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IEC Structured Text programming of a small Distributed Control System

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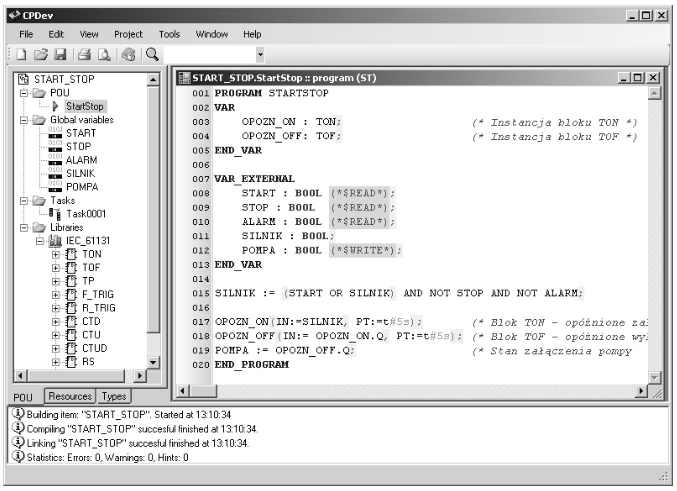
***Abstract*—A prototype environment called CPDev for programming small distributed control-and-measurement systems in Structured Text (ST) language of IEC 61131-3 standard is presented. The environment consists of a compiler, simulator and configurer of hardware resources, including communications. Programming a mini-DCS (*Distributed Control System*) from LUMEL Zielona Góra is the first application of CPDev.**



```
PROGRAM STARTSTOP
VAR
    OPOZN_ON : TON;                             (* Instancja bloku TON *)
    OPOZN_OFF: TOF;                             (* Instancja bloku TOF *)
END_VAR

VAR_EXTERNAL
    START : BOOL (*$READ*);
    STOP : BOOL  (*$READ*);
    ALARM : BOOL (*$READ*);
    SILNIK : BOOL;
    POMPA : BOOL (*$WRITE*);
END_VAR

SILNIK := (START OR SILNIK) AND NOT STOP AND NOT ALARM;

OPOZN_ON(IN:=SILNIK, PT:=t#5s);             (* Blok TON - opóźnione za
OPOZN_OFF(IN:= OPOZN_ON.Q, PT:=t#5s);       (* Blok TOF - opóźnione wy
POMPA := OPOZN_OFF.Q;                       (* Stan załączenia pompy
END_PROGRAM
```

```
Building item: "START_STOP". Started at 13:10:34
Compiling "START_STOP" succesful finished at 13:10:34.
Linking "START_STOP" succesful finished at 13:10:34.
Statistics: Errors: 0, Warnings: 0, Hints: 0
```

Fig. 1. User interface in CPDev environment

I. Introduction

DOMESTIC control-and-measurement industry manufactures transmitters, actuators, drives, PID (*Proportional-Integral-Derivative*) and PLC (*Programmable Logic*) controllers, recorders, etc. Connected into distributed systems, they are used for automation of small and medium scale plants. However, engineering tools used for programming such devices are rather simple and do not correspond to IEC 61131-3 standard [2] (Polish law since 2004).

This paper presents current state of work on engineering environment called CPDev (*Control Program Developer*) for programming small control-and-measurement devices and distributed mini-systems according to the IEC standard (digits dropped for brevity). First implementation involves instruments from LUMEL Zielona Góra [7]. Initial information on CPDev was presented at the previous IMCSIT conference [5]. Similar environments have been described in [1], [6].

The CPDev environment (called also package) consists of three programs executed by PC and one by the controller. At the PC side we have:

- CPDev compiler of ST language,
- CPSim software simulator,
- CPCon configurer of hardware resources.

The programs exchange data through files in appropriate formats. The CPDev compiler generates an universal code executed by virtual machine VM at the controller side. The machine operates as an interpreter. The code is a list of primitive instructions of the virtual machine language called VMASM assembler. VMASM is not related to any particular processor, however it is close to somewhat extended typical assemblers. In this way, portability of the compiled code for different hardware platforms is provided. On the contrary, other solutions are usually built around the concept of translating IEC language programs into C code [6].

