sysWORXX series

System Manual

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Changes

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1 Introduction

Thank you for choosing a SYS TEC sysWORXX device. This product provides to you an innovative, Linux-based and high-capacity compact controller to process standard industrial signals. Due to its numerous in- and outputs and communication interfaces it is well-suitable as central control in distributed automation appliances.

Please take some time to read through this manual carefully. It contains important information about the commissioning, configuration, and programming of this device. It will assist you in getting familiar with the functional range and usage. This document describes all the main features and configuration options of a sysWORXX device. More information for each individual device can be found in the corresponding document listed in Table 1. This document is otherwise mostly applicable to all our sysWORXX devices. Some sections of this documents may not apply fully to each individual sysWORXX device, because specific hardware must be present on the device (e.g., digital, or analog intputs, number of interfaces, LTE modem, etc.).

As Linux-based compact controller, the module is programmable in multiple programming languages, like C/C++, C#, Java, and Python and in IEC 61131-3. Also, the Node-RED node editor is available. All these options allow highly efficient software development for this module. The on-board firmware contains the entire PLC runtime environment including CANopen connection with CANopen Master Functionality. Thus, the module can operate control tasks such as linking in- and outputs or converting rule algorithms. Data and occurrences can be exchanged with other nodes (e.g., superior main controller, I/O slaves and so forth) via CANopen network, Ethernet (UDP protocol) and serial interfaces (UART). The numerous in- and outputs that the module provides can be decentrally extended by CANopen devices. CANopen IO modules of *sysWORXX Automation Series* are well-suited for this. Those modules are also designed for processing industrial standard signals (24VDC, 0-10VDC, 0-20mA etc.).

This device uses Debian GNU/Linux as operating system. This allows for an execution of other user-specific programs while PLC firmware is running. If necessary, those other user-specific programs may interchange data with the PLC program via the process image or the Node-RED nodes for reading and writing of variable values. More information about this is provided in the specific language Application Notes listed in Table 1.

The Linux applied is licensed under GNU General Public License, version 2 (see Appendix B) contains the license text. All sources are accessible from our GitHub repository (https://github.com/systec-electronic). We also offer an VirtualBox-Image for Linux development on our website, which includes all the sources as well.

The PLC system and the PLC-, C# and C/C++ programs developed by the user are **not** subject to GNU General Public License!

For device specific information, consult the separate technical documentation. This document is complemented by other manuals, e.g. for the OpenPCS IEC 61131 programming system. Table 1 in section 2 lists relevant manuals for this device. This table also references documentation to other software components and programming languages which are supported, such as Node-RED, C# or Java. Please also refer to those complementary documents.

For more information, optional products, updates et cetera, we recommend you to visit our website: https://www.systec-electronic.com. The content of this website is updated periodically and provides you with downloads of the latest software releases and manual versions.

2 Overview

Table 1 lists up all relevant manuals for the device.

Table 1: Overview of relevant manuals

Information about…	In which manual?
Basic information about the device (configuration, administration, process image, connection assignment, firmware update, reference designs et cetera)	In this manual
Technical documentation for the specific sysWORXX devices	• sysWORXX CTR-500 - L-2842 • sysWORXX CTR-700 - L-2843 • sysWORXX CTR-750 - L-2844
Basics about the *OpenPCS* IEC 61131 programming system	Brief instructions for the programming system (Entry "*OpenPCS Dokumentation*" in the *OpenPCS* program group of the start menu) (Manual no.: L-1005)
Complete description about the *OpenPCS* IEC 61131 programming system, basics of PLC programming according to IEC 61131-3	Online help about the *OpenPCS* programming system
Command overview and description of standard function blocks according to IEC 61131-3	Online help about the *OpenPCS* programming system
SYS TEC extension for IEC 61131-3: - String functions - UDP function blocks - SIO function blocks - FB for RTC, Counter, EEPROM, PWM/PTO	User Manual *"SYS TEC-specific extensions for OpenPCS / IEC 61131-3"* (Manual no.: L-1054)
CANopen extension for IEC 61131-3 (network variables, *CANopen* function blocks)	User Manual *"CANopen extension for IEC 61131-3"* (Manual no.: L-1008)
Textbook about PLC programming according to IEC 61131-3	IEC 61131-3: Programming Industrial Automation Systems John/Tiegelkamp Springer-Verlag ISBN: 3-540-67752-6 (a short version is available as PDF on the *OpenPCS* installation CD)

One can also use Node-RED, Java or C# to program the device. The following table provides links to the websites of those projects. On these sites you will also find guides and references on how to use these programming environments for developing applications. Getting started with these environments is described in this document.

Project	Website
Node-RED	https://nodered.org/
Mono / C#	http://www.mono-project.com/
OpenJDK / Java	http://openjdk.java.net/

3 Safety Guidelines

This product may only be operated by personnel qualified for the specific task in accordance with the corresponding documentation for this specific task. This relates to its warning notices and safety instructions. Qualified personnel are those who, when working with these products, can identify risks and avoiding potential hazards.

This manual contains notices you have to observe in order to ensure your personal safety, as well as to prevent damage to property. These notices shown below are graded according to the degree of danger.

DANGER

Danger signs warn for potential life-threatening situations. There may be occur damage not only to the device and its surroundings, but also to the operating personnel. **Do under no circumstance ignore these warnings!**

WARNING

Warnings show, when certain situation could permanently damage the device or its surroundings. Make sure to always follow the instruction, to not harm any parts of the hardware.

NOTICE

Notices describe, which things could inflict potentially harmful things to the device. There is no imminent danger to personnel or the surrounding hardware, but the functionality of the device could be permanently impaired.

4 Information for usage

4.1 Product Identification

On each device, there is a label, identifying which device it is. An example is shown in Figure 1.

Figure 1: Label sysWORXX CTR-750

Typically, the label is printed on the top shell of the device. On some devices, the label may instead be placed on the side. A detailed explanation for the label information can be found in Table 2.

Table 2: Label description

Label	Description
Name	Name of the specific device, e.g, sysWORXX CTR-750
Model	Ordering number, which is described in further detail in the individual device manuals
Serial	Serial number – this is individual for each device
Input	Description, which voltage/power the device will need to function properly
Data Matrix	It contains the information from above and additionally the MAC addresses for each Ethernet interface. The string has the following structure: *Name_Model_Serial_MAC1_MAC2* The code reads as: *CTR-750_23031000_1234567_f8dc7a3bb9e2_f8dc7a3bb9e3*
Pictogram	1. There is a Manual and it must be read before using the device. 2. The device must not be disposed of with normal household waste. 3. The device is compliant with relevant EU legislations.

4.2 Storage

The device must be stored under the following conditions:

- Protection against moisture, frost, heat, dust, and sand
- Free from vibrations
- Relative humidity must be between 20% and 75%
- Relative humidity must not change by more than 15% within 24 hours

4.3 Intended Use

The device is designed for use in the industrial sector (EN 61000-6-2:2005 & EN 61000-6-4:2007 + A1:2011) only.

NOTICE

The approvals are voided, if certain modifications are made

- The device was opened.
- The device was physically modified, for example, additional openings were created.
- Cables are routed from the inside out of the device or from the outside into the device, for example, to connect additional peripherals.
- The specified cable lengths for the interfaces must not be exceeded.

Under certain conditions one can use the device for residential purposes and for commercial operations, if that does not significantly impact the residential purpose. In that case, one must comply with the radio frequency interference limits of the generic standard EN 61000-6-3.

Please contact us, if there is the need to use the device in any condition or sectors, which are not specified in this document.

4.4 3D Assembly Files

The STP files for each device can be downloaded from the product page on our website https://www.systec-electronic.com/.

4.5 Mounting

The device must only be installed by a trained specialist.

NOTICE

Mounting

This device is intended to be mounted on DIN rail. It is designed to be attached horizontally only (orientation does not matter). Mounting it vertically may disturb the air flow and can cause over-heating of the internal components.

NOTICE

Limitation of liability

Technical specifications and approvals of this device only apply, if expansion components with a valid CE approval are used.

Also, the installation conditions for expansion components, described in the associated documentation, must be followed.

SYS TEC electronic is not liable for functional limitations caused by the use of third-party devices or components.

4.6 Repair, Decommissioning and Disposal

Once a device has reached end-of-life, it must be taken out of service and disposed of properly. The device must not be disposed of with household waste. Instead, it must be disposed of in accordance with the current legal regulations of the respective countries it is used in.
A faulty unit must be returned to the manufacturer.
A faulty unit cannot be repaired or can only be repaired by the manufacturer.

4.7 Power Supply

The devices feature power supply inputs (24VDC ±20%) for CPU unit and optional peripheries (e.g., digital in- and outputs). For more details refer to the specific device documentation.

4.8 In- and Outputs for Industrial Standard Signals

4.8.1 Digital Inputs

Each digital input has the same supply potential. The inputs are high active with the following switching threshold:

- Input voltage > 15 VDC: is shown as ‘1’ in the process image
- Input voltage < 5 VDC: is shown as ‘0’ in the process image

Digital inputs have an internal structure as shown in Figure 2.

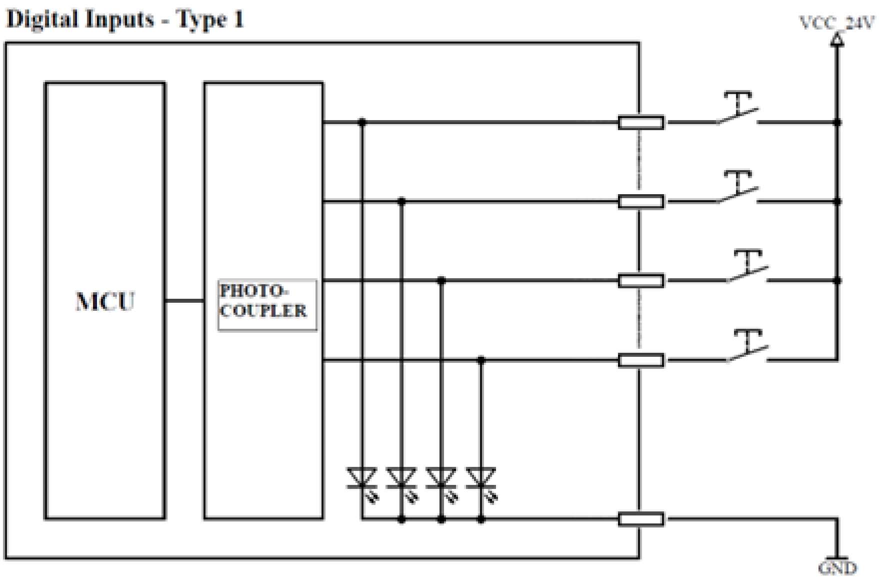

Figure 2: Setup of digital inputs

The digital inputs in a PLC program are accessible via the process image (more information can be found in the specific device documents).

4.8.2 Relay Outputs

The relays are normally-open contacts. They are high active:

- ‘1’ in process image: contact is closed
- ‘0’ in process image: contact is open

Relay outputs have an internal structure as shown in Figure 3.

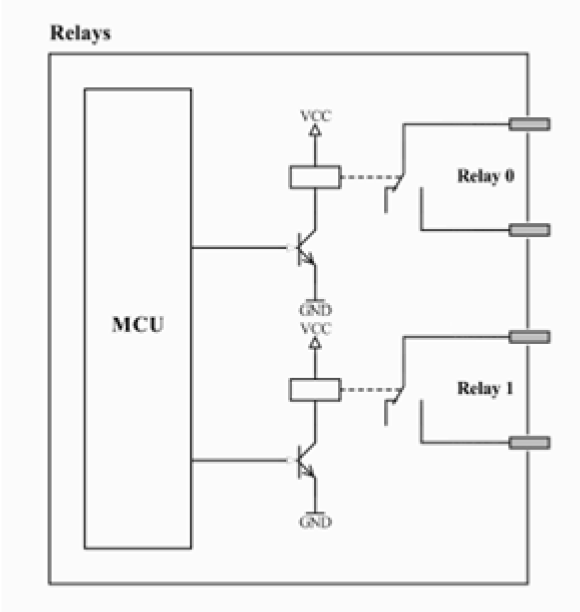

Figure 3: Setup of relay outputs

Attention! Country-typical technical standards for the usage of power supply voltage must be taken into consideration.

The Relay outputs are in a PLC program accessible via the process image (more information can be found in the specific device documents) or more general via the sysWORXX IO driver as described in chapter 6.

4.8.3 Digital Outputs

The digital outputs each connect the supply voltage Vcc of the appliance (switching positively). The maximum load current for each 24V output is 0.5A for ohmic, inductive or capacitive load. The outputs are short-circuit-proof and galvanically isolated from the CPU unit. The outputs are protected against excess voltage, reverse polarity, and excess temperature. The outputs are accessed high active:

- ‘1’ in process image: output transistor active, appliance connected with Vcc
- ‘0’ in process image: output transistor inactive, appliance disconnected from Vcc

The digital transistor outputs have an internal structure as shown in Figure 4. At and after powerup and reset the outputs are in off state.

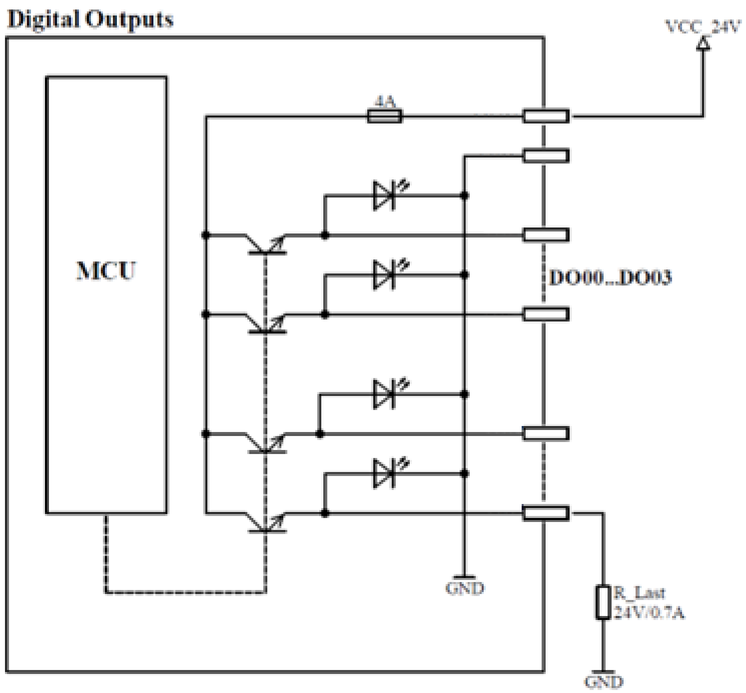

Figure 4: Setup of digital outputs

The digital outputs in a PLC program are accessible via the process image (more information can be found in the specific device documents.

4.8.4 Analog Inputs

The analog inputs are by default configured for voltage mode. In current mode, an open-loop detection is implemented reducing the input range to 4 … 20 mA. They support a resolution of 16-bit.

The inputs are protected against overvoltage.

Analog inputs have the same internal structure as shown in Figure 5.

