Using Microcomputers for Lighting Appliances Control Via DALI Bus

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Abstract: - Article concerns the DALI bus theoretical aspects and practical applications. As a state of the art technology, the DALI bus has been developed especially for illumination systems control. Authors are outlining communication basic principles related to the physical layer and they go also deeper to more complex data transaction among particular devices details. The article main topic is aimed at two device models based on microcontroller concept and developed for the DALI bus technology application possibilities demonstration. The first of those two devices is a DALI slave unit enabling the light source or multi switch with light indication components control via DALI bus. The second device measures the ambient illumination intensity, and it also detects errors at the load side at the same time. The implemented version specifications are presented as well, and the system components are described from both the design and from functional point of view.

Key-Words: - DALI bus, microcomputer, automatic control

1 Introduction

The electric illumination is a common furnishing of every habitable building nowadays. Nevertheless, it is necessary to bear in mind that the classic concept of light with corresponding switch has been implemented practically in the same arrangement and design since the end of 19th century when it starts spreading in residential buildings. It is quite a peculiar phenomenon because other electro-technology or informatics based designs have gone through a tremendous development. In spite of that, we can witness a wide range of technologies development aimed at the area of illumination control in course of last two decades.

We are more and more often encountering the notion “smart building” recently. These buildings providing occupiers with optimal indoor environment are economy and energy effective, and the frequently offer a multipurpose use of. All of that is possible due to modern technologies related to informatics, automation and control, not excepting sophisticated illumination ways realisation.

We deal with devices and smart building control algorithms development in our research project. One of many possibilities is the whole smart building parameters to be controlled with a programmable automaton (PLC) [1-2]. Such solution is comprehensive, but it suffers from high costs. Providing we want to control only one segment from the wide range of controllable parameters, we can use a cheaper solution.

This article does not deal with smart building issues as such, but it only strives to describe one alternative related to illumination systems control.

There is a pretty wide choice of smart building control systems on the market. Nevertheless, as it was already mentioned, those systems are mostly very complex sets of controlled parameters and active elements, what increases their price.

The systems on the market intended for illumination intensity only are designated entirely either for individual light, or in contrary, for large commercial premises like hotels, theatres and roomy restaurants [16-17].

The device described in this article is applicable for medium extent facilities, like family houses or smaller restaurants.

2 DALI bus

The illumination control design is based on a device incorporating microcontroller and controlled components which mutually communicating via DALI bus.

The DALI bus (Digital Addressable Lighting Interface) corresponding with the international standard IEC 62386 is a digital bus designated for illumination framework control. It is an open protocol system what means that various manufacturers can use it for their products. The

DALI bus offers a unified interface for all bus participants. The coordination scheme respects the master slave hierarchy.

The master usually acts as a controlling unit starting communication, and approaching individual slave devices. There must be at least one master unit in any DALI bus system. The slave device is a remote unite acting according to master unit commands. The slave can send data back, but only as a response for preceding inquiry [3-6].

2.1 Physical layer

The DALI bus data and commands transfer runs via two wires, and devices are parallel connected to that two wire link. One link segment can bear up to 64 unit connections in an arbitrary combination of masters and slaves. The communication rate is fixed to 1200 Bd. The DALI protocol has been developed with an idea that the data link is realized with same wires as for 230 VAC power supply distribution in one cable.

2.2 Manchester coding

The bus data transfer uses Manchester coding scheme which codes with transitions between levels. The leading edge codes the bit logic symbol 0, and the trailing edge codes the bit logic symbol 1. The signal voltage levels are typically 0-16 Volts [5].

2.3 Frames

There are composed frames from individual bits in DALI bus during transfer. The frame can be either the controlling one which serves for the master unit to approach slave devices, or the backward frame for the slave response.

The first bit in every frame is the start bit, and the frame ends with two stop bits. The time slot for one bit is constant what means 833.33 μs at the data rate of 1200 Bd. The acceptable tolerance of bit duration is +/- 10%.

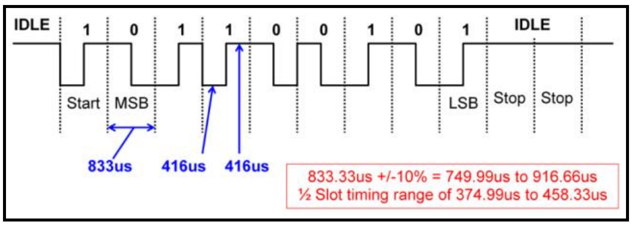

Fig. 1 The individual frame timing example in the DALI bus [5].

