Semi-Anthropomorphic 3D Printed Multigrasp Hand for Industrial and Service Robots

Zhanat Kappassov, Yerbolat Khassanov, Artur Saudabayev, Almas Shintemirov, Huseyin Atakan Varol

Department of Robotics and Mechatronics
Nazarbayev University
Astana, Kazakhstan

{zkappassov, yerbolat.khassanov, asaudabayev, ashintemirov, ahvarol}@nu.edu.kz

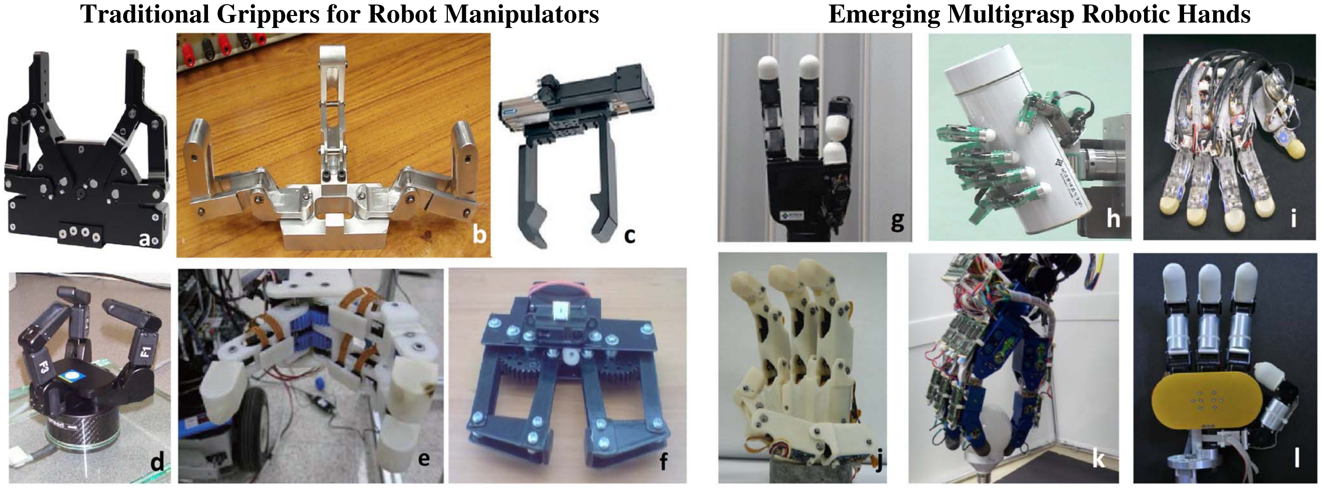
Abstract **– This paper presents the preliminary prototype design and implementation of the Nazarbayev University (NU) Hand, a new semi-anthropomorphic multigrasp robotic hand. The hand is designed to be an end effector for industrial and service robots. The main objective is to develop a low-cost, low-weight and easily manufacturable robotic hand with a sensor module allowing acquisition of data for autonomous intelligent object manipulation. 3D printing technologies were extensively used in the implementation of the hand. Specifically, the structure of the hand is printed using a 3D printer as a complete assembly voiding the need of using fasteners and bearings for the assembly of the hand and decreasing the total weight. The hand also incorporates a sensor module containing a LIDAR, digital camera and non-contact infrared temperature sensor for intelligent automation. As an alternative to teach pendants for the industrial manipulators, a teaching glove was developed, which acts as the primary human machine interface between the user and the NU Hand. The paper presents an extensive performance characterization of the robotic hand including finger forces, weight, audible noise level during operation and sensor data acquisition.**

Index Terms – Multigrasp robotic hand, intelligent industrial automation, service robotics, LIDAR.

