Communication guide for the PD

Revisions table

|  |  |  |
| --- | --- | --- |
| 1A at February 2017 | Added paragraph for revisions table |  |
| 1B at February 2017 | Continued development, yet unfinished document |  |
| 1C at February 2017 | First release |  |
| 1D at February 2017 | Added laser PS control to object 0x2210 |  |
| 1E 1 march 2017 | Added read capability of Dynamixel position, object 2103  Dynamixel offset added to parameters table |  |

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# Scope

This document explains the operation of the PD card by communication.

The PD card is controlled by CAN communication, at the baud rate of 500000.

It supports a CAN Open slave (ID=126).

In addition, it supports some specialized messages for real time communication with its master LP card.

# General explanations

## PD purpose

The purpose of the PD is to

* Operate the power sources of the robot
* Operate the manipulator, using the Dynamixel servos.

# Operating the manipulator (Dynamixel servos)

## The manipulator

The manipulator arm has 3 units:

* Humerus
* Radius
* Hand

And 3 servo axes:

* Shoulder
* Elbow
* Wrist

And the following helper units:

* Laser range finder (Interfaced to the LP card, data is coming by communication from the LP)
* Stop doors (left and right servos)
* Vacuum holder pumps with current meters (increased current is a measure of good under-pressure, meaning a good hold. Less current tells greater pump speed and probably a lost hold)

Refer the figure below



Figure 1: Parts of the robot-manipulator system, on horizontal shelf, picking a package at the right

When a package handling is due, the package position must be known to good approximation (few cm in X and Y). The coordinate system is in the figure below.



Figure 2: Coordinate system for package picking

The origin is where the wheel touches the shelf rail. This is because the robot was brought to the pick position at the same system.

Note:

* The package Y is positive if the package is at the right, negative for left package.
* The package X is always negative

Some actions need to happen. Their automatic action will be described below for right package access; left access is similar, just to opposing directions.

* The left door closes, and the right door opens
* The manipulator is placed so that the hand is parallel to the shelf line (and the package), and the laser is pointing at the package.
* A laser range reading is now expected. If it fails to be in range (normally 5cm to 23cm), action is aborted with exception and the manipulator returns to stand by position
* The hand advances towards the package until touch, keeping parallel to the package, per continuous laser readings
* The suction pumps are powered until the current is high enough for enough time.
* The manipulator pulls back while keeping a parallel hand and monitoring the vacuum. If vacuum falls, the manipulator presses the package back to original place, then retries one time. On the second return to place, the manipulator fold back to standby with exception report.
* When the manipulator is homed so that the package nearly reaches the left door, the right door closes and action is done with success.

|  |
| --- |
| The laser range is measured and reported by the LP card.  The LP must:  - Turn the Laser sensor on before package handling (using the ControlWord, object 0x2210), and let 0.2sec to stabilize  - Turn the Laser sensor on after package handling is done (again, using the ControlWord)  - In between, continuously update the laser reading via object 0x2210 |

## The Dynamixel servo system

The Dynamixel servo system consists of two RS485 chains.

The first chain is driven by 24V, and has three Dynamixel-pro units:

|  |  |  |
| --- | --- | --- |
| Motor | ID | Motor resolution count/rev |
| Shoulder | 3 |  |
| Elbow | 4 |  |
| Wrist | 5 |  |

The second chain is driven by 12V, and has two Dynamixel MX units

|  |  |  |
| --- | --- | --- |
| Motor | ID | Motor resolution count/rev |
| Left stop | 1 |  |
| Right stop | 2 |  |

The parameters of the Dynamixel, including ID change, can be set using the CAN interface.

The parameters are described in detail in the control table by Dynamixel.

Before programming any Dymamixel parameter, the corresponding Dymamixel network must be pulled out of automatic mode, so that the desired management communication take place without intervention from the normal periodic Dynamixel traffic.

# Switches and controls

## The power supply system

The PD delivers voltages to the entire robot system.

