# General setup

The purpose of the JTC (Joint Trajectory Controller) work is to implement the given trajectory of the manipulator with an open kinematic chain with six degrees of freedom. The trajectory to be realized is defined in the configuration coordinate space as the set of angular positions, angular velocities and angular accelerations for each drive. The drives are controlled by force, taking into account the influence of PID regulators on the control of the angular position. On the basis of the set values, the JTC determines the moments of force that the drives are to develop, taking into account the influence of the regulators and the coefficients of friction compensation inside the drives.

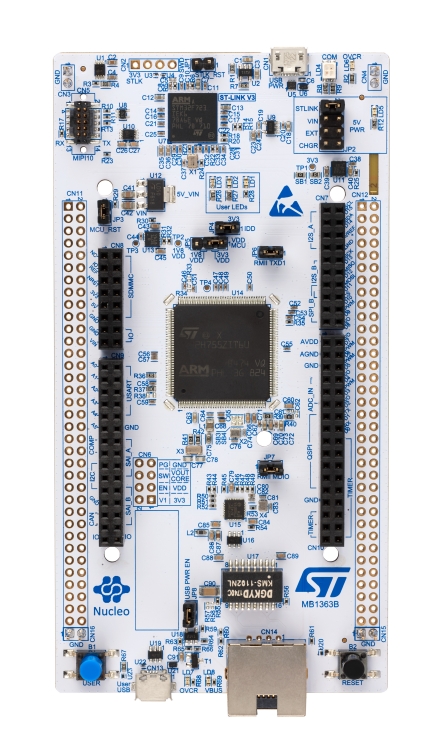
Basic assumptions about the operation of JTC (Joint Trajectory Controller):

* ability to communicate with the host chip via UART serial port and RS422 interface,
  + reading of the given trajectory in the form of position, velocity and angular acceleration for each of the six drives
  + reading the tables containing friction compensation coefficients or reading the command to use the default friction compensation factor tables for each of the six drives
  + reading the coefficients for polynomials approximating friction or reading the command to use the default coefficients for polynomials approximating friction for each of the six drives
  + reading the PID controller settings or reading the command to use the default PID controller settings for each of the six drives
  + reading the kinematic and dynamic parameters of the manipulator or reading the command to use the default values of kinematic and dynamic parameters of the manipulator
  + reading of control commands allowing to start, pause or stop trajectory execution
  + reading control commands allowing for error cleaning
  + reading the control commands that allow you to turn on Teaching Mode
  + writing telemetry data and confirmations to the host system
* implementation of a trajectory in a configuration space for a manipulator with an open kinematic chain with six degrees of freedom,
  + trajectory interpolation to increase the frequency of points to 1kHz,
  + solving the problem of inverse dynamics,
  + implementation of algorithms for PID controllers,
  + interpolation of tables containing friction compensation coefficients or friction compensation using polynomial approximation,
* ability to communicate with six drive controllers via the FDCAN bus,
  + cyclic transmission (1kHz) of data to drive controllers, containing information on the value of the set torque and the set state of the controller operation
  + cyclical reception (1kHz) of telemetry data from drive controllers containing information about the current position, speed, torque, temperature, machine condition, errors and warnings.

# Required hardware and software

## Hardware

JTC is based on the STM32H7 series microcontroller. It is compatible with the STM32H745ZI microcontroller and the NUCLEO-H745ZI-Q test board. It can also be easily adapted to the STM32H743ZI microcontroller and the NUCLEO-H743ZI2 test board. The NUCLEO-H745ZI-Q2 module view is shown below.

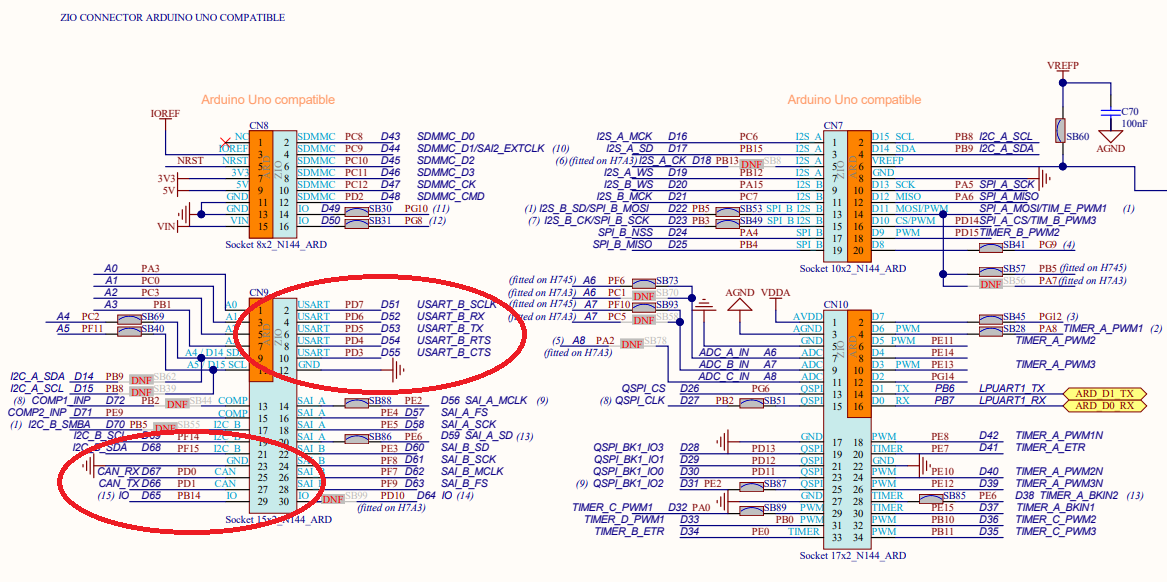


#### Rys. 2.1 Moduł NUCLEO-H745ZI-Q2

All microcontroller leads used to perform the JTC functions are available in the form of Arduino compatible connectors or via the USB socket of the ST-Link debugger / programmer. The microcontroller pins used are listed below:

#### Tabela 2.1 JTC pinout description

|  |  |  |
| --- | --- | --- |
| **GPIO number** | **Function** | **Description** |
| GPIOD.0 | FDCAN RX | FDCAN bus receiving line |
| GPIOD.1 | FDCAN TX | FDCAN bus transmitting line |
| GPIOD.3 | Safety Input | Emergency input: 0 – error, 1 – no error |
| GPIOD.4 | Safety Output | Emergency output: 0 – error, 1 – no error |
| GPIOD.5 | UART2 TX | UART transmitting line – target uart for RS422 on arduino connector |
| GPIOD.6 | UART2 RX | UART receiving line – target uart for RS422 on arduino connector |
| GPIOD.8 | UART3 TX | UART transmitting line – temporary USB uart via ST-Link |
| GPIOD.9 | UART3 RX | UART receiving line – temporary USB uart via ST-Link |



#### Rys. 2.2 JTC pinout

## Software

The JTC firmware was developed in the Keil uVision development environment (MDK Arm https://www.keil.com/).

In the default case, when the STM32H745ZI microcontroller is used, the project must be prepared for both microcontroller cores (Cortex-M4 and Cortex-M7). First, you need to load the executable file on the Cortex-M4 core once. Then load the executable on the Cortex-M7 core. There is no need to reload the executable on the Cortex-M4 core when modifying the project. All calculations are done on the Cortex-M7 core.

When changing the platform to the STM32H743ZI microcontroller, the created project contains firmware only for the Cortex-M7 core. To adapt the source files to the new platform, change the definition of the attached header file from:

##### #include <stm32h7xx.h>

##### #include <stm32h745xx.h>

on the definition:

##### #include <stm32h7xx.h>

##### #include <stm32h743xx.h>

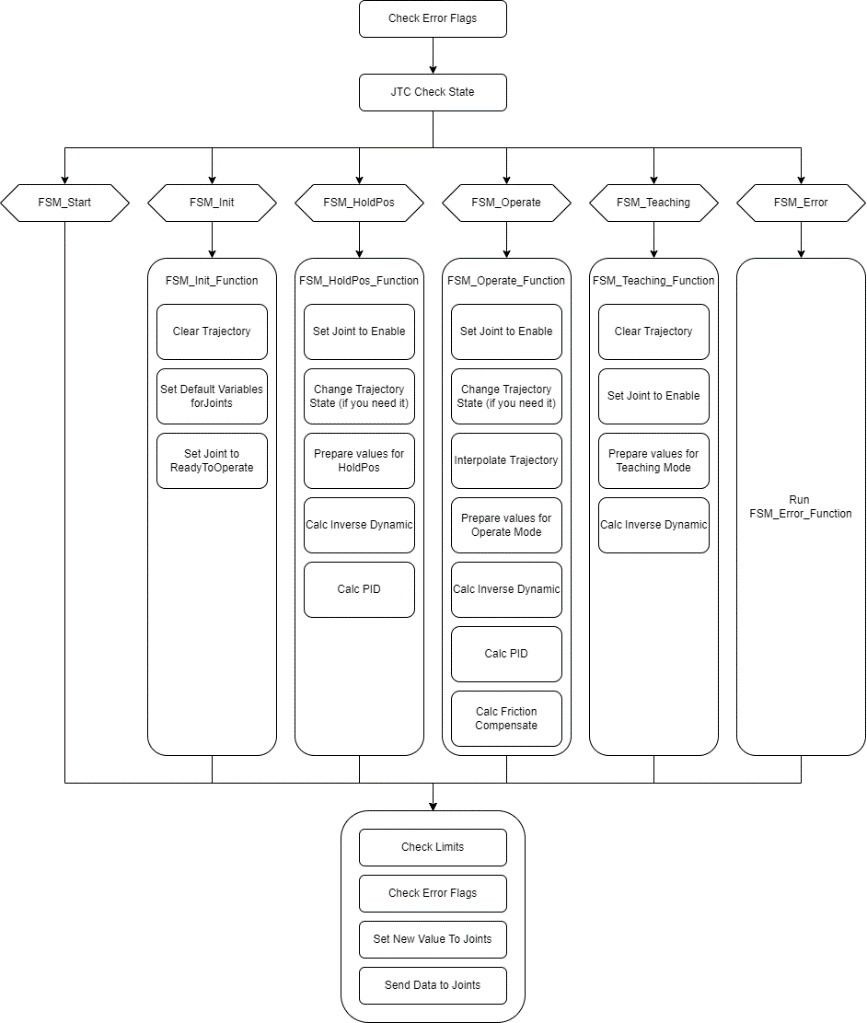
# Action logic

## General control scheme

JTC (Joint Trajectory Controller) can operate in one of six modes:

* FSM\_Start – stage right after the processor reset, system initialization,
* FSM\_Init – drive initialization, initialization of data from the host system,
* FSM\_HoldPos – JTC initialized. The drives keep their positions as set,
* FSM\_Operate – JTC follows the given trajectory,
* FSM\_ Teaching – JTC in teaching mode. Compensates for gravity, but does not hold the position you want,
* FSM\_Error – error handling.

The figure below shows a general diagram of the main function of the program. First, the software checks the error flags. Then it checks the current status of the device and the target status of the device and changes it if necessary. Next, one of the six operating modes is supported. After they are completed, the determined values are checked. If they meet the limits, the set values are updated. Communication with the joints is performed. Communication with the host chip is independent of the main program function.



#### Rys. 3.1 JTC General scheme of operation

The main function of the program is shown below.

##### static void Control\_JtcAct(void)

##### {

##### LED1\_OFF; LED2\_OFF; LED3\_OFF;

##### Control\_CheckErrorFlags();

##### Control\_JtcCheckState();

##### if(pC->Jtc.currentFsm == JTC\_FSM\_Error)

##### {

##### LED3\_ON;

##### Control\_JtcError();

##### }

##### else if(pC->Jtc.currentFsm == JTC\_FSM\_Init)

##### {

##### LED1\_ON;

##### Control\_JtcInit();

##### }

##### else if(pC->Jtc.currentFsm == JTC\_FSM\_Teaching)

##### {

##### LED1\_ON;

##### LED2\_ON;

##### Control\_JtcTeaching();

##### }

##### else if(pC->Jtc.currentFsm == JTC\_FSM\_HoldPos)

##### {

##### LED2\_ON;

##### Control\_JtcHoldPos();

##### }

##### else if(pC->Jtc.currentFsm == JTC\_FSM\_Operate)

##### {

##### LED2\_ON;

##### Control\_JtcOperate();

##### }

##### Control\_CheckLimits();

##### Control\_CheckErrorFlags();

##### Control\_SetNewTorqueValues();

##### Control\_SendDataToJoints();

##### }

## FSM\_Start

Right after the CPU reset, JTC is in FSM\_Start mode. In this mode, the main function of the program is not yet executed. In this mode, the internal circuits of the microcontroller are activated:

* change of the core clock frequency to 480MHz,
* starting the system counter with an interrupt at a frequency of 1kHz,
* starting the clock buses,
* LED configuration
* configuration of global variables
* configuration of serial ports for communication with the host system,
* configuration of the FDCAN bus for communication with drives,
* configuration of kinematic and dynamic parameters of the manipulator for calculations of inverse dynamics,
* configuration of the safety input and output,
* configuration and start-up of the counter with 1kHz interruption to support the main function of the program,

If the above procedure is performed, the device automatically switches to the FSM\_Init mode.

## FSM\_Init

In this mode, the JTC initializes the drives and initializes the device operating variables. The drives initialize by sending the Joint\_FSM\_ReadyToOperate command via FDCAN to the drives and waiting for the Joint\_FSM\_ReadyToOperate command to be received from each drive. Initialization of data from the host system consists in waiting for receiving from the information about the values of the friction coefficient tables or polynomial coefficients, the setting values of the PID controllers and the values of the kinematic and dynamic parameters of the manipulator. The host chip can either send the values of these parameters or issue a command to use the defaults. If during operation any of the drives returns to the Joint\_FSM\_Init state, JTC also returns to the initialization phase.

## FSM\_ HoldPos

JTC is in FSM\_HoldPos mode only when: all drives were properly initialized, variable values from the host chip were correctly initialized, no error occurred, the trajectory is in: TES\_Null, TES\_Stop, TES\_Pause or TES\_Finish. If the execution status is TES\_Null, it means the trajectory has not been received from the host chip or has been cleared by JTC, for example due to previous errors. In this situation, the trajectory should be sent again. If the realization status is TES\_Stop, it means that the trajectory has been received, but its realization has not been started yet. The trajectory execution variables are cleared and restored to their starting values. The trajectory should be started by sending an appropriate command. If the execution status is TES\_Pause, it means that the trajectory has been received, but its execution has been suspended. The trajectory should be resumed or stopped by sending an appropriate command. If the execution status is TES\_Finish, it means that the trajectory has been received and its execution has been completed. You must send a new trajectory, restart the current one.

In this mode, the JTC maintains the given drive positions. The moment of force depends on the values determined from the task of inverse dynamics and from PID controllers.

## FSM\_ Teaching

JTC is in FSM\_Operate mode only when: all drives were properly initialized, variable values from the host chip were correctly initialized, no error occurred. In this mode, the JTC does not hold the commanded position. The moment of force is determined only on the basis of the inverse task of dynamics for the current angular positions of the drives and assuming zero velocities and accelerations.

## FSM\_Operate

JTC is in FSM\_Operate mode only when: all drives were properly initialized, variable values from the host chip were correctly initialized, no error occurred, the trajectory is in: TES\_Execute. In this mode, it is possible to implement the trajectory.

If the execution status is TES\_Execute, it means that the trajectory has been received and it is being executed. The implementation can be suspended or stopped by sending an appropriate command. The implementation of individual trajectory points is as follows. First, the value of the trajectory points counter is checked and the possibility of reaching the end of the trajectory is checked. The JTC then interpolates the trajectory to obtain a 1ms time step. Further, the inverse dynamics problem is solved. Then, the values ​​of the correction moments of forces from PID controllers are determined. Next, the values ​​of the friction compensation coefficients are determined. Based on the above values, a target torque is determined for each drive.

## FSM\_Error

JTC goes into FSM\_Error on any error. Errors are divided into two main categories: external errors and internal errors.

External errors include:

* detection of a low state on the safety input
* receiving error information from any drive via the FDCAN bus

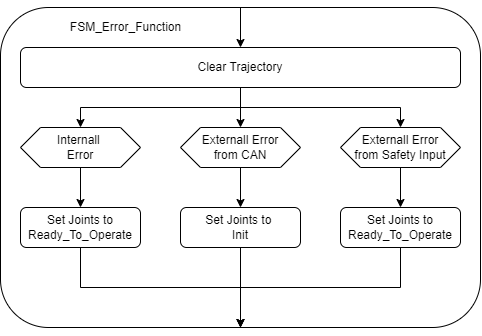
Internal errors include:

* errors in communication with drives via the FDCAN bus (timeout),
* error in communication with the host system (timeout - currently not supported),
* error concerning the exceeding of the permissible ranges for the calculated parameters of the drives (concerning the moment of force, angular position, angular velocity, angular acceleration, position error, lack of the appropriate value of the friction compensation coefficient in the table).

When an internal fault is detected, the safety output is activated. In this situation, the drives change to the Joint\_FSM\_ReadyToOperate state.

