



## **Shadow Dexterous Hand E1 Series (E1M3R, E1M3L, E1P1R, E1P1L)**

### **Technical Specification**

Release: 1 January 2013

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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 kinematics and dexterity of the human hand. It has been designed to provide comparable force output and movement precision to the human hand.

Shadow Hand systems have been used for research in grasping, manipulation, neural control, brain computer interface, industrial quality control, and hazardous material handling.

The Shadow Dexterous Hand is a self-contained system - all actuation and sensing is built into the hand and forearm. The Shadow Dexterous Hand development kit includes:

- Control systems
- Software (provided under GNU GPL or BSD as appropriate)
- ROS compliant
- PC
- Power supplies
- Tactile sensing
- Auxiliary equipment (if required)
- Documentation and training

All versions of the Hand use an EtherCAT bus (Ethernet for Control Automation Technology), providing a 100Mbps Ethernet-based communications field-bus, and full integration into ROS (Robot Operating System).

This document describes the core Shadow Dexterous Hand and both the Motor and Pneumatic actuations systems. The following table shows the model numbers

|           | Right Hand | Left Hand |
|-----------|------------|-----------|
| Motor     | E1M3R      | E1M3L     |
| Pneumatic | E1P1R      | E1P1L     |

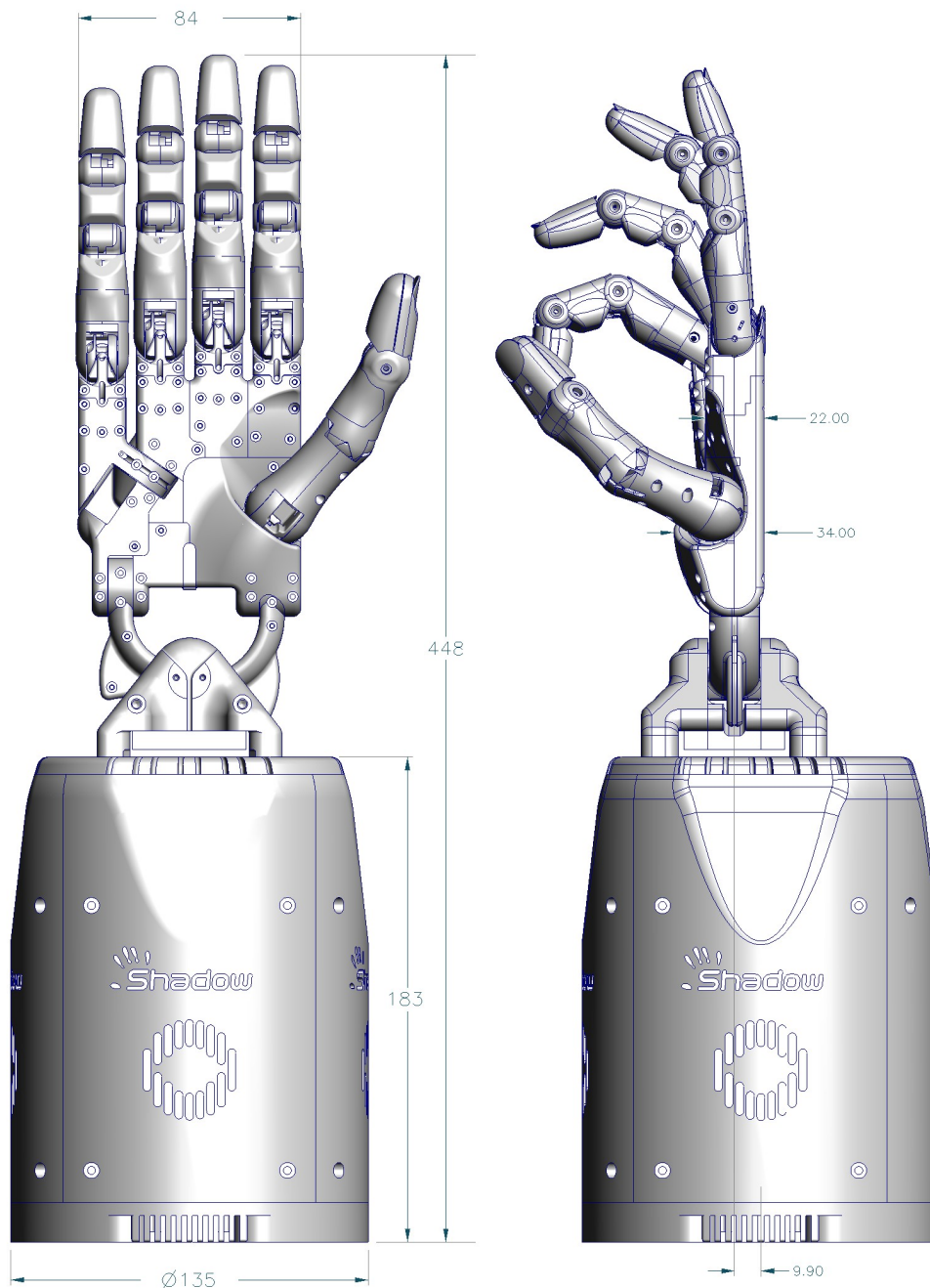
The models E1M3R and E1M3L Hands use Shadow's electric "Smart Motor" actuation system, while the E1P1R and E1P1L use the pneumatic "Air Muscle" actuation system. The "Smart Motor" integrates force and position control electronics, motor drive electronics, motor, gearbox, force sensing and communications into a compact module, 20 of which are packed into the Hand base. The "Air Muscle" system integrates pressure and position control electronics, valve drive electronics, manifold, pressure sensing and communications for 80 valves into its own compact base.

