



Very High Resolution Tiltmeter HRTM
Operating Instructions
Version 1.0.1

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1 Introduction

The *Very High Resolution Tiltmeter HRTM* is **developed for geophysical and geodetic measurement requirements**. Among others, these sensors are used in photographic zenith telescopes (PZT), laser gyroscopes, ocean-bottom sensors and for earthquake- and groundwater research. Due to their extremely high resolution, the robust construction and the powerful firmware commands the instruments can be used for various applications.

The sensors are based on a physical pendulum and a capacitive displacement transducer with a resolution of a few pico meters (10^{-12} m). Depending on the specific application, different sensor-designs are possible; but all these sensors achieve resolutions better than 1 nrad.

For data acquisition, an analog-to-digital converter with “24 bit + sign”-resolution is used. The required signals are sampled continuously with rates between 100 and 200 Hz. After averaging the data, output rates are user selectable from four samples per second to one sample per day – in the last case averaging over 10^6 samples. Averaging is done using real 48 bit integer arithmetic to avoid any numerical artefacts.

The measurement range of the system differs from type to type, but usually will cover +/-300 μ rad to +/- 2 mrad. **One digit in output signals of the sensors thus corresponds to approximately 15 to 100 μ rad. For more specific data please consult the calibration data sheet of each individual system!**

The additional data channels of the instrument are mainly intended for quality control of the tilt signals. Changes in temperature, pressure and humidity, that may have a strong influence on the tilt signals, can be recorded. For borehole systems it is optionally possible to record the orientation by an integrated compass.

As the RS232 interface is electrically isolated, cable lengths of 100 m and more are possible. For even longer connection lengths a 4-wire RS485 driver is a standard feature of the system.

For stand-alone installations a data logger with 32 Mb of internal memory is integrated.

Due to the low power consumption of the instrument (12 V /20 mA) a standard car battery can power the system for nearly 100 days.

2 Getting Started

2.1 Sensors and Interfaces

The *Very High Resolution Tiltmeter HRTM* has **several channels**:

- TiltX
- TiltY
- Two temperature sensors
- Humidity
- Pressure
- Orientation (compass)
- Motor current
- Supply voltage

Additionally a **real time clock** is integrated.

Data can be stored **internally** in a **32 MBit flash memory**.

The device has **two serial interfaces**:

- **RS232** and
- **RS485**

The interfaces are rather identical. **But note:** This version of the instrument only allows a point to point connection via RS485.

Sensors are read out cyclically. A **‘primary’ data set** consists of

- the average of eight measured values for both TiltX and TiltY and
- the measured values for temperature, humidity, pressure, orientation and motor current.

These “primary” data sets are averaged once more as required. The averaging time can be chosen according to Tab: 4.7. Additionally, the values for the supply voltage and for date and time can be recorded at the beginning of each averaging. This results in a **data set**.

Data sets can be transferred via the serial interfaces and/or saved in the internal flash memory. The content of the internal flash can also be read out via the serial interfaces.

The channel data, which are to be transferred or saved, are to be set by means of parameters (see Chapter 2). Data sets are acquired continuously based on a timing behavior (see Chapter 4.4.2) or acquisition is started by a hardware- or software-trigger (see Chapter 3.2).

2.2 Communication

To **control the tiltmeter**, an **external terminal program** (e.g. HTerm) or a **specialized control software** is needed.

An **ASCII protocol** is used on both serial interfaces. For control **two communication modes** are integrated:

- **The command mode**
- **The menu mode**

The applied mode depends on the external control program:

- If a **terminal program** is used, it is easiest to change parameters in **menu mode**, no data acquisition is possible during parameterisation.
- If a **specialized control software** is used, parameters should be set in **command mode**. Data acquisition and parameterisation are carried out in parallel.

Note:

- **Commands** are received on both interfaces in parallel
- The **interface for the acquired data** can be **selected** in the settings-menu (see chapter 4.4.1). Both interfaces can also be unselected. **Acknowledgements on commands** will always be **sent via both interfaces**.

3 Operation

3.1 Data transfer and communication

Via the serial interfaces data are exchanged in ASCII format

The parameters for transfer are:

- the baud rate (selectable, see Chapter 4.4.1)
- 8 data bits
- 1 stop bit

A data set consists of several (averaged) measurement values (see Chapter 2.1), displayed in one line, e.g.: the values for TiltX and TiltY, the humidity and the pressure. The user specifies, which data in which sequence are to be transferred (see Chapter 4.4.3):

The **maximal length of a measurement value is 8 digits plus a separator**. To separate the measurement values the **sign (+/-)** of the measurement value is used. **Carriage Return (<CR>)** marks the end of a data set.