When an external error is detected due to FDCAN receiving an error message from any drive, JTC reinitializes that drive with the Joint\_FSM\_Init command. All other drives enter the Joint\_FSM\_ReadyToOperate state. When an external fault is detected due to a low state on the safety input, the drives go to Joint\_FSM\_ReadyToOperate.

JTC sends information about any errors it detects to the host chip in real time.



#### Rys. 3.2 FSM\_Error scheme of operation

# Communication JTC – Joints

JTC is adapted to communicate with six drives via the FDCAN bus. The frequency of the FDCAN core in JTC is 85MHz. The speed in nominal mode is 1Mbps, while the speed in data mode is 5Mbps. The bus works in the FD mode with the variable communication speed enabled. The FDCAN configuration parameters are shown in the table.

#### Tabela 4.1 Configuration of the FDCAN bus

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| FDCAN core frequency | 85 MHz |
| Baudrate in nominal mode | 1 Mbps |
| Baudrate in data mode | 5 Mbps |
| Nominal Prescaler | 4 + 1 |
| Nominal Sync Jump Width | 1 + 1 |
| Nominal Time Seg1 | 11 + 1 |
| Nominal Time Seg2 | 3 + 1 |
| Data Prescaler | 0 + 1 |
| Data Sync Jump Width | 1 + 1 |
| Data Time Seg1 | 11 + 1 |
| Data Time Seg2 | 3 + 1 |

FDCAN configuration function:

##### static void Can\_FdcanConf(void)

##### {

##### // pin configuration

##### GPIOD->MODER &= ~GPIO\_MODER\_MODE0 & ~GPIO\_MODER\_MODE1;

##### GPIOD->MODER |= GPIO\_MODER\_MODE0\_1 | GPIO\_MODER\_MODE1\_1;

##### GPIOD->AFR[0] |= 0x00000099;

##### 

##### // FDCAN setup begins

##### FDCAN1->CCCR |= FDCAN\_CCCR\_INIT | FDCAN\_CCCR\_CCE;

##### // Frame in CANFD format with variable speed (BRSE bit)

##### FDCAN1->CCCR |= FDCAN\_CCCR\_BRSE | FDCAN\_CCCR\_FDOE | FDCAN\_CCCR\_TXP;

##### 

##### // transmission baudrate in nominal mode

##### FDCAN1->NBTP = (0x01 << FDCAN\_NBTP\_NSJW\_Pos) | (0x04 << FDCAN\_NBTP\_NBRP\_Pos) | (0x0B << FDCAN\_NBTP\_NTSEG1\_Pos) | (0x03 << FDCAN\_NBTP\_NTSEG2\_Pos);

##### // transmission baudrate in data mode

##### FDCAN1->DBTP = (0x01 << FDCAN\_DBTP\_DSJW\_Pos) | (0x00 << FDCAN\_DBTP\_DBRP\_Pos) | (0x0B << FDCAN\_DBTP\_DTSEG1\_Pos) | (0x03 << FDCAN\_DBTP\_DTSEG2\_Pos);

##### 

##### // all remote and non-filtered frames are discarded

##### FDCAN1->GFC = (0x03 << FDCAN\_GFC\_ANFS\_Pos) | (0x03 << FDCAN\_GFC\_ANFE\_Pos) | FDCAN\_GFC\_RRFS | FDCAN\_GFC\_RRFE;

##### // CAN\_FILTERS\_MAX of standard filters and the address of the filters

##### FDCAN1->SIDFC = (CAN\_FILTERS\_MAX << FDCAN\_SIDFC\_LSS\_Pos) | (pC->Can.filterAddrOffset << 0);

##### 

##### // CAN\_TXBUF\_MAX send buffers and address of the first send buffer

##### FDCAN1->TXBC = (CAN\_TXBUF\_MAX << FDCAN\_TXBC\_NDTB\_Pos) | (pC->Can.txBufAddrOffset << 0);

##### // transmit buffers with a size of 20 bytes

##### FDCAN1->TXESC = (CAN\_TXBUFSIZE\_CODE << FDCAN\_TXESC\_TBDS\_Pos);

##### 

##### // 12-byte receiving buffers, RXFIFO 1 and RXFIFO 0 elements with a size of 12 bytes

##### FDCAN1->RXESC = (CAN\_RXBUFSIZE\_CODE << FDCAN\_RXESC\_RBDS\_Pos) | (CAN\_RXBUFSIZE\_CODE << FDCAN\_RXESC\_F1DS\_Pos) | (CAN\_RXBUFSIZE\_CODE << FDCAN\_RXESC\_F0DS\_Pos);

##### // first receive buffer address offset

##### FDCAN1->RXBC = (pC->Can.rxBufAddrOffset << 0);

##### // CAN\_RXBUFF\_MAX receive buffers, CAN\_RXFIFO0\_MAX fifo0 and address of first fifo0

##### FDCAN1->RXF0C = (CAN\_RXFIFO0\_MAX << FDCAN\_RXF0C\_F0S\_Pos) | (pC->Can.rxFifo0AddrOffset << 0);

##### // abort from receive to buffer, these interrupts are directed to EINT0

##### FDCAN1->IE = FDCAN\_IE\_TCE | FDCAN\_IE\_DRXE;

##### // Enable interrupts from transfer complete individually for each send buffer

##### for(int i=0;i<CAN\_TXBUF\_MAX;i++)

##### FDCAN1->TXBTIE |= (1 << i);

##### // The error handling interrupt, these interrupts are directed to EINT1

##### FDCAN1->IE |= FDCAN\_IE\_ARAE | FDCAN\_IE\_PEDE | FDCAN\_IE\_PEAE | FDCAN\_IE\_WDIE | FDCAN\_IE\_BOE | FDCAN\_IE\_EWE | FDCAN\_IE\_EPE | FDCAN\_IE\_ELOE;

##### FDCAN1->ILS = FDCAN\_ILS\_ARAE | FDCAN\_ILS\_PEDE | FDCAN\_ILS\_PEAE | FDCAN\_ILS\_WDIE | FDCAN\_ILS\_BOE | FDCAN\_ILS\_EWE | FDCAN\_ILS\_EPE | FDCAN\_ILS\_ELOE;

##### // turning on the interrupt line

##### FDCAN1->ILE = FDCAN\_ILE\_EINT0 | FDCAN\_ILE\_EINT1;

##### NVIC\_EnableIRQ(FDCAN1\_IT0\_IRQn);

##### NVIC\_EnableIRQ(FDCAN1\_IT1\_IRQn);

##### }

#### Communication takes place cyclically with a frequency of 1kHz. In each communication cycle, the JTC sends a broadcast frame that is received by all drives. The frame is 20 bytes long. The frame looks like:Tabela 4.2 JTC to Joints broadcast frame

|  |  |  |  |
| --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value / Range** |
| ID | Header [B0] | uint8\_t | 0xAA |
| 0 - 1 | Joint 0 Torque [B1 – B0] | int16\_t | - |
| 2 | Joint 0 FSM [B0] | uint8\_t | 0x01 – FSM\_Init  0x02 – FSM\_ReadyToOperate  0x03 – FSM\_OperationEnable |
| 3 - 4 | Joint 1 Torque [B1 – B0] | int16\_t |  |
| … | … | … | … |
| 17 | Joint 5 FSM [B0] | uint8\_t | 0x01 – FSM\_Init  0x02 – FSM\_ReadyToOperate  0x03 – FSM\_OperationEnable |
| 18 | - | uint8\_t | 0x00 |
| 19 | - | uint8\_t | 0x00 |