2.4 Addresses, groups and commands

Any DALI bus slave device has its own address. If master device sends the control frame containing the particular slave device address in the frame address segment, the corresponding slave device responses. As a general rule, the slave device response procedure includes the frame data segment reading to check for a command to be performed. The frame data segment has 8 bits so that there could be in general one of 256 various commands to be performed [6].

Besides its own address, every device can be assigned to one or more groups. The total group number is 16. In case the master unit sends a frame with group identification code in address segment, the response comes from every member of that particular group. This is how there is possible to approach more than one device with only one inquiry unlike individual approach with corresponding number of message frames.

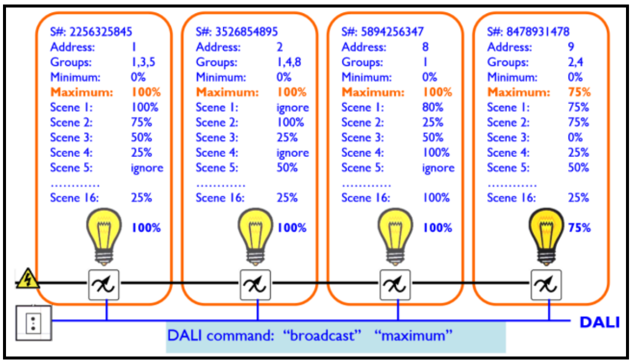

Fig. 2 "Broadcast" command activating all light sources at maximum intensity [6]

2.5 Topology

The DALI bus topology usually comprises a parallel interconnection of all devices in one network. The term network represents in our case the formation of no more than 64 units, the DALI bus power supply, DALI controller, and at least one device acting as a light source. That controller can be connected to another extensive system via a different bus. Providing we need to control more than 64 devices in our DALI bus, we have to extend it by means of other separate DALI bus interconnected via a gateway, or as the case may be, there can be more DALI bus systems unified using their master units that communicate mutually in another way.

3 The slave design concept

There is necessary to solve several problems in course of a new device for the DALI bus. Those problems are related both to the physical layer realisation aspect, and to the processing of packets in Manchester encoding.

In view of the fact that all devices are electrically isolated in the DALI bus system, it should be taken into account for circuit design. It is also necessary to ensure that the DALI bus signal conductors are independent on the polarity. The design of that can be inspired by some ready to use solutions. The DALI slave board OM13026 by NXP in Fig. can serve as an illustrative example.

The goal within our project was to utilize any DALI Master control unit that was able to communicate with DALI slave devices using standard commands, and that was meeting all above mentioned attributes. The project focus was to bring for being new DALI slave units.

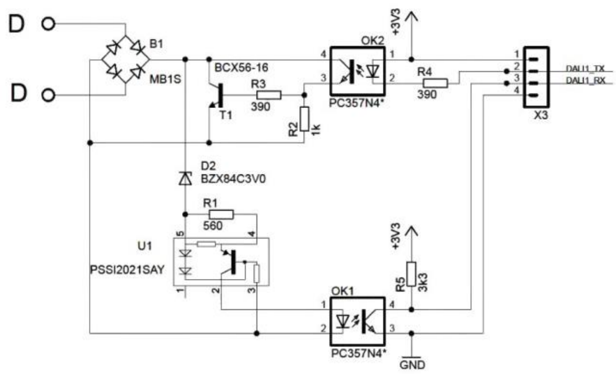

Fig. 3 The DALI bus physical layer realization using OM13026 module circuit diagram [8]

As there is evident in the Fig. 3, the galvanic isolation is realized with optocouplers (OK1 a OK2) where each data transfer direction uses one of them. It is a cheap and efficient solution which enables voltage levels conversion to a required range at the same time like in this case to 0 – 3.3 Volts.