Example: Data set (TiltX, TiltY, humidity, pressure):

```
-123456+76543-25678-2375<CR>  
-123782+76213-23577-2323<CR>
```

3.2 Trigger – Start of Data Acquisition

Data acquisition can be triggered in three different ways. The trigger type can be selected in the menu “Settings” under “measurement mode” (see Chapter 4.4.1).

3.2.1 Continuous

Data are acquired continuously and if necessary stored and/or transferred via one or both serial interfaces. The data acquisition timing and rate is to be set in the menu “timing” (Chapter 4.4.2).

3.2.2 Software-triggered:

Acquisition of a data set starts after receiving the ASCII sequence “<CR>”. If necessary, data are saved and/or transferred via one or both of the serial interfaces. The data acquisition timing is to be set in the menu “timing” (see Chapter 4.4.2).

3.2.3 Hardware-triggered:

Acquisition of a data set starts after receiving a trigger signal with a transition from “high” to “low” at the RxD of the RS485 interface. After the signal transition and a 5 ms lag-time the instrument verifies, whether the signal is still “low” to accept the trigger (debouncing) and to start the measurement. After the measurement the data are saved and/or transferred via one or both of the serial interfaces, if necessary. Data acquisition timing is to be set in the menu “timing” (see Chapter 4.4.2).



Data acquisition is only possible in command mode!!

4 Settings

4.1 Start-up

The start-up of the instrument is easiest with a terminal program (e.g. HTerm for windows PC's) on a PC using the RS232 interface.

After switching on, the tiltmeter responds via both interfaces displaying all system parameters, namely the

- Firmware version
- Data acquisition mode (triggered/continuous)
- Sample rate
- Preset channels

The device is automatically in command mode. Depending on the presettings, the instrument

- starts the measurement immediately (continuous mode) or
- starts the measurement after a hardware- or software-trigger
-

```
HW:V1
SW:V2.00 10.02.2011
SerialNumber:0815
BaudrateRS232:9600
BaudrateRS485:19200
UseRS232:yes
UseRS485:yes
XonXoff:no
MeasurementMode:CONTINUOUS
RequestedResults:XY
Memory:4 MBit
StoreDataInFlash:no
Timing:18,Averaging:128 samples, data rate:128 samples/s, sample time:1s
ALMinTiltThreshold:10000
ALMaxIterations:10
ALMaxMotorCurrent:1000
ALSpeed:30
ALMotorOnTime:3
ALWaitLoops:20
```

Fig.: 4.1: Screen display after switching on the tiltmeter

Parameter	Meaning
HW	Hardware version
SW	Software version
SerialNumber	Serial number of the instrument
BaudrateRS232	Baud rate for RS232 interface
BaudrateRS485	Baud rate for RS484 interface
UseRS232	RS232 is active for data transmission
UseRS485	RS484 is active for data transmission
XonXoff	XON/XOFF protocol is used on both serial interfaces
MeasurementMode	Measurement mode
RequestedResults	Measured channels
Memory	Integrated flash memory
StoreDataInFlash	Measured data will be stored in flash memory
Timing	Selected timing
ALMinTiltThreshold	Minimum tilt to finish auto levelling
ALMaxIterations	Maximum iterations for auto levelling
ALMaxMotorCurrent	Maximum motor current for auto levelling
ALSpeed	Speed [%] for auto levelling
ALMotorOnTime	Motor on time in auto levelling
ALWaitLoops	Wait time after one motor stops in auto levelling

Tab: 4.1: System parameters and their meaning

4.2 Navigation

The tiltmeter can be controlled in two different ways:

- In menu mode
- In command mode

! After switching on the instrument is always in command mode!

Data acquisition is executed in command mode only!

To change from command mode (no prompt) to menu mode (prompt ">") use the ASCII sequence "U<CR>", go back to command mode with "C<CR>".

In menu mode the timeout is 10 minutes. After that time the instrument ends the menu and automatically changes to the next higher level or back to command mode.

The reaction on commands of both serial interfaces (RS232 and RS485) is identical.