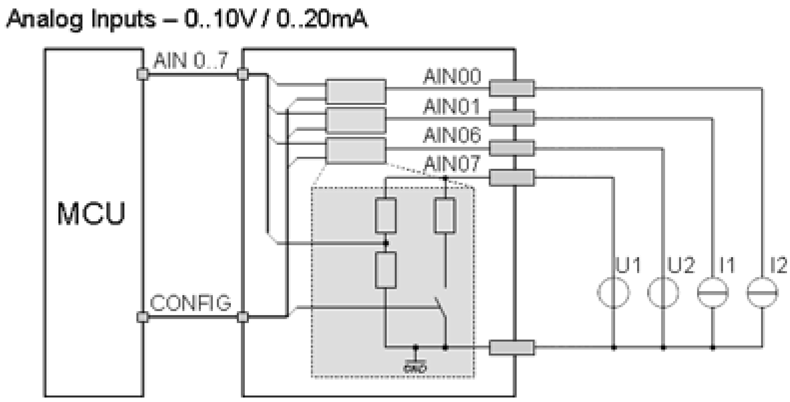

Figure 5: Setup of analog inputs

The analog inputs in a PLC program are accessible via the process image (more information can be found in the specific device documents) or more general via the sysWORXX IO driver as described in chapter 6. Also, the configuration of the inputs is handled through those functions.

Process image and I/O user space driver give a 16-bit signed value for the ADC (two's complement). In case of the Smart Controller only positive values will be returned. Thus only 15-bit with a theoretical range of 0 to 32767 are used. The value range and further information about the analog inputs can be found in the technical specifications for each specific device.

To get the real value for the voltage or current measurement, the LSB must be multiplied by the measured digits. The specific values and calculation can be found inside each individual device document.

Via CONFIG, the analog inputs can be configured for voltage or current settings – more details are described in the specific device manual.

4.8.5 Analog Outputs

The analog outputs are separated into two groups, one for voltage output 0…10V and one for current output 0…20mA respectively. The output of all available interfaces needs to be enabled by setting the general analog enable signal (AOUT_EN or DAC_EN) to *TRUE*.

The analog outputs and the general enable signal in a PLC program are accessible via the process image (more information can be found in the specific device documents) or more general via the sysWORXX IO driver as described in chapter 6.

The calculation for the analog value can be found in the device specific documentation.

4.8.6 Resistance Thermometer Detectors (RTD)

In the default configuration, all RTD inputs are configurated as PT100 in two-wire mode, but other configurations are possible and depicted in Figure 6.

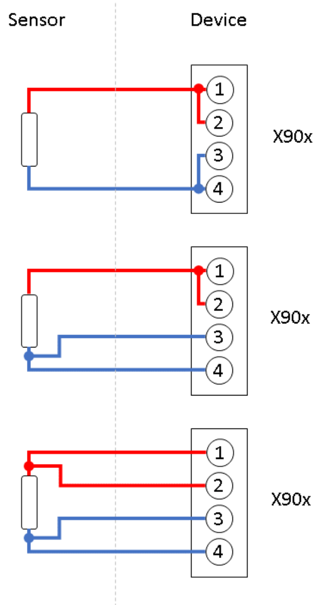

Figure 6: RTD-Wiring Schematic

The RTDs in a PLC program are accessible via the process image (more information can be found in the specific device documents) or more general via the sysWORXX IO driver as described in chapter 6. Also, the configuration of the inputs is handled through those functions.

4.8.7 Thermocouples (TC)

The TC inputs are for K-type sensors.

The TCs in a PLC program are accessible via the process image (more information can be found in the specific device documents) or more general via the sysWORXX IO driver as described in chapter 6.

4.9 Communication Interfaces

4.9.1 Serial Interfaces

The sysWORXX devices feature one service and at least one additional serial interface. They can be used as Linux-Devices. To map each interface to a Linux-Device, refer to the device specific documentation.

SERVICE
The service interface serves to administer the device. The connection to a computer is established via Micro-USB.

SERIAL
Interfaces for serial communication can be used for data exchange under control of the PLC program. RS-232 signals Rx, Tx and GND or RS-485 signals D0, D1 and COM are available. Additionally, the configuration for the RS-485 must be added to the source code of an application. When used as RS-485, termination resistors can be activated via the DIP-Switch. The termination should only be used, if the device is the last in line. By default, the interface uses RS-232 signals.

Setting up a serial interface for RS-485

RS-485 is available for the serial interfaces. To set up an interface for RS-485, the following configuration must be executed. Substitute **INTERFACE** with the targeted interface (available interfaces, are specified in the individual device documentation):

```
#include <stdio.h>
#include <string.h>
#include <strings.h>
#include <unistd.h>
#include <errno.h>
#include <stdlib.h>
#include <fcntl.h>
#include <termios.h>
#include <sys/select.h>
#include <sys/ioctl.h>
#include <linux/serial.h>

int main() {
    int iInterface = open("INTERFACE", O_RDWR | O_SYNC);

    struct serial_rs485 RS485;

    ioctl(iInterface, TIOCGRS485, &RS485);
    RS485.flags |= SER_RS485_ENABLED;
    RS485.flags &= ~SER_RS485_RX_DURING_TX;
    ioctl(iInterface, TIOCSRS485, &RS485);

    close(iInterface);
}
```

This code must be put into a C-file, compiled, and can then be executed. The following commands show, how to do this. This example assumes, that the file with the code above is called “rs485.c”.

Compiling:	`gcc -o rs485 rs485.c`
Executing:	`./rs485`

Hint: After the device is restarted, this configuration must be executed again, because each bootup, the interface is set to RS232 communication.

4.9.2 CAN Interfaces

The CAN-Bus-Transceivers are galvanically isolated to each other and to the CPU. The transceivers are supplied via two on-board DC/DC converter. CAN-Bus signals HIGH, LOW, and GND are available from withdrawable terminal-block connectors.

Section 7.7 provides detailed information about the usage of both CAN interfaces in connection with CANopen.

CAN cable: The CAN-Bus usually is a twisted pair line. At both ends of the cable, a termination resistor of **120 Ohm termination** is necessary **between CAN_H and CAN_L**. CiA (CAN in Automation) must use CAN-GND in CiA DRP 303-1. For more informations please refer to the appropriate CiA standards.

Both CAN interfaces also support the use of an internal termination resistor for one end of the CAN bus. The DIP-switch to make use of these resistors is described in the specific device manual.

4.9.3 Ethernet Interfaces

The device features up to two Ethernet interfaces (ETH0 and ETH1) which are designed as 10Base-T/100Base-TX/1000Base-TX.

The Ethernet interface serves as service interface to administer the device and it can be used for data exchange with any other devices.

4.9.4 USB-Host

The device features a USB 2.0 host interface.

5 Configuration and Administration

5.1 System Requirements and Necessary Software Tools

The administration requires any Windows or Linux computer that has available an Ethernet or USB interface. These allow a connection to administer the device via a Linux command line-interface.

All examples referred to in this manual are based on an administration using a Windows computer. Procedures using a Linux computer would be analogous.

To administrate the device the following software tools are necessary:

Terminal program

A Terminal program allows the communication with the **command shell** via **the integrated USB-to-UART bridge (USB service console) of the** device. This is required for the Ethernet configuration as described in section 5.3. After completing the Ethernet configuration, all further commands can either be entered in the Terminal program or alternatively in an SSH client (see below).

A suitable Terminal program would be *"TeraTerm",* which is available as Open Source Software (*BSD* License). The project page is located at: http://ttssh2.osdn.jp/.

Secure Shell (SSH)

SSH allows the encrypted communication with **command shell** via **Ethernet**. Using SSH requires a completed Ethernet configuration of the device according to section 5.3. As alternative solution to SSH, all commands can be used via a Terminal program.

Suitable as SSH client would be *"PuTTY"* or *"TeraTerm",* which can also be used as Terminal program (see above). "*PuTTY*" is licensed under *MIT*-License and can be downloaded at: https://www.chiark.greenend.org.uk/~sgtatham/putty/.

SFTP client

An SFTP client allows file transfer between the device and the computer. This allows for example **editing configuration files** by transferring those onto the computer where they can be edited and get transferred back to the device. Downloading files is also necessary to **update the PLC firmware**. (Advice: The update of *PLC firmware* is not identical with the update of the *PLC user program*. The PLC program is directly transferred to the module from the *OpenPCS* programming environment. No additional software is needed for that.)

Suitable as SFTP client would be *"WinSCP"* which is available as Open Source Software (GNU GPL).

For programs that communicate via Ethernet interface, such as SFTP client or TFTP server, it must be paid attention to that rights in the Windows-Firewall are released. Usually Firewalls signal when a program seeks access to the network and asks if this access should be permitted or denied. In this case access is to be permitted.

5.2 Connection Over the Serial Interface

Setting up a connection over the serial interface needs a Terminal Program like *"TeraTerm"* (see 5.1) and the *"Silicon Labs USB to UART Bridge"* driver installed on the computer. The driver can be found here: https://www.silabs.com/products/development-tools/software/usb-to-uart-bridge-vcp-drivers

Additionally, the USB host interface (SERVICE) of the device has to be connected to the computer with a µUSB cable.

If both are installed and the device is connected to the computer, *"TeraTerm"* must be started and configured as follows (see Figure 7):

- 115200 Baud
- 8 Data bit
- 1 Stop bit
- no parity
- no flow control

Note: The Port has to be the COM-interface installed with the Silicon Labs driver. This is depending on the computer on which it was installed. COM3 as shown in Figure 7 is only an example, the real number of the COM interface can vary on other computers.

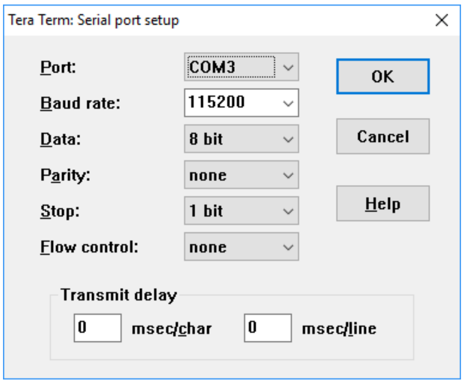

Figure 7: Terminal configuration using the example of "TeraTerm"

Clicking on OK will start the command shell. After pressing any key, the login screen should be visible and the user is able to interact with the device (see Figure 8).

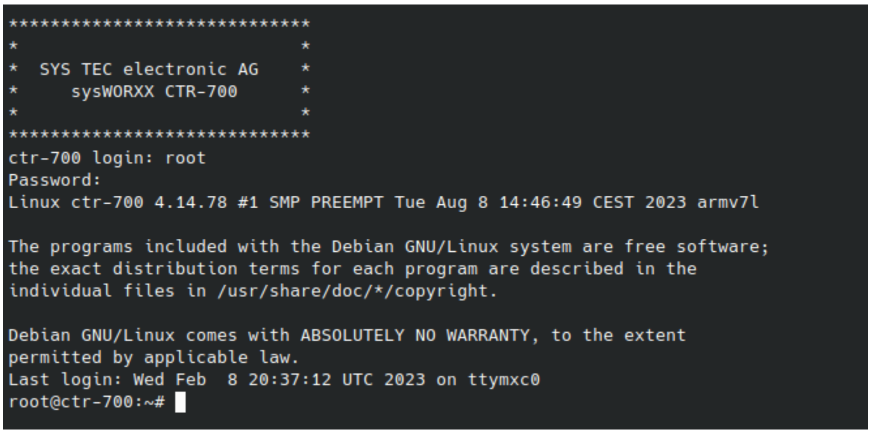

Figure 8: Login screen via SERVICE interface

For the login you need a valid user account. There are predefined and ready to use accounts already available (see section 5.7). In this example, the user *"root"* was used.

5.3 Ethernet Configuration

The device has up to two Ethernet interfaces ETH0 and ETH1.The main Ethernet configurations are saved in the configuration file in */etc/network/interfaces.* By default, only ETH0 is used and configured to use DHCP and the interface ETH1 has no configuration. The following configuration examples below use “ethX” as placeholder. Substitute “ethX” with the targeted network interface *eth0* or *eth1*. Modifications are adopted upon the next reboot.

Advice: After the configuration is finished, the serial connection between PC and the device is no longer necessary.

5.3.1 Get the Current IP Address

To get the current IP addresses of the device, one must set up a connection with a Terminal program (see 5.1). After login one can use the following command, to get a list of IP addresses:

```
ifconfig eth0
```

The parameter *eth0* is optional. If not given, *ifconfig* will print the IP addresses of all interfaces.

The following example shows the IP address *192.168.10.134* for the network interface *eth0*:

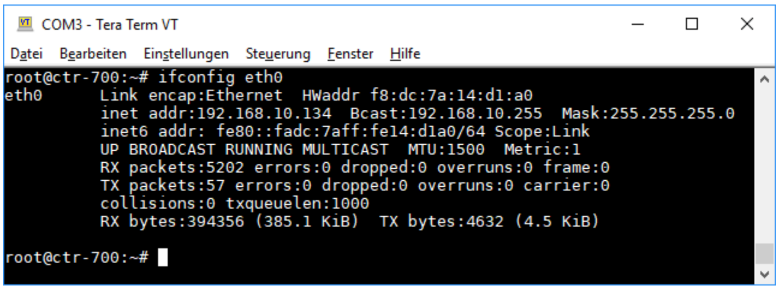

Figure 9: Example – get the IP address for eth0

5.3.2 DHCP Configuration

Add the configuration options listed below to the configuration file, to change the network interface to DHCP.

```
allow-hotplug ethX
iface ethX inet dhcp
```

5.3.3 Static IP Address Configuration

Add the configuration options listed below to the configuration file, to change the network interface to static. Use the proper configuration for your network infrastructure.

```
allow-hotplug ethX
iface ethX inet static
      address 192.168.0.100
      netmask 255.255.255.0
      network 192.168.0.0
      broadcast 192.168.0.255
      gateway 192.168.0.1
```

5.4 LTE-Modem configuration

To activate the LTE capabilities, there is the service “*enable_modem.service*”. If applicable to the device, this service is enabled by default and enables the modem on each boot-up. With the following commands can this service be disabled or re-enabled:

```
systemctl disable enable_modem.service
systemctl enable enable_modem.service
```

5.4.1 Setup and Configuration LTE connections

If the modem is enabled and working, a connection with the SIM card must be established. First, if necessary, the PIN must be set, with the following command. Exchange the dummy PIN with the real one.

```
mmcli --pin 1234 -i 0
```

After that, a connection must be configured and added to the network manager:

```
nmcli c add type gsm ifname cdc-wdm0 con-name mobile apn hologram
```

To de-/activate the connection, the following commands must be used:

```
nmcli c up mobile
nmcli c down mobile
```

Hint:
In this example, the connection is called “mobile”. This name is arbitrary and can be changed. Also, this connection must be set only once. Adding the connection again to the network manager, will create a duplicate, which, under normal circumstances, should be avoided.

5.5 PLC configuration

5.5.1 OpenPCS License Key Handling

For the usage of the PLC functions, the device needs an installed OpenPCS license key. If ordered that way, the key is normally pre-installed. To check, if a key is installed, the following command can be used:

```
cat /vendor/device
```

This command outputs not only the license key, but also other device and vendor information, such as the device specific serial number. If the line for the “LicKey” is empty, no license key is installed.

The key can also be installed, after purchase. For that, please contact us and we provide you with the license key for OpenPCS. With the following command, it can be installed (or deleted):

```
vendor_setup vendor
```

During the following setup, the device specific serial number and the license key must be added. After that, reboot the device. The service for OpenPCS can now be used as described below.