For the sake of both master and slave unit realisation is requisite to use one of up-to-date microcontrollers. DALI_RX and DALI_TX signals in Fig. 3 can be connected to such controller. Nevertheless, the Manchester encoding could be a problem for realization because not any microcontroller is able to process it directly. The LPC1343 circuit which OM13026 module incorporates can communicate only in the standard UART mode. That is why there was necessary to employ our own solution. The data transmission with DALI1_TX signal has software solution without any sophisticated hardware peripheral. The data reception DALI1_RX signal is fetched to the LPC1343 timer input set to the periodical level sampling of that signal. The samples are software-evaluated afterwards.

The communication exclusively software solution has advantage for the case that microcontroller does not provide any hardware support for given serial protocol in. It is thus possible to apply that method for every microcontroller with regards to its memory size and to its computing power.

The remarkable disadvantage of such solution is the fact that each bit processing consumes an appreciable part of computing power. The communication protocol supporting software also reduces the memory space what can matter in some applications. Much better solution represents the selection of microcontroller with inbuilt hardware Manchester encoded data processing support.

The microcontroller market offers an acceptable assortment of microcontrollers with Manchester encoded data processing support. The model from AT90PWM family [9] by Atmel [10] can be one of them. That family has been particularly designed for illumination applications, and every member of that family provides the extended function of the UART module for 16/17 bit communication in the DALI bus. Even though it is an 8-bit microcontroller which unlike the 32-bit LPC1343 does not provide such a computing power, the hardware level DALI communication handling compensates that disadvantage. The price of AT90PWM family circuits is comparable with LPC13 family members.

3.1 The DALI Slave I/O unit concept

The DALI Slave I/O unit has been designed in two variants with the same concept. One of those two variants has to provide the light source control via DALI bus, the other one has to provide the multi switch function with indicating elements. That is a user choice whether he decides to use that module either as a light source or as a multi switch.

The DALI Slave unit physical layer has been adopted from the OM13026 module. The other part of circuitry originates from the reference design by Atmel.

The DALI interface has been realized with regard to galvanic isolation with an opto-coupler just as all I/O modules.

The I/O unit block diagram is illustrated in the following Fig. 4.

3.2 The DALI Slave sensor unit concept

The sensor unit originates both in hardware and software concept mostly from the I/O unit. However, it has brought the following modifications in comparison to it:

- It does not incorporate the user entries (push-buttons).

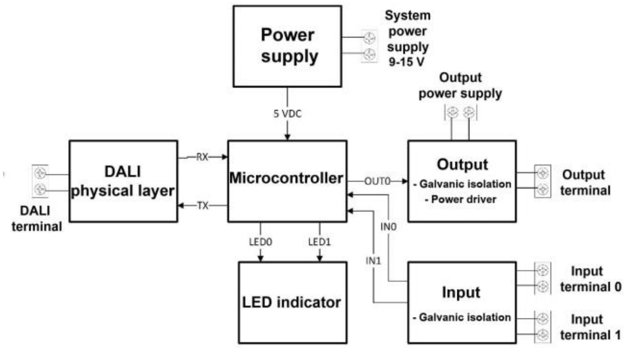

Fig. 4 The DALI Slave I/O unit block diagram.

- It has no output galvanic isolation.
- There is an output load current measurement resistor added.
- There is a voltage divider with photo-resistor for ambient illumination intensity measurement added.

Besides the ambient illumination intensity measurement and load error detection indicated with load current out of expected value, the third DALI slave unit adding in the system offers one possibility more – the DALI group utilization. In case we decide to operate only two Slave units separately in two different groups, from the practical point of view, there is no difference between the access via a direct address or via the group address.

The sensor unit concept has been generated in a block diagram form similarly to the I/O unit concept one.

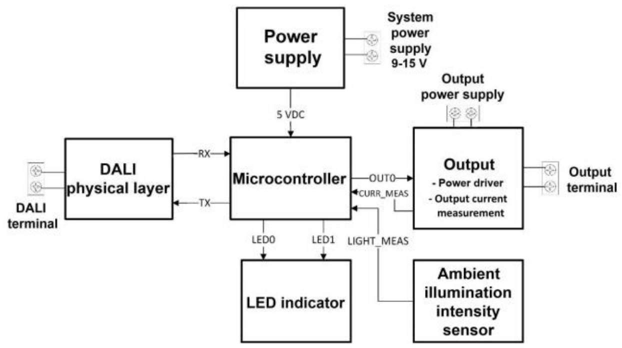

Fig. 5 The DALI Slave sensor unit block diagram.

