CANopen
Inclinometer Protocol

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< Review of functions >

The inclinometers are equipped with a standardized CANopen interface per CiA DS-301 and a device profile per CiA DSP-410. All measurement values and parameters are accessible via the object register (OR). The individual configuration can be stored in the internal, non-volatile memory buffer (EEPROM).

The following CANopen functions are available:

one Send Data object (TPDO1) with four possible operating modes:
- individual request per Remote Transmit Request telegram (RTR)
- cyclic Send per interval time
- event-driven Send when angle has changed
- synchronized Send after receipt of SYNC telegram

one Service Data object (Standard SDO)
error messages per emergency object (EMCY) with the help of:
- the general error register
- the manufacturer specific status register (Manufacturer Status)
- the error list (Predefined Error Field)

storage and reload function of all parameters (Store and Load Parameter Field)
Failure Monitoring
setting of Node ID, as well as Baud rate per OR
freely configurable limit frequency (digital filter)
configuration of minimal change of angle for TPDO1 send event

< Send PDO (TPDO1) >

Each inclinometer has exactly one Send Process Data Object (TPDO). It contains the current inclination values (longitudinal and lateral). PDO mapping of measurement values is fixed as displayed in Table 1.

Table 1. PDO mapping of TPDO1

Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
Inclination value Longitudinal (X-axis) OR: 6010 h		Inclination value lateral (Y-axis) OR: 6020 h		Not used			

< PDO communication types >

Individual request per Remote Transmit Request telegram (RTR)

A request can be sent to TPDO1 anytime by sending a Remote Transmit Request telegram. This is possible in all operating modes of the inclinometer.

Cyclic operating mode

Cyclic sending of TPDO1 is activated if the entry 1800h/05h (interval time in milliseconds) contains a value greater than 0.For this purpose the entry 1800h/02h (transmission type) must contain the value 254 (asynchronous, manufacturer specific). In the Operational mode, the inclinometer cyclically sends the TPDO1 with the set cycle duration time.

Event-driven Send when the angle has changed

The bus load caused by PDOs can be decreased by only sending the TPDO1 when the angle has changed accordingly. This function can be configured under the index 3001h in the manufacturer specific portion of the object register. For this purpose the entry 1800h/02h (transmission type) must contain the value 254 (asynchronous, manufacturer specific).

Synchronized Send after receipt of a SYNC telegram

For the synchronized transmission, the SYNC object is made available by CANopen; here, the TPDO1 is sent after each „nth" receipt of a SYNC telegram. For this purpose the entry 1800h/02h (transmission type) must contain the value n=1...240.

< Object register >

The object register of the inclinometers is divided into three parts (communication parameters, manufacturer specific portion, profile specific portion). The existing parameters can be read and written via the Standard SDO and index/subindex. Parameter changes become immediately valid with the exception of the Node ID (2000h) and the Baud rate (2001h).

The following paragraphs provide a description of all parameters in the object register of an inclinometer including index, subindex, data type, access rights and standard value (manufacturer default setting). The column Store identifies whether a parameter can be stored in the internal, non-volatile memory buffer (write„save" signature in OR index 1010h/01h).

< Communication Sample >

COB-ID	DLC	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
580h + Node ID	1 byte	CMD Type*	Index		Sub-index	Data			
	8		MSB	LSB		MSB			LSB

CMD Type

Consumer request	Server response
Read data => 40h	43h => 4-bytes data
	4Bh => 2-bytes data
	4Fh => 1-byte data
Write 4-bytes data => 23h	60h
Write 2-bytes data => 2Bh	
Write 1-bytes data => 2Fh	

