The emProtocol

This document describes the emProtocol, the protocol used to exchange information between devices in the internal IP-based network of iCub.

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The emProtocol

This document describes the emProtocol, the protocol used to exchange information between devices in the internal IP-based network of iCub.

The content of the application layer packets transported inside a UDP packet is a frame, or ROPframe containing a variable number of remote operations, or ROPs. A ROP is command aimed at manipulating a network variable, or NV.

The following sections contain a detailed description of how is defined a NV, how the ROPs operate to manipulate NVs and how the ROPs are concatenated to form a ROPframe.

Network variables

A NV is a data structure which is resident in a given device, is identified by a triple of numbers (IP, EP, ID) and has some public properties such as size and default values.

## Identification

The variable is uniquely identified inside the network by the pair (IP, ID).

The 32-bit IP is the address of the device, the 32-bit ID is the identifier of the variable on that device.

### IP

The first level of identification is the address of the device. It is represented with 32 bits.

### ID

It is the unique identifier of a NV in the space of the device. It is expressed with 32 bits.

## Size of the variable

The NV has a size whose knowledge must be public (i.e., shared between the sender and the receiver). However, this information is replicated inside the ROP for easier implementation of a protocol parser.

## Default value

The NV has a default value whose knowledge must be public. Such knowledge is used by the reset command.

Remote operation on network variables: ROP

It is possible for one device to perform a remote operation on the network variable of other device. The device sends a packet containing a ROP to the device with address IP to operate on the NV inside the device which has a given (EP, ID).

REMOTE OPERATIONS ON NETWORK VARIABLES

DEV

ROP<NV>

NV

DEV

ask<>

say<>

set<>

sig<>

rst<>

ALPKT

**Figure 1**: The Application layer packet (ALPKT) contains a remote operation ROP to be performed on a network variable of another device.

In particular, a ROP offers support for asking the value of a NV (ask), to write a value of a NV (set), to reset it to its default value (rst), but also enables a device to spontaneous signal its value to any other device (sig). The write operations can be done only on writeable NVs. Details of the protocol are in section 3.1.

## Structure of a ROP

A ROP contains the fields of the following figure.

ROP

ID

ROPC

DATA

1 BYTE

CTRL

1 BYTE

4 BYTES

0 / N BYTE

TIME

0 / 8 BYTES

SIGNATURE

0 / 4 BYTES

2 BYTES

DATASIZE

Optional with presence specified in CTRL field

Its presence depends on the ROPC type

**Figure 2**: Structure of a ROP.

### The CTRL field

It contains flags which define the composition of the ROP or requests it makes.

The VERSION:7-6 flags specifies the version of the protocol. So far only 00b is supported.

The RQSTCONF:5 flag specifies the request of signalling back a confirmation of the success of ROP using the same ROPC and some info in the CONFINFO field..

The RQSTTIME:4 flag specifies that the reply to the ROP (even a ACK/NAK) must have the TIME field.

The PLUSSIGN:3 flag specifies that the ROP does have the SIGNATURE field, thus it has 4 bytes extra after DATA.

The PLUSTIME:2 flag specifies that the TIME field is present, thus there are 8 bytes extra after SIGNATURE (if present).

The CONFINFO:1-0 field specifies if the ROP is normal (00b), an ACK (10b) or a NAK (01b). In case of ACK or NAK, the ROPC will be the same as the one being confirmed (with exception of ask<>, for which the ACK is a say<>).

ROP

VER

bit7 bit6 bit 5 bit4 bit3 bit2 bit 1 bit0

1 BYTE

RQSTCONF

RQSTTIME

PLUSTIME

PLUSSIGN

CONFINFO

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

**Figure 3**: OPTIONS field.

### The ROPC field

ROP commands are used to query the value of a NV such as with ask<> and say<>, or also to force the value of a NV, such as with set<>, or also to inform about the value of a NV, such as with sig<>. See table below for a full set of remote operations.