3.2.1 The ambient illumination value measurement

The DALI Slave sensor unit is equipped with a voltage divider composed from a photo-resistor and a common resistor in series for ambient illumination intensity measurement.

The divider input was connected directly between the microcontroller supply voltage rail and the ground rail.

That arrangement is surely not a best one. However, it serves sufficiently when the simplicity and the only indicative ambient illumination measurement have main priority. The accuracy improvement would require either a voltage reference for voltage divider input or the specialized integrated circuit designed for such purpose with the digital output of measured values.

The VT93N2 photo-resistor has been selected. Its nominal dark value is 500 kilo ohms [11].

The divider output voltage is the voltage of the two components in series common node. The output of that voltage divider was directly connected to the microcontroller AD converter input without any supplementary components for voltage level modification. There was necessary to take into account not only the AD input nominal voltage range, but also the working range of ambient illumination values for the second resistor value calculation.

4 Microcontroller

The DALI Slave units have as a core part ATMega88 microcontroller with other components supporting its function. There are decoupling capacitors connected to microcontroller supply voltage pins. LED indication diodes are also directly connected to microcontroller. The 6-pin SPI connector has been added to the circuitry for firmware loading possibility.

The microcontroller individual pin function overview brings the following table (Tab 1).

5 Final DALI Slave board

The following picture displays the final DALI Slave I/O assembled module after PCB manufacturing and component insertion and soldering.

Fig. 6 The ready to use DALI Slave I/O unit photo [3]

Table 1 Microcontroller pins function.

Pin	Data direction	Signal	Description	Note
PC2	DI	DALI RX	DALI data reception	
PC6	DI	Reset	Microcontroller Reset	
PB0	DI	IN1	Digital input push-buttons	I/O unit exclusively
PB1	DO	DALI TX	DALI data transmission	
PB2	DO	OUT0	PWM output for load control	
PB3	DO	MOSI	SPI data input (FW update)	
PB4	DI	MISO	SPI data output (FW update)	
PB5	DI	SCK	SPI clock signal (FW update)	
PB6	DO	LED1	Indication LED 1 output	
PB7	DO	LED2	Indication LED 2 output	
PD5	DI	IN0	Digital input push-buttons	I/O unit exclusively
PC0	AI	CURR _MEAS	Current measurement input	Sensor unit exclusively
PC1	AI	LIGHT _MEAS	Illumination intensity measurement input	Sensor unit exclusively

6 DALI Slave unit firmware

From the architectural point of view, firmware is divided into three main segments:

- Drivers –physical layer signals processing
- DALI services –DALI frames processing
- DALI application – DALI Slave unit functions realization

The basic architecture as it was adopted from the reference design is illustrated in the following picture:

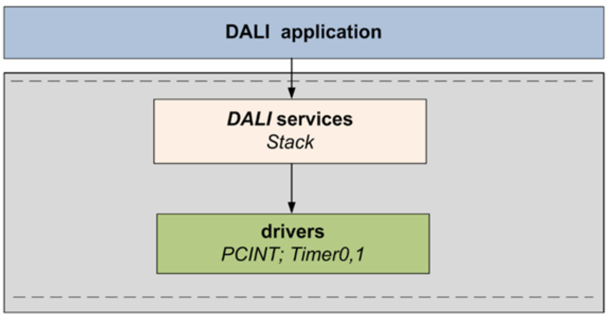

Fig. 7 DALI Slave unit firmware architecture [12].

6.1 Physical layer signals processing (drivers)

As the employed ATMEGA88 microcontroller is not endowed with any hardware interface for a direct Manchester encoded serial communication processing, it was necessary to ensure it in a purely software way. Microcontroller uses the PCINT hardware peripheral and the timer 0.

PCINT is an interrupt that is activated at any value change on microcontroller input pin. In our case, it is PC2 pin which is DALI_RX signal brought to. That signal is a direct output from the DALI physical layer. The physical layer has been adopted from the OM13026 module.

6.2 Frames processing (DALI services)

The DALI frames processing is implemented as a finite state machine which functions realizing states evaluation and the transition between them has to be periodically activated from higher software layers.