Basic characteristics of VMASM and virtual machine are given in [5]. CPSim simulator also involves the machine (in this case at the PC side).

The CPDev package is developed in C# language of .NET Framework. The virtual machine is written in ANSI C and compiled with appriopriate, platform-dependent compilers e.g. avr-gcc in case of the LUMEL's mini-DCS. Other languages and programming environments are also used in specific cases.

The implementation of CPDev components was supported by lexical diagrams (compiler), object-oriented modelling techniques (programming environment) and coloured Petri nets (communication subsystem), see [5], [9].

II. A program in ST language

Main window of user interface in the CPDev environment is shown in Fig. 1. It consists of three areas:

- tree of project structure, on the left,
- program in ST language, center,
- message list, bottom.

Tree of the `START_STOP` project shown in the figure includes Program Organization Unit (POU) with the program `PRG_START_STOP`, five global variables from `START` to `PUMP`, task `TSK_START_STOP`, and two standard function blocks `TON` and `TOF` from IEC_61131 library.

The `PRG_START_STOP` program seen in the main area is written according to ST language rules. The first part involves declarations of instances `DELAY_ON`, `DELAY_OFF` of the function blocks `TON` and `TOF`. Declarations of the global variables (`EXTERNAL`) are the second part, and four instructions of the program body, the third one. The instructions correspond to FBD (*Function Block Diagram*) shown in Fig. 2. So one can expect that certain `MOTOR` is turned on immediately after pressing a button `START` and a `PUMP` five seconds later. Pressing `STOP` or activation of an `ALARM` sensor triggers similar turn off sequence.

III. Global variables and task

Global variables can be declared in CPDev either using individual windows or collectively at a variable list. The list for the `START_STOP` project is shown in Fig. 3.

The addresses specify *directly represented variables* [2], [3] and denote relative location in controller memory (keyword AT declares the address in individual window). Here these addresses are called *local*. Variables without addresses (not used in this project) are located automatically by the compiler.

Window with declaration of the `TSK_START_STOP` task is shown in Fig. 4. A task can be executed once, cyclically or continuously (triggered immediately after completing, as in small PLCs). There is no limit on the number of programs assigned to a task, however a program can be assigned only once.

Text of the project represented by the tree is kept in an XML text file. Compilation is executed by calling `Project->Build` from the main menu. Messages appear in the lower area of the interface display (Fig. 1). If there are no mistakes, the compiled project is stored in two files. The first one contains universal executable code in binary format for the virtual machine. The second one contains mnemonic code [5], together with some information for simulator and hardware configurer (variable names, etc.).

IV. Functions and libraries

The CPDev compiler provides most of standard functions defined in IEC standard. Six groups of them followed by examples are listed below:

- type conversions: `INT_TO_REAL`, `TIME_TO_DINT`, `TRUNC`,
- numerical functions: `ADD`, `SUB`, `MUL`, `DIV`, `SQRT`, `ABS`, `LN`,
- Boolean and bit shift functions: `AND`, `OR`, `NOT`, `SHL`, `ROR`,

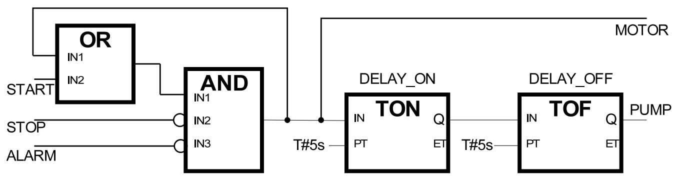
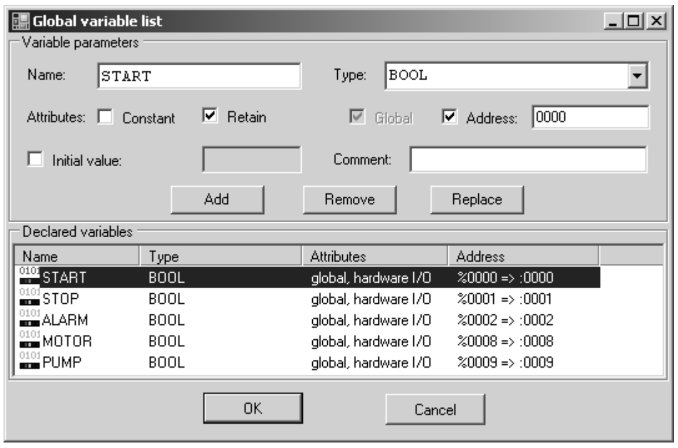