5.5.2 Setup of the Configuration File

The configuration file ***"/home/plc/bin/openpcs.cfg"*** allows for comprehensive configuration of the device. Although, working in it manually does not always make sense, because most of the adjustments may easily be edited via WEB-Frontend (compare section 5.5.1). The setup of the configuration file is similar to the file format "Windows INI-File". It is divided into "*[Sections]*" which include different entries "*Entry=*". Table 3 lists all configuration entries.

Table 3: Configuration entries of the CFG file

Section	Entry	Value	Meaning
[CAN0]	Enabled	0, 1	0: Interface CAN0 is deactivated 1: Interface CAN0 is activated, configuration takes place via entries of the configuration file below
	NodeID	1 … 127 or 0x01 … 0x7F	Node number for interface CAN0 (decimal or hexadecimal with prefix "0x")
	Bitrate in Kbit/s	10, 20, 50, 125, 250, 500, 800, 1000	Bitrate for interface CAN0
	MasterMode	0, 1	1: Master mode is activated 0: Master mode is deactivated
[CAN1]	Enabled	0, 1	0: Interface CAN1 is deactivated 1: Interface CAN1 is activated, configuration takes place via entries of the configuration file below
	NodeID	1 … 127 or 0x01 … 0x7F	Node number for interface CAN1 (decimal or hexadecimal with prefix "0x")
	Bitrate in Kbit/s	10, 20, 50, 125, 250, 500, 800, 1000	Bitrate for interface CAN1
	MasterMode	0, 1	1: Master mode is activated 0: Master mode is deactivated
[ETH0]	PortNum	Default Port no: 8888	Port number for the communication with the Programming-PC and for program download
[ProcImg]	EnableSharing	0, 1	0: No sharing of process image 1: Sharing of process image is enabled (see section 8)
[Login]	Authorization	0, 1	0: Configuration via WEB-Frontend is possible without user login 1: Configuration via WEB-Frontend requires user login
	User	Default Name: PlcAdmin	If entry *"User="* is available, only the user name defined is accepted for the login to configure via WEB-Frontend. If the entry is not available, any user registered on the device (see section 5.9) may login via WEB-Frontend.

The configuration file ***"/home/plc/bin/openpcs.cfg"*** includes the following factory settings:

```
[Login]
Authorization=1
User=PlcAdmin

[CAN0]
Enabled=1
NodeID=0x20
Baudrate=125
MasterMode=1

[CAN1]
Enabled=0
NodeID=0x30
Baudrate=125
MasterMode=0

[ETH0]
PortNum=8888

[ProcImg]
EnableExtIo=1
EnableSharing=0
```

5.6 Service Configuration and Boot Scripts

The Debian GNU/Linux installed on the device uses “systemd” for managing services. Besides the default services of the operating system, there are some additional services available. For executing simple commands on bootup of the system, one can also extend the old-fashioned *rc.local* start script.

5.6.1 Extend Shell Script in /etc/rc.local

The start script */etc/rc.local* will be executed automatically at startup of the system. This file can be altered by the user to execute additional shell commands. One must keep in mind to not block the execution of the script for a long time or start long running commands in background.

5.6.2 Add Custom Systemd Services

A much more flexible way to execute applications on boot-up or running Linux daemons, is to use “systemd” services. Users can add custom services on their own. System service files must be added in */etc/systemd/system/<YOUR_ SERVICE>.service*. The service-file must contain at least the following options:

```
[Unit]
Description=<YOUR_SERVICE_DESCRIPTION>
[Service]
ExecStart=/usr/bin/YOUR_SERVICE_EXECUTABLE
[Install]
WantedBy=multi-user.target
```

Description is the name for the service and *ExecStart* is the path to the executable file or script.
The service can be started automatically at boot-up with the following command:

```
systemctl enable YOUR_SERVICE
```

One can also disable it with the following command:

```
systemctl disable YOUR_SERVICE
```

As more in-depth examples, one could look up the service files of *OpenPCS* or *Node-RED*. The official documentation can be found in the provided man-pages or on the project site of *systemd*.
Important man-pages regarding system services:

```
man systemd
man systemd.unit
man systemd.service
```

Additional information can be found on the project homepage: https://www.freedesktop.org/wiki/Software/systemd/

5.6.3 Configure Services

The devicecomes with a few “systemd” services such as *OpenPCS,* or *Node-RED*. There are two ways to run these services:

1. The following commands are used to manually start or stop *OpenPCS* services:
   ```
   systemctl start openpcs-z5
   systemctl stop openpcs-z5
   ```

2. There is also the possibility to start the *OpenPCS* services automatically on power-on reset or reboot. These are the same commands as mentioned in Section 5.6.2:
   ```
   systemctl enable openpcs-z5
   ```
   To disable the automatic start, the following command is used:
   ```
   systemctl disable openpcs-z5
   ```

Table 4 shows some services, which can be configured by the user. Use the commands as above to run each of the services by substituting the name of the service.

Table 4: systemd services

Service file / name	Enabled by default	Description
adc-modes.service	Yes	Oneshot service, which sets up the ADC configuration from */etc/systec/adc_modes*
node-red.service	No	Enables the Node-RED programming tool, listens by default on port 1880
openpcs-lighttpd.service	No	Web configuration frontend for OpenPCS
openpcs-z4.service	No	OpenPCS RT, uses the CANopen (CAN0) for communication to OpenPCS on the PC **Hint:** This service can only be started if “openpcs-z5.service” is not running.
openpcs-z5.service	No	OpenPCS RT, uses Ethernet (UDP) for communication to OpenPCS on the PC **Hint:** This service can only be started if “openpcs-z4.service” is not running.

5.7 Predefined User Accounts

All user accounts listed in Table 5 are predefined upon delivery. Those allow for a login to the command shell and at the SFTP server of the device.

Table 5: Predefined user accounts

User name	Password	Remark
root	root	Predefined root user for the administration (system configuration, user administration, software updates etc.)
user	user	Main user account
PlcAdmin	Plc123	Administration user for OpenPCS (root user alias; provided for compatibility reasons to older products)

Hint: To secure the device, users must change all predefined passwords (see 5.10). If users are not needed, they can be disabled or removed except the "root" user. Additionally, SSH can be configured for public key authentication for even better security.

5.8 Remote Access

5.8.1 Remote Login to the Command Shell

In some cases, the administration requires the ability to typing shell commands manually. Therefore, the user must be directly logged in at the module. There are two different possibilities:

- Logging in is possible with the help of a **Terminal program** (e.g., TeraTerm, see section 5.1) via the serial interface **SERVICE**.
- Alternatively, the login is possible using an **SSH client** (e.g., PuTTY or also TeraTerm) via the Ethernet interface **ETH0**.

For logging in with SSH via PuTTY or TeraTerm, the IP address provided in section 5.1 must be used.

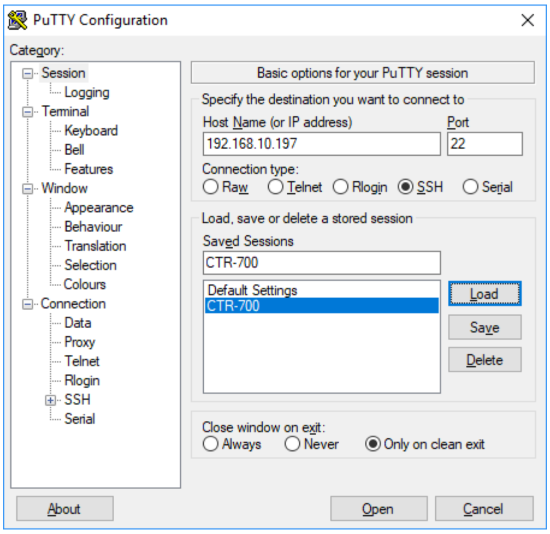

Figure 10: SSH login PuTTY

Logging in is possible in the Terminal window (if connected via Service) or in the SSH window (if connected via ETH0). The following user account is preconfigured for the administration of the module upon delivery (also compare section 5.7):

User: *root*
Password: *root*

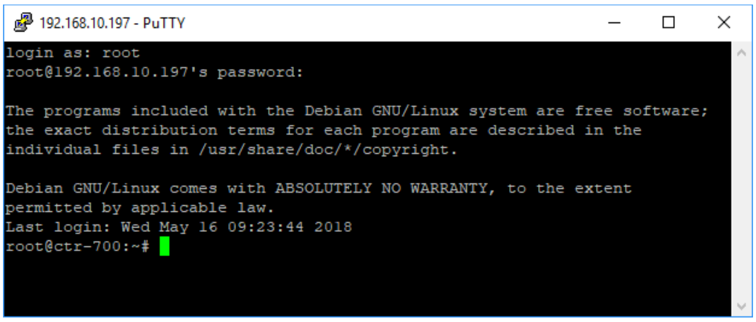

Figure 11: Login to the device

Figure 11 shows the login using PuTTY.

5.8.2 Login to the SFTP Server

The device has available a SFTP server that allows file exchange with any computer (up- and download of files). *"WinSCP"* - which is available as open source - is suitable as SFTP client for the computer (see section 5.1). It consists of only one EXE file, needs no installation, and may be started immediately. After program start, dialog *"WinSCP Login"* appears (see Figure 13) and must be adjusted according to the following configurations:

File protocol: SFTP
Host name: IP address for the device as set in section 5.3
User name: *root* (for predefined user account, see section 5.7)
Password: *root* (for predefined user account, see section 5.7)

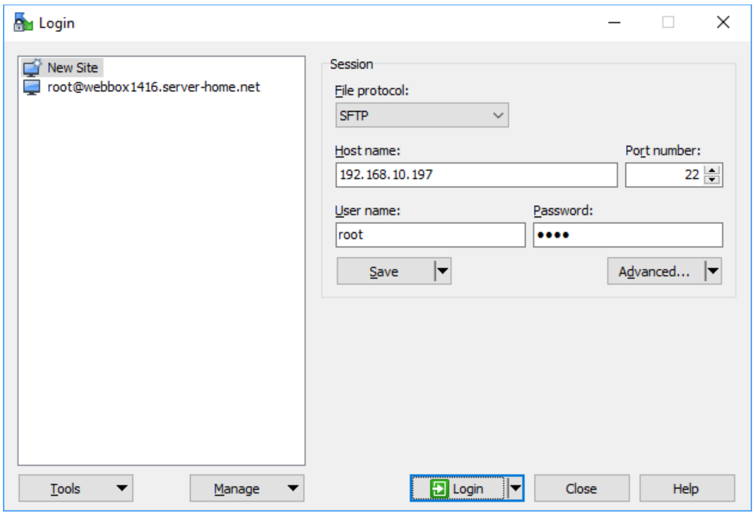

Figure 12: Login settings for WinSCP

After using pushbutton *"Login"*, the SFTP client logs in to the device and lists up the active content of directory *"/root"* in the right window. Figure 13 shows SFTP client *"WinSCP"* after successful login to a device.

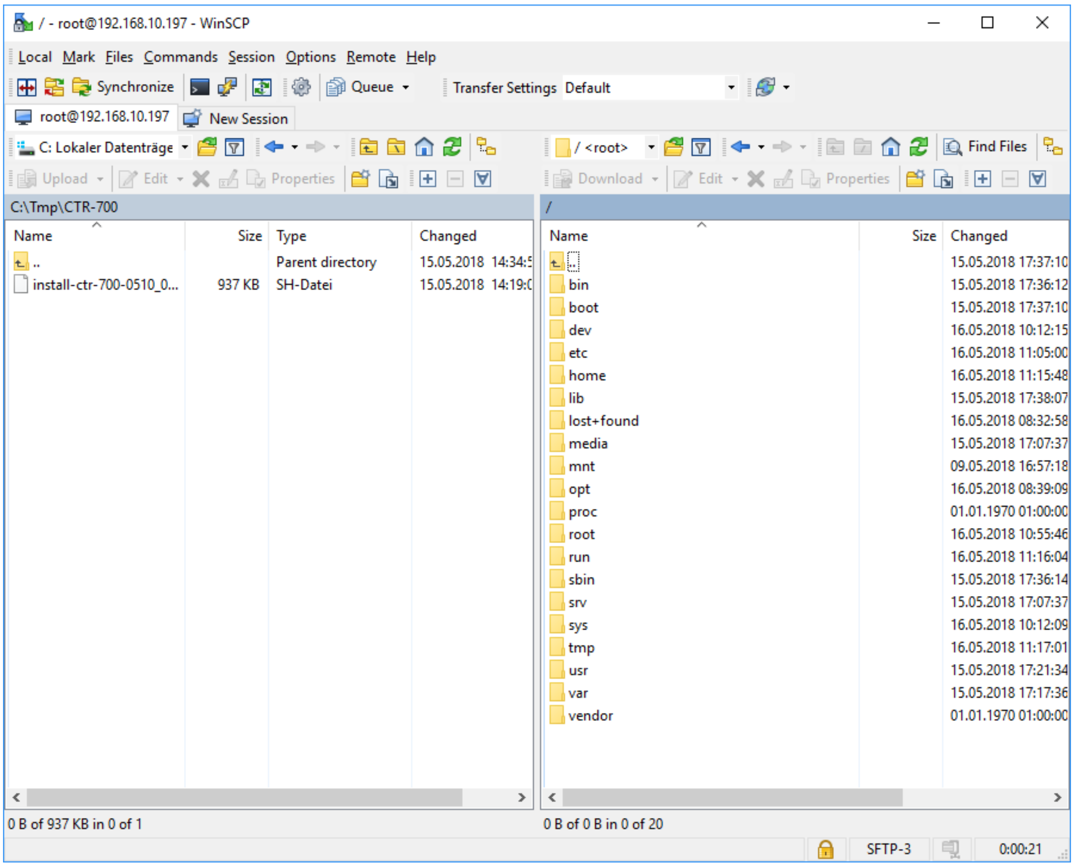

Figure 13: FTP client for Windows "WinSCP"

After successful login, configuration files on the device may be edited by using pushbuttons *"F4"* or *"F4 Edit"* within the SFTP client *"WinSCP"* (select transfer mode *"Text"*). With the help of pushbutton *"F5"* or *"F5 Copy"*, files may be transferred between the computer and the device, e.g. for data backups or to transfer installation files for firmware updates (select transfer mode *"Binary"*).

5.9 Adding and Deleting User Accounts

Adding and deleting user accounts requires the login as described in section 5.8.1.

Adding a new user account takes place via Linux command *"useradd"*. To create a new user, one can use the command *"useradd"* as follows:

```
useradd [options] [username]
```

Advice: **If the new user account shall be used to access web frontend, the user name must be entered into the configuration file (for details about logging in to WEB-Frontend please compare section 5.5.1 and 5.5.2).**

To **delete** an existing user account from the device, Linux command *"userdel"* plus the respective user name must be used:

```
userdel [options] [username]
```

To get a full list of options for one of the commands, run it with the "*--help*" argument.

5.10 How to Change the Password for User Accounts

Changing the password for user accounts requires login as described in section 5.8.1.

To change the password for an existing user account, Linux command *"passwd"* plus the respective user name must be entered:

```
passwd <username>
```

Figure 14
exemplifies the password change for a user named *"testuser"*.