I. INTRODUCTION

There is a vast collection of industrial grippers that have been developed for the manipulation of rigid and non-rigid objects (see Fig. 1(a-f)). Low-cost, simplicity, robustness, operation speed, grip forces, ease of programming and deployment effort are the main parameters considered in the design of the industrial grippers. Most of these industrial grippers are capable of employing only a single grasping pattern, which is usually a two (or three) point pinch grasp. For instance, RL1 [1] is activated by a single motor and can execute only a three point grasp pattern. This simplifies both the mechanical design and programming of the end effector. Robotiq's two-finger adaptive gripper (see fig.1 (a)) is mainly used for simple object manipulation purposes. It has a maximum payload of 4 kg and grip force which can reach up to 100N [2]. Flexible Robotic Gripper [3] shown in Fig. 1 (b) is a similar example, which is used to handle a specific type of food product. Two-finger parallel gripper developed by Schunk is exceptionally easy to program and configure due to its integrated web server (see Fig. 1 (c)) [4]. Automatically reconfigurable BarrettHand has eight joints controlled by four brushless DC servomotors, which makes it very flexible (see Fig. 1 (d)) [5]. Home service robot gripper is incorporated with a pressure sensor which enables it to handle objects safely (see Fig. 1 (e)) [6]. Design and development of low-cost sensor-based autonomous friction gripper, which is capable of applying right gripping force to various objects, is presented in [7] (see Fig. 1 (f)).

Human hand on the contrary to the traditional grippers can employ multiple grasp patterns and complete much wider array of tasks. Presumably, the efficacy of the end effectors


Traditional Grippers for Robot Manipulators

Emerging Multigrasp Robotic Hands

Fig. 1. Robotiq Robot Gripper (a), Flexible Robotic Gripper (b), Schunk 2-Jaw Gripper (c), Barret Hand (d), Gripper for home service robot (e), Autonomous friction gripper (f), Anthropomorphic Robot Hand (g), Gifu Hand III (h), Robot Hand using Ultrasonic Motors (i), Yuan Ze University Robotic Hand (j), SKKU IV robot hand (k), KU Hybrid Hand (l).

for industrial and social robotics applications would also increase with the capability of executing multiple grasping patterns similar to the human hand. Recent research in the design of multiple grasp robotic hands has surged both in industry and academia. Various robotic hands have been developed with different levels of anthropomorphism to reproduce the human hand functionality (see Fig. 1 (g-l)). An anthropomorphic robotic hand with four fingers (including an opposable thumb) with 16 joints developed in [8], verifies that a stable grasping can be achieved without use of high-performance devices and precise finger motion control (Fig. 1 (g)).Five-fingered Gifu Hand III with 20 joints, developed for use in robotics research, performed a lower response time than a human hand [9] (see Fig. 1 (h)). A unique method using ultrasonic motors and elastic elements, driving a five-fingered hand is shown in [10] (see Fig. 1 (i)). Development of a four-fingered robotic hand with less than 500 grams weight and less than 35 cm length is described in [11]. In their mechatronics design methodology, developers used the advantage of computer models reutilization at various stages (see Fig. 1 (j)). The hand described in [12] incorporates fingertip tactile sensor, joint torque senor, fingertip force torque sensor and was developed for delicate object grasping (see Fig. 1 (k)). Hybrid robotic hand [13] is able to perform various grasping motions by applying one of the two modes – human hand mode and conventional robotic hand mode (see Fig. 1 (l)).

After the emergence of the multigrasp hand paradigm, a number of robotic hands got commercialized and became available on the market. Even though there are some multigrasp hands on the market, the authors are not aware of a low-cost and easily manufacturable multigrasp hand. Moreover, there are no robotic hands with an integrated sensor module, which would enable autonomous or semi-autonomous operation capabilities independent of the base manipulator. In this paper, we present our preliminary work on the design and implementation of a low-cost, semi-anthropomorphic, 3D printed multigrasp hand for industrial and service robots called Nazarbayev University (NU) Hand (See Fig. 2). In Section II, the design of the hand is presented along with the description of sensor module and teaching glove for human machine interface. In the Section III, the performance of the end effector is presented, which is followed by the conclusion and future directions of work.

II. DESIGN OF THE NU HAND

A. Design Objectives

Despite the fact that there is a big variety of postures and grasping capabilities a human hand is able to perform, there are canonical postures which incorporate the essential grasps and postures required to achieve the most of the human hand manipulation. Those are: a pointing posture; lateral grasping acquired with a thumb and forefinger; a triple grasp between the thumb, forefinger, and middle finger; cylindrical and spherical entire-hand grasp; a hook grasp; a platform posture [14]. One of our design objectives is the ability to perform these grasp patterns.