## 2 Mechanical Profile

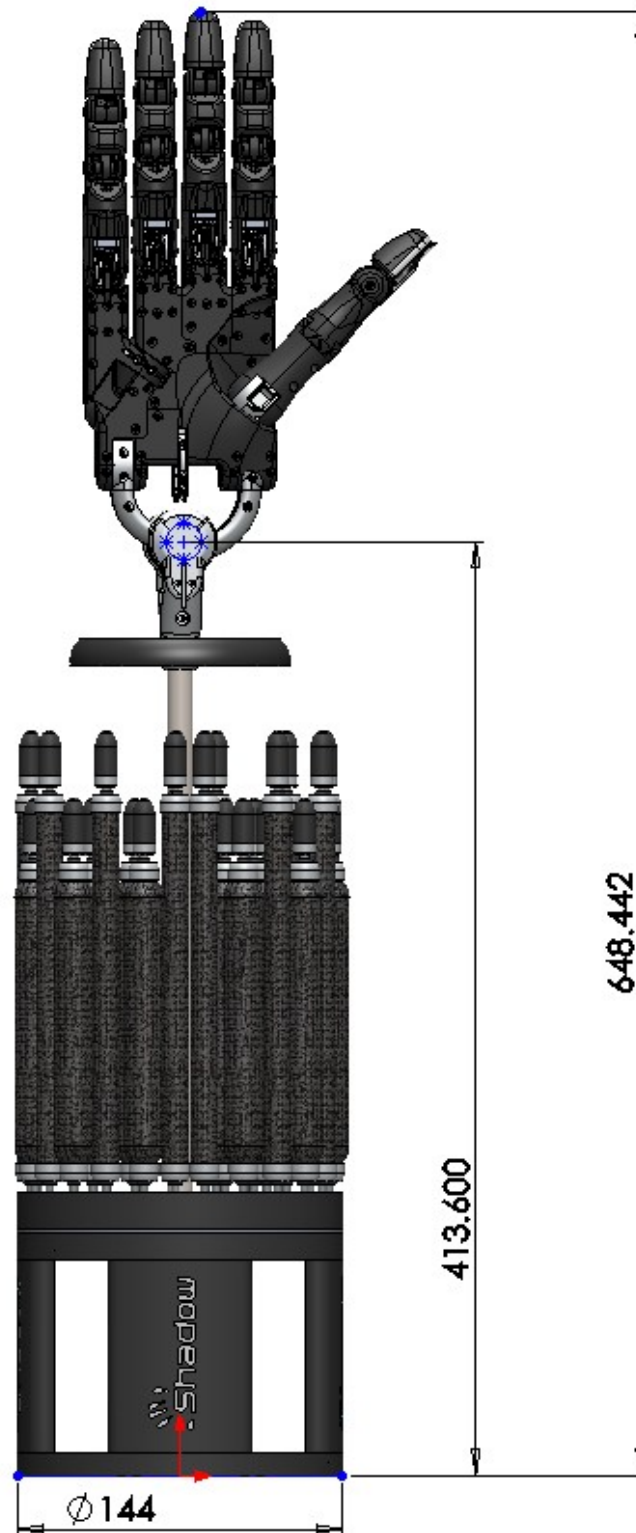
### 2.1 Dimensions

The Hand has been designed to be similar in shape and size to a typical male hand, and reproduce as closely as possible the kinematics and dexterity of the human