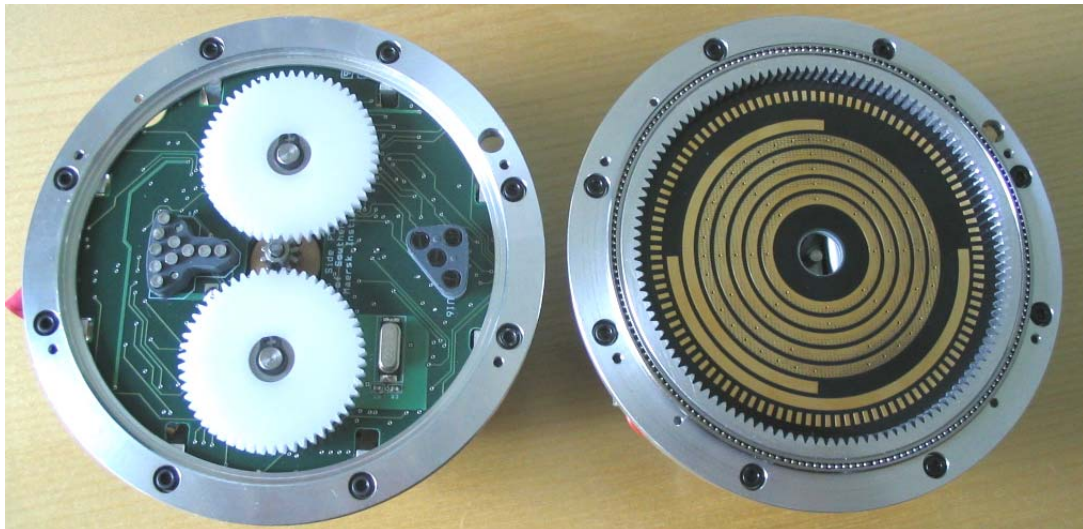
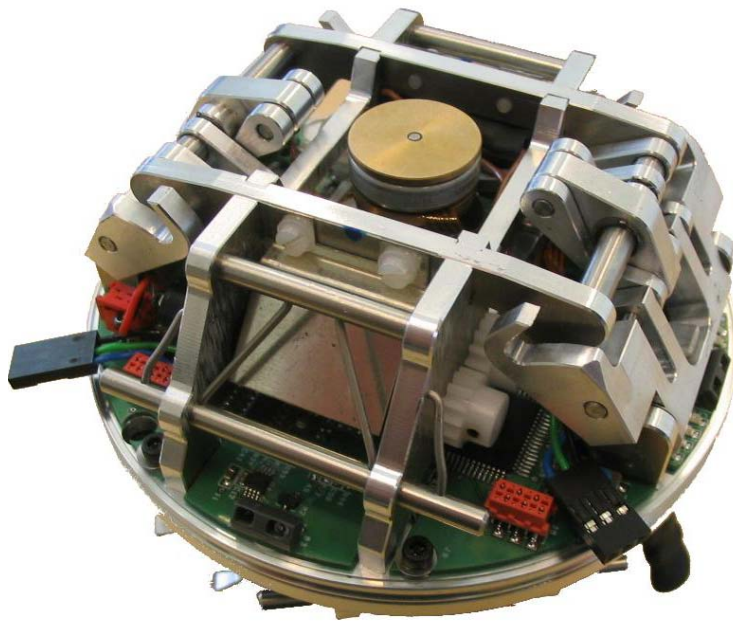