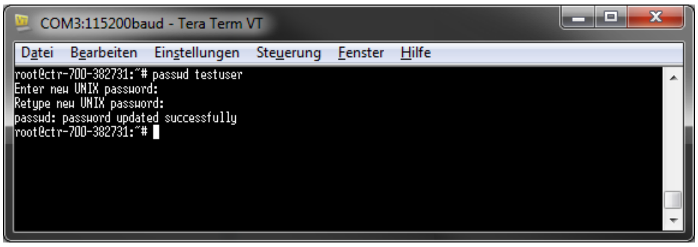

Figure 14: Changing the password for a user account

5.11 Setting the System Time and Time Zone

Setting the system time requires login to the device as described in section 5.8.1.

The current date and time must be set using the Linux command "timedatectl set-time". Linux command *"timedatectl set-time"* is structured as follows:

```
timedatectl [options] set-time "YYYY-MM-DD hh:mm:ss"
```

Example:

```
timedatectl set-time "2017-12-01 10:20:55"
```

The current system time is displayed by entering Linux command *"timedatectl"* (without parameter). Figure 15 exemplifies setting and displaying the system time.

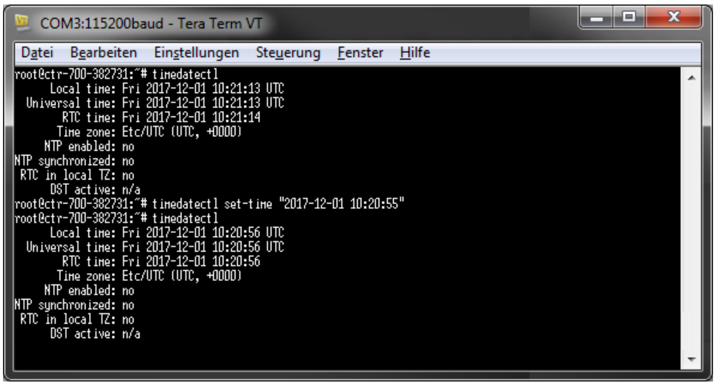

Figure 15: Setting and displaying the system time

Upon start of the device, date and time are taken over from the RTC and set as current system time of the module.

The current time zone must be set using the Linux command “timedatectl set-timezone”. Linux command ″ timedatectl set-timezone″ is structured as follows:

timedatectl [options] set-timezone [TIMEZONE]

Example:

timedatectl set-timezone Europe/Berlin

Figure 16 exemplifies setting and displaying the time zone setting.

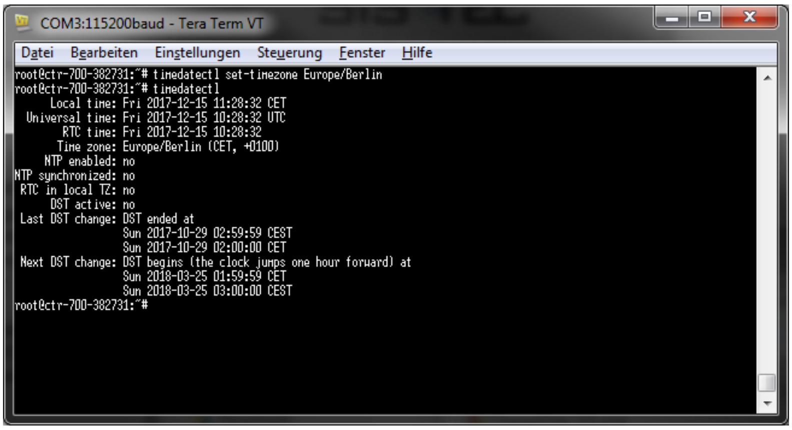

Figure 16: Setting and displaying the system time

With the following command, all available time zones can be looked up:

```
timedatectl list-timezones
```

5.12 File Systems

Table 6 lists the default filesystems and mountpoints of the device.

Table 6: File system configuration

Path	Size	Description
/	8 GiB / size of SD Card	Root filesystem where the Linux is installed to. The content of this partition is stored on the EMMC or SD Card depending on the current Boot-Mode.
/mnt	-	Target for mounting remote directories
/vendor	4 MiB	Read only configuration data of the device. These data should not be altered by the user. The content is stored on one of the general-purpose partitions (aka. “boot0”) to keep its contents event after a firmware update.

Size, usage and path of file systems which are mounted can be identified by using Linux command "df" ("disk free").

Advice: The general purpose EMMC partitions *“/dev/mmcblk2boot0”* and *“/dev/mmcblk2boot1”* contain vendor specific data. These partitions should **not** be used or altered by customers. Otherwise the device will not work as expected!

Particular information about the system login and handling the Linux command shell is given attention in section 5.8.

Since firmware version 4.2.0 a file system check is done during the bootup sequence (via initramfs). This check **may** fix any occurring issues on the root file system (SD or eMMC), but there is no guarantee this will always and completely fix all possible file system corruptions.

Advice: To completely guarantee no changes/corruptions of the file system, it is recommended to mount the partition as read-only. For our standard Debian image, this feature is **not** implemented.

5.13 Software Installation and Update

All necessary firmware components to run the device are already installed on the module upon delivery. Hence, firmware updates should only be required in exceptional cases, e.g., to input new software that includes new functionality.

5.13.1 Updating the PLC Firmware

PLC firmware represents the run time environment of the PLC. The ***PLC firmware*** can only be generated and modified by the producer; **it is not identical with the PLC user program** which is created by the PLC user. The PLC user program is directly transferred from the *OpenPCS* programming environment onto the module. No additional software is needed.

Updating the PLC firmware requires login to the command shell as described in section 5.8.1 and login to the SFTP server as described in section 5.8.2.

Updating the PLC firmware takes place via a self-extracting firmware archive that is transferred onto the device via SFTP. The respective firmware archive can be transferred into directory *"/tmp"* (see Figure 17).

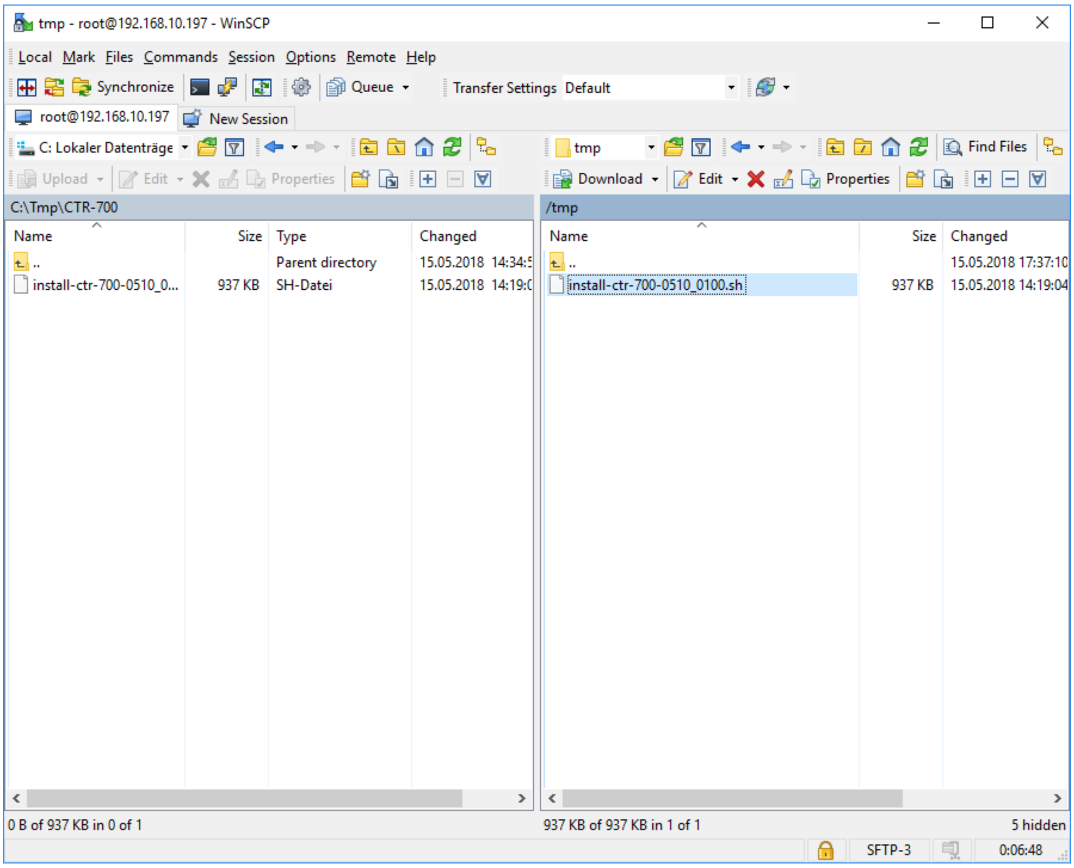

Figure 17: File transfer in SFTP client "WinSCP"

Important: To transfer the firmware archive via SFTP, transfer type “Default” or *"Binary"* must be chosen. If SFTP client *"WinSCP"* is used, the appropriate transfer mode is to be chosen from the menu bar. After downloading the firmware archive, it must be checked if the file transferred to the device has the exact same size as the original file on the computer (compare Figure 17). Any differences in that would indicate a mistaken transfer mode (e.g., *"Text"*). In that case the transfer must be repeated using transfer type *"Binary"*.

After downloading the self-extracting archive, the PLC firmware must be installed on the device. Therefore, the following commands are to be entered in the SSH window. It must be considered that the file name for the firmware archive is labeled with a version identifier (e.g., “install-ctr-700-0510_0100.sh" for version 5.10.01.00). This number must be adjusted when commands are entered:

```
cd /tmp
chmod +x install-ctr-700-0510_0100.sh
./install-ctr-700-0510_0100.sh
```

Advice: The command shell can automatically complete names if the Tab key is used ("tab completion"). Hence, it should be sufficient to enter the first letters of each file name and the system will complement it automatically. For example, *"./ins"* is completed to *"./install-ctr-700-0510_0100.sh"* if the Tab key is used.

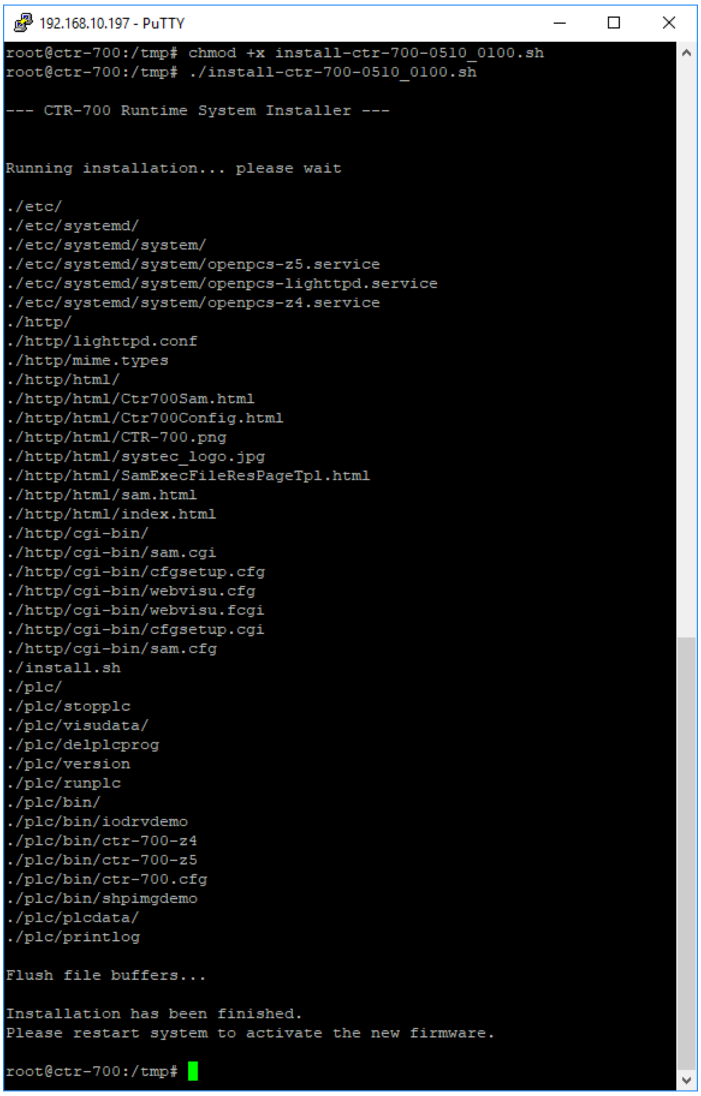

Figure 18: Installing PLC firmware

Figure 18 shows the installation of PLC firmware. After reboot the module is started using the updated firmware.

Advice:	**If the PLC firmware is updated, the configuration file is overwritten. This results in a reset of the PLC configuration to default settings. Consequently, after an update, the configuration described in section 5.4 should be checked and if necessary, it should be reset.**

5.13.2 Install Debian GNU/Linux to a SD Card for update/recovery

Advice:	**Installing Debian GNU/Linux to the SD Card will format all partitions of the SD Card. This means all data on the device will be overwritten.**

The device supports to boot from SD Card as well as from EMMC. The following steps describe how to install a new firmware version to an SD Card and boot from it. This card can then be used to install Debian GNU/Linux to the internal EMMC. The SD Card has to have a size of at least 4 GiB. The SD Card software is provided as a compressed image, which contains the whole file system of the operating system.

The SD Card Image is provided by SYS TEC. The following steps assume the file *"ctr-700-sdcard-v0100.img.zip"* is used. Newer versions will have a slightly different file name. Follow the steps to install this file to an SD Card.

1. Unzip the file
2. Download the tool *"Win32 Disk Imager"*: https://sourceforge.net/projects/win32diskimager/
   This tool will be used to copy the image file to the SD Card image.
3. Insert your SD Card
4. Run *"Win32 Disk Imager"*
   a. Choose the uncompressed SD Card image
   b. Choose the drive letter of your SD Card
   c. Click on the "Write" button to write the image to your SD Card

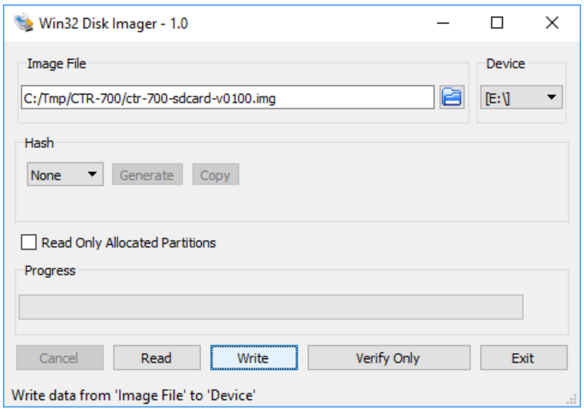

Figure 19: Write SD Card Image using Win32 Disk Imager

5. Insert the SD Card and switch the boot mode to SD Card (turn DIP-Switch like described inside the specific device manual).
6. Power-on the device

The device will now boot from the SD Card. Use a command shell as described in section 5.8.1 to work with the new firmware.

5.13.3 Install/Update Debian GNU/Linux to EMMC

Advice: **Installing Debian GNU/Linux to the EMMC will format all partitions of the EMMC. This means all data on the device will be overwritten except vendor data partitions, which contain ADC calibration data or information of purchased licenses.**

To be able to install Debian GNU/Linux to the internal EMMC of the device, one must create an SD Card as described in section 5.13.2.