hand. The fingers are all the same length, with the knuckles staggered to give comparable fingertip locations to the human hand.

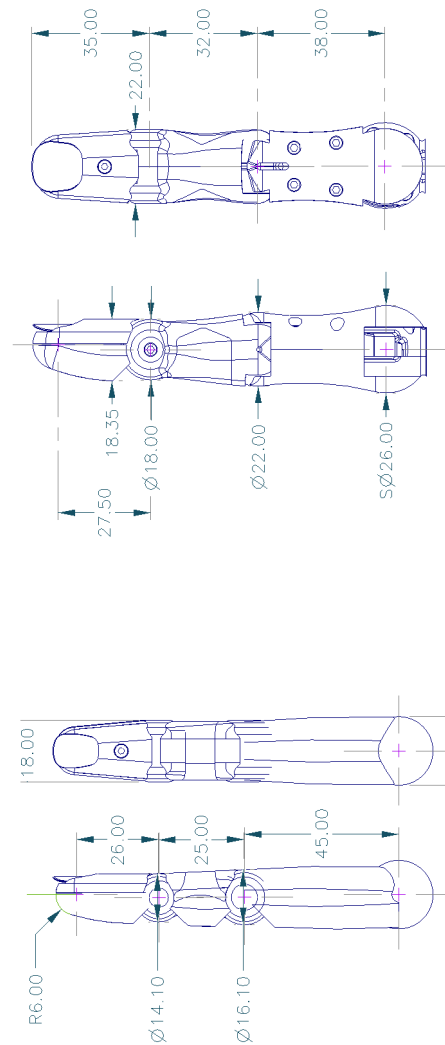
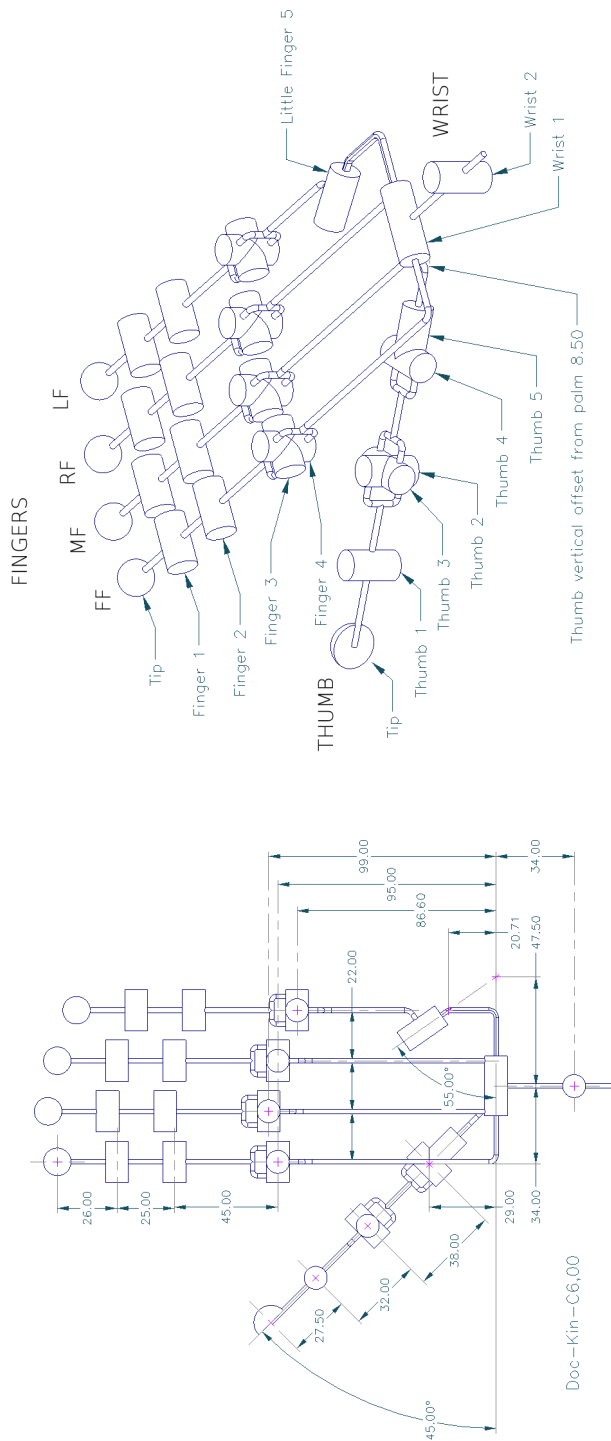
#### 2.1.1 Motor Hand (E1M3R, E1M3L)