An ability to extensively apply the multigrasp end effector in industry and service areas puts several requirements which must be met at the design stage. The robotic hand should not weight more than 1 kg – otherwise, the heavy weight of the end effector would significantly limit payload capabilities of the base manipulator. Low audible noise is another vital feature that should be met, so that the end effector can be practically used for service robotics applications. Target weight of the objects that the end effector should be capable of grasping was selected at 1 kg. This requires consideration of force and speed levels, which should suffice for grasping objects up to 1 kg.

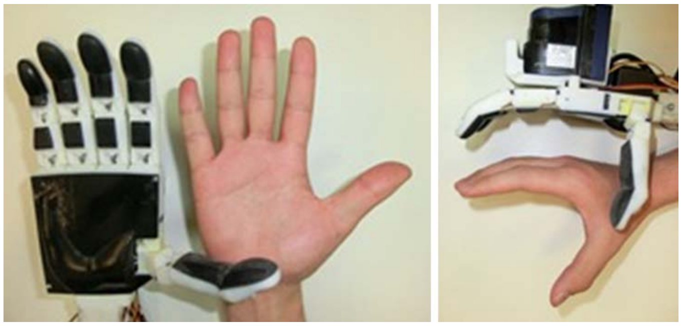


Fig. 2. The NU Hand prototype versus the hand of an average size male person.

As discussed in the Section I, low-cost of the end effector is one of the principle requirements to the system, which would allow the usage of the robotic hand for the tasks involving low-cost robots and be affordable within the service robotics sector. To fulfill this requirement, we decided to use only off-the-shelf components as well as making most of the hand structure using 3D printing. Low cost requirement also puts a soft constraint on the number of actuators in the hand. Finally, the sensor module should be integrated with the hand. Providing the ability to recognize the type and the shape of the target objects, sensor module ensures that the robotic hand can work autonomously without depending on the perception system of the main robot.

B. Hand Design

Following the specification of the design objectives, this section describes the design of the Semi-Anthropomorphic 3D Printed Multigrasp Robotic Hand (see Fig. 2). The hand consists of ten joints, which are actuated by five tendons attached to four servo motors (see Fig. 3). Use of simple servo motors eliminates the necessity of complex electronic circuits and encoders for position control, which lowers the cost and decreases the weight of the system.

Dimensions of the robot hand with sensor module are shown in Fig. 4. It is important to point out, that the hand incorporates finger and palm paddings (rubber like material printed with the 3D printer) similar to the soft tissues in the human fingers and palm to aid in conformal grasping. Special pulleys were designed to connect the servo motors to the tendons in a way that full closure of a finger occurs in 180 degrees rotation of a servo motor.

Adduction and abduction of the thumb is realized via directly connected micro servo motor. Second joint of the thumb is controlled by a digital brushless servo motor (Futaba BLS153). All joints of index finger (Digit II) are controlled by standard digital servo motor (HITEC HS322). Three remaining fingers (Digit III-V) are controlled by one servo motor (HITEC HHS322) through a differential coupling.

The hand incorporates series elastic elements (see Fig. 5) which distribute applied force between 3 fingers – middle finger, ring finger and little finger (differential coupling), and provide an extensive force control. Elastic elements act in series with tendons as in [14] (see Fig. 6). Series elastic elements are printed with 3D printer (Object Connex 260), which allows printing digital materials with different coefficients of elasticity of rubber material. In order to prevent the expansion of the central section of the series elastic elements as it is shown on the left part of the Fig. 5., rubber material is divided by rigid plastic washers (See the right part of the Fig. 5.). The stiffness of the series elastic elements is set to 2.5 N/mm. Tendons are used only to close the fingers. Opening of the fingers is performed by torsion springs. The rotational stiffness values of the thumb spring and the other springs are 7.2 N/cm and 4.4 N/cm, respectively.

