Shadow Dexterous Hand C6M2

Technical Specification

Current Release 27st June 2012

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1 Overview

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

The model C6M2 Hand uses Shadow's electric “Smart Motor” actuation system, rather than the pneumatic Air Muscle actuation system of our other Dexterous 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 Dexterous Hand is a self-contained system – all actuation and sensing required is built into the Hand. The Shadow Dexterous Hand system incorporates all necessary control systems (software provided under GNU GPL) and documentation for research and teaching purposes.

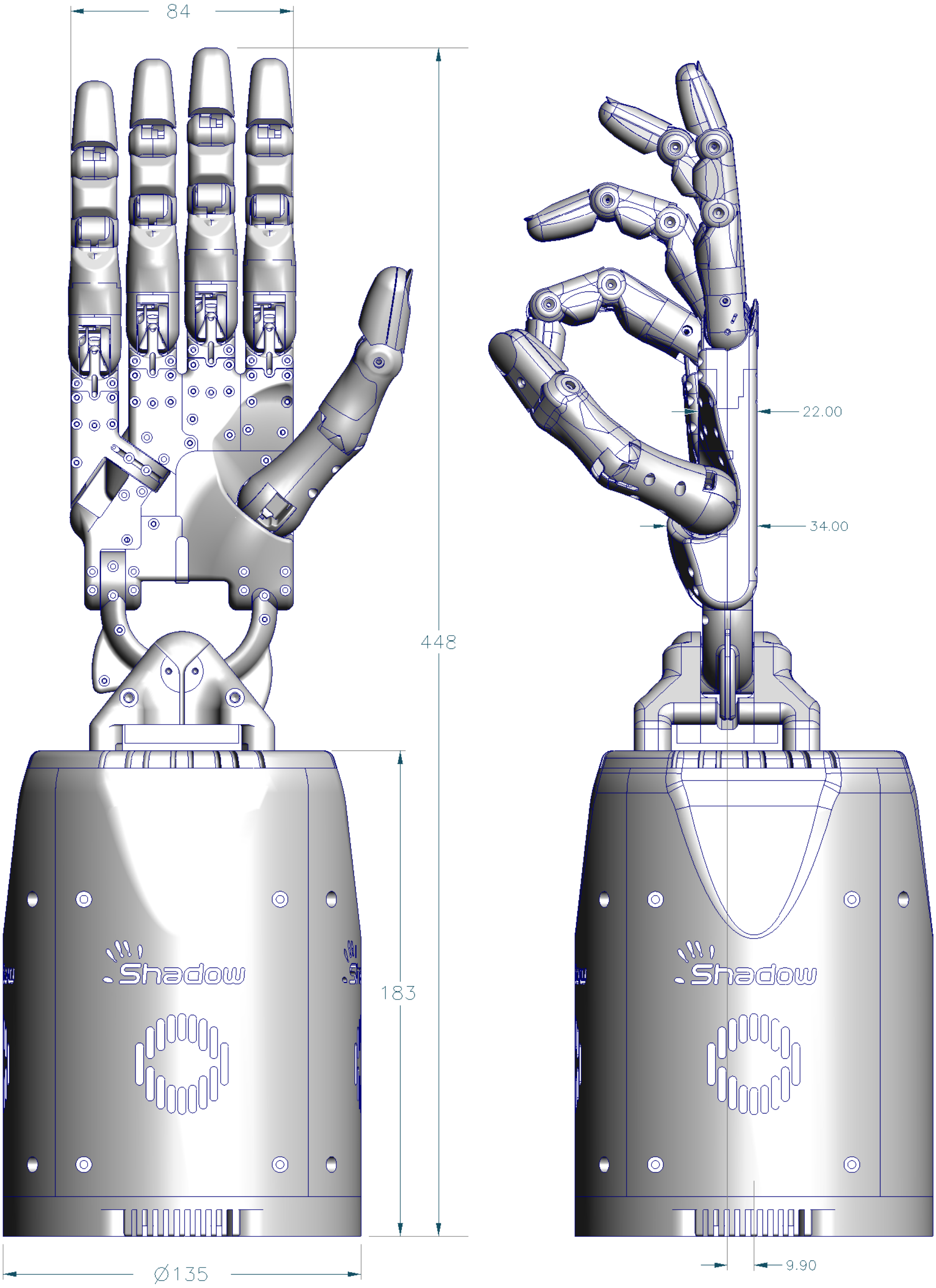
Two versions are available, with a CAN bus, or EtherCAT bus.

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 similar to a typical male hand, however the fingers are all the same length, although the knuckles are staggered to give comparable fingertip locations to the human hand.



2.2 Kinematic structure

The Dexterous Hand kinematics are as close as possible to the kinematics of the human hand.

