# Control Architecture for a Novel Dexterous Hand

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***Abstract*:** *The paper presents a control architecture for grasping task of a novel dexterous hand whose 9 DOFs are actuated by a single-motor-driven actuator through 18 clutches. The architecture highlights the use of microprocessors for real-time control of the multi-fingered hand. The controller and sensors used in the control system of the hand are also described, which are especially effective to suitability for autonomous and non-numerical or reflex control of grasp.*

***Key words:*** *Multi-fingered hand, control architecture, real-time control.*

## 1 Introduction

A novel dexterous hand named SMAH(see Fig. 1), whose 9 DOFs are actuated by a single-motor-driven actuator through 18 clutches, is currently under construction in the Robotics Research Center, Nanyang Technological University. To make the hand to perform the fine manipulation and the grasping for the demand task, it is keen necessary to develop a suitable control architecture for its control system.

The issues considered in developing a control system include pre-shape motion planning, grasping stability, flexibility and cost of system [2]. In the past, the control of pre-shape and grasping have been emphasized. Two typical examples are Stanford/JPL hand [3] and Utah/MIT hand [1]. However, the system flexibility and cost have not received the attention they should obtain. A control system should be designed as flexible as possible so that hands can meet the requirement of different tasks. In addition, a system should be cost-effective as well so that hands can be applied easily to an industrial cell. Integrating these considerations, we develop a control system for our dexterous hand SMAH. The feature of the system is that grasping control is implemented by using a microprocessor and relatively cheaper sensors. This paper aims to address an architecture for such a control system.

An outline of the paper is as follows. In Section 2, features of the physical prototype of the dexterous hand are described. Section 3 outlines the control architecture of the whole system. The details description of finger motion control and the sensors used for position and force sensing is given in Section 4. The grasping control strategy are proposed in Section 5. At the end, a conclusion remark is addressed.

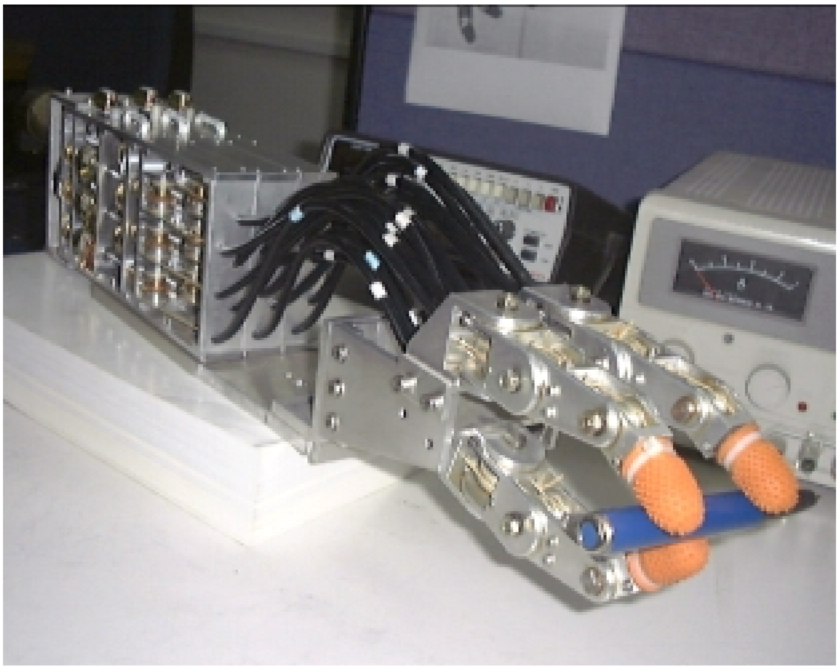


Fig. 1. The novel dexterous hand SMAH under development.

# 2 Physical Prototype

***2.1 Mechanism Description***

The hand is approximately of human-hand size and is able to pick up an object with the largest dimension of 10 cm. Currently, it comprises three fingers (including one thumb) that is the least finger number for a hand to stably grasp an arbitrary shape of object, but the finger number may vary if required. Each finger consists of three phalanges that are connected by three rotational joints. The palm is constructed with five aluminum plates connected with screws. The finger can be mounted on the palm directly. Through the four holes located at the rear plate in the palm, the hand can be attached to the service robot arm or other manipulators. The arrangement of fingers and palm is a compromise among workspace, compact size and the limitations imposed by tendon routing.

Each of joints is actuated by two wires that are driven by pulleys in the actuator system (see Fig. 2). Through changing the winding manner on the pulley as shown in Fig. 3, the number of DOF of the hand is able to vary from 1 to 9 according to a required task.