ROP

1 BYTE

**See table**

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

**Figure 4**: ROPCODE field.

|  |  |  |
| --- | --- | --- |
| ROPC(ode) | Value | Description |
| ask<id> | 0x01 | A device sends this command to request the receiver the value of NV(id).  The receiving device verifies if the NV(id) exists on the device. If it exists, it takes its local value of NV(id).val and transmits it back with a say<id, NV(id).val>. If it does not exist then the device sends back a nak-ask<id> if CTRL.RQSTCONF is set or nothing if not set.  If RQSTTIME is 1, then the reply say<> or nak-ask<id> must have PLUSTIME at 1.  If PLUSSIGN is 1, then the reply say<> or nak-ask<id> must have PLUSSIGN at 1 and have the same SIGNATURE as ask<>.  CTRL = RQSTCONF | RQSTTIME | PLUSSIGN | PLUSTIME | CONFINFO  ROPC = 0x01  DATASIZE = 0  ID = id  DATA = empty  SIGNATURE = present only if CTRL.PLUSSIGN is 1  TIME = present only if CTRL.PLUSTIME is 1. |
| say<id, val> | 0x02 | A device sends this command to respond to an ask<id> whenever the ID exists.  CTRL = PLUSSIGN | PLUSTIME (others are ignored by receiver)  ROPC = 0x02  DATASIZE = size  ID = id  DATA = data  SIGNATURE = present only if CTRL.PLUSSIGN is 1  TIME = present only if CTRL.PLUSTIME is 1. |
| set<id, val> | 0x03 | A device sends this command to make the receiver write val into NV(id).val.  The receiving device verifies if the NV(id) exists on the device and if it is writeable. If so, then it writes val into V(id).val. If field CTRL. RQSTCONF is set then the device shall also reply with ack-set<id> upon effective write or nak-set<id> if the netvar is not writeable.  If both CTRL. RQSTCONF and CTRL.RQSTTIME are set then the ack-/nak-set<> shall contain a TIME.  If both CTRL. RQSTCONF and CTRL.PLUSSIGN are set then the ack-/nak-set<> shall contain a SIGNATURE.  CTRL = RQSTCONF | RQSTTIME | PLUSSIGN | PLUSTIME | CONFINFO  ROPC = 0x03  DATASIZE = size (or 0 if CONFINFO is ACK or NAK)  ID = id  DATA = data (or empty if CONFINFO is ACK or NAK)  SIGNATURE = present only if CTRL.PLUSSIGN is 1  TIME = present only if CTRL.PLUSTIME is 1. |
| sig<id, val> | 0x04 | A device sends this command to spontaneously communicate the value of NV(id).  If CTRL.RQSTCONF is set, then the receiving node shall reply with a ack-sig<id> which shall also contain SIGNATURE and/or TIME fields if CTRL. PLUSSIGN and/or CTRL.PLUSSIGN are also set. The receiving node may send a nak-sig<> to tell the sender of the sig<> that the signalled NV is unknown.  OPTIONS = RQSTCONF | RQSTTIME | PLUSSIGN | PLUSTIME  ROPC = 0x04  DATASIZE = size (or 0 if CONFINFO is ACK or NAK)  ID = id  DATA = data (or empty if CONFINFO is ACK or NAK)  SIGNATURE = present only if CTRL.PLUSSIGN is 1  TIME = present only if CTRL.PLUSTIME is 1. |
| rst<id> | 0x05 | A device sends this command to force the receiver to revert NV(id).val to its default value.  The receiving device verifies if the NV(id) exists on the device and if it is writeable. If so, then it writes NV(id).def into NV(id).val. If field CTRL. RQSTCONF is set, then the device shall also replies with ack-rst <id> upon effective write or nak-rst<id> is the netvar is not writeable.  If both CTRL. RQSTCONF and CTRL.RQSTTIME are set then the ack-/nak-rst shall contain a TIME.  If both CTRL. RQSTCONF and CTRL.PLUSSIGN are set then the ack-/nak-rst shall contain a SIGNATURE.  CTRL = RQSTCONF | RQSTTIME | PLUSSIGN | PLUSTIME | CONFINFO  ROPC = 0x05  DATASIZE = 0  ID = id  DATA = empty  SIGNATURE = present only if CTRL.PLUSSIGN is 1  TIME = present only if CTRL.PLUSTIME is 1. |

**Table 1** – Remote operations.

### The DATASIZE field

It contains the size of the DATA field in two bytes in little endian order (LSB first). If DATA is not present DATASIZE is 0. This field is used to be able to correctly jump to location of next ROP when the DATA field is present, even when the pair (EP, ID) is not recognised by the receiver.

**Very important**: when DATA is present and DATASIZE does not match NV.siz, then, the receiver discards the ROP.

ROP

2 BYTES

NV.siz

ID

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

**Figure 5**: DATASIZE field.

### The ID field

It contains the ID of the NV being manipulated.

ROP

4 BYTES

NV.id

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

**Figure 6**: ID field.

### The DATA field

If present, it contains the value of the NV encoded in little endian order (LSB first). The DATA field is padded with zeros to become of total length a multiple of four.

The presence of the DATA field is related to the ROPCODE being used. Only ROPs such as say<>, set<>, rst<>, and sig<> have the DATA field. See table of ROPCODEs for more details.

ROP

DATASIZE BYTES + 0 padding to reach multiple of 4

NV.val

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

Figure 7: DATA field.

### The SIGNATURE field

It is present if the CTRL.PLUSSIGN is 1. It contains a four-byte signature used by the receiver for any purpose (for instance, for checking validity of message upon a pre-agreed rule).