Joint(s)	Min deg	Max deg	Min rad	Max rad	Notes
FF1, MF1, RF1, LF1	0	90	0	1.571	Coupled
FF2, MF2, RF2, LF2	0	90	0	1.571	
FF3, MF3, RF3, LF3	0	90	0	1.571	
FF4, MF4, RF4, LF4	-20	20	-0.349	0.349	
LF5	0	45	0	0.785	
TH1	0	90	0	1.571	
TH2	-25	25	-0.436	0.436	
TH3	-12	12	-0.209	0.209	
TH4	0	70	0	1.222	
TH5	-55	55	-0.960	0.960	
WR1	-45	30	-0.785	0.524	
WR2	-28	8	-0.489	0.140	

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.

2.3 Weight

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

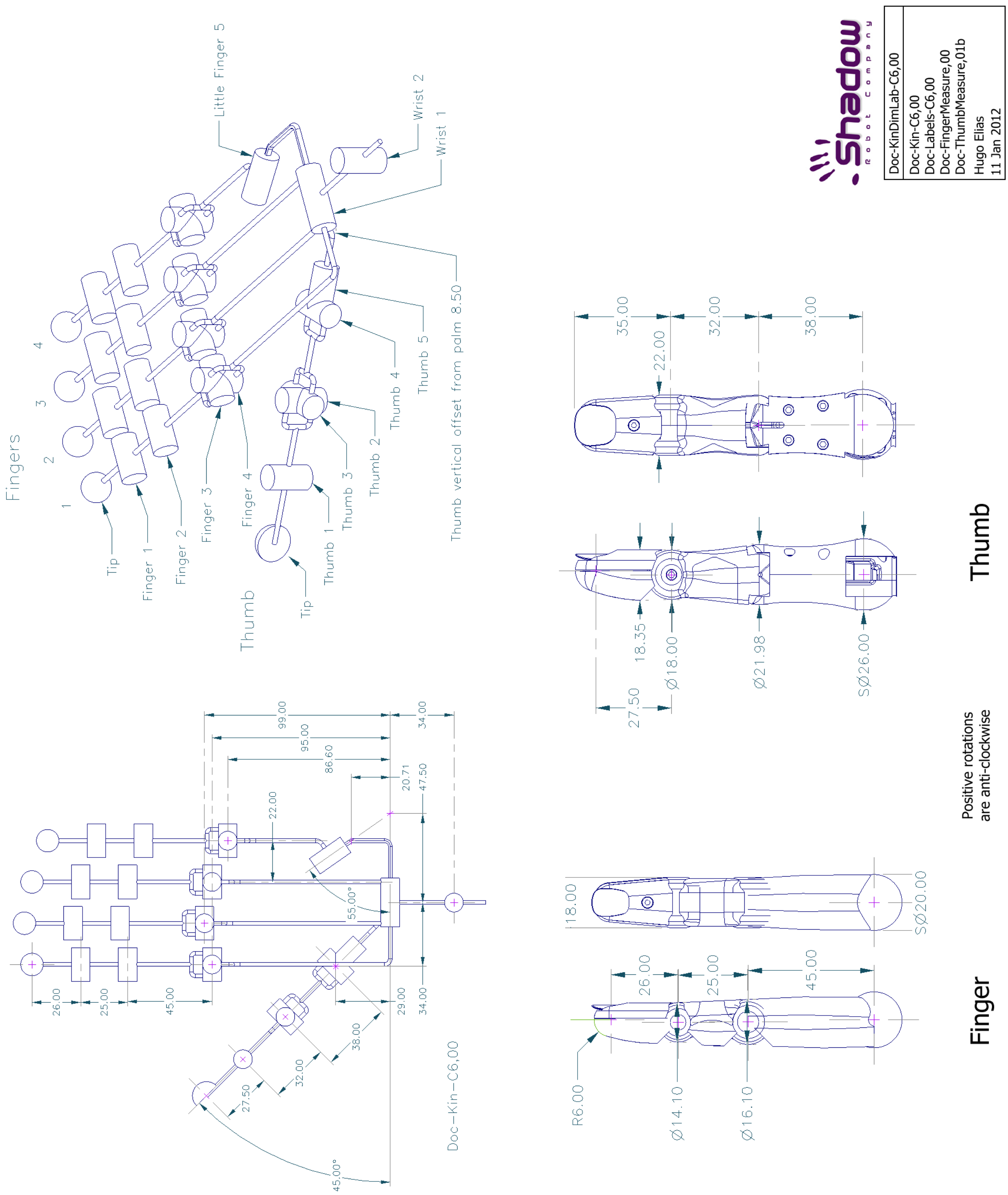
2.4 Speed

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 1 Hz.

2.5 Material

The entire system is built with a combination of metals and plastics including aluminium, brass, acetyl, polycarbonate and polyurethane flesh.