#### Then, in response, each drive sends back a telemetry frame of 12 bytes. These frames are as follows:Tabela 4.3 Joint n to JTC frame

|  |  |  |  |
| --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value / Range** |
| ID | Header [B0] | uint8\_t | Joint 0 - 0xA0, Joint 1 - 0xB0, Joint 2 - 0xC0,  Joint 3 - 0xD0, Joint 4 - 0xE0, Joint 5 - 0xF0 |
| 0 - 1 | Position [B1 – B0] | int16\_t | - |
| 2 - 3 | Velocity [B1 – B0] | int16\_t | - |
| 4 - 5 | Torque [B1 – B0] | int16\_t | - |
| 6 | Temperature [B0] | unt8\_t | - |
| 7 | FSM [B0] | uint8\_t | 0x00 – FSM\_Start  0x01 – FSM\_Init  0x02 – FSM\_ReadyToOperate  0x03 – FSM\_OperationEnable  0x0A – FSM\_TransStartToInit  0x0B – FSM\_TransInitToReadyToOperate  0x0C – FSM\_TransReadyToOperateToOperationEnable  0x0D – FSM\_TransOperationEnableToReadyToOperate  0x0E – FSM\_TransFaulyReactionActiveToFault  0x0F – FSM\_TransFaultToReadyToOperate  0xFE – FSM\_ReactionActive  0xFF – FSM\_Fault |
| 8 | MC Current Error [B0] | uint8\_t | 0x00 – MC\_NO\_ERRORS / MC\_NO\_FAULTS  0x01 – MC\_FOC\_DURATION  0x02 – MC\_OVER\_VOLT  0x04 – MC\_UNDER\_VOLT  0x08 – MC\_OVER\_TEMP  0x10 – MC\_START\_UP  0x20 – MC\_SPEED\_FDBK  0x40 – MC\_BREAK\_IN  0x80 – MC\_SW\_ERROR |
| 9 | MC Occured Error [B0] | uint8\_t | 0x00 – MC\_NO\_ERRORS / MC\_NO\_FAULTS  0x01 – MC\_FOC\_DURATION  0x02 – MC\_OVER\_VOLT  0x04 – MC\_UNDER\_VOLT  0x08 – MC\_OVER\_TEMP  0x10 – MC\_START\_UP  0x20 – MC\_SPEED\_FDBK  0x40 – MC\_BREAK\_IN  0x80 – MC\_SW\_ERROR |
| 10 | Current Error [B0] | uint8\_t | 0x00 – JOINT\_NO\_ERROR  0x01 – JOINT\_POSITION\_ENCODER\_FAILED  0x02 – JOINT\_MC\_FAILED |
| 11 | Current Warning | uint8\_t | 0x00 – JOINT\_NO\_WARNING  0x01 – JOINT\_POSITION\_NOT\_ACCURATE  0x02 – JOINT\_OUTSIDE\_WORKING\_AREA |

# Communication JTC – Host

## Introduction

Communication between the JTC and the host chip is done via the UART protocol using the RS422 interface. Communication is asynchronous, full duplex, point-to-point. Frame format 115200 8N1, (speed 115200 bps, 8 data bits, 1 stop bit, no parity, no hardware flow control). The host chip should reserve a separate COM port for each connected JTC.

#### Tabela 5.1 JTC communication - Host: communication parameters

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Mode | Asynchronous, full duplex |
| Baudrate | 115200 bps (max. 15Mbps) |
| Number of data bits | 8 |
| Number of stop bits | 1 |
| Parity control | None |
| Hardware flow control | None |

## Data format and error checking

Data is sent in a binary way in the form of frames. The frame sent to the JTC must be transmitted in a consistent manner, without time gaps. The end of the frame is detected in hardware by detecting an idle state on the receive line for the duration of the two bit transmission. The sending device is responsible for ensuring the consistency of the transmission. If the frame is transmitted intermittently, it will be treated by the JTC as several separate packets. In this situation, JTC has implemented a merge mechanism with timeout. If the interval between packets will be less than 5ms (to be determined - value depending on the speed and communication method - in RT devices there should be no interruptions at all), packets will be merged into one frame. The merging mechanism takes into account the data in the frame, in particular the expected frame length (n field - second and third bytes). If the timeout is exceeded, JTC will send an appropriate message. JTC always transmits frames in a consistent manner with no gaps. The general scheme of the frame is presented in Tabela 5.2

#### Tabela 5.2 General diagram of the JTC - Host communication frame

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value / Range** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x00 – 0xFF | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 – 0xEA60 | Length frame in bytes |
| 3 | n [B0] |
| 4 | Data 0 | uint8\_t | Depends on the variable | Example data |
| 5 | Data1 [B1] | uint16\_t  int16\_t | Depends on the variable | Example data |
| 6 | Data1 [B0] |
| 7 | Data2 [B3] | uint32\_t  int32\_t  float | Depends on the variable | Example data |
| 8 | Data2 [B2] |
| 9 | Data2 [B1] |
| 10 | Data2 [B0] |
| … | … |  |  | … |
| n-2 | CRC [B1] | uint16\_t | 0x0000 – 0xFFFF | CRC16 checksum |
| n-1 | CRC [B0] |

A frame always starts with the Header byte. Then the Frame byte is sent, which denotes the type of the frame. The frame length, which can be from 6 to 60,000 bytes, is then transmitted. Multi-byte data is transmitted starting from the oldest byte. Floats are 4 bytes in size and are transmitted from the oldest byte. The frame ends with a CRC16 check sum calculated from bytes numbered 0 to n-3 (all bytes except checksum bytes). The function that calculates the checksum is shown below.

##### uint16\_t Com\_Crc16(uint8\_t\* packet, uint32\_t nBytes)

##### {

##### uint16\_t crc = 0;

##### for(uint32\_t byte = 0; byte < nBytes; byte++)

##### {

##### crc = crc ^ ((uint16\_t)packet[byte] << 8);

##### for (uint8\_t bit = 0; bit < 8; bit++)

##### if(crc & 0x8000) crc = (crc << 1) ^ 0x1021;

##### else crc = crc << 1;

##### }

##### return crc;

##### }

## JTC - Host communication frames

### Types of frames

The table below shows basic information about all transmitted frames, such as: name, number, meaning, length, transmission direction.

Tabela 5.3 Types of frames

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Frame** | **Meaning** | **Length**  **(n)** | **Transmission direction** |
| Host\_FT\_null | 0x00 | Empty frame, do not send | - | - |
| Host\_FT\_ClearCurrentErrors | 0x01 | The command to clear the current errors in JTC | 6 | Host -> JTC |
| Host\_FT\_ClearOccuredErrors | 0x02 | The command to clear all errors in JTC | 6 | Host -> JTC |
| Host\_FT\_JtcStatus | 0x03 | Telemetry data from JTC | 165 | JTC -> Host |
| Host\_FT\_Trajectory | 0x04 | New trajectory for JTC | 14 + 36 \* x  x – liczba punktów w trajektorii | Host -> JTC |
| Host\_FT\_FrictionTable | 0x05 | New 6 Joint Friction Tables | 10566 | Host -> JTC |
| Host\_FT\_FrictionTableUseDefault | 0x06 | Command to use the default friction coefficient tables for 6 joints | 6 | Host -> JTC |
| Host\_FT\_PidParam | 0x07 | New PID settings for 6 joints | 126 | Host -> JTC |
| Host\_FT\_PidParamUseDefault | 0x08 | Command to use the 6 joint PID defaults | 6 | Host -> JTC |
| Host\_FT\_ArmModel | 0x09 | New values of dynamic and kinematic parameters of the manipulator | 538 | Host -> JTC |
| Host\_FT\_ArmModelUseDefault | 0x0A | Command to use the default dynamic and kinematic parameters of the manipulator | 6 | Host -> JTC |
| Host\_FT\_TrajSetExecStatus | 0x0B | Trajectory state change command (Stop, Pause, Execute) | 7 | Host -> JTC |
| Host\_FT\_TeachingModeEnable | 0x0C | Command to enable Teaching Mode | 6 | Host -> JTC |
| Host\_FT\_TeachingModeDisable | 0x0D | Command to disable Teaching Mode | 6 | Host -> JTC |
| Host\_FT\_FrictionPolynomial | 0x0E | New coefficient values for friction polynomials | 102 | Host -> JTC |
| Host\_FT\_FrictionPolynomialUseDefault | 0x0F | Command to use default coefficients for friction polynomials | 6 | Host -> JTC |

### Host\_FT\_ClearCurrentErrors

Command frame sent from the host chip to the JTC. 6 bytes long. Used to clear flags for current JTC errors.

#### Tabela 5.4 Host\_FT\_ClearCurrentErrors

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x01 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0x8F76 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_ClearOccuredErrors

Command frame sent from the host chip to the JTC. Used to clear flags of all JTC errors.

#### Tabela 5.5 Host\_FT\_ClearOccuredErrors

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x02 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0xD626 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_JtcStatus

Frame sent from JTC to the host chip. The frame contains confirmation of the last received command from the host and telemetry data. The first 5 bytes are the JTC response to the last frame received from the host. This answer consists of four fields:

* Frame Type – number of the frame to which the response relates received by JTC,
* Status – status of correctness of the frame received by JTC of the frame to which the response relates,
* Data Status – data correctness status in the frame received by JTC of the frame to which the response relates,
* Length – length of the frame received by the JTC and related to the response.

Then the JTC telemetry data is sent:

* JTC Current FSM - the current status of the entire JTC,
* JTC Current Errors - current JTC error flags: 0 - no error, 1 - error,
* JTC Occured Errors - JTC error flags that have occurred: 0 - no error, 1 - error,
* JTC Init Status - JTC initialization flags: 0 - initialized, 1 - uninitialized
* Joints Init Status - ionization flags: 0 - initialized, 1 - uninitialized,
* Traj Execution Status - the current status of the trajectory,
* Traj Num Current Point - number of the currently realized trajectory point (applies to trajectory with 1ms step),
* Friction Type – type of friction compensation used: polynomial approximation or table data.