These include

* 5V supply for the local logics (DSP etc.), LP, Raspberry, camera, and console. This 5V is pure hardware
* 12V supply for the stop motor and many more consumers (brakes, chakalaka, … )
* 24V supply for the manipulator motors
* Main switch for 54V for the entire robot servo

|  |
| --- |
| Only the 5V supply wakes up by hardware.  After the PD boots, the 12V, the 24V, and the main servo switch are all disabled.  The 12V, the 24V, and the main servo switch (54V) are enabled as response to software commands over the CAN lines (Object 0x2004)  This object should also be used to wake up the Dynamixel networks. |

The supply chain is as follows:



Figure 3: Power supply chain

The conditions in the circuit are:

* The Main On/Off controls the 5V PS in hardware. Without the 5V supply, nothing in the circuit works. All the supplies are down and all the switches are disconnected.
* The 12V is software controlled. Its operating is essential for the work of the 24 volt network, because the 12V supply delivers the gate drive for the 24V supply
* The 24V supply is software controlled
* The main power switch is software controlled
* The shunt (to be explained below) is software controlled

|  |
| --- |
| The safety mushroom, when pressed, disconnects the 12V, the 24V and the main power switch in hardware. |

## The shunt voltage regulator

The shunt system is meant to avoid overvoltage of the servo system.

Such over-voltage may develop by regeneration: when the servo drives stop the robot, they must pump out its kinetic energy. Part of this energy goes as returned current to the electricity system and may cause overvoltage by overflowing the storage capacitors.

On sensing over-voltage, the shunt switch closes, generating a return path to the returned (regeneration) current.

# CAN Open Object dictionary for PD

This chapter lists the CAN open objects which the PD card supports as slave, under the ID of 126.

The objects are listed by their index

## 13Object 2003 – Control discrete switches

This object targets the discrete activations on the PD.

All the sub-indices are unsigned short.

Access is write only.

|  |  |  |
| --- | --- | --- |
| Sub-index | Description | Comment |
| 4-6 | Control of air pump switches 1..3 to the manipulator | 1 = On |
| 7 | Chakalaka | 1=On |
| 8 | Stop brake | 1=On |
| 9 | Relay brake | 1=On |
| 10 | Steering brake | 1=Released |
| 11 | Wheels brake | 1=Released |
| 12 | Neck brake | 1=Released |
| 13 | Fan | 1=On |
| 14 | Tail light | 1=On |
| 15 | Discrete output #1 | Used **ONLY** for card ATP only. Using this sub-index modifies the PD settings. |
| 16 | Shunt | Used **ONLY** for card ATP only. Using this sub-index disables the shunt automatic actions. |

## Object 2004 – Control Power supply and Dynamixel presence

This object is UINT16, write only

|  |  |  |
| --- | --- | --- |
| Sub-index | Description | Comment |
| 1 | Set the 12V supply on | 1 : 0n , 0: Off |
| 2 | Set the 24V supply on | 1 : 0n , 0: Off |
| 3 | Set the 54V servo supply on | 1 : 0n , 0: Off |
| 4 | Set Dynamixel 12V network active | 1 : 0n , 0: Off |
| 5 | Set Dynamixel 24V network active | 1 : 0n , 0: Off |
| 10 | 12V Set point, in millivolts | Can be used to fine adjust the output voltage |
| 11 | 24V Set point, in millivolts | Can be used to fine adjust the output voltage |

## Object 2100 – Set or get a parameter of Shoulder, Elbow, or Wrist

This object targets the 24V Dynamixel network

SDO download:

|  |  |  |
| --- | --- | --- |
| Sub-index | Description | Type |
| 1 | Mode of operation  10: Parameter programming mode | Short int |
| 2 | Offset of the programmed parameter in the control table | Short int |
| 3 | Number of bytes to program (1 , 2 , or 4) | Short int |
| 20 | Payload data to send | Long int (if less than 4 bytes are specified in sub-index 3, the lower bytes shall be used) |
| 100 | ID list for “Set”.  Up to 3 ID’s (specify 0 if ID is not used)  (first ID)+ (2nd ID)<<8+(3rd ID)<<16  The message defined by the offset, number of bytes, and payload will be sent immediately to all the relevant IDs | Long int |
| 101 | ID list for “Get” request.  Up to 3 ID’s (specify 0 if ID is not used)  (first ID)+ (2nd ID)<<8+(3rd ID)<<16  The message requesting the parameter inquiry defined by the offset and number of bytes will be sent immediately to all the relevant IDs | Long int |

SDO upload:

|  |  |  |
| --- | --- | --- |
| Sub-index | Description | Type |
| ID of relevant axis | Uploaded data, as defined by sub-index 101 of the object | May be byte, short int, or long int (specified in uploaded SDO) |

## Object 2101 – Set or get a parameter of Left stop or Right stop

The object is very similar to 0x2100, only that it targets the 12V network.