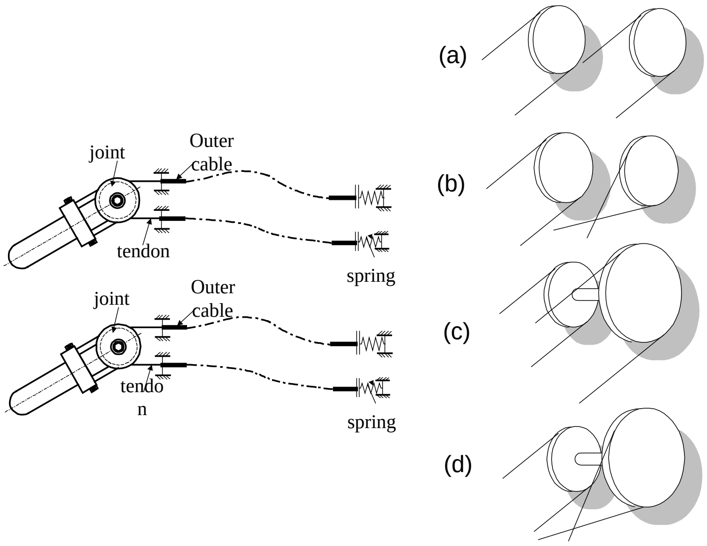



Fig. 2. DOF change in two joints, (1) two DOFs using cases (a) or (b), (2) one DOF using cases (c) or (d).

Due to application of the modular concept in design, three fingers are identical in structure and assemble. The phalanges, especially the middle phalange, in each finger are also designed according to the modular concept. In addition, the structure of all joints in the fingers is the same as well. With the special design of joints, the connection between two phalanges can be easily assembled. Thus, the link number in a finger can be extended to form a new configuration for a task change.

### *2.2 Actuator System*

It is difficult to house actuator and transmission unit within fingers because the finger must be compact and as light as possible. Tendon driven system permits the remote location of actuators, thereby providing a solution for reduced finger size. In our work, actuators and controllers of fingers are intended to install within a compact base such as an arm and a body where the power and other processors are interfaced normally.

Figure 3 shows a photo picture of the actuator system used in the hand SMAH. The system consists of one motor, 18 relatively cheap and small clutches, 9 sets of worm gears (each one connects two pulleys) and other transmission components. The construction is separated into three identical layers, which are connected to motor through a timing belt. Each layer is independent and includes three sets of worm gears that drive rotation of finger joints through cables. In principle, one set of worm gears is controlled by two clutches.

The motor as a unique power source always runs whichever finger needs motion. Through “on” or “off” state of two clutches, the power of the motor can be transmitted to each joint. Thus, the system outputs 9 independent motion totally.

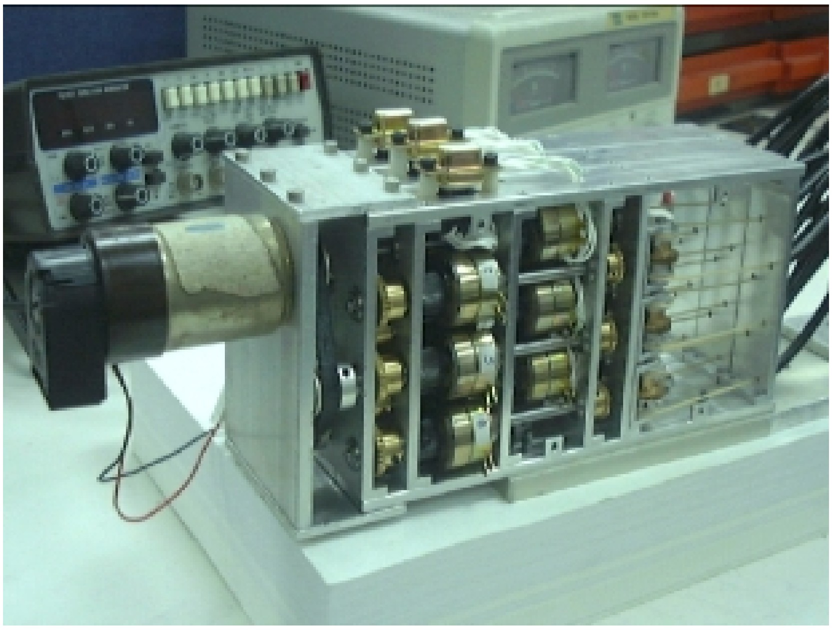


Fig.3. Single motor driven actuator.

