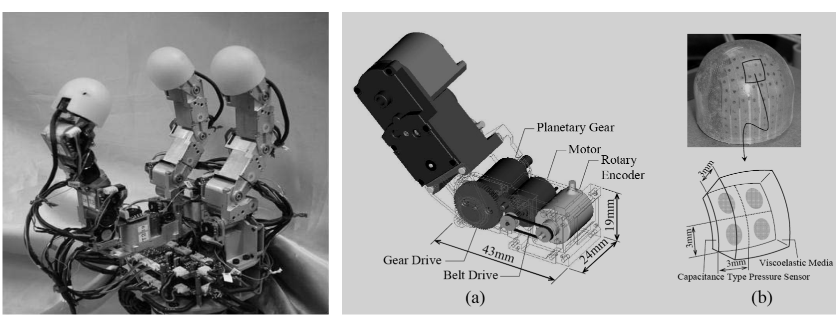

Fig. 9. (a) Joint Drive Unit (b) Tactile sensor, [18]

3 Conclusion

This article is a part of work in progress that is prepared to be looking into and surveying a number of research efforts towards building biomimetic based dexterous robotics hands. The study has indicated that, there are tremendous number of efforts towards building dexterous robotics multi-fingered hand with biomimetic based ideas and initiatives. In addition, it was shown that research is even moving towards muscles type hand fingers, which means moving totally from the concept of motor driven fingers movements and grasping. In terms of bio-inspired robotics hand design and control, technology is promising us with vital solutions in this directions.

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