## Object 2103: Set/Get manipulator action

Data type: long integer

Access: Set (Write) by specified indices

Get (Read) by specified indices

|  |  |  |
| --- | --- | --- |
| Sub-index | Description |  |
| 1 | Work mode, bit field  .0: Automatic (0: Each operation is controlled individually)  .1: Motor On (Auto modes only)  .2-3: Sequence, 0: Halt, 1: Standby, 2: Package  .4: Package direction, 1:Get, 0: put  .5..6: Side, 0: Undefined, 1: Left ,2: Right  .10..14 Individual motor on commands for manual operations  .15 Suck operation for individual mode |  |
| 10 | Individual motor off-on for Shoulder: 0 off, 1 on |  |
| 11 | Shoulder command in milli-radians |  |
| 20 | Individual motor off-on for Elbow:  0 off, 1 on |  |
| 21 | Elbow command in milli-radians |  |
| 30 | Individual motor off-on for Wrist: 0 off, 1 on |  |
| 31 | Wrist command in milli-radians |  |
| 40 | Individual motor off-on for Left stop: 0 off, 1 on |  |
| 31 | Left stop command in milli-radians (0=closed) |  |
| 50 | Individual motor off-on for Right stop: 0 off, 1 on |  |
| 51 | Right stop command in milli-radians (0=closed) |  |
| 100 | Enter laser data , 0.1 mm unit, and set laser valid |  |
| 101 | Set laser validity: 0 non valid, 1 valid |  |
| 102 | X reference of package, mm |  |
| 103 | Expected Y reference of package, mm |  |
| 104 | 1: Set all motors on for automatic action  0: Stop motion immediately |  |

Figure 4: Set Values

|  |  |  |
| --- | --- | --- |
| Sub-index | Description |  |
| 12 | Shoulder position, encoder counts |  |
| 13 | Shoulder position, miliradians |  |
| 22 | Elbow position, encoder counts |  |
| 23 | Elbow position, miliradians |  |
| 32 | Wrist position, encoder counts |  |
| 33 | Wrist position, miliradians |  |
| 42 | Left stop position, encoder counts |  |
| 43 | Left Stop position, miliradians |  |
| 52 | Right stop position, encoder counts |  |
| 53 | Right stop position, miliradians |  |

## Object 2104: Get PD status

All the sub-indices are long unsigned bit fields (4 bytes)

Access is read only

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Comment |
| 1 | BIT results |  |
| 2 | Limit switch status |  |
| 3 | Actuations status |  |

The tables below detail the fields:

**BIT Results**

|  |  |  |
| --- | --- | --- |
| Bit | Meaning | Comment |
| 0 | 24V supply inactive |  |
| 1 | 12V supply inactive |  |
| 2 | Mushroom emergency depressed |  |
| 3 | I2t (too hot) failure at shunt |  |
| 4 | Package grip failed |  |
| 5..9 | Dynamixel fail | Shoulder, elbow, wrist, left, right |
| 10 | No active sucking in suck pump #1 |  |
| 11 | No active sucking in suck pump #2 |  |
| 13..15 | Reserved |  |
| 16 | 12V supply activated |  |
| 17..19 | Failure code of 12V supply | 0: Ok  1: Input voltage out of range  2: Output overvoltage  3: Over current |
| 20 | 24V supply activated |  |
| 21-23 | Failure code of 24V supply | Similar to 12V failure codes |
| 24..31 | Reserved |  |

**Limit switch status**

|  |  |  |
| --- | --- | --- |
| Bit | Meaning | Comment |
| 0 | Manipulator switch 1 |  |
| 1 | Manipulator switch 2 |  |
| 2 | Stopper switch 1 |  |
| 3 | Stopper switch 2 |  |
| 4 | Dynamixel stop network ON | Just commanded to start |
| 5 | Dynamixel stop network boot done |  |
| 6 | Dynamixel manipulator network ON | Just commanded to start |
| 7 | Dynamixel manipulator network boot done |  |
| 8 | DISC 2 input | 1 = high |
| 9..13 | Motor on (shoulder, elbow, wrist, left,right) |  |

