Shadow
Dexterous Hand C6M

Technical Specification

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Revision History:
2008-06-01: C6M release version
2008-07-03: Corrections and clarifications
2009-08-15: Updated to final motion characteristics.

1 Overview

The Shadow Dextrous Hand is an advanced humanoid robot hand system that provides 24 movements to reproduce as closely as possible the degrees-of-freedom of the human hand. It has been designed to provide comparable force output and movement sensitivity to the human hand.

The model C6M Hand uses Shadow's electric “Smart Motor” actuation system, rather than the pneumatic Air Muscle actuation system of other Dextrous Hand systems. The “Smart Motor” integrates force and position control electronics, motor drive electronics, motor, gearbox, force sensing and communications into a compact unit.

The Shadow Dextrous Hand is a self-contained system – all actuation and sensing required is built into the Hand. The Shadow Dextrous Hand system incorporates all necessary control systems (software provided under GNU GPL) and documentation for research and teaching purposes.

Shadow Hand systems have been used for research in grasping, manipulation, neural control, and hazardous handling.

2 Mechanical Profile

2.1 Dimensions

The Hand has been designed to be as similar as possible to the average male hand. The fingers are all the same length, although the knuckles are staggered to give comparable fingertip locations to the human hand.

Finger length from tip of finger to middle of knuckle	102mm
Thumb length from tip of finger to middle of joint 4	104mm
Palm length from middle knuckle to wrist axis	99mm
Palm thickness	22mm
Palm width	84mm
Thumb base thickness	34mm
Forearm base to wrist axis	208mm

Table 1: External Dimensions of the Hand

2.2 Weight

The Hand system, (Hand, sensors, and all motors) has a total weight of 4 kg.

2.3 Speed

Movement speed is dependent on safety settings in the force control system. Typically you can expect a full-range joint movement to operate at a frequency of up to 2 Hz.

2.4 Material

The entire system is built with a combination of metals and plastics.

- Forearm: Aluminium, resin shell.
- Palm: Acetyl, aluminium, polycarbonate.
- Fingers: Acetyl, aluminium, polycarbonate fingernails and polyurethane flesh.

3 Control and Actuation

3.1 Power Consumption

The C6M Dextrous Hand is designed to use motor technology.

- Electronics: 0.7 A @ 8 V.
- Motors: 2 A max @ 24 V.

Separate power supplies are provided with the Hand.

3.2 Actuation

The Hand is driven by 20 Smart Motor units mounted below the wrist which provide compliant movements. Following the biologically-inspired design principle, a pair of tendons couple each Smart Motor to the corresponding joint of the Hand. Integrated electronics in the Smart Motor unit drives a high-efficiency rare-earth motor, and also manages corresponding tendon force sensors.

The Smart Motor unit is designed to ensure that the system is safe at all times. It monitors tendon forces and keeps them within defined limits, preventing the Hand from over-gripping objects. Motor temperature management prevents overheating of individual motors.

4 Communications

4.1 Busses

The standard interface to the Hand is a Controller Area Network (CAN) bus. The CAN interface has been tested with standard controller cards as well as the interface card supplied with the host computer.

All sensor data, components, configuration and controller setpoints can be accessed over this bus. A simple protocol developed by Shadow is used for the communication. Code for protocol interface is supplied as part of the GNU GPL-licensed codebase only; alternate licensing is also available as an option.

An embedded Ethernet interface option permits direct access to robot data and configuration by TCP/IP communication.

4.2 Robot Configuration

The protocol used allows a variety of system-specific configuration to take place. This includes:

- enable and disable a component of the robot, such as a group of sensors, or a single microcontroller module
- set sensor transmission rates,
- enable and disable joint position PID controllers individually,
- modify limits and setpoints for inner joint force PID controllers,
- modify setpoints for outer joint position PID controllers,
- change PID controller sensor and target values,
- change force and position controller P,I,D gain values,
- change operational limits such as force and temperature cutouts,
- reset components,
- track error and status indicators from the components.

The off-board PC provides access to all of these functions via shell script, device, filesystem and program code. Full documentation of the software interface and protocol is supplied.

5 Sensing

5.1 Position

A Hall effect sensor senses the rotation of each joint locally with typical resolution 0.2 degrees. This data is sampled by 12-bit ADCs and transmitted on the CAN bus. Data is transmitted in both calibrated and uncalibrated form. The sampling rate is configurable up to 180Hz.