***2.3 Design Features***

Two major design features make the hand different from the other existing hands. Firstly, unlike Stanford/JPL hand or Utah/MIT hand, multi-DOFs here are actuated by a single actuator mechanism. Since the motion component such as a clutch is relatively cheap and small, the hand is cost-effective and compact. Secondly, the hand is reliable and can be easily reconfigured due to its modular structure. The modular characteristics are reflected not only in fingers also in actuator. Three finger modules can be independently pre-assembled and tested, and then put together to form a desired hand configuration.

## 3 Control Architecture

The control architecture of the hand includes two levels as shown in Fig. 4. In the high level, the finger motion and pre-shape planing will be done through integrating vision information from the DSP processor. Shape of the hand prior to grasping is controlled by a knowledge–based system. A data structure received from the vision system contains information on the location, orientation and geometry of the target object. The geometric information contained within this data structure is combined with task information to produce the most desirable grasp mode configuration using a high-level control program. Chosen configurations are transferred to the hand control unit using a serial port. On the other hand, we also intend to use a 3D graphic simulation to reduce the complexity of pre-shape. The way is to create a virtual reality environment, in which the hand graphic model is built, to match the environment the hand locates. Through planning the graphic hand motion, we can obtain a practical hand's desired configuration.

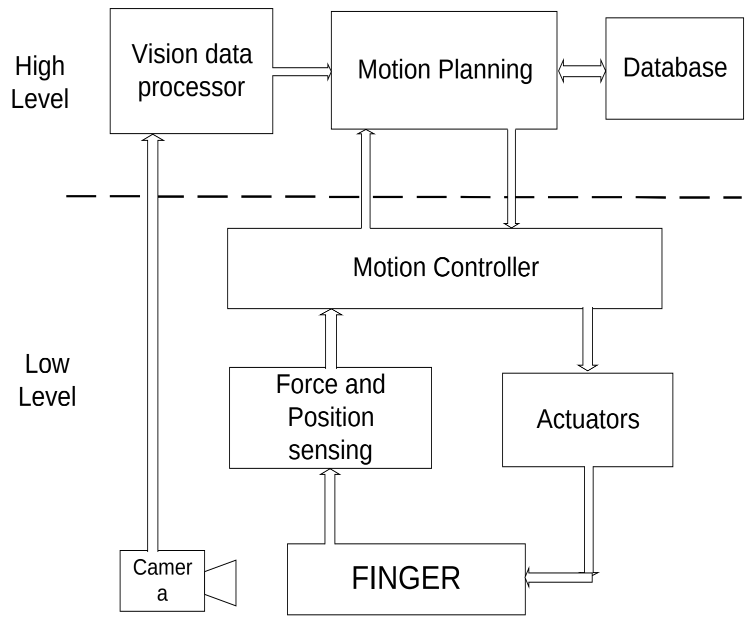



Fig. 4. Control architecture of the hand SMAH

In the low level, a force and position control is executed in the micro-processor Intel 87C196CB to control joint motion. In this level, the reaction force information is obtained through torque detection by virtue of Jacobian matrix. Joint torque is obtained from measuring the wire's tension by using strain gauges.

The figure 5 shows the hardware architecture of the control system of the hand. In the whole system, the controller needs to process 18 digital signals coming from clutches, 9 analogue signals from position sensors (potentiometers) and 9 analogue signals from force sensors (strain gauges).

The Intel 87C196CB is an 84-pins chip and has an 8-channal built-in A/D converter. It is designed for high speed calculation and fast I/O. With the addition of the CAN (controller area network) peripheral, the processor reduces point-to point wiring requirement, making it well-suited to automation application.