The receiver of the ROP with a CTRL.PLUSSIGN field being set shall send any reply (say<>, ack-xxx<>, nak-xxx<>) with the same SIGNATURE being present, so that it is used by the receiver for processing the reply information.

ROP

0 / 4 BYTES

Signature defined by the sender

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

**Figure 8**: SIGNATURE field.

### The TIME field

It is present if the CTRL.PLUSTIME field is 1. It contains the time of the preparation of the ROP. The time shall be 8-byte long, report absolute time and be measured in micro-seconds.

ROP

0 / 8 BYTES

Birth of the ROP in micro-seconds

ROPC

DATA

CTRL

TIME

SIGNATURE

DATASIZE

ID

**Figure 9**: TIME field.

Concatenation of ROPs in a single ROPframe

It is possible, to concatenate multiple ROPs to be transmitted inside a single UDP packet using the following ROPframe, which is formed by a header, a body with the ROPs, and a footer.

ROP CONCATENATION INSIDE A UPD PACKET

UDP PAYLOAD

ROPFRAME

HEADER

BODY

24 BYTES

FOOTER

0 / n BYTES

4 BYTES

**Figure 10**: The ROPframe.

## The header of the ROPframe

It contains the following fields. The values of SIZEOFBODY, NUMBEROFROPS, SEQUENCENUM, and AGEOFFRAME are represented in little endian mode (LSB first).

ROPFRAME

HEADER

BODY

28 BYTES

FOOTER

STARTCODE

SIZEOFBODY

NUMBEROFROPS

AGEOFFRAME

4 BYTES

2 BYTES

2 BYTES

8 BYTES

In sec as measured at the time of transmission

Used to recognize a valid ROPframe: 0x12345678

SEQUENCENUM

8 BYTES

**Figure 11**: The header of the ROPframe.

## The body of the ROPframe

It contains the ROPS concatenated each after the other.

ROPFRAME

HEADER

0 / n BYTES

FOOTER

ROP(i)

BODY

i = 1 .. HEADER.NUMBEROFROPS

**Figure 12**: The body of the ROPframe.

## The footer of the ROPframe

It contains a marker informing of the end of the ROPframe.

ROPFRAME

HEADER

4 BYTES

BODY

FOOTER

Used to recognize a valid ROPframe: 0x87654321

**Figure 13**: The footer of the ROPframe.

Appendix

## Timing diagrams for ROPs

Timing diagrams for ROPs which contain also actions in the receiver are shown in the following.

SEQUENCE DIAGRAM FOR ROPs in case CTRL.RQSTCONF = 0

DEV0

set<id, val>

DEV1

if NV(id) exists and is writeable:

write val into NV(id).val

DEV0

ask<id>

DEV1

say<id, val>

if NV(id) exists:

send back NV(id).val to DEV0

DEV0

sig<id, val>

DEV1

send NV(id).val following some event inside DEV1

DEV0

rst<id>

DEV1

if NV(id) exists and is writeable:

write NV(id).def into NV(id).val

If the ROP from DEV0 has CTRL.RQSTTIME = 1, any reply from DEV1 shall have CTRL.PLUSTIME = 1 and the field TIME filled with the absolute time of preparation or the reply

If the ROP from DEV0 has CTRL.PLUSSIGN = 1, any reply from DEV1 shall have CTRL.PLUSSIGN = 1 and the field SIGN filled with the same received signature.

**Figure 14**: Sequence diagrams for the main ROPs when there is no confirmation request

SEQUENCE DIAGRAM FOR ROPs in case CTRL.RQSTCONF = 1

DEV0

set<id, val>

DEV1

if NV(id) exists and is writeable:

write val into NV(id).val

send ack

else

send nak

DEV0

ask<id>

DEV1

say<id, val>

or nak-ask<id>

if NV(id) exists:

send back NV(id).val to DEV0

else

send nak

DEV0

sig<id, val>

DEV1

send NV(id).val following some event inside DEV1

the receiver sends an ack (or nak if it cannot process it)

DEV0

rst<id>

DEV1

if NV(id) exists and is writeable:

write NV(id).def into NV(id).val

send ack

else

send nak

ack-set<id>

or nak-set<id>

ack-rst<id>

or nak-rst<id>

ack-sig<id>

or nak-sig<id>

The reply ROP (ack-\*, nak-\*, say) SHALL HAVE CTRL.RQSTCONF = 0 to avoid Ping-Pong effect.

If the ROP from DEV0/1 has CTRL.RQSTTIME = 1, any reply from DEV1/0 shall have CTRL.PLUSTIME = 1 and the field TIME filled with the absolute time of preparation or the reply.

If the ROP from DEV0/1 has CTRL.PLUSSIGN = 1, any reply from DEV1/0 shall have CTRL.PLUSSIGN = 1 and the field SIGN filled with the same received signature.

**Figure 15**: Sequence diagrams for the main ROPs when there is a request of confirmation

## ID assignment in iCub

The IDs can be freely assigned, however for iCub we use the following convention.