## 2.1.2 Air Muscle Hand (E1P1R, E1P1L)



## 2.2 Kinematic Diagram



Thumb

Positive rotations  
are anti-clockwise

Finger



|                      |
|----------------------|
| Doc-KinDimLab-C6,00  |
| Doc-Kin-C6,00        |
| Doc-Labels-C6,00     |
| Doc-FingerMeasure,00 |
| Doc-ThumbMeasure,01b |
| Hugo Elias           |
| 07 Dec 2012          |

## 2.3 Kinematic structure

The Dexterous Hand kinematics are optimized to be as close as possible (within engineering constraints) to the kinematics of the human hand.

| Joint(s)           | Degrees |     | Radians |       | Notes   |
|--------------------|---------|-----|---------|-------|---------|
|                    | Min     | Max | Min     | Max   |         |
| 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  $\pm 1^\circ$  across the full range of movement.

## 2.4 Weight

The hand and forearm have a total weight of 4.2 kg.

## 2.5 Speed

Movement speed is dependent on safety settings in the control system. Typical parameters allow a full-range joint movement in free space to operate at a frequency of 1.0 Hz for the Motor Hand and 0.2 Hz for the Air Muscle Hand.

## 2.6 Material

The entire system is built with a combination of metals and plastics including aluminium, brass, acetyl, polycarbonate and polyurethane flesh. The Air Muscle Hand has additional materials including rubber, nylon and cork.