THE ATRON MODULE

Fact Sheet



ATRON Module

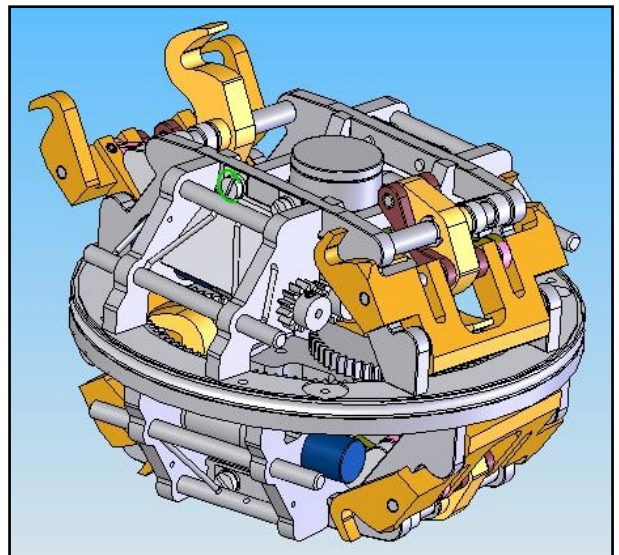
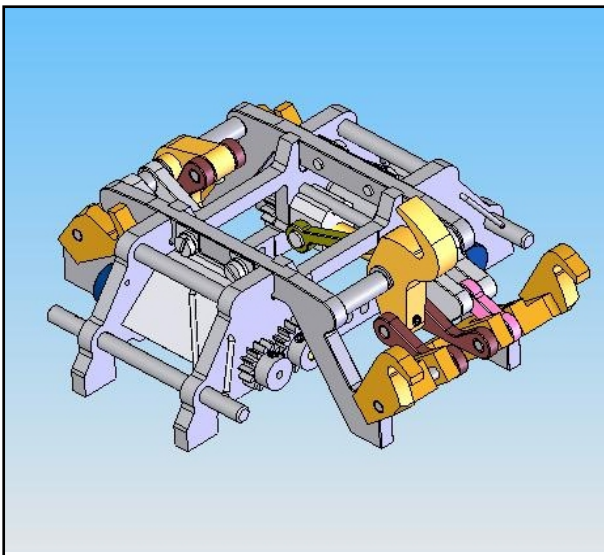
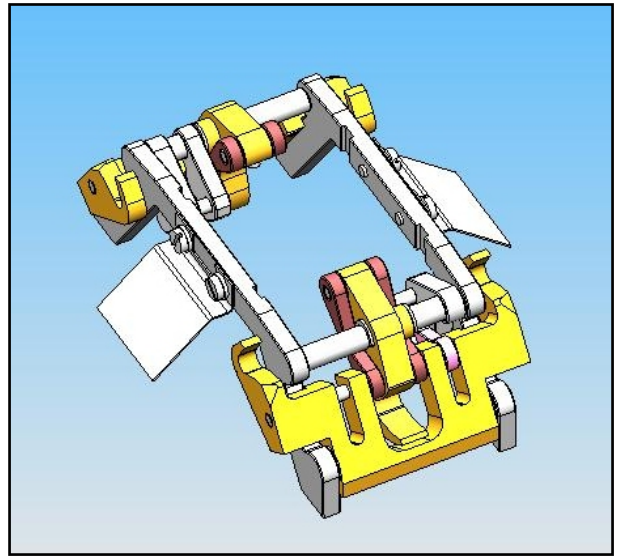
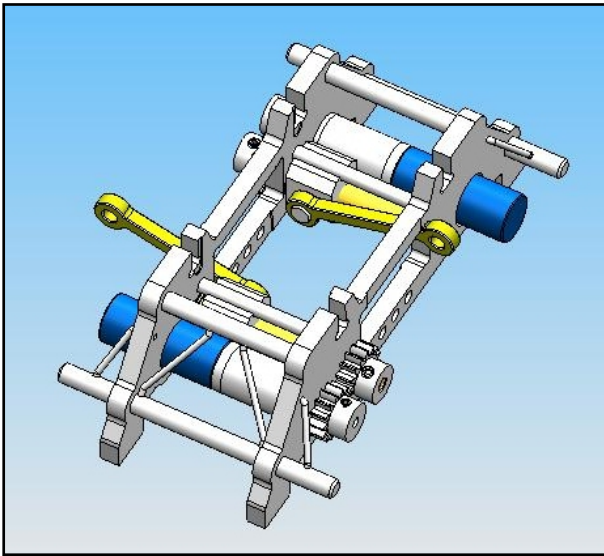