Fig. 2. `START_STOP` system for control of a motor and pump (with delay of 5 seconds)


Global variable list

Variable parameters

Name: START Type: BOOL

Attributes: ☐ Constant ☑ Retain ☑ Global ☑ Address: 0000

☐ Initial value: Comment:

Add Remove Replace

Declared variables

Name	Type	Attributes	Address
START	BOOL	global, hardware I/O	%0000 => :0000
STOP	BOOL	global, hardware I/O	%0001 => :0001
ALARM	BOOL	global, hardware I/O	%0002 => :0002
MOTOR	BOOL	global, hardware I/O	%0008 => :0008
PUMP	BOOL	global, hardware I/O	%0009 => :0009

OK Cancel

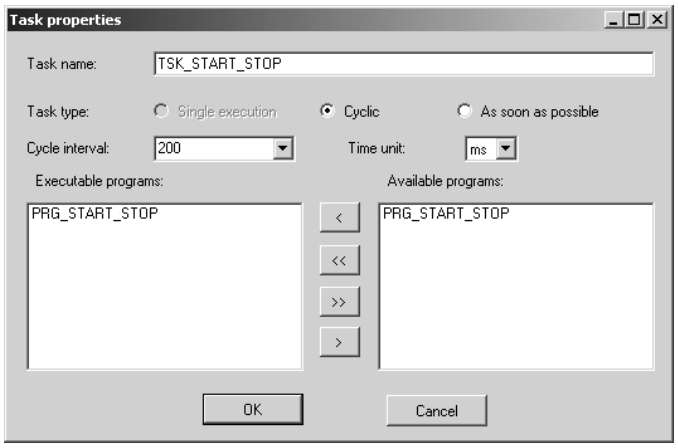
Fig. 3. Global variable list for the `START_STOP` project.

- selection and comparison functions: `SEL`, `MAX`, `LIMIT`, `MUX`, `GE`, `EQ`, `LT`,
- character string functions: `LEN`, `LEFT`, `CONCAT`, `INSERT`,
- functions of time data types: `ADD`, `SUB`, `MUL`, `DIV` (IEC uses the same names as for numerical functions).

Selector `SEL`, limiter `LIMIT` and multiplexer `MUX` from selection and comparison group are particularly useful. Variables of any numerical type, i.e. `INT`, `DINT`, `UINT` and `REAL` (called `ANY_NUM` in IEC [2], [3]) are arguments in most of relevant functions.

Typical program in ST language is a list of function block calls, where inputs to successive blocks are outputs from previous ones (see Fig. 2). So far the CPDev package provides three libraries:

- `IEC_61131` standard library,
- `Basic_blocks` library with simple blocks supplementing the standard,
- `Complex_blocks` library for continuous regulation and sequential control.


Task properties

Task name: TSK_START_STOP

Task type: ○ Single execution ● Cyclic ○ As soon as possible

Cycle interval: 200 Time unit: ms

Executable programs: PRG_START_STOP

Available programs: PRG_START_STOP

< << >> >

OK Cancel

Fig. 4. Declaration of `TSK_START_STOP` task

TABLE I
BLOCKS FROM IEC_61131 AND BASIC_BLOCKS LIBRARIES

IEC_61131			
Bistable elements		**Edge detectors**	
flip-flop	RS	rising	R_TRIG
flip-flop	SR	falling	F_TRIG
semaphore	SEMA	**Timers**	
Counters		pulse	TP
up	CTU	on-delay	TON
down	CTD	on-delay	TOF
up-down	CTUD	real time clock	RTC
Basic_blocks			
Mathematics		**Flip-flops, pulsers**	
linear function		D flop-flop	
division with non-zero divisior		T flip-flop	
square root with linear origin		JK flop-flop	
difference amplifier		one cycle delay	
integrator		pulse duration time	
pseudo-random numbers		totalizer (integration, pulse)	
Memories		square wave	
analog memory		triangle wave	
binary memory		**Filters**	
Signal analyzers		lag filter (1st order)	
maximum over time		lead filter	
minimum over time			

Table I lists blocks form the first and second libraries. Blocks such as PID controller, servo positioner, multi-step sequencer, dosing block, etc., belong to the third library.