4.2.1 Menu mode

For navigation in menu mode a terminal program with an ASCII protocol is used. The **main menu** is marked with the **prompt** “>”.

A command according to Tab: 4.4 is to be entered **in order to change to a submenu**, and a new prompt shows the current menu level: If the command “S<CR>” was entered, for example, the user changes to the submenu “Settings” and the line starts with the prompt “S>”.

Each input is acknowledged on the screen: a **wrong command** with “?”, a **wrong parameter** with “E”. A correct input is confirmed with “<CR>”.

The user can check the input with the **command** “D<CR>“ („Dump all settings“). The sensor sends the current **settings**.

! In menu mode only parameterization is realized, no measurements are performed. To carry out measurements you have to change to command mode!

Example: The user wants to set the baud rate of the serial interface RS485 to 19200 baud. The following commands have to be entered:

Command	Meaning	Prompt
U<CR>	Change to menu mode	>
S<CR>	Change to submenu „Settings“	S>
b5<CR>	Set baud rate of RS485 to 19200 baud	<CR> S>
Q<CR>	Change to main menu	>
C<CR>	Change to command mode, start measurement	

Tab: 4.2: Commands in menu mode

4.2.1 Command mode

In command mode and menu mode rather the same commands (in ASCII-format) are used.

Note: In command mode the user always has to enter the **complete** command sequence.

! In command mode parameterization and data acquisition are carried out in parallel.

The “quit”-command (“Q<CR>”, “back to main menu”) is not allowed in command mode!

Example: The user wants to set the baud rate of the serial interface RS485 to 19200 baud. The following command sequence has to be entered:

Command	Meaning	Prompt
Sb5<CR>	Set baud rate of RS485 to 19200 baud	<CR>

Tab: 4.3: Commands in command mode

In command mode there is no need to navigate through the submenus.

Each input is acknowledged on the screen: a **wrong command** with “?”, a **wrong parameter** with “E”. A **correct input** is acknowledged with “<CR>”.

4.3 Measurement parameters

The following parameters can be measured:

- Tilt in x- and y-direction
- Two different temperatures
- Pressure
- Humidity
- Orientation (integrated compass)
- Motor current
- Supply voltage
- Time / date (integrated)

The rate of data acquisition is variable TiltX and TiltY are always measured. All other parameters and their sequence are freely selectable, as well as the rate of data acquisition.

All data values are in digits, this means conversion to physical units must be performed according to the calibration data sheet (see Chapter 1).

Parameters have to be set externally via one of the both serial interfaces using ASCII-format.

4.4 Main menu

In the main menu different actions can be performed (see Tab: 4.4):

- 1.) It is possible to **switch to one of the following submenus**:
 - Submenu **Settings** (of the device)
 - Submenu **Timing** (of the measurements)
 - Submenu **Output format** (Selection of data to be measured)
 - Submenu **Memory** (data handling)
 - Submenu **Levelling** (of the device)
 - Submenu **Factory Settings** (of the device)
- 2.) It is possible to **control the motor** for manual positioning of the Tiltmeter.
- 3.) If the device is **in software-triggered mode**, a measurement can be started.
- 4.) Measurements can be activated or deactivated
- 5.) The **current settings** can be **sent**.

Command	Prompt	Meaning	Comment
S<CR>	S>	Change to Settings	Set baud rate, clock, serial interfaces and measurement mode
T<CR>	T>	Change to Timing	Timing of the measurement
O<CR>	O>	Change to Output format	Selection of channels
M<CR>	M>	Change to Memory	Data storage (e.g. flash memory)
L<CR>	L>	Change to Levelling	Levelling commands, motor control
F<CR>	F>	Change to Factory settings	Access code needed
R<CR>	<CR>	Execute one Measurement	Only possible in software-triggered-mode
C<CR>	<CR>	Change to command mode	Only possible in menu mode
U<CR>	>	Change to menu mode	Only possible in command mode
D<CR>	<CR>	Dump all settings	
a<CR>	<CR>	Set Motor speed to 20%	
b<CR>	<CR>	Set Motor speed to 25%	
c<CR>	<CR>	Set Motor speed to 30%	
d<CR>	<CR>	Set Motor speed to 40%	
e<CR>	<CR>	Set Motor speed to 60%	
f<CR>	<CR>	Switch both motors off	
g<CR>	<CR>	Motor 1 turn left	
h<CR>	<CR>	Motor 1 turn right	
i<CR>	<CR>	Motor 2 turn left	
j<CR>	<CR>	Motor 2 turn right	
A<CR>	<CR>	Activate measurements	
X<CR>	<CR>	Deactivate measurements, save all data	

Tab: 4.4: Main Menu

! In case of data storage to the internal flash memory, the measurement **MUST** be deactivated with the command **“X<CR>”** before cutting the power supply!! Otherwise loss of data can occur!

