Shadow Dexterous Hand C5

Technical Specification

Current release: 20061108

Revision History:

20060810:	C5 release version
20060905:	Controllability (5.1) parameters and Tactile Sensor (7.1) parameters added
20060906:	Bus compatibility statement (3.1) added
20061106:	Distal joint and wrist joint clarifications and corrections (6.1)

1 Overview

The Shadow Dextrous Hand is an advanced humanoid robot hand system that reproduces as closely as possible the 24 degrees-of-freedom of the human hand. It has been designed to provide comparable force output and movement sensitivity to the human hand. All design measurements were taken directly from the corresponding body parts of the engineering team.

The Shadow Dextrous Hand is a self-contained system. The forearm region contains the muscles and the valve manifold. The Shadow Dextrous Hand system incorporates all necessary control systems (software provided under GNU GPL) and documentation for research and teaching purposes.

2 Mechanical Profile

2.1 Dimensions

The Hand has been designed to be as similar as possible to the average hand of the human male. The forearm structure is comparable in length to the human forearm, although at the base it widens to 146mm.

Finger length from tip of finger to middle of knuckle	100mm
Thumb length	102mm
Palm length from middle knuckle to wrist axis	99mm
Palm thickness	22mm
Palm width	84mm
Thumb base thickness	34mm
Forearm base to wrist axis	434mm

Table 1: External Dimensions of the Hand

2.2 Weight

The Hand, sensors, muscles and valve manifold have a combined weight of 3.9 kg. The centre of mass is approximately 160mm from the base.

2.3 Speed

There is some variation in movement speeds between the parts of the Hand. Also, different methods of movement produce different maximum speeds. However, the general movement is on average about half the speed of that of a human. For example, the time for transition from open to clenched is 0.2 seconds approx.

2.4 Material

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

- Forearm bone: Steel.
- Palm: Acetyl, aluminium, polycarbonate.
- Fingers: Acetyl, aluminium, polycarbonate fingernails and polyurethane flesh.
- Base: Acetyl, rubber, brass, cork.

2.5 Strength

Because the system is compliant, these are approximate measures of the maximum available output torques. The Hand is capable of holding its own weight. Measured force and torque maxima for the joints are given in the table below.

Joint	Maximum Force (N)	Maximum Torque (Nm)
THJ1 (Flex.)	15.9	0.4
THJ2 (Flex.)	10.2	0.58
THJ3 (Flex.)	6.7	0.38
THJ5 (Flex.)	5.65	0.54
FFJ2 (Flex.)	9.4	0.46
FFJ3 (Flex.)	2.9	0.27
MFJ2 (Flex.)	7.3	0.36
MFJ3 (Flex.)	2.6	0.24
RFJ2 (Flex.)	8	0.39
RFJ3 (Flex.)	2.2	0.21
LFJ2 (Flex.)	6.3	0.31
LFJ3 (Flex.)	2.5	0.24
WRJ1 (Flex.)	225	26.65
WRJ1 (Ext.)	57	4.22

Table 2: Force and Torque Maxima

3 Control and Actuation

3.1 Power Consumption

The Shadow Dextrous Hand is designed to use air muscle technology, and so the system requires both electric current and a source of compressed air.

- Electronics: 0.5 A @ 8 V.
- Valves: 1 A max @ 28 V.
- Compressed air (Filtered and oil free) @ 3.5 bar
  (Consumption: each muscle has volume approximately 0.015 litres; worst case consumption for whole hand 24 litres/min).

3.2 Actuation

The Hand is driven by 40 Air Muscles mounted on the forearm. These provide compliant movements. Following the biologically-inspired design principle, tendons couple the air muscles to the joints. Integrated electronics at the base of the hand system drive the pneumatic valves for each muscle and also manage corresponding muscle pressure sensors.