After a SD Card is available, follow the steps to install the Linux Image from SD Card to the EMMC and boot it afterwards:

1. Insert the SD Card and switch the boot mode to SD Card (turn DIP-Switch like described inside the specific device manual).
2. Start / boot the device
3. Login to a command line shell as described in section 5.8.1
   User: root
   Password: root
4. Execute the following command to install the Linux to the EMMC. This will take a few minutes to execute.

```
debian-emmc.sh
================================
 SYS TEC sysWORXX CTR-500

 Installing Debian to eMMC
================================

...
...
...

Debian Flashed. Press any key to continue...
```

5. Switch the boot mode to EMMC (turn DIP-Switch like described inside the specific device manual).
6. Reboot or shutdown the system. The device will now boot from EMMC.

```
reboot
```

Now the Debian GNU/Linux is installed to the EMMC memory and it can be booted. Using the EMMC has several benefits. The storage is most of the time faster than using an SD Card and it is more reliable in terms of durability.

6 Library sysWORXX IO

The sysWORXX IO library enables access to the different inputs and outputs of the device as well as additional device information. The header file with the public interface is located at "**/usr/include/sysworxx_io.h**".

More information to the sysWORX IO library is described in the device specific manuals.

7 PLC Functionality

To program the device according to IEC 61131-3, the system *OpenPCS* of the company infoteam Software GmbH (http://www.infoteam.de) is available. This programming system has been extended and adjusted for this device by the company SYS TEC electronic AG. Hence, it is possible to program the device graphically in KOP/FUB, AS and CFC as well as textually in AWL or ST. Downloading the PLC program onto the module takes place via Ethernet (UDP) or CANopen – depending on the firmware configuration. Addressing in- and outputs and creating a process image follows the SYS TEC scheme for compact control units. Hence, PLC programs developed by the user can be operated on different SYS TEC control modules without adjustments. Like all other SYS TEC controls, this device supports backward documentation of the PLC program as well as the debug functionality including watching and setting variables, single cycles, breakpoints, and single steps.

Further information about the supported PLC functionalities, e.g., retain variables or function blocks, can be found in the documents referenced in Table 1.

7.1 Starting the PLC Runtime

The PLC runtime is not enabled by default. To activate the automatic start, one must enable the services *“openpcs-z4”* or *“openpcs-z5”* as described in section 5.6.3.

If enabled, the device loads all necessary firmware components upon power-on or reset and starts running the PLC program afterwards (if enabled). Hence, the device is suitable for the usage in independent control systems. In case of power breakdown, such systems resume the execution of the PLC program independently and without user intervention.

7.2 Programming the Device

The device is programmed with IEC 61131-3-conform *OpenPCS* programming environment. There exist additional manuals about *OpenPCS* that describe the handling of this programming tool. Those are part of the software package *"OpenPCS"*. All manuals relevant are listed in Table 1.

The firmware is based on standard firmware for SYS TEC's compact control units. Consequently, it shows identical properties like other SYS TEC control systems. This affects especially the process image setup (see section 7.3) as well as the functionality of control elements (DIP-Switch, Run/Stop switch, Run-LED, Error-LED).

Depending on the firmware version used, it provides numerous function blocks to the user to access communication interfaces. Section 5.6.3 describes the selection of the appropriate firmware version.

A complete listing of supported firmware functions and function blocks by each device is documented in the individual specification. Detailed information about using the CAN interfaces in connection with CANopen is provided in section 7.7.

7.3 Process Image of the Device

7.3.1 Firmware Function Blocks

Supported function blocks are described in the device specific manuals.

7.3.2 Local In- and Outputs

Compared to other SYS TEC compact control systems, this device obtains a process image with identical addresses. All supported in- and outputs are listed in the specific device manuals.

7.3.3 Network Variables for CAN1

Contrary to interface CAN0, interface CAN1 of the device is designed as static object dictionary. Thus, at interface CAN1 the device acts as a CANopen I/O device. All static network variables for CAN1 are accessible via the marker section of the process image.

Section 7.3.3 includes more detailed information about CAN interface CAN1 and the network variables that are provided by it in the marker section.

7.4 Communication Interfaces

7.4.1 Serial Interfaces

The devices features one service and multiple serial interfaces (see specific device documentation mentioned in Table 1). Details about hardware activation are included in section 4.9.1.

The interfaces may be used from a PLC program via function blocks of type *"SIO_Xxx"* (see manual *"SYS TEC-specific Extensions for OpenPCS / IEC 61131-3"*, Manual no.: L-1054).

7.4.2 CAN Interfaces

Both CAN interfaces allow for data exchange with other devices via network variables and they are accessible from a PLC program via function blocks of type *"CAN_Xxx"* (see *"User Manual CANopen Extension for IEC 61131-3"*, Manual no.: L-1008).

Section 7.3.3 provides detailed information about the usage of the CAN interfaces in connection with CANopen.

7.4.3 Ethernet Interface

Details about the hardware activation are included in section 4.9.3

The interface is accessible from a PLC program via function blocks of type *"LAN_Xxx"* (see manual *"SYS TEC-specific Extensions for OpenPCS / IEC 61131-3"*, Manual no.: L-1054).

The exemplary PLC program *"UdpRemoteCtrl"* illustrates the usage of function blocks of type *"LAN_Xxx"* within a PLC program.

7.5 Control and Display Elements

7.5.1 Run/Stop Switch

The Run/Stop switch makes it possible to start and interrupt the execution of the PLC program. Together with start and stop pushbuttons of the *OpenPCS* programming environment, the Run/Stop switch represents a "logical" AND-relation. This means that the PLC program will not start the execution until the local Run/Stop switch is positioned to *"Run"* **AND** additionally the start command (cold, warm or hot start) is given by the *OpenPCS* user interface. The order hereby is not relevant. A run command given by *OpenPCS* while at the same time the Run/Stop switch is positioned to *"Stop"* is visible through quick flashing of the Run- and Error-LED.

7.5.2 Run-LED (green)

The Run-LED provides information about the activity state of the control system. The activity state is shown through different modes:

Table 7: Display status of the Run-LED

LED Mode	PLC Activity State
Off	The PLC is in state *"Stop"*: • the PLC does not have a valid program, • the PLC has received a stop command from the *OpenPCS* programming environment or • the execution of the program has been canceled due to an internal error
Quick flashing in relation 1:8 to pulse	The PLC is on standby but is not yet executing: • The PLC has received a start command from the *OpenPCS* programming environment but the local Run/Stop switch is still positioned to *"Stop"*
Slow flashing in relation 1:1 to pulse	The PLC is in state *"Run"* and executes the PLC program.
Quick flashing in relation 1:1 to pulse	The PLC is in mode *"Reset"*

7.5.3 Error-LED (red)

The Error-LED provides information about the error state of the control system. The error state is represented through different modes:

Table 8: Display status of the Error-LED

LED Mode	PLC Error State
Off	No error has occurred; the PLC is in normal state.
Permanent light	A severe error has occurred: • The PLC was started using an invalid configuration (e.g. CAN node address 0x00) and had to be stopped or • A severe error occurred during the execution of the program and caused the PLC to independently stop its state *"Run"* (division by zero, invalid Array access, ...), see below
Slow flashing in relation 1:1 to pulse	A network error occurred during communication to the programming system; the execution of a running program is continued. This error state will be reset independently by the PLC as soon as further communication to the programming system is successful.
Quick flashing in relation 1:1 to pulse	The PLC is in mode *"Reset"*
Quick flashing in relation 1:8 to pulse	The PLC is on standby, but is not yet running: • The PLC has received a start command from the *OpenPCS* programming environment but the local Run/Stop switch is positioned to *"Stop"*

In case of severe system errors such as division by zero of invalid Array access, the control system passes itself from state *"Run"* into state *"Stop"*. This is recognizable by the permanent light of the Error-LED (red). In this case, the error cause is saved by the PLC and is transferred to the computer and shown upon next power-on.

7.6 Local Deletion of a PLC Program

PLC programs can only be deleted with an established connection via a terminal program, SSH or SFTP (see section 7.1). First, the device has to be stopped (S2 switched to left), then the file *PlcArchv.bin* found in ***"/home/plc/plcdata/"*** can be deleted. Only the file has to be deleted not the directory!

7.7 Using CANopen for CAN Interfaces

The featured CAN interfaces are usable as CANopen Manager (conform to CiA Draft Standard 302). The configuration (active/inactive, node number, Bitrate, Master on/off) is described in section 5.4.

The CAN interfaces allow for data exchange with other devices via network variables and they are usable from a PLC program via function blocks of type *"CAN_Xxx"*. More details are included in *"User Manual CANopen Extension for IEC 61131-3"*, Manual no.: L-1008.

The CANopen services **PDO** (***P***rocess ***D***ata ***O***bjects) and **SDO** (***S***ervice ***D***ata ***O***bjects) are two separate mechanisms for data exchange between single field bus devices. Process data sent from a node (**PDO**) are available as broadcast to interested receivers. PDOs are limited to 1 CAN telegram and therewith to 8 Byte user data maximum because PDOs are executed as non-receipt broadcast messages. On the contrary, **SDO** transfers are based on logical point-to-point connections ("Peer to Peer") between two nodes and allow the receipted exchange of data packages that may be larger than 8 Bytes. Those data packages are transferred internally via an appropriate amount of CAN telegrams. Both services are applicable for interface CAN0 as well as for CAN1.

SDO communication basically takes place via function blocks of type *"CAN_SDO_Xxx"* (see *"User Manual CANopen Extension for IEC 61131-3"*, Manual no.: L-1008). Function blocks are also available for PDOs (*"CAN_PDO_Xxx"*). Those should only be used for particular cases in order to also activate non-CANopen-conform devices. For the application of PDO function blocks, the CANopen configuration must be known in detail. The reason for this is that the PDO function blocks only use 8 Bytes as input/output parameter, but the assignment of those Bytes to process data is subject to the user.

Instead of PDO function blocks, network variables should mainly be used for PDO-based data exchange. Network variables represent the easiest way of data exchange with other CANopen nodes. Accessing network variables within a PLC program takes place in the same way as accessing internal, local variables of the PLC. Hence, for PLC programmers it is not of importance if e.g. an input variable is allocated to a local input of the control or if it represents the input of a decentralized extension module. The application of network variables is based on the integration of DCF files that are generated by an appropriate CANopen configurator. On the one hand, DCF files describe communication parameters of any device (CAN Identifier, etc.) and on the other hand, they allocate network variables to the Bytes of a CAN telegram (mapping). The application of network variables only requires basic knowledge about CANopen.

For this device, the usage of PDO-based network variables is different for each CAN interface CAN0 and CAN1. Sections 7.7.1 and 7.7.2 provide more detail on this.

In a CANopen network, exchanging PDOs only takes place in status *"OPERATIONAL"*. If the device is not in this status, it does not process PDOs (neither for send-site nor for receive-site) and consequently, it does not update the content of network variables. The CANopen Manager is in charge of setting the operational status *"OPERATIONAL"*, *"PRE-OPERATIONAL"* etc. (mostly also called "CANopen Master"). In typical CANopen networks, a programmable node in the form of a PLC is used as CANopen-Manager. This device is able to take over tasks of the CANopen Manager at both CAN interfaces CAN0 and CAN1. How the Manager is activated is described in section 5.4.

As CANopen Manager, it is able to parameterize the CANopen I/O devices ("CANopen-Slaves") that are connected to the CAN bus. Therefore, upon system start via SDO it transfers DCF files generated by the CANopen configurator to the respective nodes.

7.7.1 CAN Interface CAN0

Interface CAN0 features a dynamic object dictionary. This implicates that after activating the PLC, the interface does not provide communication objects for data exchange with other devices. After downloading a PLC program (or its reload from the non-volatile storage after power-on), the required communication objects are dynamically generated according to the DCF file which is integrated in the PLC project. Thus, CAN interface CAN0 is extremely flexible and also applicable for larger amount of data.

For the PLC program, all network variables are declared as *"VAR_EXTERNAL"* according to IEC61131-3. Hence, they are marked as „outside of the control“, e.g.:

```
VAR_EXTERNAL
    NetVar1 : BYTE ;
    NetVar2 : UINT ;
END_VAR
```

A detailed procedure about the integration of DCF files into the PLC project and about the declaration of network variables is provided in manual *"User Manual CANopen Extension for IEC 61131-3"* (Manual no.: L-1008).

When using CAN interface CAN0 it must be paid attention that the generation of required objects takes place upon each system start. This is due to the dynamic object directory. "Design instructions" are included in the DCF file that is integrated in the PLC project. **Hence, changes to the configuration can only be made by modifying the DCF file.** This implies that after the network configuration is changed (modification of DCF file), the PLC project must again be translated and loaded onto the device.

7.7.2 CAN Interface CAN1

On the contrary to interface CAN0, interface CAN1 is provided as static object dictionary. This means that the amount of network variables (communication objects) and the amount of PDOs available are both strongly specified. During runtime, the configuration of PDOs is modifiable. This implies that communication parameters used (CAN Identifier, etc.) and the allocation of network variables to each Byte of a CAN telegram (mapping), can be set and modified by the user. Thus, only the number of objects (amount of network variables and PDOs) is strongly specified in the static object dictionary. Consequently, application and characteristics of objects can be modified during runtime. For this reason, at interface CAN1 the device acts as a CANopen I/O device.

All network variables of the PLC program are available through the marker section of the process image. Therefore, 252 Bytes are usable as input variables and also 252 Bytes as output variables. To enable any data exchange with other CANopen I/O devices, the section of static network variables is mapped to different data types in the object dictionary (BYTE, SINT, WORD, INT, DWORD, DINT). Variables of the different data types are located within the same memory area which means that all variables represent the same physical storage location. Hence, a WORD variable interferes with 2 BYTE variables, a DWORD variable with 2 WORD or 4 BYTE variables. Figure 20 shows the positioning of network variables for CAN1 within the marker section.

CAN1 Input Variables

	CAN1 IN0	CAN1 IN1	CAN1 IN2	CAN1 IN3	CAN1 IN4	CAN1 IN5	CAN1 IN6	CAN1 IN7	...	CAN1 IN244	CAN1 IN245	CAN1 IN246	CAN1 IN247	CAN1 IN248	CAN1 IN249	CAN1 IN250	CAN1 IN251
BYTE / SINT, USINT	%MB 0.0 (Byte0)	%MB 1.0 (Byte1)	%MB 2.0 (Byte2)	%MB 3.0 (Byte3)	%MB 4.0 (Byte4)	%MB 5.0 (Byte5)	%MB 6.0 (Byte6)	%MB 7.0 (Byte7)		%MB 244.0 (Byte244)	%MB 245.0 (Byte245)	%MB 246.0 (Byte246)	%MB 247.0 (Byte247)	%MB 248.0 (Byte248)	%MB 249.0 (Byte249)	%MB 250.0 (Byte250)	%MB 251.0 (Byte251)
WORD / INT, UINT	%MW 0.0 (Word0)		%MW 2.0 (Word1)		%MW 4.0 (Word2)		%MW 6.0 (Word3)		...	%MW 244.0 (Word122)		%MW 246.0 (Word123)		%MW 248.0 (Word124)		%MW 250.0 (Word125)	
DWORD / DINT, UDINT	%MD 0.0 (Dword0)				%MD 4.0 (Dword1)					%MD 244.0 (Dword61)				%MD 248.0 (Dword62)			

CAN1 Output Variables

	CAN1 OUT0	CAN1 OUT1	CAN1 OUT2	CAN1 OUT3	CAN1 OUT4	CAN1 OUT5	CAN1 OUT6	CAN1 OUT7	...	CAN1 OUT244	CAN1 OUT245	CAN1 OUT246	CAN1 OUT247	CAN1 OUT248	CAN1 OUT249	CAN1 OUT250	CAN1 OUT251
BYTE / SINT, USINT	%MB 256.0 (Byte0)	%MB 257.0 (Byte1)	%MB 258.0 (Byte2)	%MB 259.0 (Byte3)	%MB 260.0 (Byte4)	%MB 261.0 (Byte5)	%MB 262.0 (Byte6)	%MB 263.0 (Byte7)		%MB 500.0 (Byte244)	%MB 501.0 (Byte245)	%MB 502.0 (Byte246)	%MB 503.0 (Byte247)	%MB 504.0 (Byte248)	%MB 505.0 (Byte249)	%MB 506.0 (Byte250)	%MB 507.0 (Byte251)
WORD / INT, UINT	%MW 256.0 (Word0)		%MW 258.0 (Word1)		%MW 260.0 (Word2)		%MW 262.0 (Word3)		...	%MW 500.0 (Word122)		%MW 502.0 (Word123)		%MW 504.0 (Word124)		%MW 506.0 (Word125)	
DWORD / DINT, UDINT	%MD 265.0 (Dword0)				%MD 260.0 (Dword1)					%MD 500.0 (Dword61)				%MD 504.0 (Dword62)			

Figure 20: Positioning of network variables for CAN1 within the marker section

Table 9 shows the representation of network variables through appropriate inputs in the object dictionary of interface CAN1.