The finite state machine for frames processing is in non active state most of time (Idle state) waiting for frame arrival. If a frame comes, it is processed, and the state machine transits in other possible states depending on coming data – reception repeat, answer sending, or back to idle state as the case may be.

IEC62386-100 standard requires the obligatory pause between individual states transition. Our design respects that requirement. Standard also sets down that arriving frame is only valid providing it is obtained two times in course of a 100 milliseconds period. The reason for that is the erroneous data reception exclusion. Provided that condition is fulfilled, the frame related command is executed, and state machine transits in idle state. If there is not possible to receive same frame within 100 milliseconds, the state machine transits in idle state directly.

The finite state automaton is displayed in the following picture:

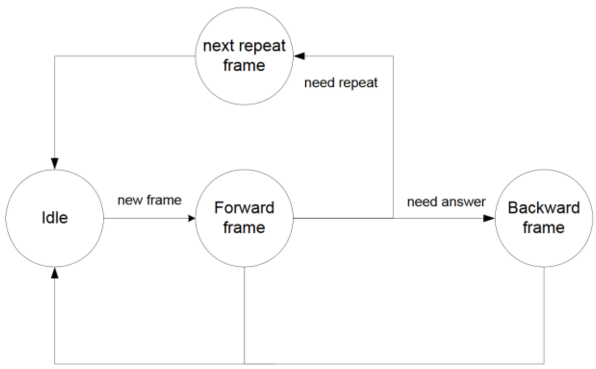

Fig. 8 The DALI frame processing by the Slave unit state diagram [14]

6.3 Application layer (DALI application)
The term "application layer" in our project is to be understood as all what is on the highest level from the software architecture point of view, and what implements the functionality as such.

The application layer term in our project is to be understood from the software point of view as a highest level implementing the Slave unit functionality as such from the user position. There has been created several smaller software modules which task is to mediate for application layer the microcontroller hardware components access.

The list of those software modules is as follows: LEDs.c, inputs.c, sensing.c.

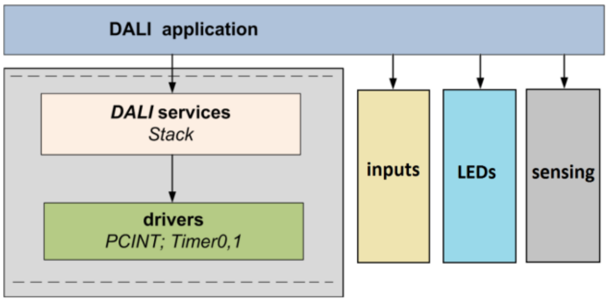

Fig. 9 The DALI slave unit architecture resulting form.

6.4 Supported DALI commands
Any command captured during arriving DALI frames processing is transferred to the application layer for further processing.

Every command has its value within enumeration type (enum), and its particular implementation is located within a switch block where is to be jumped according to the "enum" value to.

Because of simplicity, there are only a few remarkable commands presented in the following table (Table 2).

Table 2 Selected DALI Slave unit commands list.

Comm. code	Command name (enum)	Command description
0	OFF	Immediate output setting to 0 value, device switching over to "OFF" mode
1	UP	Gradual lightening for 200ms period providing device is in "ON" mode
2	DOWN	Gradual dimming for 200ms period providing device is in "ON" mode
3	STEP_UP	Lightening of one step in the range of 1-254 providing device is in "ON" mode
4	STEP_DOWN	Dimming of one step in the range of 1-254 providing device is in "ON" mode
32	RESET	Device Reset to initial state
144	QUERY _STATUS	Device state inquiry
231	SET _INDICATION _LED_1	Indication LED 1 switch on
232	CLEAR _INDICATION _LED_1	Indication LED 1 switch off

7 The entire system test
The test fixture for assembled modules has been created. As was mentioned above, the commercial unit OM13046 by NXP was selected as the DALI Master device. It is practically a converter between the DALI bus and the USB interface. It is based on the LPC134x microcontroller. That device is supplied directly via USB port, and it uses the HID (Human Interface Device) class for communication with a PC. That concept makes PC software development much easier because there is possible to make use of Windows and NET platform native drivers.

From the hardware point of view, that OM13046 module includes the DALI bus physical layer with optocouplers galvanic isolation.