< Communication parameters (per CiA DS-301) >

Index	Sub-index	Parameter	Data type	Access	Standard value	Store
1000h	0	Device type (device profile 410, two axes)	UNS32	const	2019Ah	
1001h	0	Error register	UNS8	ro	0	
1003h	Predefined error field					
	0	Number of error entries	UNS32	rw	0	
	1...5	Error code (oldest error in highest index)	UNS32	ro	0	
1005h	0	COB ID SYNC message	UNS32	rw	80h	
100Ah	0	Software version ("xyy")	VSTR	const	typical	
1010h	Store parameters					
	0	Highest supported subindex	UNS32	ro	1	
	1	Store all parameters (signature: "save"- 65766173h)	UNS32	rw	0	
1011h	Reload manufacturer default setting		UNS32			
	0	Highest supported subindex	UNS32	ro	1	
	1	Reload all manufacturer default settings (signature: "load"- 64616F6Ch)	UNS32	rw	0	
1014h	0	COB ID emergency message	UNS32	ro	80h+NID	
1015h	0	Off-time between two EMCY messages (a multiple of 100 μs)	UNS16	rw	0	x
1017h	0	Heartbeat interval time (a multiple of 1 ms, 0 deactivated)	UNS16	rw	0	x

Index	Sub-index	Parameter	Data type	Access	Standard value	Store
1018h	Identity object					
	0	Highest supported subindex	UNS8	ro	4	
	1	Vendor ID	UNS32	ro	0h	
	2	Product code	UNS32	ro	typical	
	3	Revision No.	UNS32	ro	typical	
	4	Serial No.	UNS32	ro	typical	
1200h	Server SDO1 parameter					
	0	Highest supported subindex	UNS8	ro	2	
	1	COB ID Client > Server	UNS32	ro	600h+NID	
	2	COB ID Server > Client	UNS32	ro	580h+NID	
1800h	Transmit PDO1 communication parameters					
	0	Highest supported subindex	UNS8	ro	5	
	1	COB ID	UNS32	ro	180h+NID	
	2	Transmission type (synchronous / asynchronous manufacturer specific)	UNS8	rw	FFh	x
	3	Off-time between two TPDO messages (a multiple of 100 µs, 0 deactivated)	UNS16	rw	0	
	4	Compatibility entry	UNS8	rw	0	x
	5	Interval time for cyclic Send (a multiple of 1 ms, 0 deactivated)	UNS16	rw	0	x

Error register (1001h)

The error register displays the general error status of the device. Each Bit represents an error group. If a Bit is set (=1), at least one error of this group remains active at this time.

The content of this register is transmitted in each EMCY message. The following error groups may occur:

Bit 7...Bit 6	Bit 5	Bit 4	Bit 3	Bit 2...Bit 1	Bit 0
Not used	Profile specific error	Not used	Temperature error	Not used	At least one error active

If the device remains in the error status (at least one error active), it is displayed by set Bit 0.
During active monitoring of the internal device temperature (5001h/01h = 1), Bit 3 is set when set limit values (5001h/02h...03h) have been underreached or rather overreached.
A profile specific error (sensor error) is displayed by Bit 5.

Predefined error field (1003h)

Each inclinometer compiles an error list concerning the five errors that have occurred last.
The entry 1003h/00h contains the number of error entries in the error field. All other subindices contain all occurred error states in chronological sequence; the error that has occurred last may always be found under subindex 01h. The oldest error may be found in the highest subindex (value of 1003h/00h) available and is removed first from the list when more than five errors have occurred. If an error occurs, a new error entry is added to 1003h and an EMCY message is sent as well.

An erorr entry is structured as follows:

Additional information field (Bit 31...Bit 16)	Error code (Bit 15...Bit 0)
Bit 15...Bit 0 of the manufacturer status register 1002h (at the time the error has occurred)	4200h (temperature error) 5000h (hardware error) FF00h (device specific error)

The error list may be completely deleted by writing 0 into the entry 1003h/00h.

Store parameters (1010h) and reload (1011h)

If parameters are changed in the OR, the changes become immediately valid with the exception of Node ID (200h) and Baud rate (2001h). The changed parameters must be stored in the internal EEPROM so that they remain active after a reset. By writing the signature „save" (65766173h) into the entry 1010h/01h all active parameters of the OR are sent to the non-volatile memory buffer.