Table 9: Representation of network variables for CAN1 by entries in the object dictionary

OD section	OD variable / EDS input	Data type CANopen	Data type IEC 61131-3
Inputs (inputs for this device)			
Index 2000H Sub 1 … 252	CAN1InByte0 … CAN1InByte251	Unsigned8	BYTE, USINT
Index 2001H Sub 1 … 252	CAN1InSInt0 … CAN1InSInt251	Integer8	SINT
Index 2010H Sub 1 … 126	CAN1InWord0 … CAN1InWord125	Unsigned16	WORD, UINT
Index 2011H Sub 1 … 126	CAN1InInt0 … CAN1InInt125	Integer16	INT
Index 2020H Sub 1 … 63	CAN1InDword0 … CAN1InDword62	Unsigned32	DWORD, UDINT
Index 2021H Sub 1 … 63	CAN1InDInt0 … CAN1InDInt62	Integer32	DINT
Outputs (outputs for this device)			
Index 2030H Sub 1 … 252	CAN1OutByte0 … CAN1OutByte251	Unsigned8	BYTE, USINT
Index 2031H Sub 1 … 252	CAN1OutSInt0 … CAN1OutSInt251	Integer8	SINT
Index 2040H Sub 1 … 126	CAN1OutWord0 … CAN1OutWord125	Unsigned16	WORD, UINT
Index 2041H Sub 1 … 126	CAN1OutInt0 … CAN1OutInt125	Integer16	INT
Index 2050H Sub 1 … 63	CAN1OutDword0 … CAN1OutDword62	Unsigned32	DWORD, UDINT
Index 2051H Sub 1 … 63	CAN1OutDInt0 … CAN1OutDInt62	Integer32	DINT

The object dictionary of interface CAN1 in total has available 16 TPDO and 16 RPDO. The first 4 TPDO and RPDO are preconfigured and activated according to the Predefined Connection Set. The first 32 Byte of input and output variables are mapped to those PDOs. Table 10 lists all preconfigured PDOs for interface CAN1.

Table 10: Preconfigured PDOs for interface CAN1

PDO	CAN-ID	Data
1. RPDO	0x200 + NodeID	%MB0.0 … %MB7.0
2. RPDO	0x300 + NodeID	%MB8.0 … %MB15.0
3. RPDO	0x400 + NodeID	%MB16.0 … %MB23.0
4. RPDO	0x500 + NodeID	%MB24.0 … %MB31.0
1. TPDO	0x180 + NodeID	%MB256.0 … %MB263.0
2. TPDO	0x280 + NodeID	%MB264.0 … %MB271.0
3. TPDO	0x380 + NodeID	%MB272.0 … %MB279.0
4. TPDO	0x480 + NodeID	%MB280.0 … %MB287.0

Due to limitation to 16 TPDO and 16 RPDO, only 256 Bytes (2 * 16PDO * 8Byte/PDO) of total 504 Bytes for network variables in the marker section (2 252Bytes) can be transferred via PDO. Irrespective of that it is possible to access all variables via SDO.

The configuration (mapping, CAN Identifier etc.) of interface CAN1 typically takes place via an external Configuration Manager that parameterizes the object dictionary on the basis of a DCF file created by the CANopen configurator. By using default object inputs 1010H und 1011H, the device supports the persistent storage and reload of a backed configuration.

Alternatively, the configuration (mapping, CAN Identifier etc.) of the static object dictionary for interface CAN1 can take place from the PLC program by using SDO function blocks. Therefore, inputs *NETNUMBER* and *DEVICE* must be used as follows:

```
NETNUMBER  := 1;           (* Interface CAN1 *)
DEVICE     := 0;           (* local Node     *)
```

The PLC program example *"ConfigCAN1"* exemplifies the configuration of interface CAN0 through a PLC program by using function blocks of type *"CAN_SDO_Xxx"*.

8 Data Exchange via Shared Process Image

8.1 Overview of the Shared Process Image

This device is using the operating system Debian, which is based on Linux. Thus, it is possible to execute other user-specific programs simultaneously to running the PLC firmware. The PLC program and a user-specific C/C++ application can exchange data by using the same process image (shared process image). Implementing user-specific applications **is based on the Software** we distribute via GitHub or our website.

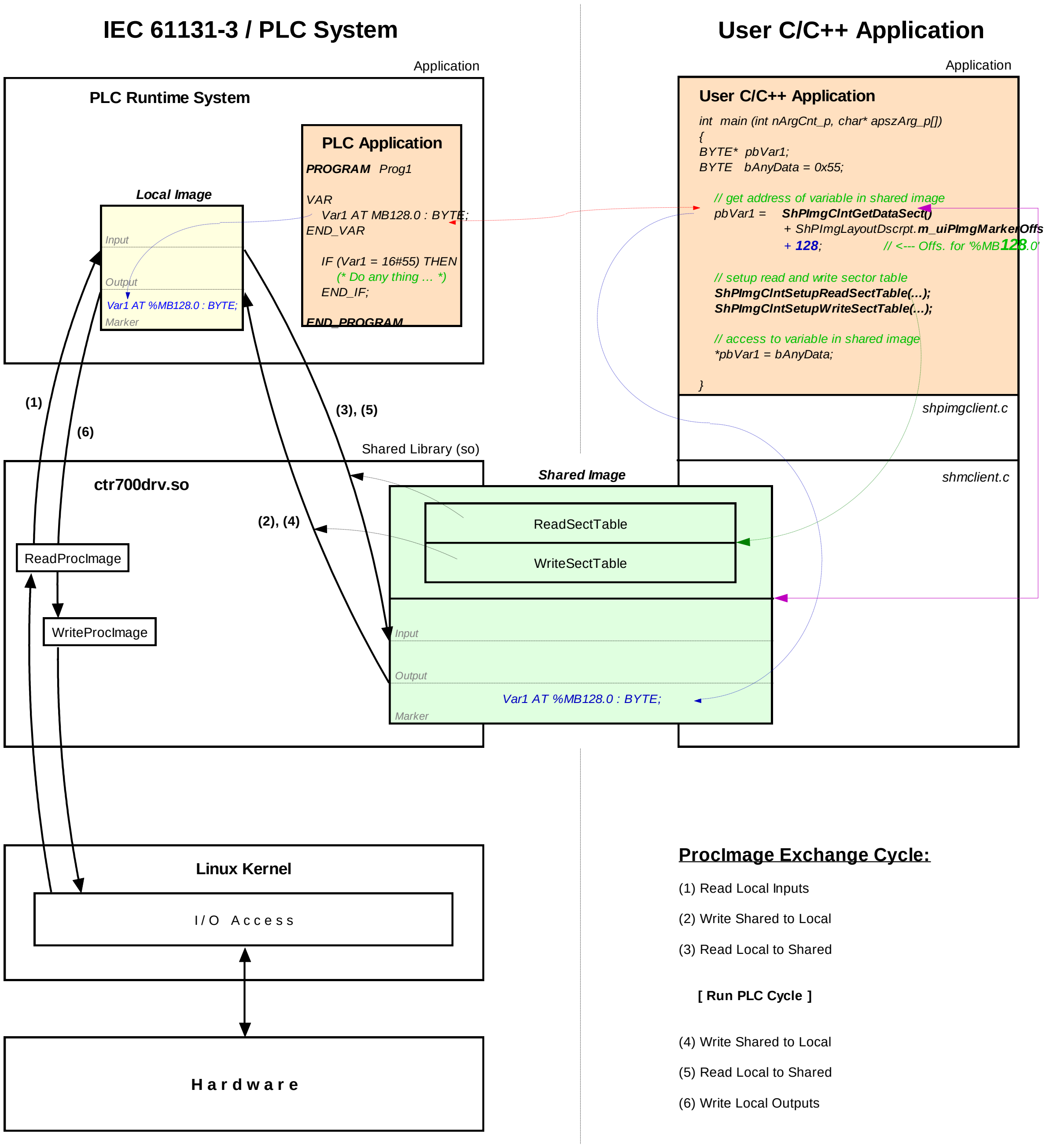

Figure 21: Overview of the shared process image

Not all variables are utilizable via the shared process image within a C/C++ application. Only those directly addressed variables that the PLC program generates within the process image. As shown in Figure 21, two separate process images are used for the data exchange with an external application inside of the PLC runtime system. This is necessary to meet the IEC 61131-3 requirement that the initial PLC process image may not be modified during the entire execution of one PLC program cycle. Thereby, the PLC program always operates with the internal process image that is locally generated within the PLC runtime system ("Local Image" in Figure 21). This is integrated within the PLC runtime system and is protected against direct accesses from the outside. On the contrary, the user-specific, external C/C++ application always uses the shared process image ("Shared Image" in Figure 21). This separation of two process images enables isolation between accesses to the PLC program and the external application. Those two in parallel and independently running processes now must only be synchronized for a short period of time to copy the process data.

An activation of **option *"Share PLC process image"*** within the PLC configuration enables data exchange with external applications (see section 5.5.1). Alternatively, entry *" EnableSharing="* can directly be set within section *"[ProcImg]"* of the configuration file (see section 5.5.2). The appropriate configuration setting is evaluated upon start of the PLC firmware. By activating option *"Share PLC process image"*, the PLC firmware creates a second process image as Shared Memory ("Shared Image" in Figure 21). Its task is to exchange data with external applications. Hereby, the PLC firmware functions as Server and the external, user-specific C/C++ application functions as Client.

ReadSectorTable and ***WriteSectorTable*** both control the copying of data between the two process images. Both tables are filled by the Client (external, user-specific C/C++ application) and are executed by Server (PLC runtime system). The Client defines ranges of the PLC process image from which it will read data (*ReadSectorTable*) or in which it will write data (*WriteSectorTable*). Hence, the terms *"Read"* and *"Write"* refer to data transfer directions from the viewpoint of the Client.

Sections to read and write may comprise all sections of the entire process image – input, output as well as marker sections. This allows for example that a Client application writes data into the input section of the PLC process image and reads data from the output section. Figure 21 shows the sequence of single read and write operations. Prior to the execution of a PLC program cycle, the physical inputs are imported into the local process image of the PLC (1). Afterwards, all sections defined in *WriteSectorTable* are taken over from the shared process image into the local process image (2). By following this sequence, a Client application for example is able to overwrite the value of a physical input. This may be used for simulation purposes as well as for setting input data to constant values (*"Forcen"*). Similarly, prior to writing the process image onto the physical outputs (6), sections defined in *WriteSectorTable* are taken over from the shared process image into the local process image. (4). Thus, a Client application is able to overwrite output information generated by the PLC program.

The PLC firmware provides the **setup of the process image**. The Client application receives information about the setup of the process image via function ***ShPImgClntSetup()***. This function enters start offsets and values of the input, output and marker sections into the structure of type *tShPImgLayoutDscrpt*. Function ***ShPImgClntGetDataSect()*** provides the start address of the shared process image. Upon defining a variable within the PLC program, its absolute position within the process image is determined through sections (%I = Input, %Q = Output, %M = Marker) and offset (e.g. %MB**128**.0). In each section the offset starts at zero, so that for example creating a new variable in the marker section would be independent of values in the input and output section. Creating a corresponding **pair of variables** in the PLC program as well as in the C/C++ application allows for data exchange between the PLC program and the external application. Therefore, both sides must refer to the same address. Structure *tShPImgLayoutDscrpt* reflects the physical setup of the process image in the PLC firmware including input, output and marker sections. This is to use an addressing procedure for defining appropriate variables in the C/C++ application that is comparable to the PLC program. Hence, also in the C/C++ program a variable is defined in the shared process image by indicating the respective section and its offset. The following example illustrates the creation of a corresponding variable pair in the PLC program and C/C++ application:

PLC Program

```
VAR
    Var1 AT MB128.0 : BYTE;
END_VAR
```

C/C++ Application

```
BYTE*  pbVar1;

pbVar1 =   ShPImgClntGetDataSect()
         + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs
         + 128;     // <--- Offset for '%MB128.0'
```

As described above, ***ReadSectorTable*** and ***WriteSectorTable*** manage the copy process to exchange variable contents between the PLC and the C/C++ program. Following the example illustrated, the Client (C/C++ application) must enter an appropriate value into the *WriteSectorTable* to transfer the value of a variable from the C/C++ application to the PLC program (*WriteSectorTable*, because the Client "writes" the variable to the Server):

```
// specify offset and size of 'Var1' and define sync type (always or on demand?)
WriteSectTab[0].m_uiPImgDataSectOffs = ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 128;
WriteSectTab[0].m_uiPImgDataSectSize = sizeof(BYTE);
WriteSectTab[0].m_SyncType           = kShPImgSyncOnDemand;

// define the WriteSectorTable with the size of 1 entry
ShPImgClntSetupWriteSectTable (WriteSectTab, 1);
```

If several variable pairs are generated within the same transfer direction for the data exchange between the PLC program and the C/C++ application, they should possibly all be defined in one coherent address range. Thus, it is possible to list them as one entry in the appropriate SectorTable. The address of the first variable must be set as the *SectorOffset* and the sum of the variable sizes as *SectorSize*. Combining the variables improves the efficiency and the performance of the copy processes.

For each entry of the *WriteSectorTable* an appropriate *SyncType* must be defined. It determines whether the section is generally taken over from the shared process image into the local image whenever there are two successive PLC cycles (***kShPImgSyncAlways***) or whether it is taken over on demand (***kShPImgSyncOnDemand***). If classified as *SyncOnDemand*, the data only is copied if the respective section before was explicitly marked as updated. This takes places by calling function ***ShPImgClntWriteSectMarkNewData()*** and entering the corresponding *WriteSectorTable*-Index (e.g. 0 for *WriteSectTab[0]* etc.).

kShPImgSyncAlways is provided as *SyncType* for the *ReadSectorTable* (the value of the member element *m_SyncType* is ignored). The PLC firmware is not able to identify which variables were changed by the PLC program of the cycle before. Hence, all sections defined in *ReadSectorTable* are always taken over from the local image into the shared process image. Thus, the respective variables in the shared process image always hold the actual values.