Fig. 10 The DALI Master module by NXP company [13]

The test fixture comprises of following components:

- 2pcs DALI Slave I/O unit
- 1pc DALI Slave sensor unit
- 1pc DALI-Master unit
- 24VDC adaptor for DALI bus power supply
- 9VDC adaptor for DALI units power supply
- 3pcs light source
- 4pcs push-button

Test fixture enables particularly following functions:

- User entry via 4 individual push-buttons.
- 3 light sources power control (9V LED „bulbs“).
- User adjustable events indication with 6 LED indicators.
- One failure detection (load disconnect) at one light source.
- Ambient illumination intensity sensing.
- DALI bus power supply.

There were tested all commands individually and communication possibilities by means of this set.

8 PC applications for control and configuration

8.1 PC application description

PC application has been created for the DALI bus based whole system control and configuration. The intention of that application is to provide user with a universal tool for the system management as a whole.

The main PC application functionality can be summarized in following points:

- To provide user with a graphical interface for the DALI bus system configuration and control.
- To provide user a possibility to manage the configuration data of individual DALI bus tapped devices.
- To establish communication with the DALI Master unit.
- To implement the system control functions.

8.2 The initial concept

The initial concept is mainly related to the particular DALI Master unit used for the design. The MO13046 module by NXP company is the core of our concept. That module manufacturer offers the PC application including source codes as well. Unquestionable advantage is grounded in the implemented communication with the DALI Master unit via USB interface and HID protocol. The extended support of DALI bus is implemented as well.

The main task of our project PC application development was to extent the original application by NXP company with a configuration data management possibility.

The original application has been adopted from DALI Development Kit Revision 2 [15].

8.3 PC application implementation

8.3.1 Applied technologies

The PC application is exclusively composed in C# language over the .NET platform. The Microsoft Visual Studio Express 2013 has been chosen as a development environment.

That application exploits in large extent XML language, or its extended version XML Schema, for storing individual DALI Slave unit data and information.

The application is composed for Windows operational system, and it was tested in Widows 7 environment. The communication via USB interface and bus is implemented with the operational system native drivers.

The application part implementing control functions is composed as a multithread system.

8.3.2 Architecture

The application main parts are illustrated in the following figure:

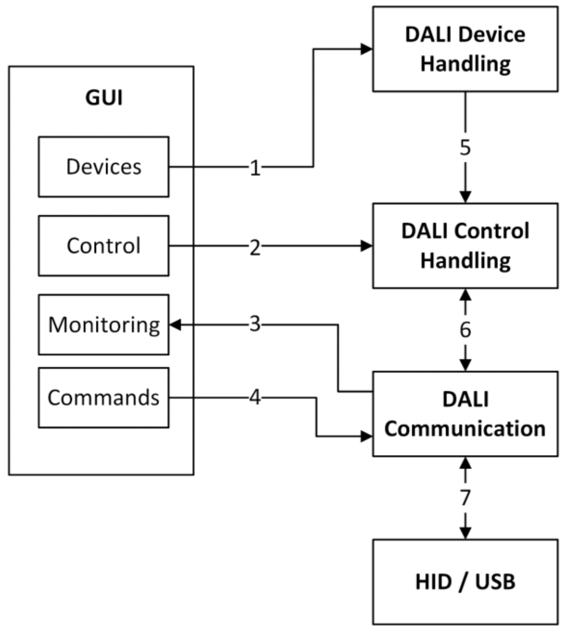

Fig. 11 The PC application basic blocks and their relations.

The meaning of individual blocks in the figure 11 is as follows:

- **GUI** – Block of user – system interface. It is dividend in further four parts
  - **Devices** – It incorporates graphical elements for the DALI Slaves devices information files loading and management.
  - **Control** – It enables the whole DALI bus system operation to be configured by means of graphical elements. It supports the actions and events creation with which user defines how the DALI Slave unit are communicating with each other.
  - **Monitoring** – It contains the text output on all events in the DALI bus system.
  - **Commands** – It makes possible to enter directly the DALI bus by means of manually sent DALI commands.
- **DALI Devices Handling** – An administration module implementing data with individual DALI

Slave units description. It enables download, parsing and XML files data processing.