**Actuations status**

|  |  |  |
| --- | --- | --- |
| Bit | Meaning | Comment |
| 0 | Steering brake released |  |
| 1 | Wheel brake released |  |
| 2 | Neck brake released |  |
| 3 | Shunt active |  |
| 4 | 54V Servo drive gate drive on |  |
| 5 | Air pump #1 active |  |
| 6 | Air pump #2 active |  |
| 7 | Air pump #3 active |  |
| 8 | Chakalaka on |  |
| 9 | Stop brake released (power on to release drive) | Unused |
| 10 | Stop Relay engaged | Unused |
| 11 | Fan on |  |
| 12 | Tail lamp on |  |
| 13 | Disc1 on | Unused |
| 14 | Servo power on |  |
| 15 | Reserved |  |
| 16..23 | Package handling sub-state | 0: Idle  100: Done  255: Error |

## Object 2208: Parameters of the manipulator system

All the parameters are IEEE32 floating point numbers

Access is Get/Set

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Nominal |
| 1 | Length of Humerus, m |  |
| 2 | Length of Raduis, m |  |
| 3 | Length of hand, m |  |
| 4 | Turn limit of Shoulder (each direction, rad) |  |
| 5 | Turn limit of Elbow (each direction, rad) |  |
| 6 | Turn limit of Wrist (each direction, rad) |  |
| 7 | Turn limit of left stop, rad |  |
| 8 | Turn limit of left stop, rad |  |
| 9 | Distance on the X axis between the shoulder pivot and the wheel – shelf touch point |  |
| 10 | Distance on the Y axis between the center pivot and the wheel – shelf touch point |  |
| 11 | Stop position when released |  |
| 12 | Stop position when locking |  |
| 20 | Offset of shoulder actuator, Dynamixel counts | The value read when the actuator is at mechanical zero |
| 21 | Offset of shoulder elbow, Dynamixel counts |  |
| 22 | Offset of shoulder wrist, Dynamixel counts |  |
| 23 | Offset of shoulder Left door, Dynamixel counts |  |
| 24 | Offset of shoulder Right door, Dynamixel counts |  |

Table 1: table of fixed parameters

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Nominal |
| 100 | Minimum range for initial laser reading |  |
| 101 | Maximum range for initial laser reading |  |
| 102 | Offset between laser reading and package distance:  Distance = laser reading – offset |  |
| 103 | Time in good vacuum for starting the pull back |  |
| 104 | Stand by distance on the Y axis between the elbow and the shoulder (for right access the elbow will be at negative Y and vice versa) |  |
| 105 | Time for the entire suck operation |  |
| 106 | Time for the entire suck release operation |  |
| 107 | Suck filter threshold: If sucking filter output exceeds this value, the sucker is active | 20000 |

Table 2: Table of tunable

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Nominal |
| 200 | Shunt activation voltage, Volt |  |
| 201 | Shunt discontinuation voltage, Volts |  |
| 202 | Output over voltage , Volt (unused) |  |
| 203 | Shunt I2t limit Watt |  |
| 204 | I2tLimitFilterCst: I2t filter constant at 4096usec  I2t(k+1) = I2t(k) + I2tLimitFilterCst( V^2/R - I2t(k) )  Thus I2tLimitFilterCst = 0.00496 /(Time constant, sec) |  |
| 205 | Shunt Conductance (1/Ohm) |  |

Figure 5: Shunt parameters

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Nominal |
| 300 | Minimum battery voltage(V) for operation of 24V supply (manipulator power) | 28 |
| 301 | Maximum battery voltage(V) for operation of 24V supply (manipulator power) | 40V |
| 302 | Nominal set point for the 24V manipulator power | 25.5 |

Figure : Parameters of the power supply

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Nominal |
| 1030-1034 | Proportional gain of controls  (Shoulder,Elbow,Wrist,Lstop,Rstop) |  |
| 1035-1039 | Acceleration limiter of controls (Shoulder,Elbow,Wrist,Lstop,Rstop) |  |