ATRON Module Characteristics

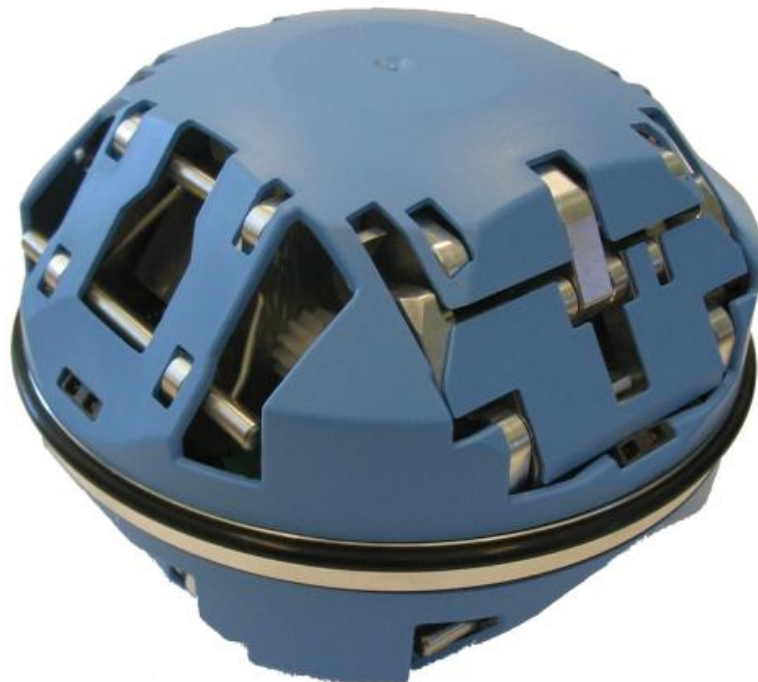
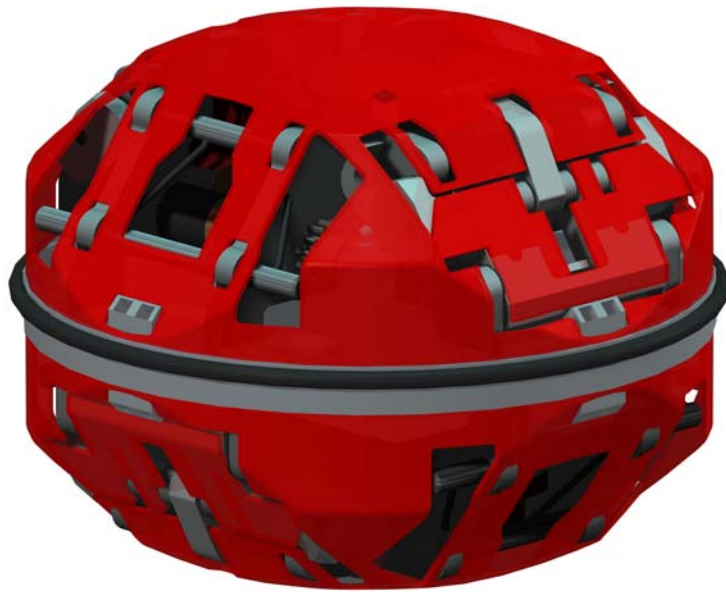
Key Features:

- Self-assembling robots (i.e. shape-changing robots)
- 100 modules produced for large-scale experiments
- Self-repairing algorithms and cell-biology-inspired control
- Power sharing to modules with low energy
- Battery charging throughout the structure
- Sphere-shaped (maximum diameter 11.4 cm), total weight 825 grams
- Connection/disconnection time 2 seconds, 90-degree centre rotation time 3 seconds
- Typical operation time per charge 150 minutes
- Lattice structure corresponds to the titanium atoms in the CuTi_3 crystal lattice
- 1 degree of freedom, 8 connectors (4 active and 4 passive)
- Optical inter-modular communication between each connector pair
- Wired (through gold-plated slip ring) intra-modular communication between the two hemispheres
- Absolute and relative position sensing between hemispheres
- Misalignment correction between connecting ATRON modules
- Charging and power-sharing capabilities throughout a connected structure of ATRON modules.
- Dual axis accelerometer for orientation awareness
- Fully self-contained (batteries, sensors, actuators, processing)
- The mechanical construction of the ATRON module consists of three parts, two frame parts and a centre arrangement.
- Strong aluminium 7075 frame parts
- Printed circuit boards (1 placed in the northern hemisphere, 4 in the southern hemisphere)
- 2 Rechargeable Lithium-Ion Polymer batteries (nominal voltage 3.0 – 4.2 V, 920 mAh)