2.6 Kinematic Diagram



3 Communications

Two versions of the hand are available with different communication buses: CAN and EtherCAT.

3.1 CAN

3.1.1 Performance

CAN (Controller Area Network) is a 1Mb bus originally designed for use in cars. On the CAN version of the hand, the position control loop happens within the hand. Motor units receive joint sensor data from the bus, and move the motor accordingly. The CAN interface has been tested with standard controller cards as well as the interface card supplied with the host computer.

3.1.2 Features

All sensor data, components, configuration and controller set-points 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 code base only; alternate licensing is also available as an option.

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
- enable and disable joint position PID controllers individually
- modify limits and set-points for inner joint force PID controllers
- modify set-points 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 cut-outs
- reset components
- adjust data transmission rates from motors and tactile sensors
- track error and status indicators from the components

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

3.1.3 Control

A micro-controller at each motor reads relevant joint sensor data from the CAN bus, and uses a PID loop to calculate a PWM value to drive the motor. The PID loop speed is limited by the sensor transmission rate, which has a maximum frequency of 200Hz.

3.2 EtherCAT

3.2.1 Performance

EtherCAT (Ethernet for Control Automation technology) is a 100Mb ethernet-based fieldbus. It is currently used in Willow Garage's PR2 robot, making this version of the hand compatible with the PR2.

3.2.2 Features

The EtherCAT bus requires a powerful PC with a standard Ethernet port. The EtherCAT protocol used by the hand is simpler than the CAN protocol, since the position control loop happens in the host:

- enable and disable torque controllers
- change torque control PID values
- change operational limits such as force and temperature cut-outs
- reset motors
- adjust data transmission rates from motors and tactile sensors
- track error and status indicators from the components
- download new firmware into the motors

3.2.3 Control

As standard, the EtherCAT hand implements a position control strategy. Nonetheless, other types of control can be considered, as these loops close through the host PC. For this reason, much more complex control strategies can be implemented, fusing information from joint and tactile sensors and even visual signals.

The torque loop is closed inside the motor unit at 5kHz. The PID settings for this loop can be changed in real time. Alternatively, new firmware can be downloaded into the motor units if you require a different control strategy.

3.3 Comparison

	CAN hand	EtherCAT Hand
Sensors		
Joint Sensor update rate	100Hz	1000Hz
Tactile sensor update rate	100Hz	1000Hz
Motor torque sensor update rate	30Hz	500Hz
PID Control Loops		
Torque control loop rate	1000Hz	5000Hz
Position control loop rate	100Hz	1000Hz
Torque control at	Motor	Motor
Position control at	Motor	Host
Other features		
Firmware bootloading	no	yes
6-axis IMU	no	(in development)

4 Sensing

All sensor data are available at the PC at various rates depending on the type of bus, and the rate setting for that sensor.

4.1 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. Both raw ADC values, and calibrated real-world values can be accessed.

4.2 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 used locally for torque control. The data are also transmitted back to the PC. The force sensors have a resolution of about 30mN. They are zeroed, but not calibrated. I.E. A reading of zero means zero difference between the tendons, and a positive reading of 100 means approximately 3N.

4.3 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 are used internally to ensure safety and reliability.

5 Features

5.1 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 CAN / EtherCAT bus.

The EtherCAT hand uses a PIC32 in the palm.

5.2 Smart Motor nodes

Each of the twenty Smart Motor nodes drives a motor using PWM. The Smart Motor node implements a PID controller, which can be set to do force control on the tendons at the motor end, or position control on the joints.

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.

5.3 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.

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

6 PC

A standard x86-compatible PC running Debian GNU/Linux with the RTAI real-time system and Shadow's GPL robot code is supplied for CANbus systems. 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 a CAN bus interface.

EtherCAT Hands are supplied with a standard mutli-core PC running Ubuntu 10.04 with an additional network card is supplied. The driver and other useful packages are installed by default on the computer. The software is based on the ROS meta-operating system.

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.

The host PC also provides ROS integration, allowing the Hand to be used as part of a larger ROS robotic platform or in a stand-alone configuration.

7 Power

7.1 Power Consumption

Power supplies are provided with the Hand. Either:

- 24 V @ 5 A
- 48 V @ 2.5 A

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

Fig 1: CyberGlove

9 Change list

Date	Person	Changes
27 June 2012	Armando De La Rosa T.	Clarifications to control strategies
24 May 2012	Gavin Cassidy	Updated ranges in 2.2 Kinematic structure
12 Jan 2012	Hugo Elias	Updated kinematic diagram Added dimensions diagram Added EtherCAT hand spec Added CAN vs EtherCAT comparison table Updated look and feel
17 Nov 2011		Updated to C6M2, including a number of corrections.
15 Aug 2009		Updated final motion characteristics
3 Jul 2008		Corrections and clarifications
1 Jun 2008		Created document