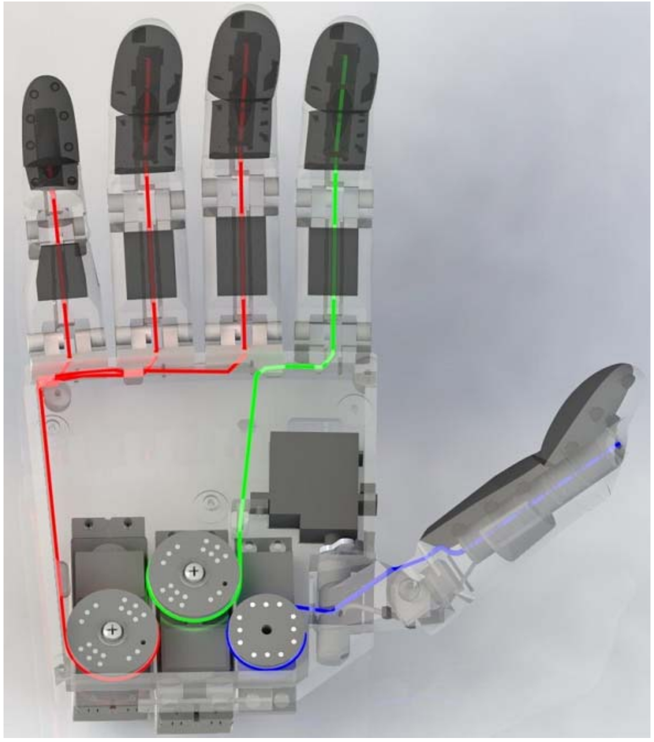


Fig. 3. Computer rendering of NU Hand indicating routing of five tendons from the three motors. The motor for thumb abduction/adduction is direct drive and does not have a tendon.

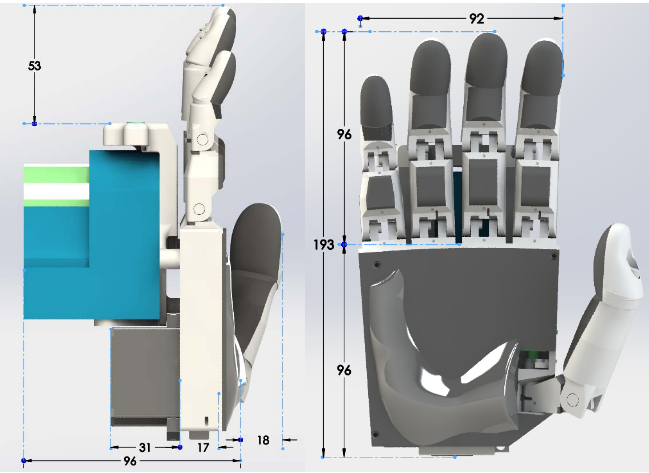


Fig. 4. Side (left) and bottom (right) views of the NU Hand with dimensions (All dimensions are in mm).

As mentioned in the Design Objectives, it is important to point out that palm, fingers and rubber paddings of the robotic hand were printed as a single assembly at one time. No fasteners or bearings are used in the hand decreasing the total weight. The hand incorporates a mounting adapter for easy attachment to industrial manipulators.

Ten joints incorporated into the hand provide ten degrees of freedom. It is important to note that, having four servo motors, thus having number of actuators less than number of degrees of freedom, the robotic hand is underactuated. Underactuation allows the fingers to perform conformal grasping around objects minimizing the need for additional number of actuators and programming. Grasping patterns of the multigrasp robot hand is shown in Fig. 7.

C. *Human-Machine Interface: Teaching Glove*

Fig. 5. Two different approaches considered for the implementation of the series elastic elements in NU Hand.

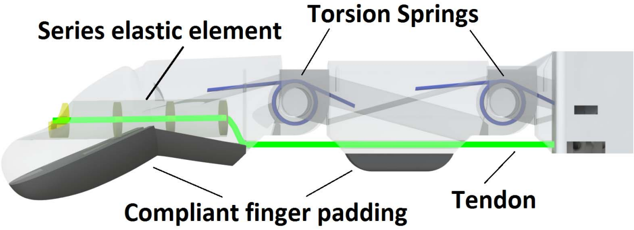


Fig. 6. Index finger cross section view of the NU Hand showing tendon routing, series elastic element, torsional springs and compliant finger padding.