The user can develop functions, function blocks and programs, and store them in his libraries. Tables of single-size are available only.

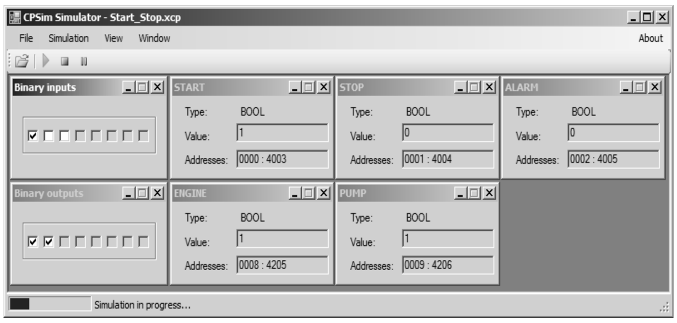
V. CPSim SIMULATOR

The compiled project may be verified by simulation before downloading into the controller. The CPSim simulator can be used in two ways:

- before configuration of hardware resources (simulation of the algorithm),
- after configuration of the resources (simulation of the whole system).

The first way involves logic layer of the CPDev environment. PC computer operates as a virtual machine executing universal code. The second way requires configuration of hardware resources, so it is application dependent. The CPCon configurer generates hardware allocation map (see below) that assigns local addresses to physical ones and specifies conversion of ST data formats into formats accepted by hardware. The objective is to bring simulation close to the hardware level, so CPSim uses both the code and the map. Simulation window of the `START_STOP` project is shown in Fig. 5. The two faceplates on the left present values of three inputs and two outputs (`TRUE` is marked). The user can select faceplates, arrange them on the screen and assign variables. Simulated values can be set both in group and in individual faceplates.

So far the window of Fig. 5 is used for simulation only. In future it will be also employed for on-line tests (*commissioning*).



	START	STOP	ALARM	ENGINE	PUMP
Type:	BOOL	BOOL	BOOL	BOOL	BOOL
Value:	1	0	0	1	1
Addresses:	0000 : 4003	0001 : 4004	0002 : 4005	0008 : 4205	0009 : 4206

Simulation in progress...