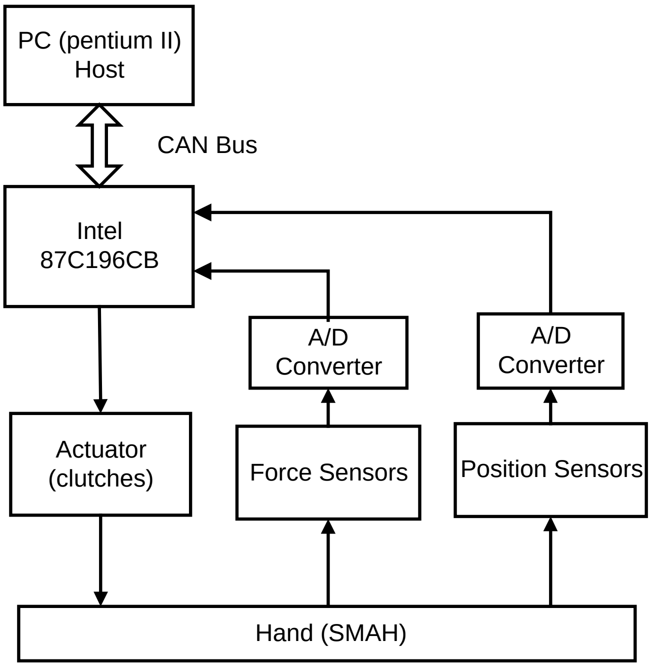



Fig. 5. The hardware Architecture of the Hand

## 4 Finger Motion Control

Due to the special feature of the actuator, the finger motion is obtained through engaging clutches. So our task is not to control motor but to control the period of engaging time of clutches.

### *4.1 Clutch Motion Control*

The motion transmission through clutch from motor (input) to worm gear (output) can be schematically shown in Fig. 6. The rotation direction of output depends on the shifting of "on" or "off" of a clutch couple. The angular position and velocity can be determined by:

$$\begin{cases} \omega = \lambda \omega_0 \\ \theta = \lambda \omega t \end{cases}$$

where $\lambda = \frac{t_n}{t_p}$ is the duty factor of control signal in clutches, $\omega$ and θ are angular velocity and position of worm gear respectively, $\omega_0$ is angular velocity of motor. Thus, through controlling engaging time $t$ of the clutch and duty factor λ of the input signal, we can determine joint's motion information.

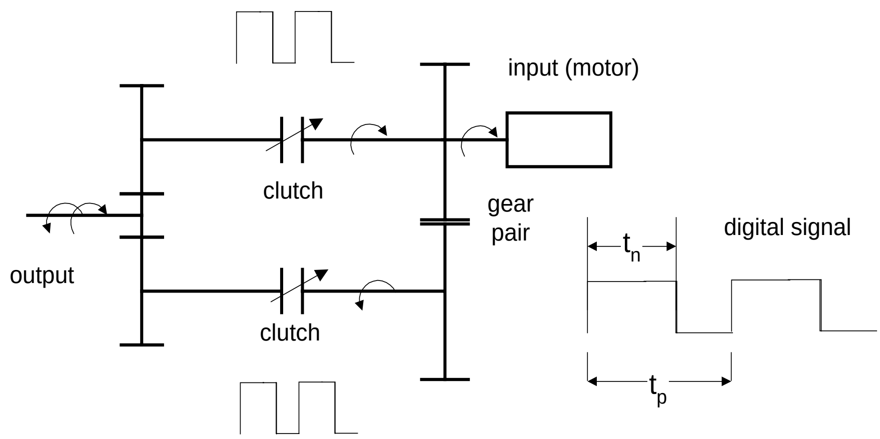



Fig. 6. Schematic chart of motion transmission through clutches.

### *4.2 Motion Control of Finger*

After the controller receive the value of desired position (task position) from the host, the corresponding finger should follow the given trajectory to reach the proximity of the object. To avoid damage the object and maintain a demand responding frequency, we hope that the moving process of finger is divide into two stages. That is that fingers approach object with a relatively faster speed while grasp object with a relatively slower speed.

Position control can be combined with force control in a useful control scheme called "stiffness control", in which for the fingertip motion, restoring forces are exerted proportionally to the deviation of the position from a desired nominal trajectory. Fig.7 shows a scheme for position and force control of a finger.

Since the hand is designed for "reflex" grasping. The primary feedback loop is intended to close around those specific signals which determine the hand-object relations: contact event and contact force. In light of this objective, true servo control which include stable, high precision position and velocity control is not required. A low finger speed facilitates position control design. These considerations have led us to avoid using shaft encoders. Instead, we use small conductive plastic potentiometers (made by Bourns).