Fig. 7. Different grasp patterns achieved by NU Hand.

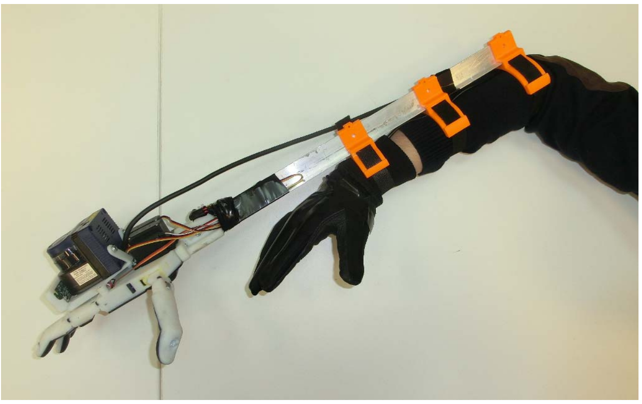


Fig. 8. NU Hand and the teaching glove worn by a user.

Teaching glove was made by attaching flex sensors to the glove (see Fig. 8). Flexion of sensors increases resistance across the sensor which is used to measure the closing of the finger. Four sensors were used to detect extension/flexion of thumb (Spectra Symbol FS7954), middle and index fingers (Spectra Symbol FS7548) and adduction/abduction of thumb finger. Data from the sensors are collected by the NI-DAQ 6221 data acquisition card. The low pass filtered data from the data acquisition card are sent to Arduino board. Arduino program converts voltage value to a Pulse Width Modulation (PWM) signal and outputs it to the corresponding servo motor. Teaching glove will be used as an interface for teaching the end effector to perform various grasping patterns for different objects. Full human machine interface setup is shown in Fig. 8.

D. *Sensor Module*

Sensor housing incorporated into robotic hand accommodates a non-contact temperature sensor (Melexis MLX90614), LIDAR sensor (Hokuyo UBG-04LX-F01) and RGB camera (Logitech C310). Data obtained from these sensors are intended to be used for object detection, recognition, pose estimation and manipulation. The ability to recognize an object, as well as possession of such information as its size, shape and pose, with relevant algorithms implemented, allows for generation of a specific grasping pattern, required for manipulating the object. Non-contact temperature sensor shows temperature of the object and prevents from contact with the hot objects in order to avoid damage.

As seen on the Fig. 9, information obtained from the sensors is delivered to the main computer either directly or via a simple microcontroller (Arduino). The computer then responds by sending analog outputs to the Arduino board, which is connected to the four servo motors in the hand. Arduino board generates pulse width modulation (PWM) signals to control the servo motors.

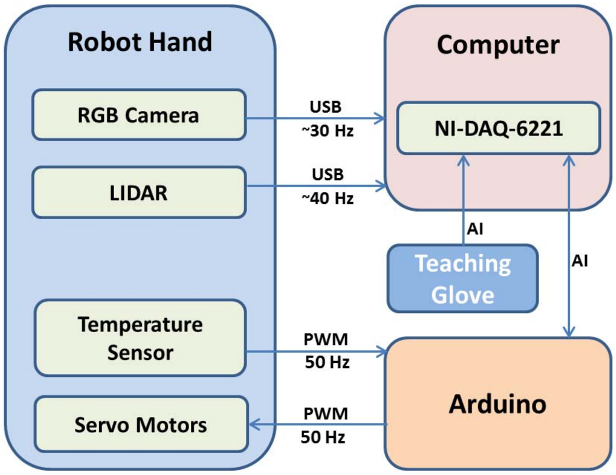


Fig. 9. Sensor Module Block Diagram

III. PERFORMANCE OF THE NU HAND

The total mass of the hand without actuators and sensor module is 220 g. Total mass increases to 574 g when the motors and sensor housing are added. Finger pull force capabilities were measured by attaching a string to the fingertip measuring the tension of the string using a force gauge (Extech 475044). Pull force of the index finger was measured as 6 N; pull force of middle, ring and little fingers measured was 4.5 N – due to the presence of six torsion springs, as opposed to two in the index finger. Combined pulling force was measured around 10 N.