The command **“X<CR>”** saves all data to the flash memory

After switching on, the tiltmeter is ready to measure.

4.4.1 Submenu “Settings“

In the **Settings** menu

- The user selects **the serial interface(s) for data transfer**
- Their **baud rate**
- **time and date** of the internal real time clock can be checked and set
- the **measurement mode** can be selected (software/hardware-triggered, continuous)

The commands are listed in Tab: 4.5. After their change, parameters are saved immediately. With the **command “D<CR>”** the settings are sent.

Command	Meaning	Parameter	Comment
Bn<CR>	Baud rate RS485	n=0: 1200 n=1: 2400 n=2: 4800 n=3: 9600 n=4: 14400 n=5: 19200 n=6: 38400 n=7: 57600 n=8: 115200	
bn<CR>	Baud rate RS232	n=0: 1200 n=1: 2400 n=2: 4800 n=3: 9600 n=4: 14400 n=5: 19200	
Cs<CR>	Set clock	Format: s=dd.mm.yyyy hh:mm:ss	The format is not verified!
c<CR>	Read clock	Format: dd.mm.yyyy hh:mm:ss	
R<CR>	Output to RS485		
r<CR>	No output to RS485		
T<CR>	Output to RS232		
t<CR>	No output to RS232		
X<CR>	Use XON/XOFF		for RS232 and RS485
x<CR>	Use no XON/XOFF		
Mc<CR>	Measurement mode	c=C: continuous c=S: Software triggered c=H: hardware triggered	See chapter 3.2!!
D<CR>	Dump all settings		All settings of the current submenu are sent
Q<CR>	Quit		main menu (only in menu mode)

Tab: 4.5: Submenu “Settings“

4.4.2 Submenu “Timing“

In the **Timing** menu the user can **set and check the number of averages** (‘primary’ data set, see Chapter 2.1.) **Possible values n** for the timing **are listed in Tab: 4.7**

Command	Meaning	Parameter	Comment
D<CR>	Get timing	Reply format: Timing:n, Averaging: xxxxx samples, data rate: yyyy samples/s, sample time:zz	
Sn<CR>	Set timing	n=see Tab: 4.7	
Q<CR>	Quit		Change to main menu (only in menu mode)

Tab: 4.6: Submenu „Timing“ – Overview

Number n	Number of Samples	Measurement time [s]	Measurement time [min]	Measurement time [h]
0	1048576	86398,29	1439,97	24,00
1	524288	43199,15	719,99	12,00
2	524288	28799,43	479,99	8,00
3	262144	21599,57	359,99	6,00
4	262144	14399,72	240,00	4,00
5	131072	10799,79	180,00	3,00
6	131072	7199,86	120,00	2,00
7	65536	3599,93	60,00	1,00
8	32768	1799,96	30,00	0,50
9	8192	600,00	10,00	0,17
10	4096	300,00	5,00	0,08
11	2048	120,00	2,00	0,03
12	1024	60,00	1,00	0,02
13	512	30,00	0,50	0,01
14	256	15,00	0,25	0,00
15	128	10,00	0,17	0,00
16	64	5,00	0,08	0,00
17	32	2,00	0,03	0,00
18	16	1,00	0,02	0,00
19	8	0,50	0,01	0,00
20	4	0,25	0,00	0,00
21	2	0,10	0,00	0,00

Tab: 4.7: Timings

4.4.3 Submenu “Output“

In the **Output menu** the user selects the **channels, which are to be collected in a data set**. Depending on the preferences in the submenu “Settings”, data are transferred via one or both of the two serial interfaces. In addition – if set in the memory menu – measurement data sets are stored to the internal flash memory. The sequence of the data is determined by the sequence of their selection.