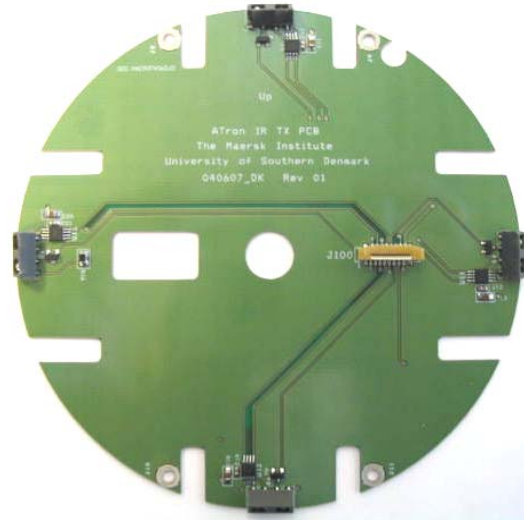
CAD Models



From CAD Model to Real Module

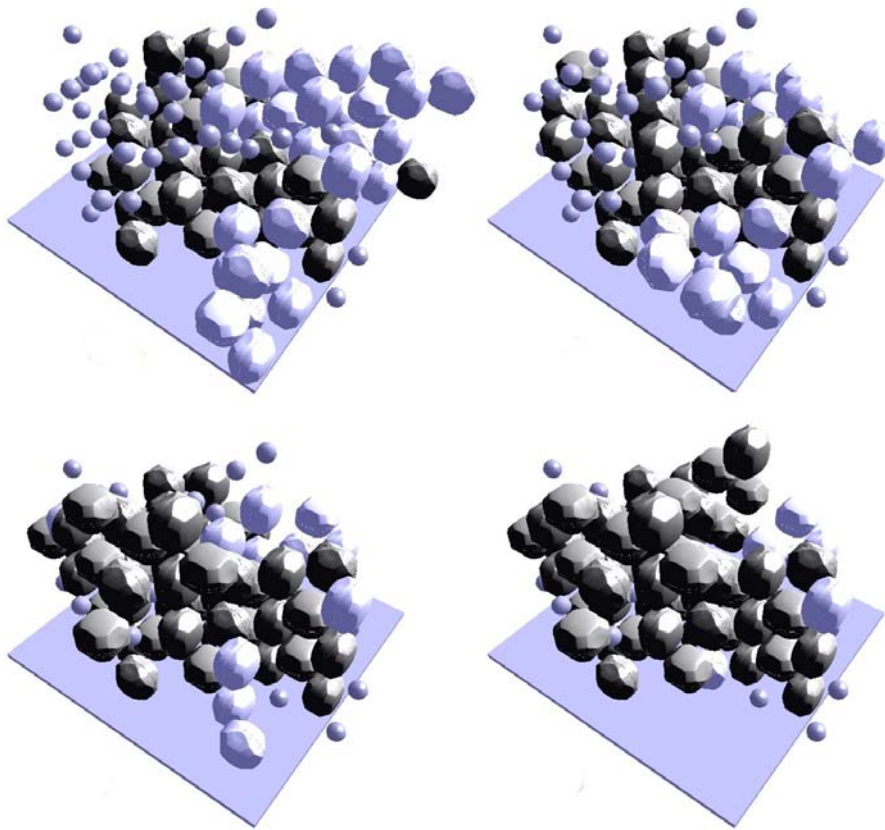


Printed Circuit Boards

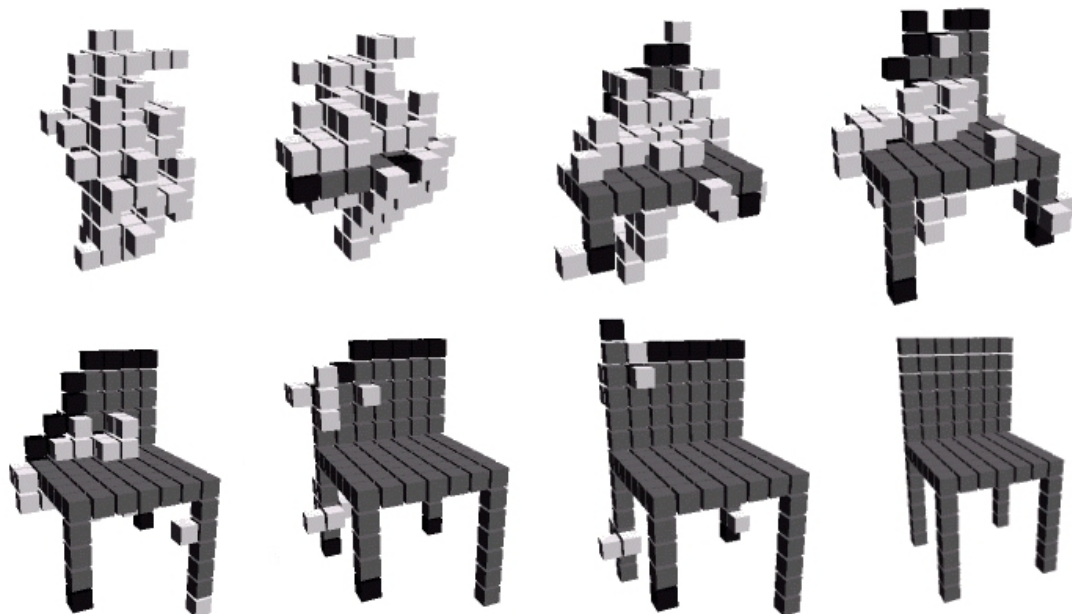


Each module carries five printed circuit boards (one in the northern hemisphere and four in the southern hemisphere).