Fig. 5. Simulation of the `START_STOP` project

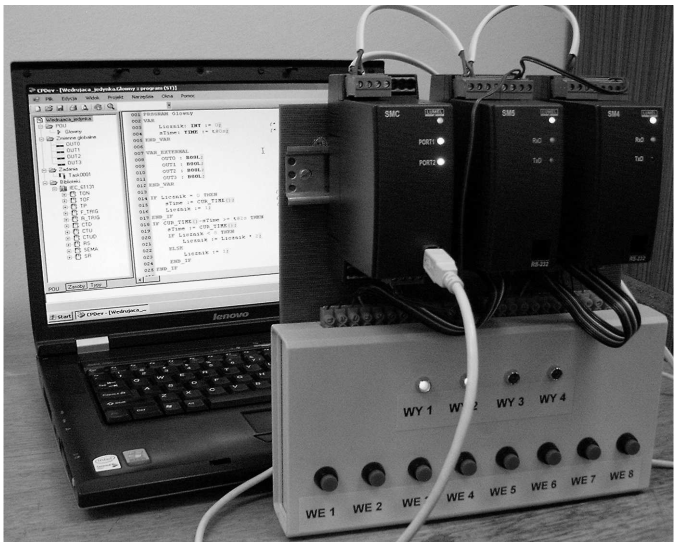


Fig. 6. Test set-up of mini-DCS system with SMC controller and SM I/O modules

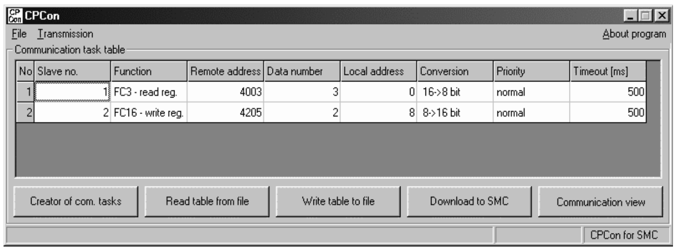
VI. CPCON CONFIGURER AND MINI-DCS

The CPCon configurer defines hardware resources for particular application. The example considered here involves mini-DCS with SMC programmable controller, I/O modules of SM series and eventually other devices from LUMEL Zielona Góra [7]. Modbus RTU protocol is employed [4] on both sides of the SMC.

Fig. 6 shows test realization of the system with SMC controller (on the left), SM5 binary input module (middle), and SM4 binary output module (on the right). The console with pushbuttons and LEDs (below) is used for testing. The PC runs first the CPDev package and a SCADA (*Supervisory Control And Data Acquisition*) system later. PC and SMC are connected via USB channel configured as a virtual serial port.

The CPCon configurer functions are as follows:

- configuration of a communication between SMC and SM I/O modules,



Communication task table

No	Slave no.	Function	Remote address	Data number	Local address	Conversion	Priority	Timeout [ms]
1	1	FC3 - read reg.	4003	3	0	16->8 bit	normal	500
2	2	FC16 - write reg.	4205	2	8	8->16 bit	normal	500

Fig. 7. Communication configuration of the `START_STOP` project.

- creation of file with hardware resource allocation map,
- downloading the files with executable code and map to the SMC.

Recall that having the map the CPSim can be used in the second simulation mode.

Main window of the CPCon configurer is shown in Fig. 7. The `Transmission` slot sets speed, parity and stop bits for PC↔SMC and SMC↔SM communications. `Communication task table` determines what question↔answer and command↔acknowledgment transactions take place between SMC controller (*master*) and SM modules (*slaves*). The transactions are called *communication tasks* and represented by the rows of the table. The DCS system is configured by filling the rows, either directly in the table or interactively through a few windows of `Creator of com. tasks` (bottom).

The first row specifies communication between SMC and SM5 binary input module (remote). SM5 is connected to pushbuttons in the console (Fig. 6) which, in case of the `START_STOP` project, set the variables `START`, `STOP` and `ALARM` (Figs. 1, 2). In SMC these variables have consecutive addresses beginning from `0000` (Fig. 3). SM5 places the inputs in consecutive 16-bit registers beginning from `4003`. So all variables can be read in a single Modbus transaction with the code `FC3` (read group of registers [4]). However, since BOOL occupies single byte in CPDev, the interface of the virtual machine has to perform 16→8 bit conversion.

Communication tasks are handled by SMC during pauses that remain before end of the cycle, after execution of the program. Single transaction takes 10 to 30 ms, depending on speed (max. 115.2 kbit/s). If the pause is large, the task can be executed a few times. It has been assumed that the task with `NORMAL` priority is executed twice slower than the task with `HIGH` priority, and the task with `LOW` priority three times slower. As seen in Fig. 7, the communication with SM5 module has `NORMAL` priority. The `Timeout` within which transaction must be completed is 500 ms.

Second row of the `Communication task table` defines communication with the SM4 binary output module. SM4 controls the console LEDs. Two consecutive variables, `MOTOR` and `PUMP`, the first one with the local address `0008`, are sent to SM4 by single message with the code `FC16` to remote addresses beginning from `4205` (write group of registers). This time 8→16 bit conversion is needed.

VII. Conclusions

CPDev environment for programming industrial controllers and other control-and-measurement devices according to IEC 61131-3 standard has been presented. The environment consists of ST language compiler, project simulator, and configurer of hardware resources, including communications. The user can program his own function blocks and create libraries. Mini-DCS control-and-measurement system form LUMEL is the first application of the package.

Programs written in the future in other IEC languages, first of all in FBD, will also be compiled to the VMASM code and executed by the virtual machine. Appriopriate compilers are under development. XML format for data exchange between languages has already been defined by PLCOpen [1], [8].

Acknowledgment

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