The PLC firmware and the C/C++ application both use the shared process image. To prevent conflicts due to accesses from both of those in parallel running processes at the same time, the shared process image is internally protected by a semaphore. If one process requires access to the shared process image, this process enters a critical section by setting the semaphore first and receiving exclusive access to the shared process image second. If the other process requires access to the shared process image at the same time, it also must enter a critical section by trying to set the semaphore. In this case, the operating system identifies that the shared process image is already being used. It blocks the second process until the first process leaves the critical section and releases the semaphore. Thereby, the operating system assures that only one of the two in parallel running processes (PLC runtime system and C/C++ application) may enter the critical section and receives access to the shared process image. To ensure that both processes do not interfere with each other too much, they should enter the critical section as less as possible and only as long as necessary. Otherwise, the PLC cycle time may be extended and runtime variations (Jitter) may occur.

The client application has available two functions to set the semaphore and to block exclusive access to the shared process image. Function ***ShPImgClntLockSegment()*** is necessary to enter the critical section and function ***ShPImgClntUnlockSegment()*** to leave it. The segment between both functions is called protected section, because in this segment the client application holds access to the shared process image without competition. The consistency of read or written data is only guaranteed within such a protected section. Outside the protected section, the shared process image may anytime be manipulated by the PLC runtime system. The following example shows the exclusive access to the shared process image in the C/C++ application:

```
ShPImgClntLockSegment();
{
    // write new data value into Var1
    *pbVar1 = bAnyData;

    // mark new data for WriteSectorTable entry number 0
    ShPImgClntWriteSectMarkNewData (0);
}
ShPImgClntUnlockSegment();
```

For the example above, *kShPImgSyncOnDemand* was defined as *SyncType* upon generating entry *WriteSectorTable*. Hence, taking over variable *Var1* from the shared process image into the local image can only take place if the respective section was beforehand explicitly marked as updated. Therefore, it is necessary to call function ***ShPImgClntWriteSectMarkNewData()***. Since function *ShPImgClntWriteSectMarkNewData()* does not modify the semaphore, it may only be used within a protected section (see example) – such as the code section between *ShPImgClntLockSegment()* and *ShPImgClntUnlockSegment()*.

The synchronization between local image and shared process image by the PLC runtime system only takes place in-between two successive PLC cycles. A client application (user-specific C/C++ program) is not directly informed about this point of time, but it can get information about the update of the shared process image from the PLC runtime system. Therefore, the client application must define a callback handler of the type *tShPImgAppNewDataSigHandler*, e.g.:

```
static  void  AppSigHandlerNewData (void)
{
    fNewDataSignaled_l = TRUE;
}
```

This callback handler must be registered with the help of function ***ShPImgClntSetNewDataSigHandler()***. The handler is selected subsequent to a synchronization of the two images.

The **callback handler of the client application is called within the context of a Linux signal handler** (the PLC runtime system informs the client using Linux function *kill()*). Accordingly, all common **restrictions** for the Linux signal handler also apply to the callback handler of the client application. In particular, it is only allowed to call a few operating system functions that are explicitly marked as reentrant-proof. Please pay attention to not make reentrant calls of local functions within the client application. As shown in the example, only a global flag should be set for the signaling within the callback handler. This flag will later on be evaluated and processed in the main loop of the client application.

8.2 API of the Shared Process Image Client

As illustrated in Figure 21, the user-specific C/C++ application exclusively uses the API (Application Programming Interface) provided by the s*hared process image client*. This API is declared in the header file *shpimgclient.h* and implemented in the source file *shpimgclient.c*. It contains the following types (partly defined in *shpimg.h*) and functions:

Structure *tShPImgLayoutDscrpt*

```
typedef struct
{
    // definition of process image sections
    unsigned int        m_uiPImgInputOffs;      // start offset of input section
    unsigned int        m_uiPImgInputSize;      // size of input section
    unsigned int        m_uiPImgOutputOffs;     // start offset of output section
    unsigned int        m_uiPImgOutputSize;     // size of output section
    unsigned int        m_uiPImgMarkerOffs;     // start offset of marker section
    unsigned int        m_uiPImgMarkerSize;     // size of marker section

} tShPImgLayoutDscrpt;
```

Structure ***tShPImgLayoutDscrpt*** describes the setup of the process image given by the PLC firmware. The client application receives the information about the setup of the process image via function *ShPImgClntSetup()*. This function enters start offsets and values of input, output and marker sections into the structure provided upon function calling.

Structure *tShPImgSectDscrpt*

```
typedef struct
{
    // definition of data exchange section
    unsigned int        m_uiPImgDataSectOffs;
    unsigned int        m_uiPImgDataSectSize;
    tShPImgSyncType     m_SyncType;             // only used for WriteSectTab
    BOOL                m_fNewData;

} tShPImgSectDscrpt;
```

Structure ***tShPImgSectDscrpt*** describes the setup of a *ReadSectorTable* or *WriteSectorTable* entry that must be defined by the client. Both tables support the synchronization between the local image of the PLC runtime system and the shared process image (see section 8.1). Member element *m_uiPImgDataSectOffs* defines the absolute start offset of the section within the shared process images. The respective start offsets of the input, output and marker sections can be determined through structure *tShPImgLayoutDscrpt*. Member element *m_uiPImgDataSectSize* determines the size of the section which may include one or more variables. Member element *m_SyncType* only applies to entries of the WriteSectorTable. It determines whether the section is generally taken over from the shared process image into the local image whenever there are two successive PLC cycles (***kShPImgSyncAlways***) or whether it is taken over on demand (***kShPImgSyncOnDemand***). If classified as *SyncOnDemand*, the data must be marked as modified by calling function *ShPImgClntWriteSectMarkNewData()*. It sets the member element *m_fNewData* to TRUE. The client application should never directly modify this member element.

Function *ShPImgClntSetup*

```
BOOL  ShPImgClntSetup  (tShPImgLayoutDscrpt* pShPImgLayoutDscrpt_p);
```

Function ***ShPImgClntSetup()*** initializes the *shared process image client* and connects itself with the storage segment for the shared process image which is generated by the PLC runtime system. Afterwards, it enters the start offsets and values of the input, output and marker sections into the structure of type *tShPImgLayoutDscrpt* provided upon function call. Hence, the client application receives notice about the process image setup managed by the PLC firmware.

If the PLC runtime system is not active when the function is called or if it has not generated a shared process image (option *"Share PLC process image"* in the PLC configuration deactivated, see section 8.1), the function will return with the return value FALSE. If the initialization was successful, the return value will be TRUE.

Function *ShPImgClntRelease*

```
BOOL  ShPImgClntRelease  (void);
```

Function ***ShPImgClntRelease()*** shuts down the s*hared process image client* and disconnects the connection to the storage segment generated for the shared process image by the PLC runtime system.

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

Function *ShPImgClntSetNewDataSigHandler*

```
BOOL  ShPImgClntSetNewDataSigHandler  (
        tShPImgAppNewDataSigHandler pfnShPImgAppNewDataSigHandler_p);
```

Function ***ShPImgClntSetNewDataSigHandler()*** registers a user-specific callback handler. This callback handler is called after a synchronization of both images. Registered callback handlers are cleared by the parameter NULL.

The **callback handler is called within the context of a Linux signal handler**. Accordingly, all common **restrictions** for the Linux signal handler also apply to the callback handler (see section 8.1).

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

Function *ShPImgClntGetHeader*

```
tShPImgHeader*  ShPImgClntGetHeader  (void);
```

Function ***ShPImgClntGetHeader()*** provides a pointer to the internally used structure type *tShPImgHeader* to manage the shared process image. The client application does usually not need this structure, because all data that it includes can be read and written through functions of the API provided by the *shared process image client*.

Function *ShPImgClntGetDataSect*

```
BYTE*  ShPImgClntGetDataSect  (void);
```

Function ***ShPImgClntGetDataSect()*** provides a pointer to the beginning of the shared process image. This pointer represents the basic address for all accesses to the shared process image; including the definition of sections *ReadSectorTable* and *WriteSectorTable* (see section 8.1).

Funktionen Functions *ShPImgClntLockSegment* and *ShPImgClntUnlockSegment*

```
BOOL  ShPImgClntLockSegment  (void);
BOOL  ShPImgClntUnlockSegment  (void);
```

To exclusively access the shared process image, the client application has available two functions - function ***ShPImgClntLockSegment()*** to enter the critical section and function ***ShPImgClntUnlockSegment()*** to leave it. The segment between both functions is called protected section, because in this segment the client application holds unrivaled access to the shared process image (see section 8.1). The consistency of read or written data is only guaranteed within such a protected section. Outside the protected section, the shared process image may anytime be manipulated by the PLC runtime system. To ensure that the client application does not interfere with the PLC runtime system too much, the critical sections should be set as less as possible and only as long as necessary. Otherwise, the PLC cycle time may be extended and runtime variations (Jitter) may occur.

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

Function *ShPImgClntSetupReadSectTable*

```
BOOL ShPImgClntSetupReadSectTable (
    tShPImgSectDscrpt* paShPImgReadSectTab_p,
    unsigned int uiNumOfReadDscrptUsed_p);
```

Function ***ShPImgClntSetupReadSectTable()*** initializes the *ReadSectorTable* with the values defined by the client. The client hereby determines those sections of the PLC process image from which it wants to read data (see section 8.1). Parameter *paShPImgReadSectTab_p* holds elements of the structure *tShPImgSectDscrpt* and must be transferred as start address of a section. Parameter *uiNumOfReadDscrptUsed_p* indicates how many elements the section has.

kShPImgSyncAlways is provided as *SyncType* for the *ReadSectorTable*.

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

Function *ShPImgClntSetupWriteSectTable*

```
BOOL ShPImgClntSetupWriteSectTable (
    tShPImgSectDscrpt* paShPImgWriteSectTab_p,
    unsigned int uiNumOfWriteDscrptUsed_p);
```

Function ***ShPImgClntSetupWriteSectTable***() initializes the *WriteSectorTable* with the values defined by the client. The client hereby determines those sections of the PLC process image from which it wants to write data (see section 8.1). Parameter *paShPImgWriteSectTab_p* holds elements of structure *tShPImgSectDscrpt* and must be transferred as start address of a section. Parameter *uiNumOfWriteDscrptUsed_p* indicates how many elements the section has.

For each entry in the *WriteSectorTable* the *SyncType* must be defined. This *SyncType* defines whether the section is always taken over into the local image between two PLC cycles (***kShPImgSyncAlways***) or only on demand (***kShPImgSyncOnDemand***). If taken over on demand, the respective section is explicitly marked as updated by calling *ShPImgClntWriteSectMarkNewData()*.

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

Function *ShPImgClntWriteSectMarkNewData*

```
BOOL  ShPImgClntWriteSectMarkNewData  (unsigned int uiWriteDscrptIdx_p);
```

For the content of a section that is held by the *WriteSectorTable*, function ***ShPImgClntWriteSectMarkNewData()*** marks this content as modified. This function is used (for sections with *SyncType* ***kShPImgSyncOnDemand***) to initiate the copy process of data from the shared process image into the local image of the PLC.

Function *ShPImgClntWriteSectMarkNewData()* directly accesses the header of the shared process image without setting a semaphore before. Hence, it may only be used within the protected section – in the code section between *ShPImgClntLockSegment()* and *ShPImgClntUnlockSegment()*.

If executed successfully, the function delivers return value TRUE. If an error occurs, it will deliver return value FALSE.

8.3 Creating a User-Specific Client Application

The software package we offer on our GitHub and website is the precondition for the implementation of user-specific C/C++ applications. It contains a complete Linux development system in the form of a VirtualBox image. Hence, it allows for an easy introduction into the C/C++ software development for the device. Thus, the VirtualBox image is the ideal basis to develop Linux-based user programs on the same host PC that already has the *OpenPCS* IEC 61131 programming system installed on it. The VirtualBox image of the Linux development system includes the GNU-Crosscompiler Toolchain for ARM processors. Additionally, it includes essential server services that are preconfigured and usable for effective software development.

As illustrated in Figure 21, the user-specific C/C++ application uses the API (files *shpimgclient.c* and *shpimgclient.h*) which is provided by the *shared process image client*. The *shared process image client* is based on services provided by the *shared memory client* (files *shmclient.c* and *shmclient.c*). Both client implementations are necessary to generate a user-specific C/C++ application. The directory of the s*hared process image demo* contains the respective files. The path is depending on the device, e.g. */projects/**CTR-700**/user/shpimgdemo*. To create own user-specific client applications, it is recommended to use this demo project as the basis for own adaptations and extensions. Moreover, this demo project contains a Makefile with all relevant configuration adjustments that are necessary to create a Linux application. Table 11 lists all files of the directory *shpimgdemo* and classifies those as general part of the C/C++ application or as specific component for the demo project *"shpimgdemo"*.

Table 11: Content of the archive files "shpimgdemo.tar.gz"

File	Necessary for all C/C++ applications	In particular for demo *"shpimgdemo"*
shpimgclient.c	x	
shpimgclient.h	x	
shmclient.c	x	
shmclient.h	x	
shpimg.h	x	
global.h	x	
Makefile	draft, to be adjusted	
shpimgdemo.c		x
trmio.c		x
trmio.h		x
trace.c		x

The demo project can be built by calling command *"make".* Here on the example of the CTR-700:

```
cd  /projects/CTR-700/user/shpimgdemo
make
```

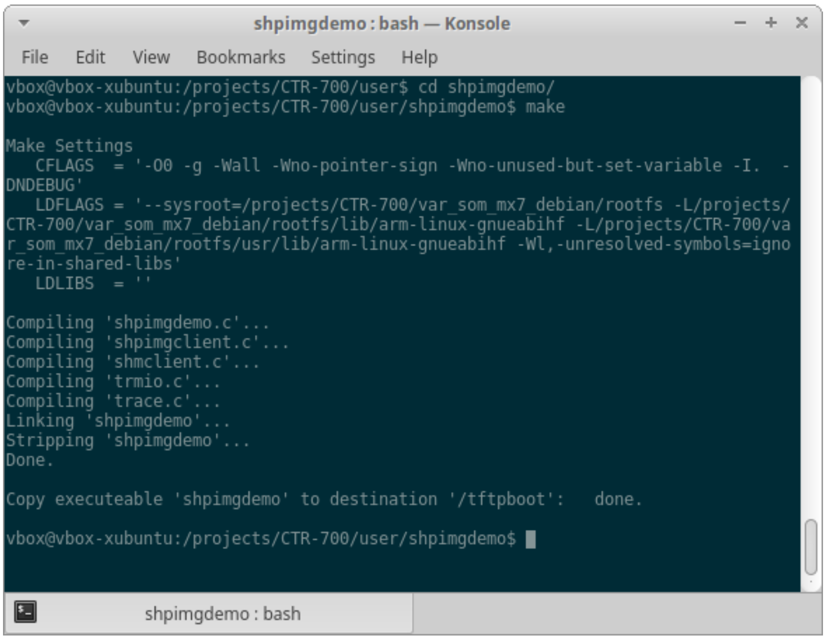

Figure 22: Generating the demo project "shpimgdemo" in the Linux development system

Section 8.4 describes the usage and handling of the demo project *"shpimgdemo"*.