Three modes of actuation are used in the Hand system. An opposing pair of muscles permits full control and variable compliance of the movement for most joints. Conditionally-coupled drive is used for the Middle and Distal phalanges of the fingers to produce human movement characteristics.

4 Communications

4.1 Busses

The hand system presents a Controller Area Network (CAN) bus interface to the outside world. The CAN interface has been tested with standard controller cards as well as the supplied interface cards.

All sensor data, components, configuration and controller setpoints can be accessed over this bus. A simple protocol is used for the communication. Example code for protocol interface is supplied as part of the GPL 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,
- set sensor transmission rates,
- enable and disable valve PID controllers individually,
- change PID controller sensor and target, as well as P,I,D gain values,
- change the CAN addresses used by a component,
- reset components.

The off-board PC provides access to all these function over CANBUS via shell script, device, filesystem and program code.

5 Sensing

5.1 Position

A Hall effect sensor measured with typical resolution 0.2 degrees senses the rotation of each joint. This data is sampled locally by 12-bit ADC′s and transmitted on the CANBUS. The sampling rate is configurable up to 180Hz.

5.2 Pressure

The pressure in each muscle is sensed by a solid-state pressure sensor mounted directly on the valve manifold, and measured with 12-bit resolution across the range of $0 - 4$ bar.

6 Kinematics

6.1 Kinematic structure

Joint	Connects	Range	Muscle Type
First, Middle, Ring finger			
1	Distal - Middle	-20 – +90	Coupled pair
2	Middle - Proximal	0 – +90	
3	Proximal - Knuckle	-20 – +90	Pair
4	Knuckle - Palm	-25 – +25	Pair
Little Finger			
1	Distal - Middle	-20 – +90	Coupled Pair
2	Middle - Proximal	0 – +90	
3	Proximal - Knuckle	-20 – +90	Pair
4	Knuckle - Metacarpal	-25 – +25	Pair
5	Metacarpal – Palm	0 – +40	Pair
Thumb			
1	Distal - Middle	-20 – +90	Pair
2	Middle-Proximal 1	-40 – +40	Pair
3	Middle-Proximal 2	-15 – +15	Pair
4	Proximal-Palm 1	0 – +80	Pair
5	Proximal-Palm 2	-60 – +60	Pair
Wrist			
1	Palm-Wrist	-55 – +45	Pair
2	Wrist-Forearm	-30 – +10	Pair

Table 3: 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 muscle types are:

Coupled Pair: the two joints are coupled such that the angle of Joint 2 is less than the angle of Joint 1; two muscles drive these joints.

Pair: Two antagonistic muscles drive this joint

The distal and middle joints 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 movement from 0 to -20 of the distal joint is a purely passive movement.

The little finger has an extra joint in the palm.