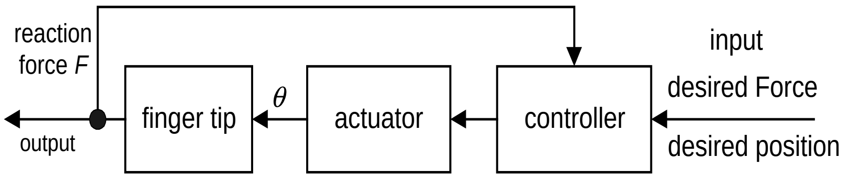
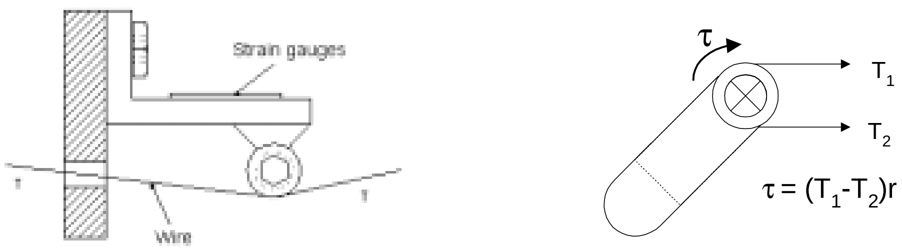



Fig. 7. Block diagram of force and position control of fingers.

Force feedback enable hand positioning in order to reach a desired force balance. To sense the reaction force, strain gauge sensors are used to measure cable tension on each cable so as to minimize the transformation required in the servo loop. The cable tension measuring method is show in Fig. 8.




(a) (b)

Fig. 8. Measuring method of joint torque, (a) measure wire tension, (b) calculate torque.

Position and force sensors described above provide the necessary feedback signals to the controller. Potentiometers and strain gauges are assembled in the front of the actuator box. As described in grasping control, the location of position and force sensors don't affect the grasping control of the hand.

## 5 Grasping Control

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The desired force pattern is specified by a set of threshold values, one for each sensor which take part in the particular grasp execution. Hence, the grasping process conducts as follows. We issue a command to move the finger to a desired (target) position. The target

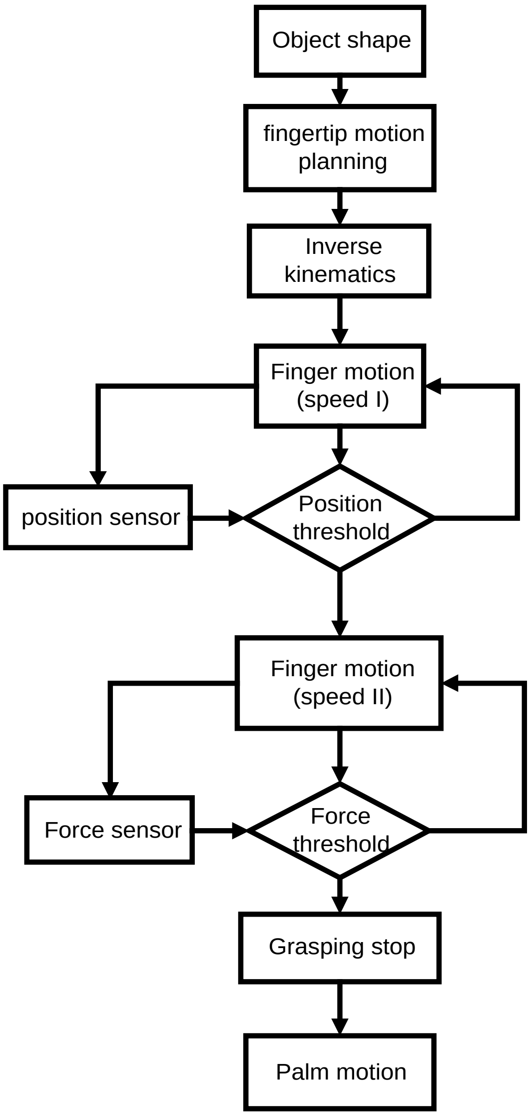


Fig. 9 Flowchart of grasping control

position is an estimated position at which the prescribed force threshold will be exceeded for each sensor by an increment sufficiently small to insure that the hand is not damaged. During the finger moving, the force sensors' output is monitored. When prescribed force for a particular sensor is reached, motion of the corresponding finger is stopped. An increase in force is possible by a small amount of additional motion. The "estimated target position" is required to prevent possible damage to hand or object. While the hand is not completely equipped with force sensors an unconditional force command could produce an uncontrolled contact event between the object and an insensitive hand section. A grasping control flowchart can be seen in Fig. 9.

## 6 Conclusion

In this paper, we have presented a control architecture for the hand SMAH. The control system uses a microprocessor Intel 87C198CB as its controller. The position and force sensors are relatively cheaper components: potentiometers and strain gauges. Due to using such a control architecture, the whole system achieves the features of flexibility and low cost.

The hand SMAH is intended to be capable of supporting a wide range application where object of complex shape need to be handled properly. Our future works will concerns the study of grasping strategy and slip sensing. In addition, we also find that the friction force existing in mechanism is very big, which has to be considered in controlling the hand.

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