Channels to be selected:

- Compass
- Temperature 1
- Temperature 2
- Pressure
- Humidity
- Motor current
- Ground
- Supply voltage
- Date/Time
- Serial number

Command	Meaning	Parameter	Comment
C<CR>	Compass		Acquire compass values
T<CR>	Temperature1		Acquire temperature 1 value
U<CR>	Temperature2		Acquire temperature 2 value
P<CR>	Pressure		Acquire pressure value
H<CR>	Humidity		Acquire humidity
M<CR>	Motor current		Acquire motor current
G<CR>	Ground		Acquire ground signal
S<CR>	Supply voltage		Acquire supply voltage
D<CR>	Date/time		Acquire date and time. Format: ddmmyyyy hhmmss
N<CR>	Serial number		Acquire serial number
F<CR>	Format		Send current output format
R<CR>	Reset		Reset output format
Q<CR>	Quit		main menu (only in menu mode)

Tab: 4.8: Submenu „Output“ – Overview

Example: The commands are entered in menu mode. The following **channels** should be measured:

- TiltX,
- TiltY,
- Humidity,
- Pressure,
- Date/Time.

Command	Meaning	Prompt
U<CR>	Change to menu mode	>
O<CR>	Change to submenu „Output“	O>
H<CR>	Measure humidity	O>
P<CR>	Measure pressure	O>
D<CR>	Record Date, Time	O>
Q<CR>	Change to main menu	>
C<CR>	Change to command mode, start measurement	

Tab: 4.9: Selection of channels for a data set

! If the selection of channels is changed, all data of the flash memory are deleted!

4.4.4 Submenu „Memory“

In the **Memory menu**

- storage of the measured data to the flash memory is activated/deactivated
- all data in the memory can be deleted
- output of the saved data via the serial interfaces can be initiated

Command	Meaning	Parameter	Comment
S<CR>	Store data in flash memory		Activates data storage to the flash memory
s<CR>	Don't store data in flash memory		Activates data storage to the flash memory
L<CR>	Delete		Deletes data in the flash memory
G<CR>	Output data to Interface(s)		via the serial interfaces
D<CR>	Dump all setting		All settings of the current submenu are sent
Q<CR>	Quit		main menu (only in menu mode)

Tab: 4.10: Submenu „Memory“ – Overview

4.4.5 Submenu “Levelling”

In the Levelling menu

- the **motor** of the tiltmeter can be **controlled** and
- the **instrument** can be **levelled**
- The **levelling** can be performed **manually** or
- **Automatically.**

Command	Meaning	Parameter	Comment
a<CR>	Set Motor speed to 20%		
b<CR>	Set Motor speed to 25%		
c<CR>	Set Motor speed to 30%		
d<CR>	Set Motor speed to 40%		
e<CR>	Set Motor speed to 60%		
f<CR>	Switch both motors off		
g<CR>	Motor 1 turn left		
h<CR>	Motor 1 turn right		
i<CR>	Motor 2 turn left		
j<CR>	Motor 2 turn right		
x<CR>	Increase motor on time (ALMotorOnTime)		Only in auto levelling
y<CR>	Decrease motor on time (ALMotorOnTime)		Only in auto levelling
m<CR>	Increase motor off time (ALWaitLoops)		Only in auto levelling
n<CR>	Decrease motor off time (ALWaitLoops)		Only in auto levelling
A<CR>	Start automatic levelling		
In<CR>	Max. iterations for automatic levelling(ALMaxIterations)	n=2...10	
Tn<CR>	Min. tilt for automatic levelling (ALMinTiltThreshold)	n = 1000 ... 50000	
Cn<CR>	Max. current for automatic levelling (ALMaxMotorCurrent)		
D<CR>	Dump all setting		All settings of the current submenu are sent
Q<CR>	Quit		Main menu (only in menu mode) Levelling menu (in auto levelling)

Tab: 4.11: Submenu “Levelling” – Overview

Auto Levelling

During auto levelling the instrument independently tries to minimize the tilt in x and y direction below a minimal threshold value (`ALMinTiltThreshold`). For this purpose the motors are alternately controlled.

Auto levelling is cancelled

- If the **motor current exceeds a maximum limit** (`ALMaxMotorCurrent`)
- If the **maximum number of iterations is exceeded** (`ALMaxIterations`)
- If the **tilt falls below the threshold** (`ALMinTiltThreshold`)
- If the **user cancels the levelling** by entering “Q”

4.4.6 Submenu “Factory settings“

In the menu “**Factory settings**” the **serial number** is set. The parameters of the tiltmeter can be **reset to the factory settings**.