Figure 7: Control parameters

## Object 2204: Read measured quantities

This object is read-only. All the returned values are 32-bit IEEE floating point.

|  |  |  |
| --- | --- | --- |
| Sub-index | Meaning | Units |
| 1 | 24V output supply | Volts |
| 2 | 54V output supply | Volts |
| 3 | Current consumption from 54 volts | Amp |
| 4 | Current of air pump #1 | Amp |
| 5 | Current of air pump #2 | Amp |
| 6 | Current of air pump #3 | Amp |
| 7 | 36V input supply | Volts |
| 8 | 54V input supply | Volts |
| 9 | Duplicate of sub-index 8 |  |
| 10 | 12V output supply | Volts |
| 11 | Duplicate of sub-index 10 |  |
| 12 | Unused, provision for 5V current |  |
| 13 | 5V output supply | Volts |
| 14 | Shunt current | Amp |
| 15 | Current output at 24V | Amp |
| 16 | Current output at 12V | Amp |
| 17 | Detector filter for pump 1 sucking | Normalized |
| 18 | Detector filter for pump 2 sucking | Normalized |

## Object 2210: Control word

This object is write only.

This is a bit field. 32 bit long, written as unsigned long (4 bytes)

Only sub-index 0 is valid

|  |  |  |
| --- | --- | --- |
| Bit | Meaning | Comment |
| 0 | Automatic work (otherwise manipulator and stops can be programmed individually) | 1 = Automatic |
| 1 | Motors On | 1 = motors on (only if Automatic) |
| 2 | Standby | 0: Nothing  1 = Go to standby (only if Motors on AND Automatic AND (NOT Package) ) |
| 3 | Package | 0: Nothing  1 = Go to standby (only if Motors on AND Automatic AND (NOT Standby) ) |
| 4 | Package get | 0: Put package  1: Get package |
| 5:6 | Side | 0: Undefined  1: Package to the left  2: Package to the right |
| 7 | Laser Valid | 1: Laser reading is valid |
| 8 | Brake Valid |  |
| 9 | Release wheels | Only if Brake Valid  1: release wheel brakes  0: Engage wheel brakes |
| 10 | Release steering | Only if Brake Valid  1: release steering brakes  0: Engage steering brakes |
| 11 | Release neck | Only if Brake Valid  1: release neck brakes  0: Engage neck brakes |
| 12 | Turn laser sensor on | 1: Turn on power supply to laser sensor  0: Turn it off |
| 13..14 | Reserved |  |
| 15 | Don’t process control word | 1: Ignore control word, use laser report only |
| 16..31 | Laser distance, in 1/10mm units | Acceptable range 1 to 32768  Only if Laser Valid |

# Operational communication

The operational communications are composed of:

* Commands
* Status reports.

Most commands are made simply by standard SDO confirmed services. The exception is the control + laser object, sent periodically.

The status reports are by pre-mapped PDO service, in response to a sync.

The mapping is described below:

PDO 1 TX:

|  |  |  |
| --- | --- | --- |
| Byte | Meaning | Comment |
| 0..3 | CBIT status | Object 0x2014 sub index 1 |
| 4..5 | Discrete activations | Object 0x2014 sub index 3, least word |
| 6-7 | Switch readings | Object 0x2014 sub index 2, least word |

PDO 2 TX:

|  |  |  |
| --- | --- | --- |
| Byte | Meaning | Comment |
| 0 | State of manipulator state machine |  |
| 1 |  |  |
| 2..3 | X position of tip, mm | w.r.t robot wheel center |
| 4..5 | Y position of tip, mm | w.r.t active frame, as defined by active side  (if no left or right is defined, Y refers to robot center) |
| 6..7 | Angle of normal to hand, 16bit/rev | 0 angle is to the robot drive direction (never happens), 16384 = 90deg is towards to robot right |

PDO 1 RX: (non-synchronous, accepted on receive)

|  |  |  |
| --- | --- | --- |
| Byte | Meaning | Comment |
| 0..3 | Control word and laser measurement | Object 0x2210 |
| 4..5 | Reserved |  |
| 6..7 | Password | 0x1234 |