- **DALI Control Handling** – Main control module for the whole DALI bus. It treats all devices having been defined in the DALI Devices Handling according to the user defined rules.
- **DALI Communication** – That module realizes communication in the DALI bus.
- **HID / USB** – It implements HID class into USB bus. It processes data transmission and reception on the byte level. It exploits the Windows native drivers.

The relations between individual blocks meaning is as follows:

1. User interactions with DALI Devices Handling module.
2. User interactions with DALI Control Handling module.
3. All DALI bus traffic data dump processing for their text output conversion.
4. User interactions for a direct DALI commands dispatching.
5. DALI Slave data fading by DALI Control Handling module.
6. Bidirectional communication ensuring DALI bus control.
7. Bidirectional communication ensuring individual bytes exchange between the application and the DALI Master unit.

8.3.3 Graphical interface

As the figure in Architecture section indicated, the graphical user interface (GUI) is structured in four main parts. Each of those parts has its own bookmark on one of main forms – DaliForm.cs.

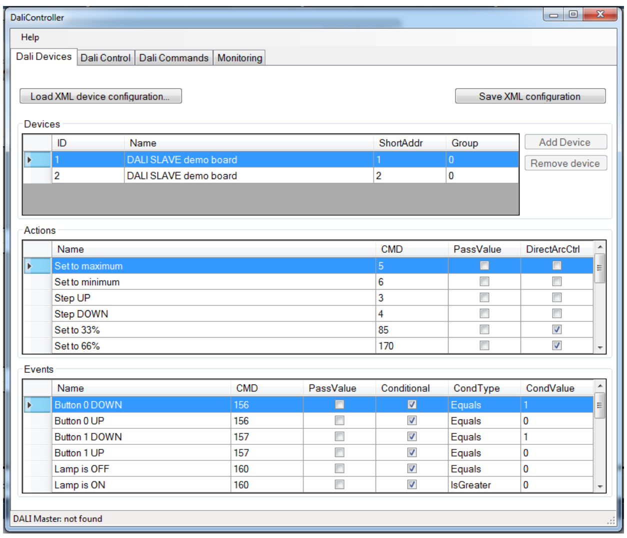

Fig. 12 Sample of DataGridView component in PC application

The application offers also a few auxilliary forms:

- A form for dynamic behaviour new rule adding.
- Error listing form.
- Form displaying information on application.

8.3.4 Configuration data management

According to its nature, the configuration data can be splitted in two parts: data related to DALI Slave unit static description and data related to the whole system dynamic behaviour. Data is stored in XML files in both parts.

From the implementation point of view, the XML files handling is realised with DataSet class offered in the SystemData module of .NET platform. The DataSet class enables to load a whole XML file including XML Scheme, parse it by itself and create a set of interlinked data tables based on the XML structure. The DataSet class instance can be regarded as a simple entity-relation database which is present as a whole in the memory in course of program run.

The question why to store data as a XML file, and to convert it to E-R form afterwards, and back to XML form again at modified data storing, suggests itself. It looks more simple to make use of a data format enabling to store information in interlinked tables. However, the initial idea was that data in and external file should be directly readable by user independently of PC application, even with the assistence of a common text editor. From tha reason, the XML proved as a very convenient tool.

8.3.5 DALI Slave unit static characteristic

All DALI Slave units are described in one XML file in relation to the PC application. Each device has a fixed number of parameters defined, and it has an arbitrary number of so called actions and events which are supported by it.

The DALI Slave unit parameters

The DALI Slave unit parameters are defined as tag <device> attributes, and their list is indicated in the following table :

Table 3 DALI Slave unit parameters

Par.	Data Type	Range	Description
ID	Integer	>0	DALI Slave unit ID for PC application internal purposes
Name	String	-	DALI Slave unit name for application internal purposes
Short Addr	Integer	0-64	DALI Slave unit physical address
Group	Integer	0-16	DALI group affiliation

Actions supported by DALI Slave unit

The action is any activity in range of DALI Slave unit capability. As for instance, it could be an output switch on or switch off, its setting to a required value, or such as a value overflow. As a rule, the action is based on DALI Slave unit commands. User can define an arbitrary number of supported actions, nevertheless, it is always necessary for these actionsto be based on a device supported command. The list of actions is tag encapsulated <actions> in the XML file.