The OR may be reset to the manufacturer default via the entry 1011h/01h and by writing the signature„load" (64616F6CH) into this entry. Thus the default parameters are written into the non-volatile memory buffer with the exception of the Node ID
(2000h) and the Baud rate (2001h). After a „reset application" (NMT command) or rather a hardware reset, the changes become valid; if only a „reset communication" (NMT command) is sent, only the default settings of the communication parameters become valid.

After the„save" and„load" command, a reset should not occur for a minimum time period of approx. one second; this ensures that the parameters are correctly stored in the EEPROM.
Storing device parameters in the internal EEPROM may take a relative long time. This is why the „save" and „load" commands are immediately answered, but storing is executed retroactively and„in addition to."

< Transmit PDO1 – transmission type (1800h) >

With the help of the entry 1800h/02h it can be determined how sending the PDOs is to be initiated.

Transmission type	Description
1...240	Synchronous (cyclic) Only synchronized transmission via SYNC possible
254	Asynchronous, manufacturer specific Cyclic operating mode and/or send when angle has changed can be activated via respective configuration.

Manufacturer specific portion

Index	Sub -index	Parameter	Data type	Access	Standard value	Store
2101h	0	Node ID (1...127)	UNS8	rw	10 (0Ah)	x
2102h	0	Baud rate (in kBit/s)	UNS16	rw	250	x
3000h	0	Limit frequency digital filter (0 = deactivated or 300...25000, in mHz)	UNS16	rw	3000	x
3001h	TPDO1 Send when angle has changed					
	0	Highest supported subindex	UNS16	ro	3	x
	1	Send when angle has changed activate/ deacticate (1/0)	UNS16	rw	0	x
	2	Minimal change of angle for longitudinal (X) axis (5/10...1000, in °/100)	UNS16	rw	100	x
	3	Minimal change of angle for lateral (Y) axis (5/10...1000, in °/100)	UNS16	rw	100	

Node ID (2000h) and Baud rate (2001h)

After a change has occurred, the Node ID and the Baud rate only become valid after a reset (reset application, reset communication and hardware reset). This is why the two parameters must be transferred to the EEPROM with the save command (1010h/01h) after a change has occurred. After a reset, all COB IDs are recalculated and reset according to the predefined connection set.
The Baud rate is set in kBit/s. { 10, 20, 50, 125, 250, 500, 800, 1000 }

Limit frequency digital filter (3000h)

The inclinometer offers the possibility to render continually forming angle values insensitive against external, interfering vibration. With the help of a parameterizable low-pass filter parasitic vibrations may be suppressed. The limit frequency may be set individually between 0.3 and 25 Hz. The digital filter inside the sensor is a Butterworth Low-pass 8th Order. Values of 300 (= 0.3 Hz) to 25000 (= 25 Hz) are thereby permissable. The digital filter is deactivated by the value 0.

TPDO1 – Send when angle has changed (3001h)

Via the entry 3001h/01h the event-driven Send of the TPDO1 can be activated (= 1) or rather deactivated (= 0) when the angle has changed. For activation to occur, the transmission type of the TPDO1 must be set to„asynchronous, manufacturer specific" (1800h/02h = 254).

Subindices 02h and 03h are used to separately set the minimally needed angle change for longitudinal (X) and lateral (Y) axis. These two angle values are provided in °/100 (hundredfold angle value) and may be freely set from 5 or rather 10 to 1000.

If Send is activated when the angle changes, the inclinometer, while in Operational status, will always reissue the TPDO1 when the inclination value of the longitudinal and/or lateral axis has changed per the angle value preset under 3001h/02h and 03h. Here, the angle variations are always determined and checked between the actual inclination value and the angle value sent last via the TPDO1. Every time the status changes into Operational, the inclinometer alerts to the current position by a singular send of TPDO1 (only when 3001h/01h = 1).