## 3 Communications

All versions of the Hand use an EtherCAT bus. EtherCAT (Ethernet for Control Automation Technology) is a 100Mbps ethernet-based fieldbus. It is currently used in a number of systems, such as Willow Garage's PR2 robot, making these versions of the Hand compatible with the PR2, and any other research or industrial control systems that are EtherCAT/ROS compatible. The EtherCAT bus plus ROS requires a powerful multi-core PC (supplied) with a standard Ethernet port. The EtherCAT protocol used by the hand is simple since the position control loop happens in the host (documentation supplied)

### 3.1 Motor Hand Features

- Enable and disable torque control
- Change torque control PID values
- Change operational limits such as force and temperature cut-outs
- Reset motors
- Adjust data transmission rates for motors and tactile sensors
- Track error and status indicators from the components
- Download new firmware into the Smart Motor modules

### 3.2 Air Muscle Hand Features

- Reset valve drivers units in the manifold.
- Adjust data transmission rates for valve drivers and tactile sensors
- Track error and status indicators from the components
- Download new firmware into the valve drivers

### 3.3 Control

As standard, the EtherCAT Hand implements a position control strategy in the host PC. Other control algorithms can be used as much more complex control strategies can be implemented, fusing information from joint and tactile sensors and even visual signals via ROS

In the Motor Hand, 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, or a new version is available from Shadow. All other control loops run at 1kHz through the host.

In the Air Muscle Hand there are no internal control loops and all loops run at 1kHz from the host. New firmware can be downloaded into the valve drivers if you require a different control strategy, or a new version is available from Shadow.

The PID controllers are set up in the configuration or boot phase of the system, can be changed on the fly, and can be configured to operate from sensor data and from user-supplied values, permitting control of joint position, force, Air Muscle pressure, or user-supplied parameters.

### 3.4 Micro-controllers

Microchip PIC18Fxx80 micro-controllers are used for embedded control throughout the robot system, except on the palm, where a PIC32 is used; and on the Pressure Sensor Tactiles (PSTs), where PSoCs are used. The firmware is available upon request by customer under Non-Disclosure Agreement (NDA). All micro-controllers are connected to the internal bus and can be accessed via the EtherCAT interface.

## 4 Sensing

All sensor data are presented to the PC at various rates depending on the rate setting for that sensor. Typical rates are:

|              | Update Rate | Bits |
|--------------|-------------|------|
| Position     | 1000 Hz     | 12   |
| PST          | 500 Hz      | 11   |
| Force        | 5000 Hz     | 12   |
| Temperature  | 100 Hz      | 12   |
| Current      | 100 Hz      | 12   |
| Voltage      | 100 Hz      | 12   |
| Air Pressure | 1000 Hz     | 12   |

### 4.1 Position

A Hall effect sensor senses the rotation of each joint locally with typical resolution 0.2 degrees. This data is sampled in the Hand by 12-bit ADCs. Data is provided to the communication bus in raw form, and is calibrated at the host.

### 4.2 Tactile Sensing

All Shadow Hands have Pressure Sensor Tactiles (PSTs) fitted as standard in the fingertips. They are a single region sensor with high sensitivity. The data is sampled by an 11-bit ADC. Raw temperature compensated data is available.

The PSTs can be substituted for other tactile sensors (see section: 8 Options). A protocol in the palm firmware can detect different types of compatible sensors and configure them correctly.

### 4.3 Force (Motor Hand only)

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 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.

### 4.4 Temperature and Current (Motor Hand only)

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 to ensure safety and reliability.

### 4.5 Pressure (Air Muscle Hand only)

The air pressure of each Air Muscle is sensed in the Valve Array by a solid-state pressure sensor mounted directly on the valve manifold, measured with 12-bit ADCs mounted on the Valve Driver unit, and available as raw data on the communication bus. The host calibrates the raw data into SI units across the range of 0 – 400 kPa.

### 4.6 Hand Sensor Node

The Hand Sensor Node, which is made up of a number of PCBs throughout the palm, fingers and thumb, reads joint position data and tactile sensing data, provides this to the communication bus in raw form, and is calibrated at the host. Other sensors can be attached to the Hand sensor node by request and arrangement.

## 5 Actuation

### 5.1 Smart Motors (Motor Hand only)

Each of the twenty Smart Motor nodes drives a Maxon 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.