5.2 Force

A separate force sensor measures the force in each of the pair of tendons driven by the Smart Motor unit. This data is captured by 12-bit ADCs and transmitted on the CAN bus, as well as being available to the Smart Motor unit for control.

5.3 Temperature and Current

The current flow through the motor unit, and the temperature of the motor unit, are measured internally to the Smart Motor unit, and this data is made available on the CANbus as well as being used internally to ensure safety and reliability.

6 Kinematics

The Dextrous Hand kinematics are as close as possible to the kinematics of the human hand (c.f. Fig. 1 below)

6.1 Kinematic structure

Finger	Joint	Connects	Range in °	Coupled?
First, Middle, Ring	1	Distal - Middle	0 – +90	Coupled
	2	Middle - Proximal	0 – +90	
	3	Proximal - Knuckle	0 – +90	
	4	Knuckle - Palm	-25 – +25	
Little	1	Distal - Middle	0 – +90	Coupled
	2	Middle - Proximal	0 – +90	
	3	Proximal - Knuckle	-10 – +90	
	4	Knuckle - Metacarpal	-25 – +25	
	5	Metacarpal – Palm	0 – +40	
Thumb	1	Distal - Middle	-10 – +90	
	2	Middle-Proximal 1	-30 – +30	
	3	Middle-Proximal 2	-15 – +15	
	4	Proximal-Palm 1	0 – +75	
	5	Proximal-Palm 2	-60 – +60	
Wrist	1	Palm-Wrist	-40 – +20	
	2	Wrist-Forearm	-30 – +10	

Table 2: Joints and Ranges of Motion

The thumb has 5 degrees of freedom and 5 joints.

Each finger has 3 degrees of freedom and 4 joints

The distal joints of the fingers are coupled in a manner similar to a human finger, such that the angle of the middle joint is always greater than or equal to the angle of the distal joint. This allows the middle phalange to bend while the distal phalange is straight.

The little finger has an extra joint in the palm provided to allow opposition to the thumb.

All joints except the finger distal joints are controllable to +/- 1° across the full range of movement.