< Profile specific portion (per CiA DSP-410) >

Index	Sub -index	Parameter	Data type	Access	Standard value	Store
6000h	0	Resolution (a multiple of 0.001°)	UNS16	ro	Typical	
6010h	0	Inclination value longitudinal (X-axis, hundredfold angle value in °, >> TPDO1)	INT16	ro	...	
6011h	0	Inversion, longitudinal, activate/ deactivate (1/0)	UNS8	rw	0	**x**
6020h	0	Inclination value lateral (Y-axis, hundredfold angle value in °, >> TPDO1)	INT16	ro	...	
6021h	**0**	Inversion, lateral, activate/ deactivate (1/0)	UNS8	rw	0	x

Inclination values, longitudinal and lateral (6010h and 6020h)

The current angle values of the inclination axes are accessible via SDO access to the object register (in every device mode), as well as via TPDO. The recalculation of the hundredfold, signed 16-Bit inclination value (two's complement) is as follows:
Example: Value of 6010h = -237, Resolution of 6000h = 100
-237 / (100 * 0.001) -23.7 °

Stop inversion (6011h and 6021h)

Reassignment of the mathematical prefix of the inclination value is made possible by the operating parameter settings of an inclinometer (6011h and 6021h). This option is deactivated per manufacturer default, this means the direction of the angle value
(polarity of the axes) corresponds to the mapping displayed on the type plate of the device.

< Emergency messages >

Each inclinometer supports EMCY messages which are sent in case of sensor, temperature, hardware or guarding errors. If one of these errors occurs, the OR entries 1001h (Error Register), 1002h (Manufacturer Status Register) and 1003h (Predefined Error Field) are activated (please refer to paragraphs Error register (1001h) and Predefined error field (1003h)).

After an error has been corrected, the device sends an EMCY message with the„error reset" code (0h) and the current status of the error register, as well as the manufacturer status register. The current device status („pre-operational, operational or stopped") is not impacted by the error states except by the guarding error.

EMCY message protocol

- EEC (Emergency error code) - see Table EEC
- ER (Error Register) - see Table ERA
- EB (Error bits) - see Table EB

ID	byte0	byte1	byte2	byte3	byte4	byte5	byte6	byte7
80h + Node ID	EEC		ER	EB	Not used			

Table EEC – Emergency error code

Code	Description
0000h	Error reset or no error
1000h	Generic error
6100h	Internal software – generic
8100h	Communication – generic
8110h	CAN overrun (objects lost)
8120h	CAN in error passive mode
8130h	Life guard error or heartbeat error
8140h	recovered from bus off
8200h	Protocol error - generic
8240h	Unexpected SYNC data length

Table ER – Error register

Code(bits)	Description
00h	Generic error
01h	Current
02h	Voltage
04h	Temperature
08h	Communication error
10h	Device profile specific
20h	Reserved(always 0bit)
40h	Manufacturer specific

Table EB - Error bits

Code(bits)	Description
00h	No error
01h	CAN bus warning
06h	CAN receive bus passive
07h	CAN transmit bus passive
12h	CAN transmit bus is off
14h	CAN receive buffer has overflowed
18h	SYNC message timeout
19h	Unexpected SYNC data length
1Ah	Error with PDO mapping
20h	Emergency buffer is full

< Failure monitoring >

Failure monitoring functions Heartbeat monitoring methods can be used.

< Heartbeat >

Heartbeat is a failure monitoring mechanism which functions without RTR telegrams. For this purpose the inclinometer cyclically sends a Heartbeat message which contains the status of the device. The master is able to monitor these telegrams. Heartbeat is activated as soon as a value greater than „0" is entered into the register Heartbeat Interval Time (1017h).

< COB Ids >

The CAN identifiers of the communication objects are set according to the predefined connection set at each reset (communication, application and hardware reset) depending on the preset Node ID (2000h). Table 10 displays the basis for calculation and example values (Node ID = 10).

Communication object	Calculation of COB ID	Example value (Node ID = 10)
NMT	0h	0h
SYNC	80h	80h
EMCY	80h + Node ID	8Ah
TPDO1	180h + Node ID	18Ah
Standard SDO (Client > Server)	600h + Node ID	60Ah
Standard SDO (Server > Client)	580h + Node ID	58Ah
Heartbeat	700h + Node ID	70Ah