Then the telemetry data for communication via CAN is sent:

* CAN Status - current CAN status,
* CAN Current Errors - current CAN error flags: 0 - no error, 1 - error,
* CAN Occured Errors - current CAN error flags: 0 - no error, 1 - error,

Then the telemetry of the drives is sent:

* Joint Current FSM - current drive status,
* Joint mcCurrentError - data received from the drive via CAN, details in the drive operation description,
* Joint mcOccuredError - data received from the drive via CAN, details in the drive operation description,
* Joint currentError - data received from the drive via CAN, details in the drive operation description,
* Joint currentWarning - data received from the drive via CAN, details in the drive operation description,
* Joint Internall Current Errors - current operating errors of the drive generated in JTC,
* Joint Internall Occured Errors - drive operation errors caused by JTC,
* Joint Current Position - data received from the drive via CAN,
* Joint Current Velocity - data received from the drive via CAN,
* Joint Current Torque - data received from the drive via CAN,
* Joint Current Temp - data received from the drive via CAN.

#### Tabela 5.6 Host\_FT\_JtcStatus

|  |  |  |  |
| --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** |
| 0 | Header | uint8\_t | 0x9B |
| 1 | Frame | uint8\_t | 0x03 |
| 2 | n [B1] | uint16\_t | 0x00A5 |
| 3 | n [B0] |
| 4 | Response Frame Type [B0] | uint8\_t | 0x00 – 0xFF |
| 5 | Response Status [B0] | uint8\_t | 0x00 – Idle  0x01 – No Error  0x02 – Incorrect Header  0x03 – Incorrect FrameType  0x04 – Incorrect CRC  0x05 – Discontinuous Frame |
| 6 | Response Data Status [B0] | uint8\_t | 0x00 – Idle  0x01 – No Error  0x02 – Traj Too Many Points  0x03 – Traj Too Many Segs  0x04 – Traj Incorrect Seg Order  0x05 – Traj Incorrect Step Time |
| 7 - 8 | Response Length [B1 - B0] | uint16\_t | 0x0006 – 0xEA60 |
| 9 | JTC Current FSM [B0] | uint8\_t | 0x00 – JTC\_FSM\_Start  0x01 – JTC\_FSM\_Init  0x02 – JTC\_FSM\_Operate  0x03 – JTC\_FSM\_Error |
| 10 – 11 | JTC Current Errors [B1 – B0] | uint16\_t | B0.0 – Emergency Input Status  B0.1 – Emergency Output Status  B0.2 – Internall Error  B0.3 – Externall Error  B0.4 – Internall Joints Error  B0.5 – Internall CAN Error  B0.6 – Internall COM Error  B0.7 – Externall Joints Error |
| 12 – 13 | JTC Occured Errors [B1 – B0] | uint16\_t | B0.0 – Emergency Input Status  B0.1 – Emergency Output Status  B0.2 – Internall Error  B0.3 – Externall Error  B0.4 – Internall Joints Error  B0.5 – Internall CAN Error  B0.6 – Internall COM Error  B0.7 – Externall Joints Error |
| 14 | JTC Init Status [B0] | uint8\_t | B0.0 – Friction Table Init Status  B0.1 – Pid Parameters Init Status  B0.2 – Arm Model Init Status |
| 15 | Joints Init Status [B0] | uint8\_t | B0.0 – Joint 0 Init Status  B0.1 – Joint 1 Init Status  B0.2 – Joint 2 Init Status  B0.3 – Joint 3 Init Status  B0.4 – Joint 4 Init Status  B0.5 – Joint 5 Init Status |
| 16 | Traj Execution Status [B0] | uint8\_t | 0x00 – TES\_Null  0x01 – TES\_Stop  0x02 – TES\_Pause  0x03 – TES\_Execute  0x04 – TES\_Finish  0x05 – TES\_TransNullToStop |
| 17 – 20 | Traj Num Curr. Point [B3 – B0] | uint32\_t | 0x00000000 – 0x0001D4C0 |
| 21 | Friction Type [B0] | uint8\_t | 0x00 – JTC\_FT\_Polynomial  0x01 – JTC\_FT\_Table |
| 22 | CAN Current Status [B0] | uint8\_t | 0x00 – CAN\_NoError  0x01 – CAN\_Error |
| 23 – 26 | CAN Current Errors [B3 – B0] | uint32\_t | B0.0 – Transmit Timeout  B1.0 – Joints 0 Receive Timeout  B1.1 – Joints 0 Receive Timeout  B1.2 – Joints 0 Receive Timeout  B1.3 – Joints 0 Receive Timeout  B1.4 – Joints 0 Receive Timeout  B1.5 – Joints 0 Receive Timeout |
| 27 – 30 | CAN Occured Errors [B3 – B0] | uint32\_t | B0.0 – Transmit Timeout  B1.0 – Joints 0 Receive Timeout  B1.1 – Joints 0 Receive Timeout  B1.2 – Joints 0 Receive Timeout  B1.3 – Joints 0 Receive Timeout  B1.4 – Joints 0 Receive Timeout  B1.5 – Joints 0 Receive Timeout |
| 31 | Joint 0 Current FSM [B0] | uint8\_t | 0x00 – FSM\_Start  0x01 – FSM\_Init  0x02 – FSM\_ReadyToOperate  0x03 – FSM\_OperationEnable |
| 32 | Joint 0 MC Current Errors [B0] | uint8\_t | Value from CAN. See joint description |
| 33 | Joint 0 MC Occured Errors [B0] | uint8\_t | Value from CAN. See joint description |
| 34 | Joint 0 Current Errors [B0] | uint8\_t | Value from CAN. See joint description |
| 35 | Joint 0 Current Warnings [B0] | uint8\_t | Value from CAN. See joint description |
| 36 – 37 | Joint 0 Internall Errors [B1 – B0] | uint16\_t | B0.0 – Calculated pos over limit  B0.1 – Calculated vel over limit  B0.2 – Calculated acc over limit  B0.3 – Calculated torque over limit  B0.4 – Position error over limit  B0.5 – Friction table value over limit |
| 38 – 39 | Joint 0 Internall Occured Errors [B1 – B0] | uint16\_t | B0.0 – Calculated pos over limit  B0.1 – Calculated vel over limit  B0.2 – Calculated acc over limit  B0.3 – Calculated torque over limit  B0.4 – Position error over limit  B0.5 – Fric table value over limit |
| 40 – 41 | Joint 0 Current Position [B3 – B0] | float | Value from CAN. See joint description |
| 42 – 43 | Joint 0 Current Velocity [B3 – B0] | float | Value from CAN. See joint description |
| 48 – 51 | Joint 0 Current Torque [B3 – B0] | float | Value from CAN. See joint description |
| 52 | Joint 0 Current Temperature [B0] | uint8\_t | Value from CAN. See joint description |
| 54 | Joint 1 Current FSM [B0] | uint8\_t | 0x00 – FSM\_Start  0x01 – FSM\_Init  0x02 – FSM\_ReadyToOperate  0x03 – FSM\_OperationEnable |
| … | … | … | … |
| 162 | Joint 5 Current Temperature [B0] | uint8\_t | Value from CAN. See joint description |
| 163 | CRC [B1] | uint16\_t | - |
| 164 | CRC [B0] |

Function that sends data from JTC:

##### static void Host\_ComPrepareFrameJtcStatus(void)

##### {

##### uint8\_t \*buf = Com.txFrames[Host\_TxFN\_JtcStatus].frame;

##### uint8\_t idx = 0;

##### buf[idx++] = (uint8\_t)Host\_FT\_Header;

##### buf[idx++] = (uint8\_t)Host\_FT\_JtcStatus;

##### buf[idx++] = (uint8\_t)(0 >> 8); // Space for the number of bytes in the frame

##### buf[idx++] = (uint8\_t)(0 >> 0); // Space for the number of bytes in the frame

##### buf[idx++] = (uint8\_t)Com.rxFrame.frameType;

##### buf[idx++] = (uint8\_t)Com.rxFrame.status;

##### buf[idx++] = (uint8\_t)Com.rxFrame.dataStatus;

##### buf[idx++] = (uint8\_t)(Com.rxFrame.receivedLength>>8);

##### buf[idx++] = (uint8\_t)(Com.rxFrame.receivedLength>>0);

##### 

##### buf[idx++] = (uint8\_t)pC->Jtc.currentFsm;

##### buf[idx++] = (uint8\_t)(pC->Jtc.errors >> 8);

##### buf[idx++] = (uint8\_t)(pC->Jtc.errors >> 0);

##### buf[idx++] = (uint8\_t)(pC->Jtc.occuredErrors >> 8);

##### buf[idx++] = (uint8\_t)(pC->Jtc.occuredErrors >> 0);

##### buf[idx++] = (uint8\_t)pC->Jtc.jtcInitStatus;

##### buf[idx++] = (uint8\_t)pC->Jtc.jointsInitStatus;

##### buf[idx++] = (uint8\_t)Traj.currentTES;

##### buf[idx++] = (uint8\_t)(Traj.numInterPoint >> 8);

##### buf[idx++] = (uint8\_t)(Traj.numInterPoint >> 0);

##### buf[idx++] = (uint8\_t)pC->Jtc.fricType;

##### buf[idx++] = (uint8\_t)pC->Can.statusId;

##### buf[idx++] = (uint8\_t)(pC->Can.statusFlags >> 24);

##### buf[idx++] = (uint8\_t)(pC->Can.statusFlags >> 16);

##### buf[idx++] = (uint8\_t)(pC->Can.statusFlags >> 8);

##### buf[idx++] = (uint8\_t)(pC->Can.statusFlags >> 0);

##### buf[idx++] = (uint8\_t)(pC->Can.statusOccurredFlags >> 24);

##### buf[idx++] = (uint8\_t)(pC->Can.statusOccurredFlags >> 16);

##### buf[idx++] = (uint8\_t)(pC->Can.statusOccurredFlags >> 8);

##### buf[idx++] = (uint8\_t)(pC->Can.statusOccurredFlags >> 0);

##### 

##### union conv32 x;

##### for(int num=0;num<JOINTS\_MAX;num++)

##### {

##### buf[idx++] = (uint8\_t)(pC->Joints[num].currentFsm >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].mcCurrentError >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].mcOccuredError >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].currentError >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].currentWarning >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].internallErrors >> 8);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].internallErrors >> 0);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].internallOccuredErrors >> 8);

##### buf[idx++] = (uint8\_t)(pC->Joints[num].internallOccuredErrors >> 0);

##### 

##### x.f32 = pC->Joints[num].currentPos;

##### buf[idx++] = (uint8\_t)(x.u32 >> 24);

##### buf[idx++] = (uint8\_t)(x.u32 >> 16);

##### buf[idx++] = (uint8\_t)(x.u32 >> 8);

##### buf[idx++] = (uint8\_t)(x.u32 >> 0);

##### 

##### x.f32 = pC->Joints[num].currentVel;

##### buf[idx++] = (uint8\_t)(x.u32 >> 24);

##### buf[idx++] = (uint8\_t)(x.u32 >> 16);

##### buf[idx++] = (uint8\_t)(x.u32 >> 8);

##### buf[idx++] = (uint8\_t)(x.u32 >> 0);

##### 

##### x.f32 = pC->Joints[num].currentTorque;

##### buf[idx++] = (uint8\_t)(x.u32 >> 24);

##### buf[idx++] = (uint8\_t)(x.u32 >> 16);

##### buf[idx++] = (uint8\_t)(x.u32 >> 8);

##### buf[idx++] = (uint8\_t)(x.u32 >> 0);

##### 

##### buf[idx++] = (uint8\_t)pC->Joints[num].currentTemp;

##### }

##### // Number of bytes in frame and CRC

##### buf[2] = (uint8\_t)((idx + 2) >> 8);

##### buf[3] = (uint8\_t)((idx + 2) >> 0);

##### uint16\_t crc = Com\_Crc16(buf, idx);

##### buf[idx++] = (uint8\_t)(crc >> 8); // CRC

##### buf[idx++] = (uint8\_t)(crc >> 0); // CRC

##### Com.txFrames[Host\_TxFN\_JtcStatus].status = Host\_TxFS\_ReadyToSend;

##### Com.txFrames[Host\_TxFN\_JtcStatus].len = idx;

##### Com.txFrames[Host\_TxFN\_JtcStatus].active = false;

##### }

### Host\_FT\_Trajectory

The frame is sent from the host chip to the JTC. Used to send a new trajectory. The maximum length of the trajectory is 12,000 points. Each point consists of six angular position values, six angular velocity values and six angular acceleration values (a total of 18 numbers of the type int16\_t - 36 bytes). The data is sent in the form of numbers of the int16\_t type. Determining the value in the int16\_t format should be performed according to the following formulas:

* pos(int16\_t) = pos(float) / 3.141592 \* 32767.0
* vel(int16\_t) = vel(float) / 6.283185 \* 32767.0
* acc(int16\_t) = acc(float) / 12.566370 \* 32767.0

The trajectory must be transmitted in segments no longer than 1500 points. Each segment is sent as a separate frame. JTC each time confirms the receipt of a data frame by sending information about its correctness or errors. The trajectory must consist of at least one segment. The number of segments cannot exceed 100. The segments must be sent in the sequence from segment number 0 to segment number x-1 (x = number of segments). Correct transmission of segment number 0 clears the current trajectory and changes JTC to the TES\_Null status. After receiving all the segments, the JTC goes to the TES\_Stop status. Then the trajectory can be started. In case of an incorrect transmission of a given segment, it should be sent again. In case of sending the segments in the wrong order, start again transmitting the whole trajectory from the segment number 0. The host can stop sending the trajectory at any time and start transmitting it from the beginning. The table below shows a frame transmitting one segment.

Tabela 5.7 Host\_FT\_Trajectory

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x04 | Type of frame |
| 2 | n [B1] | uint16\_t | - | Length frame in bytes |
| 3 | n [B0] |
| 4 - 5 | Trajectory number | uint16\_t | 0x00 | Data |
| 6 - 7 | Segment number | uint16\_t | 0x0000 – 0x0063 | Data |
| 8 - 9 | Number of segments | uint16\_t | 0x0001 – 0x0064 | Data |
| 10 - 11 | Step time | uint16\_t | 0x0001 – 0xFFFF | Data |
| 12 - 13 | Point 0 Joint 0 Pos [B1 – B0] | int16\_t | - | Data |
| … | … | … | … | … |
|  | Point 0 Joint 5 Pos [B1 – B0] | int16\_t | - | Data |
|  | Point 0 Joint 0 Vel [B1 – B0] | int16\_t | - | Data |
| … | … | … | … | … |
|  | Point 0 Joint 5 Vel [B1 – B0] | int16\_t | - | Data |
|  | Point 0 Joint 0 Acc [B1 – B0] | int16\_t | - | Data |
| … | … | … | … | … |
|  | Point 0 Joint 5 Acc [B1 – B0] | int16\_t | - | Data |
|  | Point 1 Joint 0 Pos [B1 – B0] | int16\_t | - | Data |
| … | … | … | … | … |
|  | Point k-1 Joint 5 Acc [B1 – B0] | int16\_t | - | Data |
|  | CRC [B1] | uint16\_t | - | CRC16 checksum |
|  | CRC [B0] |

A function that receives data in JTC:

##### static void Host\_ComReadFrameTrajectory(uint8\_t\* buf)

##### {

##### uint16\_t idx = 4, np;

##### uint16\_t nd = Com.rxFrame.expectedLength;

##### uint16\_t crc1 = Com\_Crc16(buf, nd-2);

##### uint16\_t crc2 = ((uint16\_t)buf[nd-2]<<8) + ((uint16\_t)buf[nd-1]<<0);

##### if(crc1 == crc2)

##### {

##### Com.timeout = 0;

##### uint16\_t trajNum = ((uint16\_t)buf[idx++]<<8);

##### trajNum += ((uint16\_t)buf[idx++]<<0);

##### uint16\_t segNum = ((uint16\_t)buf[idx++]<<8);

##### segNum += ((uint16\_t)buf[idx++]<<0);

##### uint16\_t segMax = ((uint16\_t)buf[idx++]<<8);

##### segMax += ((uint16\_t)buf[idx++]<<0);

##### uint16\_t stepTime = ((uint16\_t)buf[idx++]<<8);

##### stepTime += ((uint16\_t)buf[idx++]<<0);

##### 

##### // the number of points in the received segment

##### np = (nd - 14) / (3 \* JOINTS\_MAX \* 2);

##### // Too many points have already been taken from this trajectory

##### if((Traj.numRecPoints + np) > TRAJ\_POINTSMAX)

##### {

##### Com.rxFrame.dataStatus = Host\_RxDS\_TrajTooManyPoints;

##### return;

##### }

##### // Too many segments on this trajectory have already been received

##### if(segNum > TRAJ\_SEGSSMAX || segMax > TRAJ\_SEGSSMAX)

##### {

##### Com.rxFrame.dataStatus = Host\_RxDS\_TrajTooManySegs;

##### return;

##### }

##### // segment with wrong number was received (nip: wrong sequence of transmitted segments)

##### if(segNum != 0 && (((int16\_t)(segNum - Traj.numSeg) != 1) || (segNum >= segMax)))

##### {

##### Com.rxFrame.dataStatus = Host\_RxDS\_TrajIncorrectSegOrder;

##### return;

##### }

##### // an incorrect time step was received (e.g. stepTime = 0)

##### if(stepTime == 0)

##### {

##### Com.rxFrame.dataStatus = Host\_RxDS\_TrajIncorrectStepTime;

##### return;

##### }

##### // the received data is correct

##### Com.rxFrame.dataStatus = Host\_RxDS\_NoError;

##### // segment 0 means new trajectories, the previous one is cleared

##### if(segNum == 0)

##### Control\_TrajClear();

##### // checking if the received segment is the last one in the trajectory

##### if(segNum == (segMax-1))

##### {

##### Traj.comStatus = TCS\_WasRead; // last segment

##### Traj.targetTES = TES\_Stop;

##### }

##### else

##### Traj.comStatus = TCS\_IsRead;

##### Traj.numTraj = trajNum;

##### Traj.numSeg = segNum;

##### Traj.maxSeg = segMax;

##### Traj.stepTime = stepTime;

##### Traj.flagReadSeg[Traj.numSeg] = true;

##### Traj.numPointsSeg[Traj.numSeg] = np;

##### for(uint16\_t i=Traj.numRecPoints;i<Traj.numRecPoints+np;i++)

##### {

##### for(uint16\_t j=0;j<JOINTS\_MAX;j++)

##### {

##### Traj.points[i].pos[j] = ((uint16\_t)buf[idx++]<<8);

##### Traj.points[i].pos[j] += ((uint16\_t)buf[idx++]<<0);

##### }

##### for(uint16\_t j=0;j<JOINTS\_MAX;j++)

##### {

##### Traj.points[i].vel[j] = ((uint16\_t)buf[idx++]<<8);

##### Traj.points[i].vel[j] += ((uint16\_t)buf[idx++]<<0);

##### }

##### for(uint16\_t j=0;j<JOINTS\_MAX;j++)

##### {

##### Traj.points[i].acc[j] = ((uint16\_t)buf[idx++]<<8);

##### Traj.points[i].acc[j] += ((uint16\_t)buf[idx++]<<0);

##### }

##### }

##### Traj.numRecPoints += np;

##### }

##### else

##### {

##### Com.rxFrame.status = Host\_RxFS\_ErrorIncorrectCrc;

##### }

##### }

### Host\_FT\_FrictionTable

The frame is sent from the host chip to the JTC. Used to set new values for the friction compensation tables. The data field contains values for six drives. The values are sent starting with drive number 0. The size of the array for one drive is 22 lines and 20 columns. The first line contains the velocity values in rad / s. The second line shows the temperature in degrees Celsius. The following lines contain the values of the frictional moment for the given speed and temperature. All data in the table are in float format. When the JTC receives this frame, the friction compensation mode changes to JTC\_FT\_Table (see the description of the Host\_FT\_JtcStatus frame).

#### Tabela 5.8 Host\_FT\_FrictionTable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x05 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x2946 | Length frame in bytes |
| 3 | n [B0] |
| 4 - 7 | Joint 0 Vel 0 [B3 – B0] | float | - | Data |
| … | … | … | … | … |
|  | Joint 0 Vel 19 [B3 – B0] | float | - | Data |
|  | Joint 0 Temp 0 [B3 – B0] | float | - | Data |
| … | … | … | … | … |
|  | Joint 0 Temp 19 [B3 – B0] | float | - | Data |
|  | Joint 0 Fric 0,0 [B3 – B0] | float | - | Data |
|  | … | … | … | … |
|  | Joint 0 Fric 0,19 [B3 – B0] | float | - | Data |
|  | Joint 0 Fric 1,0 [B3 – B0] | float | - | Data |
|  | … | … | … | … |
|  | Joint 0 Fric 19,19 [B3 – B0] | float | - | Data |
|  | Joint 1 Vel 0 [B3 – B0] | float | - | Data |
| … | … | … | … | … |
| 10560 - 10563 | Joint 5 Fric 19,19 [B3 – B0] | float | - | Data |
| 10564 | CRC [B1] | uint16\_t | - | CRC16 checksum |
| 10565 | CRC [B0] |

A function that receives data in JTC:

##### static void Host\_ComReadFrameFricionTable(uint8\_t\* buf)

##### {

##### uint16\_t nd = Com.rxFrame.expectedLength;

##### uint16\_t crc1 = Com\_Crc16(buf, nd-2);

##### uint16\_t crc2 = ((uint16\_t)buf[nd-2]<<8) + ((uint16\_t)buf[nd-1]<<0);

##### uint16\_t idx = 4;

##### if(crc1 == crc2)

##### {

##### Com.timeout = 0;

##### // the received data is correct

##### Com.rxFrame.dataStatus = Host\_RxDS\_NoError;

##### union conv32 x;

##### for(int num=0;num<JOINTS\_MAX;num++)

##### {

##### for(int i=0;i<JOINTS\_FRICTABVELSIZE;i++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[num].fricTableVelIdx[i] = x.f32;

##### }

##### for(int i=0;i<JOINTS\_FRICTABTEMPSIZE;i++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[num].fricTableTempIdx[i] = x.f32;

##### }

##### for(int i=0;i<JOINTS\_FRICTABVELSIZE;i++)

##### {

##### for(int j=0;j<JOINTS\_FRICTABTEMPSIZE;j++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[num].fricTable[i][j] = x.f32;

##### }

##### }

##### }

##### Joints\_FindMinMaxVelTempInFrictionTabeIdx();

##### pC->Jtc.flagInitGetFrictionTable = false;

##### }

##### else

##### {

##### Com.rxFrame.status = Host\_RxFS\_ErrorIncorrectCrc;

##### }

##### }

### Host\_FT\_FrictionTableUseDefault

Command frame sent from the host chip to the JTC. Used to restore the default values of the friction compensation tables. When the JTC receives this frame, the friction compensation mode changes to JTC\_FT\_Table (see the description of the Host\_FT\_JtcStatus frame).

#### Tabela 5.9 Host\_FT\_FrictionTableUseDefault

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x06 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0x0AE6 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_PidParam

The frame is sent from the host chip to the JTC. Used to set new PID settings. The data field contains values for six drives. The values are sent starting with drive number 0. 5 numerical float values (20 bytes) are sent for each drive. The values are:

* gain of the proportional element pidKp,
* strengthening of the inertial element pidKi,
* gain of the derivative element pidKd,
* saturation of the error integral - minimum value of pidErrorIntMin,
* saturation of the error integral - maximum value of pidErrorIntMax

#### Tabela 5.10 Host\_FT\_PidParam

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x07 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x7E | Length frame in bytes |
| 3 | n [B0] |
| 4 - 7 | Joint 0 pidKp [B3 – B0] | float | - | Data |
| 8 - 11 | Joint 0 pidKi [B3 – B0] | float | - | Data |
| 12 - 15 | Joint 0 pidKd [B3 – B0] | float | - | Data |
| 16 - 19 | Joint 0 pidErrorIntMin [B3 – B0] | float | - | Data |
| 20 – 23 | Joint 0 pidErrorIntMax [B3 – B0] | float | - | Data |
| 24 – 27 | Joint 1 pidKp [B3 – B0] | float | - | Data |
| … | … | … | … | … |
| 120 - 123 | Joint 5 pidErrorIntMax [B3 – B0] | float | - | Data |
| 124 | CRC [B1] | uint16\_t | - | CRC16 checksum |
| 125 | CRC [B0] |

A function that receives data in JTC:

##### static void Host\_ComReadFramePidParam(uint8\_t\* buf)

##### {

##### uint16\_t nd = Com.rxFrame.expectedLength; //JOINTS\_MAX \* 7 \* 4 + 4;

##### uint16\_t crc1 = Com\_Crc16(buf, nd-2);

##### uint16\_t crc2 = ((uint16\_t)buf[nd-2]<<8) + ((uint16\_t)buf[nd-1]<<0);

##### uint16\_t idx = 4;

##### if(crc1 == crc2)

##### {

##### Com.timeout = 0;

##### // the received data is correct

##### Com.rxFrame.dataStatus = Host\_RxDS\_NoError;

##### Joints\_SetDefaultVariables();

##### union conv32 x;

##### for(int i=0;i<JOINTS\_MAX;i++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[i].pidKp = x.f32;

##### 

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[i].pidKi = x.f32;

##### 

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[i].pidKd = x.f32;

##### 

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[i].pidErrorIntMin = x.f32;

##### 

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[i].pidErrorIntMax = x.f32;

##### }

##### 

##### pC->Jtc.flagInitGetPidParam = false;

##### }

##### else

##### {

##### Com.rxFrame.status = Host\_RxFS\_ErrorIncorrectCrc;

##### }

##### }

### Host\_FT\_PidParamUseDefault

Command frame sent from the host chip to the JTC. It is used to restore the default values of PID regulators.