8.4 Example for Using the Shared Process Image

The demo project *"shpimgdemo"* (described in section 8.3) in connection with the PLC program example *"RunLight"* both exemplify the data exchange between a PLC program and a user-specific C/C++ application.

Technical Background

The PLC program generates some variables in the process image as directly addressable variables. In a C/C++ application, all those variables are usable via the shared process image. For the PLC program example *"RunLight"* those are the following variables:

```
 (* variables for local control via on-board I/O's *)
bButtonGroup        AT %IB0.0    : BYTE;
iAnalogValue        AT %IW8.0    : INT;
bLEDGroup0          AT %QB0.0    : BYTE;
bLEDGroup1          AT %QB1.0    : BYTE;

(* variables for remote control via shared process image  *)
uiRemoteSlidbarLen  AT %MW512.0 : UINT;      (* out: length of slidebar          *)
bRemoteStatus       AT %MB514.0 : BYTE;      (* out: Bit0: RemoteControl=on/off *)
bRemoteDirCtrl      AT %MB515.0 : BYTE;      (* in:  direction left/right        *)
iRemoteSpeedCtrl    AT %MW516.0 : INT;       (* in:  speed                       *)
```

Variables of the PLC program are accessible from a C/C++ application via the shared process image. Therefore, sections must be generated for the *ReadSectorTable* and *WriteSectorTable* on the one hand and on the other hand, pointers must be defined for accessing the variables. The following program extract shows this using the example *"shpimgdemo.c"*. Function *ShPImgClntSetup()* inserts the start offsets of input, output and marker sections into the structure *ShPImgLayoutDscrpt*. Hence, on the basis of the initial address provided by *ShPImgClntGetDataSect()*, the absolute initial addresses of each section in the shared process image can be determined. To identify the address of a variable, the variable's offset within the particular section must be added. For example, the absolute address to access the variable *"bRemoteDirCtrl AT %MB515.0 : BYTE;"* results from the sum of the initial address of the shared process image (pabShPImgDataSect), the start offset of the marker section (*ShPImgLayoutDscrpt.m_uiPImgMarkerOffs* für *"%M…"*) as well as the direct address within the marker section which was defined in the PLC program (515 for "%MB515.0"):

```
    pbPImgVar_61131_bDirCtrl          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 515);
```

The following code extract shows the complete definition of all variables in the demo project used for exchanging data with the PLC program:

```
// ---- Setup shared process image client ----
fRes = ShPImgClntSetup (&ShPImgLayoutDscrpt);
if ( !fRes )
{
    printf ("\n*** ERROR *** Init of shared process image client failed");
}

pabShPImgDataSect = ShPImgClntGetDataSect();


// ---- Read Sector Table ----
// Input Section:       bButtonGroup AT %IB0.0
{
    ShPImgReadSectTab[0].m_uiPImgDataSectOffs                                    =
                ShPImgLayoutDscrpt.m_uiPImgInputOffs + 0;
    ShPImgReadSectTab[0].m_uiPImgDataSectSize = sizeof(BYTE);
    ShPImgReadSectTab[0].m_SyncType           = kShPImgSyncAlways;

    pbPImgVar_61131_bButtonGroup          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgInputOffs + 0);
}

// Output Section:      bLEDGroup0 AT %QB0.0
//                      bLEDGroup1 AT %QB1.0
{
    ShPImgReadSectTab[1].m_uiPImgDataSectOffs                                    =
                ShPImgLayoutDscrpt.m_uiPImgOutputOffs + 0;
    ShPImgReadSectTab[1].m_uiPImgDataSectSize = sizeof(BYTE) + sizeof(BYTE);
    ShPImgReadSectTab[1].m_SyncType           = kShPImgSyncAlways;

    pbPImgVar_61131_bLEDGroup0          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgOutputOffs + 0);
    pbPImgVar_61131_bLEDGroup1          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgOutputOffs + 1);
}

// Marker Section:      uiSlidbarLen AT %MW512.0
//                      bStatus      AT %MB514.0
{
    ShPImgReadSectTab[2].m_uiPImgDataSectOffs                                    =
                ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 512;
    ShPImgReadSectTab[2].m_uiPImgDataSectSize   =       sizeof(unsigned   short   int)
                                                + sizeof(BYTE);
    ShPImgReadSectTab[2].m_SyncType           = kShPImgSyncAlways;

    pbPImgVar_61131_usiSlidbarLen   =   (unsigned   short   int*)   (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 512);
    pbPImgVar_61131_bStatus          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 514);
}
```

```
fRes = ShPImgClntSetupReadSectTable (ShPImgReadSectTab, 3);
if ( !fRes )
{
    printf ("\n*** ERROR *** Initialization of read sector table failed");
}

// ---- Write Sector Table ----
// Marker Section:      bDirCtrl    AT %MB515.0
//                      iSpeedCtrl AT %MB516.0
{
    ShPImgWriteSectTab[0].m_uiPImgDataSectOffs                              =
                 ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 515;
    ShPImgWriteSectTab[0].m_uiPImgDataSectSize = sizeof(BYTE) + sizeof(WORD);
    ShPImgWriteSectTab[0].m_SyncType           = kShPImgSyncOnDemand;

    pbPImgVar_61131_bDirCtrl          =          (BYTE*)          (pabShPImgDataSect
               + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 515);
    psiPImgVar_61131_iSpeedCtrl      =      (short      int*)      (pabShPImgDataSect
                    + ShPImgLayoutDscrpt.m_uiPImgMarkerOffs + 516);
}

fRes = ShPImgClntSetupWriteSectTable (ShPImgWriteSectTab, 1);
if ( !fRes )
{
    printf ("\n*** ERROR *** Initialization of write sector table failed");
}
```

Realization

To enable the execution of the *shared process image demo* without previous introduction into the Linux-based C/C++ programming for the device, the module comes with a preinstalled, translated and ready-to-run program version and PLC firmware (*"/home/plc/bin/shpimgdemo"*). The following description refers to this program version. Alternatively, the demo project can be newly-generated from the corresponding source files (see section 8.3) and can be started afterwards. As I/O-Simulator for practical controlling of the demo-program an I/O-Box is available from SYS TEC.

The following steps are necessary to run the *shared process image demo*:

1. **Activate option *"Shared PLC process image"*** in the PLC configuration (see sections 8.1, 5.5.1 and 5.5.2).

2. Open the PLC program example *"RunLight"* in the *OpenPCS* IEC 61131 programming system und build the project for a target hardware of the type, e.g. *"SYSTEC – CTR-700"*

3. Select the network connection to the device and download the program.

4. Start the PLC program on the device.

5. Login to the command shell as described in section 5.8.1.

6. Switch to the directory *"/home/plc/bin"* and call the demo program *"shpimgdemo"*:

   ```
   cd                                                    /home/plc/bin
   ./shpimgdemo
   ```

   The digital outputs of the device are selected as runlight. The speed is modifiable via the analog input AI0. With the help of digital inputs DI0 and DI1, the running direction can be changed. After starting the demo program *"shpimgdemo"*, actual status information about the runlight is indicated cyclically in the terminal (see Figure 23).

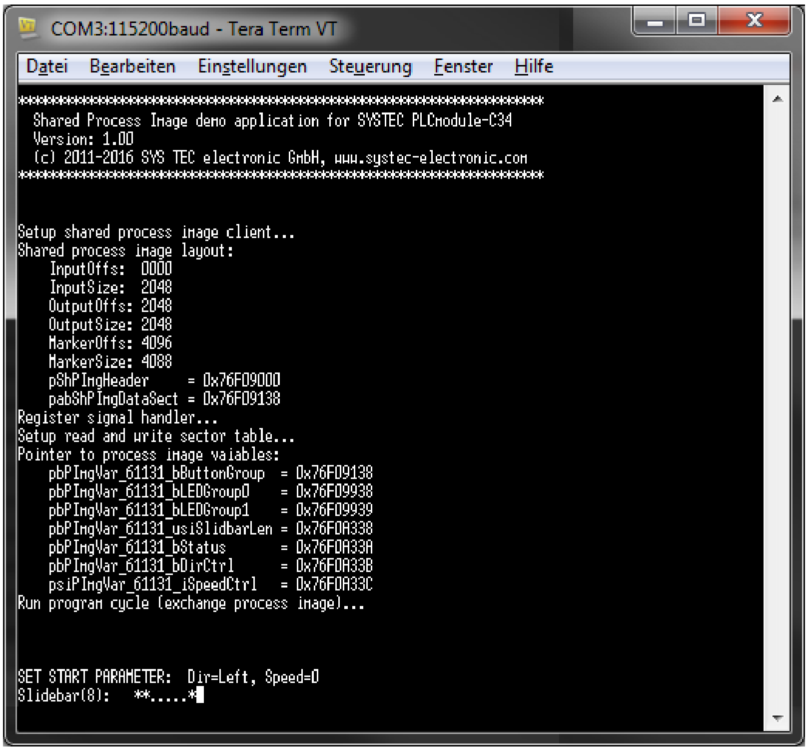

Figure 23: Terminal outputs of the demo program "shpimgdemo" after start

7. By activating of digital input DI3, the control of the runlight direction and speed is handed over to the demo program *"shpimgdemo"*. Afterwards, the running direction may be set by the C application by using the cursor pushbuttons left and right (← and →) in the terminal window and the speed may be changed by using cursor pushbuttons up and down (↑ and ↓).

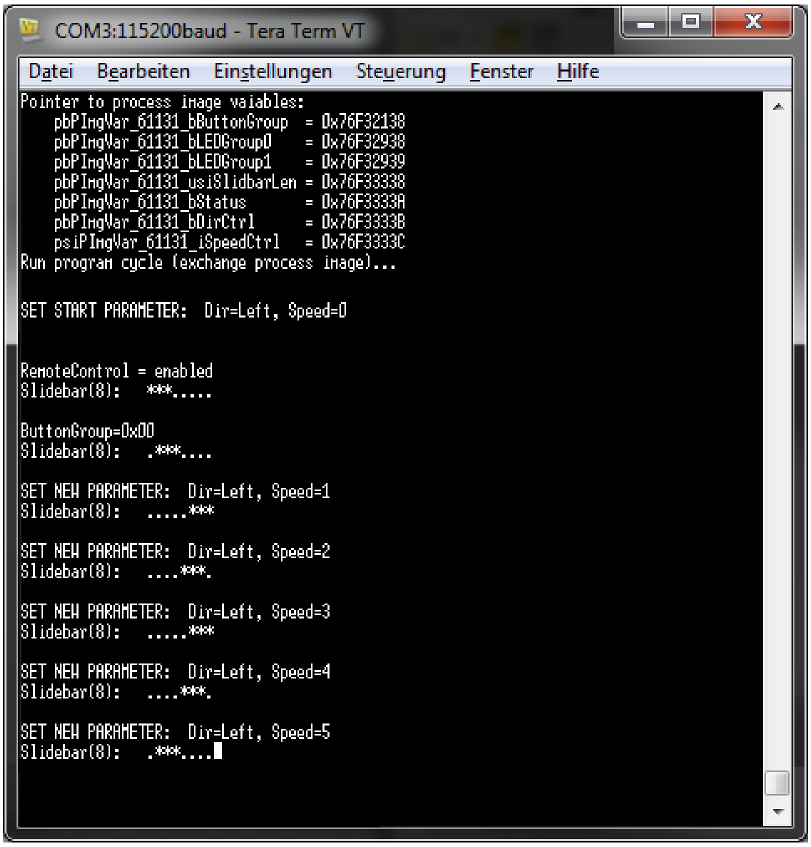

Figure 24: Terminal outputs of the demo program "shpimgdemo" after user inputs

Figure 24 shows the terminal outputs of the demo program *"shpimgdemo"* in answer to activating the cursor pushbuttons.

The demo program *"shpimgdemo"* may be terminated by pressing "Ctrl+C" in the terminal window.

9 Troubleshooting

If there are any problems with the device, which are not covered by this section or any other part of this document, please contact our support under +49 (0) 37 65 / 38 600-0 or support@systec-electronic.com.

9.1 Wrong time in Node-RED or other applications

Error Behavior:

The shown time or time zone on the device is wrong. This may include some applications like Node-RED.

Cause:

The device has only has a buffer capacitor and no internal battery, which means after a certain time, some settings may get lost.

Solution:
If the device has access to the internet, the time will set itself on the next restart. If this is not the case, one must set the time manually, described in Section 5.11.

9.2 Error during installation of additional packages

Error Behavior:

Installing packages with "`apt install`" fail with the following error message:

```
E: Failed to fetch … 404 Not Found [IP: 151.101.12.204 80]
E: Unable to fetch some archives, maybe run apt-get update or try with –
fix-missing?
```

Cause:

The package manager apt cannot install packages, if it is not initially used with the "update" subcommand.

Solution:
Before installing any packages, one must use the command "`apt update`" first. If this still fails, use "`apt update –fix-missing`"

Appendix A: Technical Specification

For device specific technical information, please look in the corresponding documents, mentioned in Table 1.

Appendix B: Third Party Software Components

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Paho MQTT Embedded/C

The Eclipse Paho MQTT package is a client library for MQTT embedded devices.

Project URL: https://github.com/eclipse/paho.mqtt.embedded-c

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Mono

Mono is an open source implementation of Microsoft's .NET Framework based on the ECMA standards for C# and the Common Language Runtime.

Project URL: https://github.com/mono/mono

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```
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The Mono distribution does include a handful of pieces of code that
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licenses, those include:

Build Time Code
===============

This is code that is used at build time, or during the maintenance of
Mono itself, and does not end up in the redistributable part of Mono:

* gettext

  m4 source files used to probe features at build time: GPL

* Benchmark Source Files

  Logic.cs and zipmark.cs are GPL source files.

* mono/docs/HtmlAgilityPack

  MS-PL licensed

* mcs/jay: 4-clause BSD licensed

* mcs/nunit24: MS-PL

* mcs/class/I18N/mklist.sh, tools/cvt.sh: GNU GPLv2

Runtime Code
============

The following code is linked with the final Mono runtime, the libmono
embeddable runtime:

* support/minizip: BSD license.

* mono/utils/memcheck.h: BSD license, used on debug builds that use Valgrind.

* mono/utils/freebsd-dwarf.h, freebsd-elf_common.h, freebsd-elf64.h freebsd-
elf32.h: BSD license.

* mono/utils/bsearch.c: BSD license.

* mono/metadata/w32file-unix-glob.c, w32file-unix-glob.h: BSD license

Class Library code
==================
```

These are class libraries that can be loaded by your process:

* mcs/class/RabbitMQ.Client: dual licensed in Apache v2, and Mozilla Public License 1.1

* mcs/class/Compat.ICSharpCode.SharpZipLib and mcs/class/ICSharpCode.SharpZipLib are GPL with class-path exception. Originates with the SharpDevelop project.

* mcs/class/System.Core/System/TimeZoneInfo.Android.cs

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API Documentation
=================

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From: james.newtonking@gmail.com [mailto:james.newtonking@gmail.com] On Behalf Of James Newton-King
Sent: Tuesday, June 05, 2007 6:36 AM
To: Konstantin Triger
Subject: Re: Support request by Konstantin Triger for Json.NET

Hey Kosta

I think it would be awesome to use Json.NET in Mono for System.Web.Extensions.

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I can waive that statement for you and Mono. Would that be acceptable?

Regards,
James

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