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

6.2 Kinematic Layout

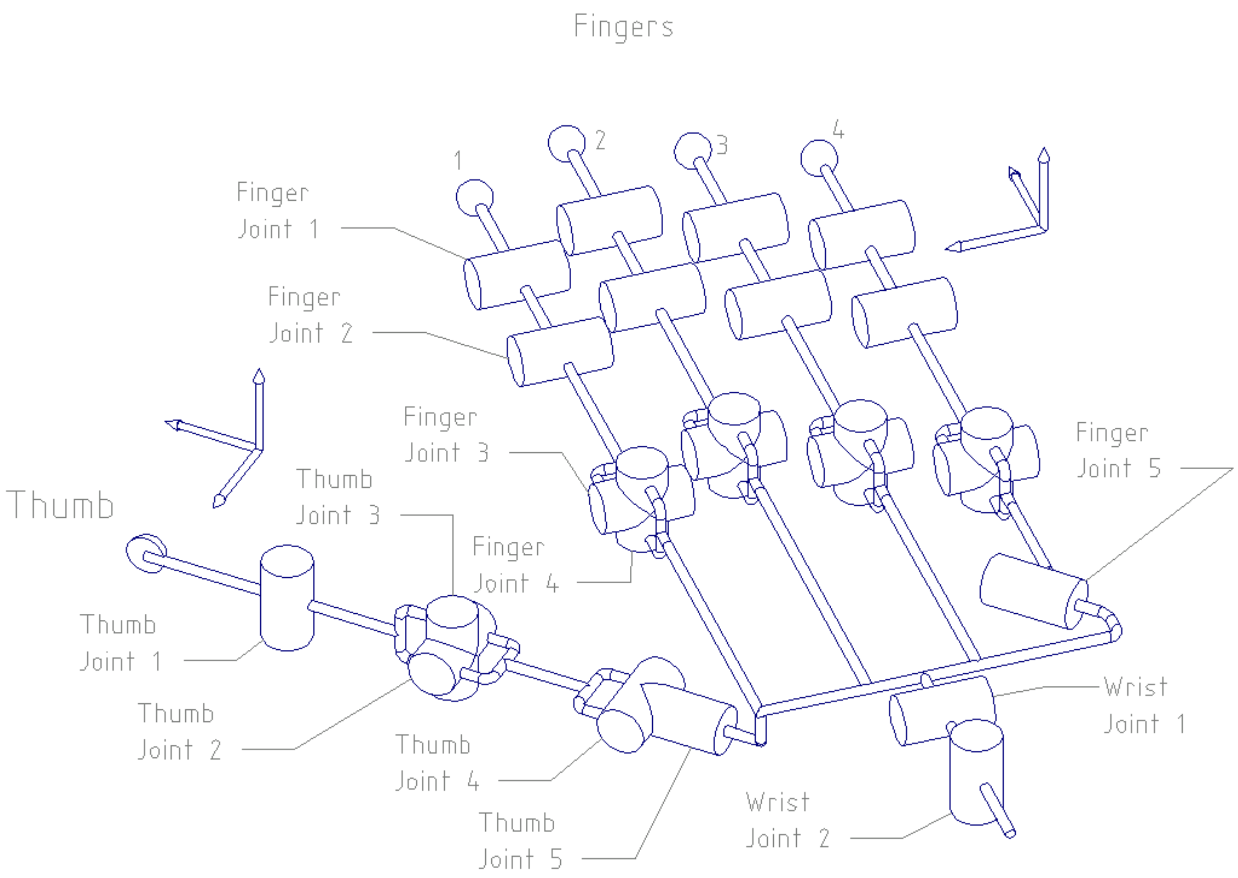

Fig 1: Kinematics of the Hand

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.
- Valves: Valve driver nodes at base of forearm incorporating per-muscle pressure sensing and providing timed and PID control.

7.2 On-board control

The valve driver boards implement PID control of individual valves. 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 programmes, scripts and graphical examples of this are provided.

7.3 Off-board control

A standard x86-compatible PC (VIA Mini-ITX: others by arrangement) 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 CANBUS 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

PIC18F4580 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 CANBUS.

7.5 Valve control nodes

Each of the four valve control nodes:

- Drives a set of valves at 0.25mS resolution.
- Runs up to 20 configurable real-time PID controllers (one per valve).

The PID controllers can be configured to operate from sensor data and from user-supplied values, permitting control of joint position, muscle pressure, or user-supplied parameters.

7.6 Hand sensor node

The Hand Sensor Node, mounted throughout the palm, reads joint position data and provides this to the communication bus.

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 Tactile Sensing

Tactile sensing can be provided on the finger and thumb tips. This consists of 34 tactels distributed approximately evenly across the tip.

Each tactel will produce a measurable output change for an applied weight of 10g, and provides an output range up to 1000g.

The sensing electronics introduces +/-1g of noise in the 1-10g range, and less at higher ranges.

Data from the tactile sensor is transmitted across the CANBUS and made available at the host PC as with other sensor data.

The tactile sensing performance is guaranteed for one year, and the sensors can be easily detached for maintenance if required.