The DALI Slave unit supported events

Besides a whole range of actions, the DALI Slave unit can support also so called events. Event is to be undestood as any predefined state which DALI Slave unit gets in or it registers that. An event is also bound to a particular DALI command. Moreover, it also defines conditions to be fulfilled for the event occurrence positive evaluation. The typical event example can serve a button pushed by user. The event list in XML file is encapsulated with tag <events>, and any event is also described with an array of parameters.

8.3.6 DALI Slave unit dynamic characteristic

Alike DALI Slave unit static characteristic data, DALI Slave unit dynamic characteristic data is stored in one XML file.

Rules definition

There is a list of rules defined in XML file. Each rule is tag encapsulated <rule> , and it defines which event is bound to which action, and as the case may be, how often should the system verify whether an event has happened.

<u>The rule can be understood as a complete instruction for an action which the system has to react with to that event.</u>

Rules execution

The each rule performance itself carries out the function *void ExecuteRule (RuleEntry rule)* which accepts just one RuleEntry class instance. More rules can be carried out thanks to the multithread access.

Employment example

The figure below illustrates a one light control also with indication simple example. That situation ensures a switch on and switch off of a light connected to the module with address 2 with the help of buttons connected to module with address 1. The actual light state is indicated with a LED 0 on the module with address 1.

That situation covers following four rules :

- **LIGHT 0 – TURN ON** – A rule ensuring the light switch on at the module 2. There is an interrogation of button 0 at the module 1 if it is pressed every 200 milliseconds.
- **LIGHT 0 – TURN OFF** – A rule ensuring the light switch of at the module 2. There is an interrogation of button 1 at the module 1 if it is pressed every 200 milliseconds.
- **LIGHT 0 – INDICATION ON** – A rule ensuring the LED 0 indication switch on at the module 1. There is an interrogation of light at the module 2 if it is lit every 1000 milliseconds.
- **LIGHT 0 – INDICATION OFF** – A rule ensuring the LED 0 indication switch off at the module 1. There is an interrogation of light at the module 2 if it is lit every 1000 milliseconds.

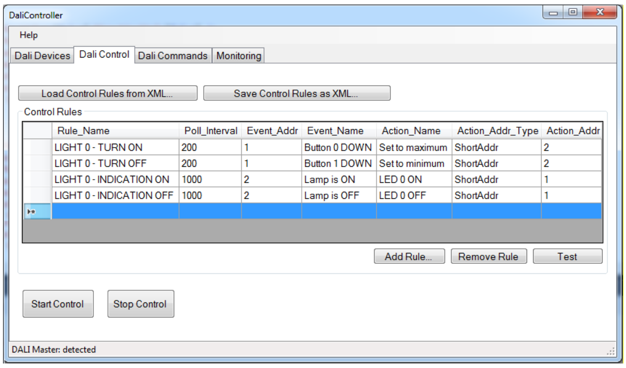

Fig. 13 One light source control with indication example

8.4 Direct access to the DALI bus

The PC application control functions exploiting is not the only way how to access the DALI bus. The original concept by NXP company offered the DALI bus direct access.

User can select what command is to be transferred to what address via DALI bus by means of simple graphical elements. That functionality has been preserved in the current PC application version. The data dispatching by user behaves identically like in case of controlling function, as a stand-alone thread so that it can be performed with other functions at the same time.

The DALI bus direct access graphical form illustrates the figure below.

Unlike the application control functions, the direct access is independent on XML file units definitions so that it makes it possible to dispatch all commands supported with DELI standard. That is useful expecially at the functionality debugging of unknown DALI devices.

8.5 Monitoring
There is possible to monitor entire communication in within the bounds of the system. The monitoring comprises one big text field where all DALI bus activities are recorded in. There is rule title where the communication arised from indicated in every record heading.

Conclusion
Article describes some aspects of DALI bus application in the field of illumination systems control.

Inspired by the most convenient concept, there have been created two unit types for communication via DALI bus. The functionality of those units was demonstrated on the test fixture comprising both units and other accessories forming, together with units, a complete field applicable DALI system.

There has been also designed and implemented PC application for that DALI system configuration and control within the bounds of our project. All parts of our project were successfully implemented so that the system has been proved and its functionality can be extended in the future. The model relation to the real control application increase its versatility for both DALI bus technology principle demonstration, and for educational purposes in the area of smart building technologies principles and design.

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