An access code is needed to get to the menu “Factory settings”.

Command	Meaning	Parameter	Comment
Ss<CR>	Set serial number	s= S/N	Format: alphanumerical, max. 20 characters
R<CR>	Reset Settings		Reset and save settings
D<CR>	Dump all setting		All settings of the current submenu are sent
Q<CR>	Quit		main menu (only in menu mode)

Tab: 4.12: Submenu “Factory Settings“ – Overview

The command D<CR> sends all settings of the submenu “Factory settings”.

```
HW:V1
SW:V2.00 27.02.2011
SerialNumber:0815
```

Fig.: 4.2: Screen display after entering the command D<CR> in the submenu “Factory settings”

The command R<CR> resets the Tiltmeter to the factory settings:

```
SerialNumber:0815
BaudrateRS232:9600
BaudrateRS485:19200
UseRS232:yes
UseRS485:yes
XonXoff:no
MeasurementMode:CONTINUOUS
RequestedResults:XY
StoreDataInFlash:no
Timing:18,Averaging:128 samples, data rate:128 samples/s, sample time:1s
ALMinTiltThreshold:10000
ALMaxIterations:10
ALMaxMotorCurrent:1000
ALSpeed:30
ALMotorOnTime:3
ALWaitLoops:20
Operation mode:Command
```

Fig.: 4.3: Factory Settings

5 Annex

5.1 Installing New Software

How to proceed:

- switch off the instrument
- connect the meter to the host PC using the serial interface cable
- start the program *CVMegaload*
- select the active COM-Port
- set the baud rate to 9600
- select the new program file to be downloaded to the tiltmeter
- switch on the tiltmeter
- download will start automatically
- after download terminate the program *CVMegaload*

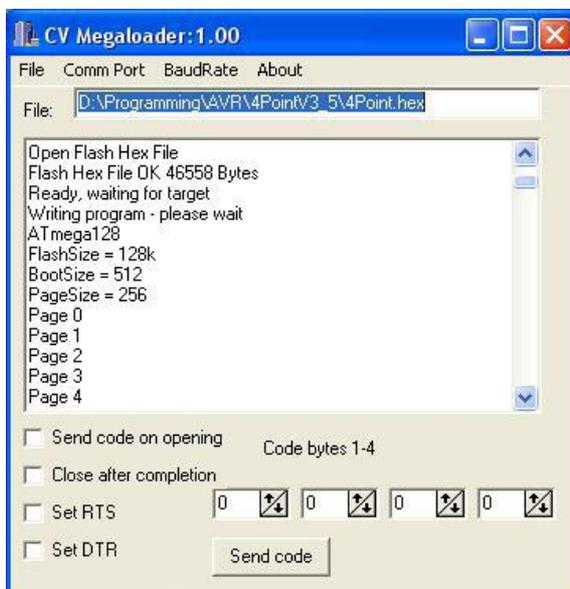


Fig. 5.1: After starting the download

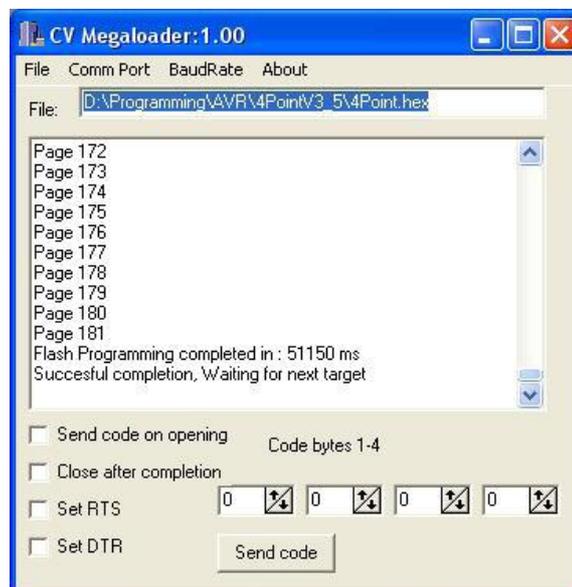


Fig. 5.2: After termination of download

5.2 Abbreviations

mrad	milli radian
μrad	micro radian
nrad	nano radian
prad	pico radian
<CR>	Carriage return