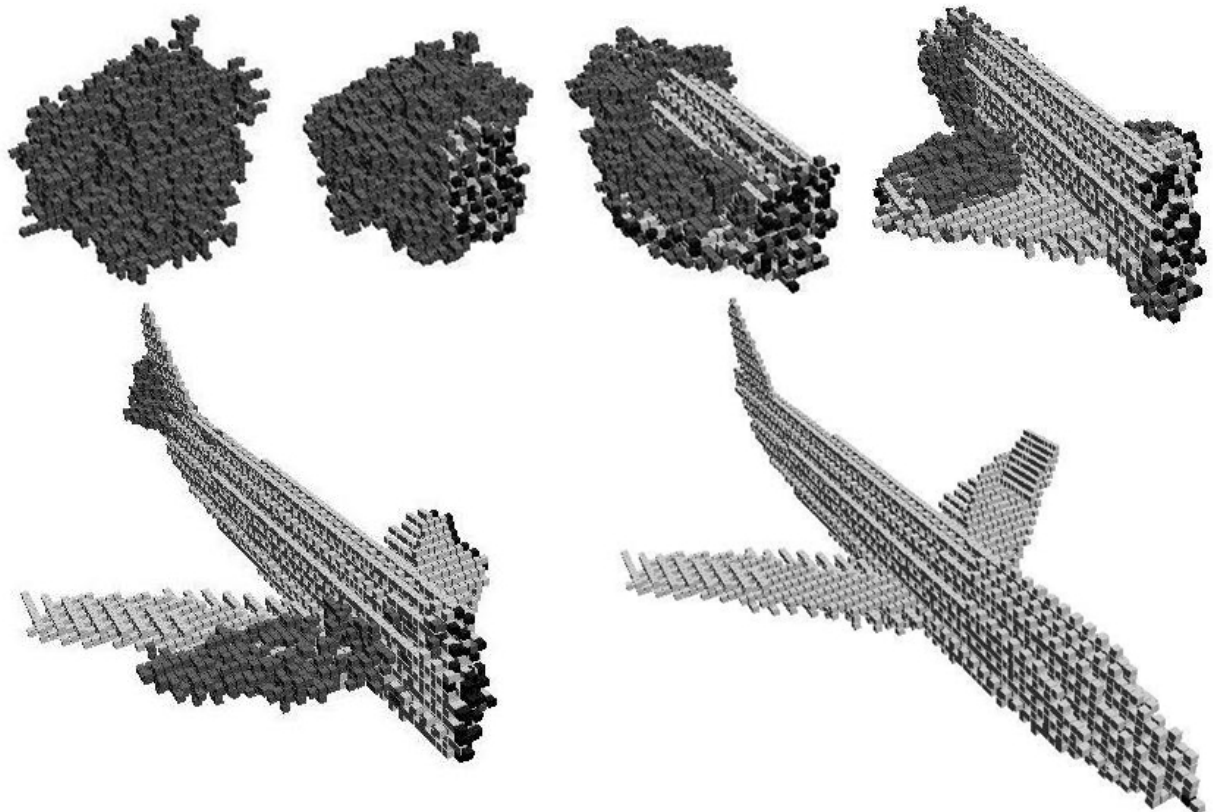
Abstract ATRON Simulation Example



General Abstract Simulation Example



From CAD Drawing to Simulation



Technical Details

Frames

The frames (mechanical parts) of the two hemispheres are custom-made with high precision on a five-axis CNC machine. The material used is aluminium 7075, which is four times harder than ordinary aluminium.

Manufacturer: Almexa (Denmark)

Web site: <http://www.almexa.dk>

Centre Arrangement

The centre arrangement (two metal rings joined by the centre bearing) joins the two hemispheres together. They are made of ALmgSi 0.5. One of the rings is equipped with an inner tooth wheel with 118 teeth.