6.2 Kinematic Layout

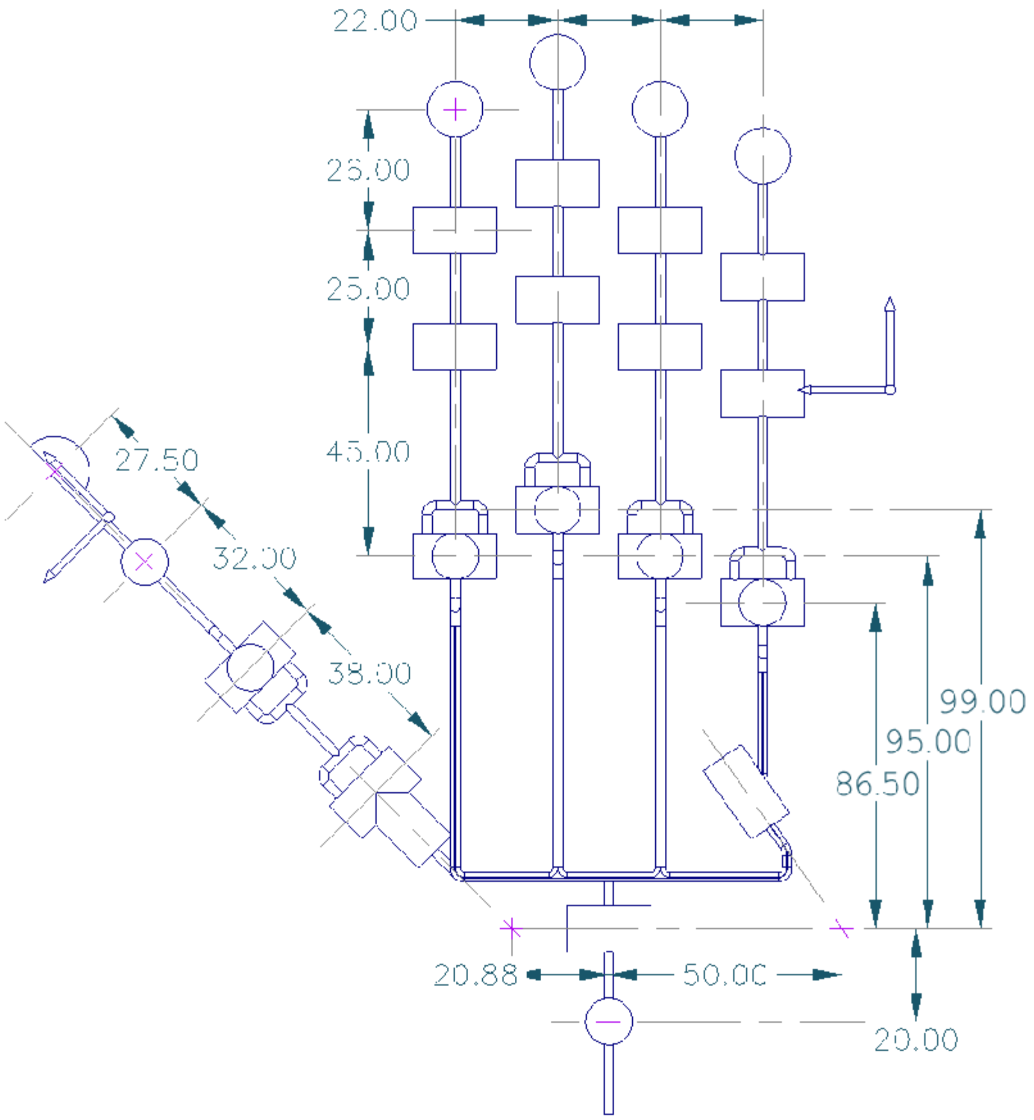

Fig 1: Kinematics of the Hand

7 System View

7.1 Electronics

- Bus: Controller Area Network (CAN) bus interface to on-board electronics. Optional Ethernet on-board.
- Palm Sensor: 7 ADCs distributed across the palm provide 26 active 12-bit sensing channels.
- Motors: Smart Motor units integrated into the forearm incorporating per-tendon force sensing and providing timed and PID control.

7.2 On-board control

The Smart Motor boards implement PID control of force and position of the joints. This control can be flexibly configured to take set point and target data from a variety of sources. These controllers can be configured via the standard robot interface, and appropriate programs, scripts and graphical examples of this are provided.

7.3 Off-board control

A standard x86-compatible PC running Debian GNU/Linux with the RTAI real-time system and Shadow's GPL robot code is supplied. This can be used for initial set up, evaluation and operation, as well as serving as a template for your own control system. The PC is fitted with an external CAN bus interface.

Software in the host PC provides sensor calibration and scaling, mappings from sensor names to hardware and permits easy access to all robot facilities from C code, shell scripts, or GUI.

7.4 Micro-controllers

Microchip PIC18Fxx80 micros are used for embedded control throughout the robot system. The firmware is provided as source on the host PC. All micro-controllers are connected to the robot CAN bus.

7.5 Smart Motor nodes

Each of the twenty Smart Motor nodes drives a motor using PWM with 1kHz update frequency. The Smart Motor node implements two nested PID controllers. The inner one controls tendon force, with tunable hard limits on maximum forces to provide compliance. The outer controller sets the required tendon force, and typically does this from joint position error, so it controls joint position.

The PID controllers are set up in the configuration or boot phase of the system, and can be configured to operate from sensor data and from user-supplied values, permitting control of joint position, joint force, or user-supplied parameters. There is a mechanism to switch quickly between controller settings.

7.6 Hand sensor node

The Hand Sensor Node, which is made up of a number of PCBs throughout the palm, reads joint position data and provides this to the communication bus in both calibrated and raw form.

Other sensors can be attached to the Hand sensor node by request and arrangement.

7.7 Open platform

- All source code for the micro-controllers and schematics for the electronics subsystems are provided on the host PC.
- Example RTAI real-time code along with full documentation is provided, along with access to e-mail support from Shadow.
- Solid models (VRML) and kinematic data supplied for use in 3D modelling

packages.

- Software layer supports easy interfacing between this and other systems, as well as quick prototyping of algorithms and tools.

8 Options

The following options may be selected at the time of ordering.

8.1 Left Hand

The Left Hand is functionally identical to the standard Hand, but mirrored for use in a bi-manual system.

8.2 CyberGlove integration

The Dextrous Hand system can be supplied integrated with a CyberGlove for lab or remote use.

Fig 2: CyberGlove