The thumb finger requires 0.25 sec to close from fully open position and the same time for opening from the fully closed position. The index finger requires 0.7 seconds to fully close and 0.6 seconds to fully open. The middle, ring and little fingers require 1.45 seconds to fully close and 0.7 seconds to fully open. Difference between closing and opening times for index, middle, ring and little fingers exists because servo motors are responsible for closing the fingers, while torsion springs are responsible for opening the fingers.

Sound level during operation is important for robotic hands and end effectors. Even though there are usually no restrictions on the noise level in industrial environments, high noise level would decrease the acceptability of the robot hand for service robotics applications. Audible noise measurement was measured using a sound level meter (Extech 407732) at one meter distance. During the movement of all fingers of the hand with maximum speed, the sound level was measured 60 dBA.

Figure 10 shows image and the point cloud data acquired using the sensor module. Both sensors complement each other for object recognition purposes. Point clouds provide reliable data with a lower data rate. Multiple consecutive readings with the LIDAR sensor need to be acquired in order to construct a meaningful point cloud of an object. On the other hand, digital camera receives complete images of the object at each sampling time. However, the image data can be affected adversely by the illumination, shadows, glares, etc.

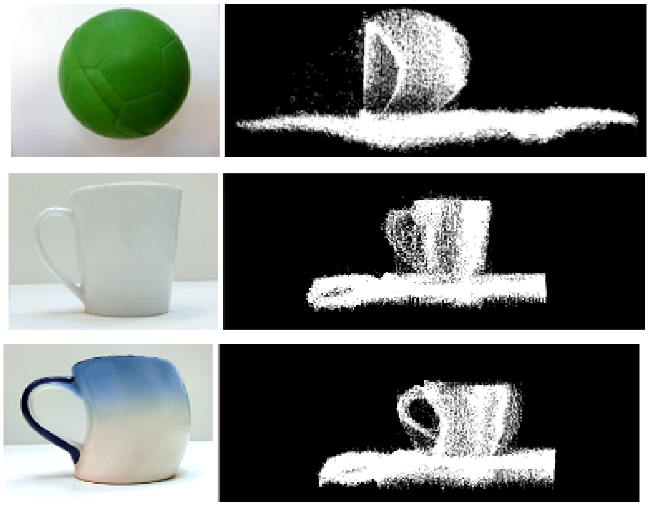


Fig. 10. RGB images (left) and point clouds (right) of three different objects acquired from the sensor module.

TABLE I

PERFORMANCE METRICS OF NU HAND

Structural characteristics	
Mass (without motors and sensor module)	220 g
Mass (with motors and sensor module)	574 g
Functional characteristics	
Thumb (full close/full open)	0.25 s/ 0.25 s
Index (full close/full open)	0.7 s/ 0.6 s
Middle (full close/full open)	1.45 s/ 0.7 s
Thumb adduction/abduction (full close/full open)	0.15 s/ 0.15 s
Index finger pull force	6 N
Middle finger pull force	4.5 N
Index + Middle finger pull force	10 N
Audible noise	60 dBA

IV. CONCLUSION

This paper describes the development of the multigrasp robotic hand suitable for industrial and service robotics applications. The semi-anthropomorphic end effector was shown to achieve the eight canonical posture and grasping patterns.

Based on the design objectives specified for the system, features such as low-cost and ease of robotic hand manufacturing were achieved; the hand was designed to perform conformal grasping using only four servo motors. Sensor module, containing LIDAR sensor, digital camera and temperature sensor, was incorporated into the robotic hand to provide the ability for autonomous intelligent object manipulation.

Future work includes design and implementation of an embedded system for the NU hand and incorporation of additional sensing elements such as accelerometers, gyroscopes, capacitive touch sensors and depth cameras. The hand will also be attached to a robot manipulator and used as a test bed for investigation of intelligent automation techniques.

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