In iCub the ID is further divided into four subfields of 8 bits each for easier identification of the variable: EP, ENT, INDEX, and TAG.

The most significant byte identify what is called an ENDPOINT, the following byte specifies the ENTITY, then one byte specifies what is the INDEX of the specified entity, whereas the less significant byte represents a TAG of what we want to address inside that particular entity.

### The endpoint

The endpoint, or EP, expresses a logical grouping of variables of the same kind. For instance it represents the variables used for motion-control or for analog-sensors.

### The entity

The entity, or ENT, expresses an object inside a given endpoint. For instance it represents the joint in endpoint motion-control or the strain in endpoint analog-sensors.

### The index

The inded, or IND, expresses the number of the entity under identification. For instance it represents the joint number 1 or number 2.

### The tag

The tag, or TAG, expresses which variable is addressed inside a given entity with a given index. For instance it represents the torque PID configuration of joint number 1.

ID

INDEX

ENTITY

TAG

It expresses the variable of the entity under manipulation. For instance a joint can have the torque PID configuration, or its status, or also its setpoint.

It expresses the index of the entity under manipulation: it can be 0, 1, 2 or 3 in case there are up to four joints in a given board.

It tells the kind of object of the endpoint under manipulation. For EP motion control: a joint, a motor or a controller. For EP analog sensors: a strain, a mais, and an external torque. For EP management: the communication, the application. For EP skin: the skin.

ENDPOINT

LSB

MSB

It is a logical grouping of variables: management, motion-control, analog sensors, skin.

**Figure 16**: ID assignment in iCub. The 32 bits are organised to contain specific information on the kind of data to be manipulated.

## Examples of assignation of IP, ID

In the following it is reported an example of how the pair (IP, ID) has been assigned in the case of board EB1 in iCub.

We shall also describe the binary of a ROP of kind set related to motion control.

### The board EB1

The board EB1 is representative of the left upper arm of iCub and as such it performs motion control on four joints with four motors and works as a gateway of one strain analog sensor. Moreover, the board can be configured to periodically signal some values and to enter or exit a 1 ms control mode loop.

Those functionalities are organised with ROPs related to a number of network variables which can be grouped into three endpoints: one for motion control, one for analog sensors, and one for board management.

The ROP we describe is set<”position PID of joint 2”, value>, where value is a 16 bytes struct of value {0x01, 0x02, …, 0x10}.

### The IP assignment

Every device which wants to communicate with the EB1 board shall send a ROP related to a variable with IP equal to the IP address of the board EB1: 100.0.1.1.

The IP value is not contained inside the ROP. It is just used to send the UDP packet to the EB1 board.

### The ID assignment

The variables related to motion control shall have EP equal to eoprot\_endpoint\_motioncontrol (0x01), those related to analog sensors shall have EP equal to eoprot\_endpoint\_analogsensors (0x0021), and those related to management shall have EP equal to eoprot\_endpoint\_management (0x0001).

In board EB1, the motion control endpoint contains four joints, four motors and one controller, the analog sensors endpoint contains one strain, and the management endpoint contains configuration of communication and of the application.

### The ID assignment for a motion control variable

The 32 bits ID is partitioned to contain the endpoint eoprot\_endpoint\_motioncontrol, the type of entity (joint, motor, or controller), its number, and the tag of that particular entity.

For example, the ID of a variable related to position PID of joint 3 has the following field values:

* ID.ENDPOINT = eoprot\_endpoint\_motioncontrol (0x01),
* ID.ENTITY = eomc\_entity\_joint (0x00),
* ID.INDEX = 0x03 (first is index 0),
* ID.TAG = eoprot\_tag\_mc\_joint\_config\_pidposition (0x02).

### The ROP

It is the following.

ROP

01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10

10

DATA

DATASIZE

00

03

set

CTRL

02 03 00 01

ID

ENDPOINT = 0x01 (eoprot\_endpoint\_motioncontrol)

ENTITY = 0x00 (eomc\_entity\_joint)

INDEX = 0x03 (the fourth)

TAG = 0x02 (eoprot\_tag\_mc\_joint\_config\_pidposition)

**Figure 17**: Binary for a set command (in hexadecimal values).

## Non-mandatory properties of network variable

Other properties which are not contained inside the protocol but that are useful are the following.

### RW mode

It tells if ROPs can or cannot write variables.

|  |  |
| --- | --- |
| RW mode | Description |
| RO | The NV can be read by not written by a ROP. It is used for inputs to the board, such as an ADC, or a status. |
| RW | The NV can be read and written by a ROP. It is used for outputs of the board, such as a PWM or for a configuration. |
| WO | The NV keeps a value which is meaningful only if written but not meaningful to read back. It can be used for commands. |

**Table 2** – RW modes.