Manufacturer: CFT tandhjulsfabrik (Denmark)

Web site: <http://www.cft.dk>

Centre Bearing

The two hemispheres (centre plates) are fixed together by a thin section ball bearing. The ultra slim ball bearing has a small cross sectional width even though its diameter is large.

Key specifications:

Cross sectional width 2.5 mm
Outer Ø 90 mm

Manufacturer: Kaydon (USA)

Web site: <http://www.kaydon.com>

Tooth Wheels

Each module is equipped with 11 tooth wheels. Each of the four active connectors uses a pair of small plastic tooth wheels to transfer the rotational motion from the connector motors to the linear motion of the lead screw. The centre motor is equipped with a small stainless steel tooth wheel, which is placed between two big plastic tooth wheels. The big tooth wheels share the load from the centre motor and rotate the inner ALmgSi tooth wheel. Each tooth wheel is custom-made.

Key specifications:

Material POM
Number of teeth 14, 16, 54
Maximum Ø 11.20, 12.60, 39.20
Modul 0.7
Angle 20 degrees

Material stainless steel
Number of teeth 10
Maximum Ø 8.40
Modul 0.7
Angle 20 degrees

Manufacturer: CFT Tandhjulsfabrik (Denmark)

Web site: <http://www.cft.dk>

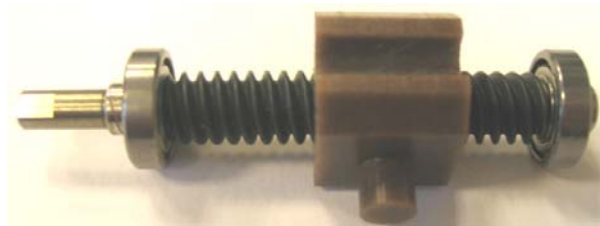


Lead Screw

The four active connectors each uses a custom-made lead screw to transfer the rotational motion from the connector motors to a linear motion moving the connectors.

Key specifications:

Lead 2.44 mm
Ø 4.76 mm
Length 43.2 mm



Manufacturer: Kerk Motion (USA) Web site: <http://www.kerkmotion.com>

Slip Ring

Each module has a slip ring installed in the centre arrangement. The slip ring combined with carbon brushes are used for signal and power transfer between the two hemispheres. The slip ring is also used by the optical encoder, which allows absolute and relative positions to be measured. The five inner rings are used for signal and power transfer, and the divided rings (six and seven) are used for measurement of absolute position in four 90-degree positions. The outer divided ring is for measurement of the relative position.

Key specifications:

Ø 90 mm
Two layer print
Mask black
Surface chemic Ni/Au

Manufacturer: Bent Hede Elektronik (Denmark)
Web site: <http://www.bhe.dk>



Carbon Brushes

Ten micro carbon brushes are used for signal and power transfer between the two hemispheres in each module. Depending on the requirements of the signals, one or more brushes are used in the same track in the slip ring. Each carbon brush is pressed against the slipring by small springs.

Key specifications:

Brush with cu cable
Size Ø 2.5, length 3.0 mm

Manufacturer: Elektrokul A/S (Denmark) Web site: <http://www.elektrokul.dk>

Actuators and Drivers

Each module is equipped with six actuators (five motors and one solenoid):

- Four DC motors are used for connection/disconnection of the four active connectors.
- One brushless DC motor is used for the rotation of the two hemispheres with respect to each other.
- One solenoid is used as a rotational lock mechanism between the two hemispheres.

Connector Motors with Gearboxes

The four active connectors are actuated by DC motors equipped with planetary gearboxes. Both parts are produced by Maxon motors, motor: RE 10 (metal edition), gearbox: GP 10A (metal edition).

Key specifications:

Connector motor:

Nominal voltage 6.0 Volt
Assigned power rating 1.5 Watt
Maximum efficiency 76 %
No load speed 12400 rpm
Stall torque 3.01 mNm

Gearbox:

Reduction 64:1
Maximum efficiency 73 %
Recommended input speed < 800 rpm
Max. continuous torque at gear output 0.010Nm



Dimensions and weight:

Ø 10 mm, length 24.7mm, weight 10 grams Ø 10 mm, length 17.2 mm, weight 7.7 grams

Manufacturer: Maxon Motor (Switzerland)

Web site: <http://www.maxonmotor.com>

Center Motor with Gearbox

The rotation of the two hemispheres with respect to each other is actuated by a brushless DC motor equipped with a planetary gearbox.