#### Tabela 5.11 Host\_FT\_PidParamUseDefault

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x08 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0x11E7 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_ArmModel

The frame is sent from the host chip to the JTC. Used to set new values for kinematic and dynamic parameters of the manipulator. The data field contains values in the float format (4 bytes). First, the joint coordinate system parameters are sent. Then the parameters of the coordinate systems, moments of inertia and masses for the links are sent.

#### Tabela 5.12 Host\_FT\_ArmModel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x09 | Type of frame |
| 2 | n [B1] | uint16\_t | 0x021A | Length frame |
| 3 | n [B0] |
| 4 - 7 | Joint 0 Origin X [B3 – B0] | float | - | Data |
| 8 - 11 | Joint 0 Origin Y [B3 – B0] | float | - | Data |
| 12 - 15 | Joint 0 Origin Z [B3 – B0] | float | - | Data |
| 16 - 19 | Joint 0 Origin Roll [B3 – B0] | float | - | Data |
| 20 – 23 | Joint 0 Origin Pitch [B3 – B0] | float | - | Data |
| 24 – 27 | Joint 0 Origin Yaw [B3 – B0] | float | - | Data |
| 28 – 31 | Joint 1 Origin X [B3 – B0] | float | - | Data |
| … | … | … | … | … |
|  | Joint 6 Origin Yaw [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin X [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin Y [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin Z [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin Roll [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin Pitch [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Origin Yaw [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Ixx [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Ixy [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Ixz [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Iyy [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Iyz [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Inertia Izz [B3 – B0] | float | - | Data |
|  | Link 0 Inertial Mass [B3 – B0] | float | - | Data |
|  | Link 1 Inertial Origin X [B3 – B0] | float | - | Data |
| … | … | … | … | … |
| 532 - 535 | Link 6 Inertial Mass [B3 – B0] | float | - | Data |
| 536 | CRC [B1] | uint16\_t | - | CRC16 checksum |
| 537 | CRC [B0] |

A function that receives data in JTC:

##### static void Host\_ComReadFrameArmModel(uint8\_t\* buf)

##### {

##### uint16\_t nd = Com.rxFrame.expectedLength;

##### uint16\_t crc1 = Com\_Crc16(buf, nd-2);

##### uint16\_t crc2 = ((uint16\_t)buf[nd-2]<<8) + ((uint16\_t)buf[nd-1]<<0);

##### uint16\_t idx = 4;

##### if(crc1 == crc2)

##### {

##### Com.timeout = 0;

##### // the received data is correct

##### Com.rxFrame.dataStatus = Host\_RxDS\_NoError;

##### union conv32 x;

##### for(int i=0;i<ARMMODEL\_DOF+1;i++)

##### {

##### for(int j=0;j<6;j++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Arm.Joints[i].origin[j] = x.f32;

##### }

##### }

##### for(int i=0;i<ARMMODEL\_DOF+1;i++)

##### {

##### for(int j=0;j<6;j++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Arm.Links[i].origin[j] = x.f32;

##### }

##### for(int j=0;j<6;j++)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Arm.Links[i].innertia[j] = x.f32;

##### }

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Arm.Links[i].mass = x.f32;

##### }

##### pC->Jtc.flagInitGetArmModel = false;

##### }

##### else

##### {

##### Com.rxFrame.status = Host\_RxFS\_ErrorIncorrectCrc;

##### }

##### }

### Host\_FT\_ArmModelUseDefault

Command frame sent from the host chip to the JTC. Used to restore the default values of the manipulator's kinematic and dynamic parameters.

#### Tabela 5.13 Host\_FT\_ArmModelUseDefault

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0A | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0x7F87 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_TrajSetExecStatus

Command frame sent from the host chip to the JTC. Used to change the trajectory execution mode. The allowed modes are: STOP, PAUSE, EXECUTE.

#### Tabela 5.14 Host\_FT\_TrajSetExecStatus

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0A | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CMD | uint8\_t | 0x01 – STOP  0x02 – PAUSE  0x03 – EXECUTE | New trajectory mode |
| 5 | CRC [B1] | uint16\_t | CRC = 0x5DDC (for CMD = 0x01)  CRC = 0x 6DBF (for CMD = 0x02)  CRC = 0x 7D9E (for CMD = 0x03) | CRC16 checksum |
| 6 | CRC [B0] |

### Host\_FT\_TeachingModeEnable

Command frame sent from the host chip to the JTC. Used to turn on Teaching Mode.

#### Tabela 5.15 Host\_FT\_TeachingModeEnable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0C | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0xCD27 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_TeachingModeDisable

Command frame sent from the host chip to the JTC. Used to disable Teaching Mode.

#### Tabela 5.16 Host\_FT\_TeachingModeDisable

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0D | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0xFA17 | CRC16 checksum |
| 5 | CRC [B0] |

### Host\_FT\_FrictionPolynomial

The frame is sent from the host chip to the JTC. Used to set new values for the polynomial coefficients for friction compensation. The data field contains values for six drives. The values are sent starting with drive number 0. For each drive 4 numerical values of the float type are sent (16 bytes). When the JTC receives this frame, the friction compensation mode changes to JTC\_FT\_Polynomial (see the description of the Host\_FT\_JtcStatus frame).

#### Tabela 5.17 Host\_FT\_FrictionPolynomial

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0E | Type of frame |
| 2 | n [B1] | uint16\_t | 0x66 | Length frame in bytes |
| 3 | n [B0] |
| 4 - 7 | Joint 0 Coef 0 [B3 – B0] | float | - | Data |
| 8 - 11 | Joint 0 Coef 1 [B3 – B0] | float | - | Data |
| 12 - 15 | Joint 0 Coef 2 [B3 – B0] | float | - | Data |
| 16 - 19 | Joint 0 Coef 3 [B3 – B0] | float | - | Data |
| 20 – 23 | Joint 1 Coef 0 [B3 – B0] | float | - | Data |
| … | … | … | … | … |
| 116 - 119 | Joint 5 Coef 3 [B3 – B0] | float | - | Data |
| 120 | CRC [B1] | uint16\_t | - | CRC16 checksum |
| 121 | CRC [B0] |

A function that receives data in JTC:

##### static void Host\_ComReadFrameFricionPolynomial(uint8\_t\* buf)

##### {

##### uint16\_t nd = Com.rxFrame.expectedLength;

##### uint16\_t crc1 = Com\_Crc16(buf, nd-2);

##### uint16\_t crc2 = ((uint16\_t)buf[nd-2]<<8) + ((uint16\_t)buf[nd-1]<<0);

##### uint16\_t idx = 4;

##### if(crc1 == crc2)

##### {

##### Com.timeout = 0;

##### // received data are correction

##### Com.rxFrame.dataStatus = Host\_RxDS\_NoError;

##### union conv32 x;

##### for(int num=0;num<JOINTS\_MAX;num++)

##### {

##### for(int i=JOINTS\_FRICCOEFFMAX-1;i>=0;i--)

##### {

##### x.u32 = ((uint32\_t)buf[idx++]<<24);

##### x.u32 += ((uint32\_t)buf[idx++]<<16);

##### x.u32 += ((uint32\_t)buf[idx++]<<8);

##### x.u32 += ((uint32\_t)buf[idx++]<<0);

##### pC->Joints[num].fricCoeff[i] = x.f32;

##### }

##### }

##### pC->Jtc.fricType = JTC\_FT\_Polynomial;

##### pC->Jtc.flagInitGetFrictionTable = false;

##### }

##### else

##### {

##### Com.rxFrame.status = Host\_RxFS\_ErrorIncorrectCrc;

##### }

##### }

### Host\_FT\_FrictionPolynomialUseDefault

#### Command frame sent from the host chip to the JTC. Used to restore the coefficients of the friction approximation polynomial to their default values. When the JTC receives this frame, the friction compensation mode changes to JTC\_FT\_Polynomial (see the description of the Host\_FT\_JtcStatus frame).

#### Tabela 5.18 Host\_FT\_FrictionPolynomialUseDefault

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Byte number** | **Name** | **Format** | **Value** | **Description** |
| 0 | Header | uint8\_t | 0x9B | Header |
| 1 | Frame | uint8\_t | 0x0F | Type of frame |
| 2 | n [B1] | uint16\_t | 0x0006 | Length frame in bytes |
| 3 | n [B0] |
| 4 | CRC [B1] | uint16\_t | 0xA347 | CRC16 checksum |
| 5 | CRC [B0] |