### 5.2 Valve Drivers (Air Muscle Hand only)

Each of the four Valve Driver nodes drives 10 Shadow Air Muscles (20 valves) using PWM. All PID loops run from the host at 1kHz, and can be set to do pressure control on the Air Muscles or position control on the joints.

## 6 PC and Software

All Hands are supplied with a standard multi-core PC running Ubuntu 10.04 with 2 EtherCAT compatible network ports (more optional). The drivers 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 Python and/or C++.

### 6.1 Open platform

- All source code for the micro-controllers and schematics for the electronics subsystems are available on request under Non-Disclosure Agreement (NDA).
- Example code along with documentation is provided, along with access to e-mail support from Shadow.
- Solid models (VRML) and kinematic data are supplied via ROS.
- An open software layer supports easy interfacing between this and other systems, as well as quick prototyping of algorithms and tools.

### 6.2 ROS

The Shadow Dexterous Hand is fully compatible with ROS (Robot Operating System [www.ros.org](http://www.ros.org)) providing a full range of capabilities including:

- Control
- Visualisation
- Simulation

The `sr_hand` package provides a simulated model of the Hand running in the Gazebo simulator. It integrates full physics model for grasping and manipulation development. The `shadow_robot_ethercat` stack provides the drivers for the Hand.

All the back-ends (simulated or real) present the same interface to your software - selection is simply made depending on which launch file is used, be it the real Hand or the simulated Hand - making it easy to test software away from the hardware and then run on the real hardware.

## 7 Power

Power supplies are provided with the Hand (Compressor not included).

### 7.1 Motor Hand Consumption

- 48 V @ 2.5 A

### 7.2 Air Muscle Hand Consumption

- 48 V @ 1.0 A
- Compressed air (filtered and oil free) @ 3.5 bar.
- Each muscle has a volume of 0.015 litres; so maximum consumption for a full Hand is 24 litres/min. We recommend a compressor that can provide 7 bar, with a flow rate of 1 cfm, a reservoir of 3 litres or more, and if it will be around people, ultra-quiet (approx. 40dB/1m). A regulator is included with all Air Muscle Hands.

## 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. Models E1M3L and E1P1L

### 8.2 CyberGlove Integration

The Dexterous Hand system can be supplied integrated with a 22 sensor CyberGlove for lab or remote use.



### 8.3 BioTac Integration

Produced by Syntouch, the BioTac is a revolutionary tactile sensor capable of detecting the full range of sensory information that human fingers can detect: forces, micro-vibrations, and temperature.

Raw data collected from the BioTac include:

- Voltages on impedance sensing electrodes
- Absolute fluid pressure (DC Pressure)
- Dynamic fluid pressure = vibration (AC Pressure)
- Temperature (DC Temperature)
- Heat flow (AC Temperature)

Signal processing of these data enables the BioTac to do many things that humans can do by touch, such as:

- Determine point of contact
- Estimate tri-axial forces
- Estimate radius of curvature of a contacted object
- Discriminate edges, corners, and flat surfaces
- Sense initial contact, with a remarkably high sensitivity
- Detect slip
- Discriminate objects based on their texture
- Discriminate objects based on their compliance
- Discriminate objects based on their thermal properties

Shadow has partnered with Syntouch and provides a full integration option



## 9 Change list

| Date             | Person                | Changes                                                                                                                                              |
|------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| 21 December 2012 | Armando De La Rosa T. | Upgraded to E1 series. This document now includes an EtherCAT version of the Air Muscle Hand                                                         |
| 21 August 2012   | Gavin Cassidy         | Minor change to section six, paragraph two.                                                                                                          |
| 28 June 2012     | Gavin Cassidy         | Document title updated                                                                                                                               |
| 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<br>Added dimensions diagram<br>Added EtherCAT hand spec<br>Added CAN vs EtherCAT comparison table<br>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                                                                                                                                     |