Both parts are produced by Maxon motors, motor: EC 20 flat motor (brushless), gearbox: GP 19 B.

Key specifications:

Centre motor:

Nominal voltage 9.0 Volt
Assigned power rating 3.0 Watt
Maximum efficiency 62.5 %
No load speed 9800 rpm
Stall torque 8.04 mNm

Gearbox:

Reduction 84:1
Maximum efficiency 73 %
Recommended input speed < 6000 rpm
Max. continuous torque at gear output 0.2 Nm



Dimensions and weight:

Ø 20 mm, length 9.8 mm, weight 15 grams Ø 19 mm, length 23.1 mm, weight 36 grams

Manufacturer: Maxon Motor (Switzerland)

Web site: <http://www.maxonmotor.com>

Solenoid

One push type tubular solenoid is used as a rotational lock mechanism between the two hemispheres. The plunger inside the solenoid is pressed out when actuated, such that the two rotating hemispheres are locked with respect to each other. The solenoid can lock the rotation in four (90-degree) positions. The push type tubular solenoid S-63-38-35S-H is produced by Magnetic Sensor Systems.

Key specifications:

Resistance 12.1 ohm

At 100 % duty cycle (volts DC 4.8 V, power 2 watts): Maximum "on" time always "on"

At 50 % duty cycle (volts DC 6.7 V, power 4 watts): Maximum "on" time 25 seconds

At 25 % duty cycle (volts DC 9.5 V, power 8 watts): Maximum "on" time 6 seconds

At 10 % duty cycle (volts DC 15.1 V, power 20 watts): Maximum "on" time 0.5 seconds



Dimensions and weight:

Ø 9.6 mm, length 16.7 mm, weight 6.5 grams

Manufacturer: Magnetic Sensor Systems (USA) Web site: <http://www.solenoidcity.com>

Connector Motor Driver

A dual full-bridge PWM motor driver is used for driving each pair of active connector motors. The motor driver A3966SLB is produced by Allegro Microsystems.

Key specifications:

Maximum continuous output current ± 650 mA

Maximum output voltage 30 volt

Internal fixed-frequency PWM current control

Internal thermal-shutdown circuitry

Manufacturer: Allegro Microsystems (USA) Web site: <http://www.allegromicro.com>

Centre Motor Drivers

The brushless DC centre motor needs additional driver circuitry.

The ASIC driver can be used for driving three-phase sensorless, brushless DC motors using the BEMF signals for the commutation timing. It is also equipped with an internal driver for medium power applications. The brushless motor driver ASIC 5660E-06240 is produced by Micronel.

Key specifications:

Internal driver current 200 mA

Interface for driving ST's L6234 power driver

Power dissipation 500 mW

RPM adjustable by PWM

Manufacturer: Micronel (USA)

Web site: <http://www.micronel.com>

Power driver L6234

Even though the ASIC chip has an internal driver, the requirements from the centre motor exceed the ASIC specifications and an additional power driver is therefore needed. The three-phase motor driver L6234 is easily interfaced to the ASIC chip.

Key specifications:

Supply voltage 7-52 volt

Maximum pulsed output current 5 amps

Commutation frequency 50 KHz

Manufacturer: STMicroelectronics (Switzerland) Web site: <http://www.st.com>

Power Supply

Each module is powered by two rechargeable lithium-ion polymer batteries. The two batteries are installed in the southern hemisphere and connected in series. The batteries DLP 493969 are produced by Danionics.

Key specifications:

Nominal capacity 920 mAh
Minimum capacity 870 mAh
Nominal voltage 3.0 – 4.2 volt
Maximum continuous discharge current 1840 mA
Charge method CC-CV with voltage limit 4.20 Volt
Recommended charge current 460 mA
Low self-discharge (90% capacity remaining after 1 month)
80% of the original capacity is present after 400 recharge and discharge cycles.



Dimensions and weight:

Thickness 4.9 mm, width 39 mm, length 69 mm, weight 26 grams

Manufacturer: Danionics (Denmark)

Web site: <http://www.danionics.com>

Battery Charger

Each module has a built-in battery charger, such that the two rechargeable lithium-ion polymer batteries can be charged through the shared power bus. The battery charger is installed in the southern hemisphere together with the two batteries.

The stand-alone, switch-mode lithium-ion polymer battery charger MAX1757EAI is produced by Maxim.

Key specifications:

Charges up to 3 batteries	Up to 1.5 amp programmable charge current
Safely precharges near-dead cells	Input current limiting
Continuous voltage and temp. monitoring	Built-in safety timer

Manufacturer: Maxim (USA)

Web site: <http://www.maxim-ic.com>

Computing

Each module is equipped with four microcontrollers (one pair in each hemisphere):

Northern hemisphere

- One ATmega 8 controls the centre motor, connector motors, tilt sensor and the solenoid.
- One ATmega 128 controls the IR communication, communication with the southern hemisphere and the overall control of the module.

Southern hemisphere

- One ATmega 8 controls the power sharing, charging of batteries and power selection.
- One ATmega 128 controls the IR communication, connector motors and communication with the northern hemisphere.

The main reasons for choosing numerous small microcontrollers instead of one large microcontroller are that we have to reduce the power consumption and reduce the wiring between the two hemispheres. Both types of microcontrollers can be programmed in the freely available AVR GCC programming language.

ATmega 8 Microcontroller

The ATmega 8 is a high-performance, low-power 8-bit microcontroller.

Key specifications:

Flash 8 kilobyte

EEPROM 512 byte

SRAM 1 kilobyte

Max. I/O pins 23

Maximum frequency 16 MHz

Two 8-bit timer/counters

One 16-bit timer/counters

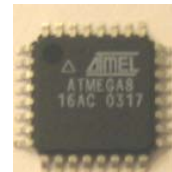
Eight-channel 10-bit ADC

Tree PWM channels

Programmable Serial USART

Master/Slave SPI Serial Interface

Byte-oriented Two-wire Serial Interface



Dimensions:

Thickness 1.2 mm, width 9 mm, length 9 mm

Manufacturer: Atmel (USA)

Web site: <http://www.atmel.com>

ATmega 128 Microcontroller

The ATmega 128 is a high-performance, low-power 8-bit microcontroller.

Key specifications:

Flash 128 kilobyte

EEPROM 4 kilobyte

SRAM 4096 byte

Max. I/O pins 53

Maximum frequency 16 MHz

Two 8-bit timer/counters

Two expanded 16-bit timer/counters

Eight-channel 10-bit ADC

Two 8-bit PWM channels

Dual programmable Serial USARTs

Master/Slave SPI Serial Interface

Byte-oriented Two-wire Serial Interface



Dimensions:

Thickness 1.2 mm, width 14 mm, length 14 mm

Manufacturer: Atmel (USA)

Web site: <http://www.atmel.com>

Communication

External Communication

The modules are able to communicate with each other via optical (IR) communication. Each connector is equipped with a pair of IR LEDs (one for transmitting and one for receiving). The IR LEDs are also used for proximity sensing. The IR LEDs are driven by the MAX3120CUA IrDA Infrared Transceiver.

Key specifications:

IrDA 1.2 Compatible: 2.4kbps to 115.2kbps
Flexible Optics Selection and Layout
120 μ A Supply Current
10nA Shutdown Supply Current
200mA, High-Current Infrared LED Drive



Manufacturer: Maxim (USA)

Web site: <http://www.maxim-ic.com>

Internal Communication

Besides I2C communication between the microcontrollers in the same hemisphere, the microcontrollers in each hemisphere must also be able to communicate with each other. The communication standard used between the two hemispheres is the RS-485. The MAX3082CSA is a RS-485 transceiver for EMI sensitive communication.

Key specifications:

Up to 115 kbps
Intended for half-duplex communication

Manufacturer: Maxim (USA)

Web site: <http://www.maxim-ic.com>

Sensors (External)

Tilt Sensor

Each module is equipped with a dual-axis accelerometer (tilt sensor). The feedback from the tilt sensor offers information to the module about its current orientation. The orientation awareness of the individual modules is useful in the control of a large-scale system. The tilt sensor used is the MXD2020E from Memsic.

Key specifications:

Measures dynamic and static accelerations
Provides digital output
Measurement range minimum ± 1.0 g
Frequency response 17 Hz

Manufacturer: Memsic (USA)

Web site: <http://www.memsic.com>

Proximity Sensor

The IR communication system mentioned in the communication section is a dual functionality system. It is also used as a proximity sensor, such that neighbouring modules or obstacles can be located.

THE ATRON MODULE Development Team:
AdapTronics Group
University of Southern Denmark
www.adaptronics.dk



HYDRA Consortium:
University of Southern Denmark
University of Edinburgh
University of Zurich
LEGO Systems A/S

Contact:

Professor Henrik Hautop Lund, University of Southern Denmark, hhl@mip.sdu.dk