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Chapter

# Automated Measurement of Traction Line Parameters for Railways

*Dušan Koniar, Libor Hargaš, Peter Šindler and Marek Paškala*

## Abstract

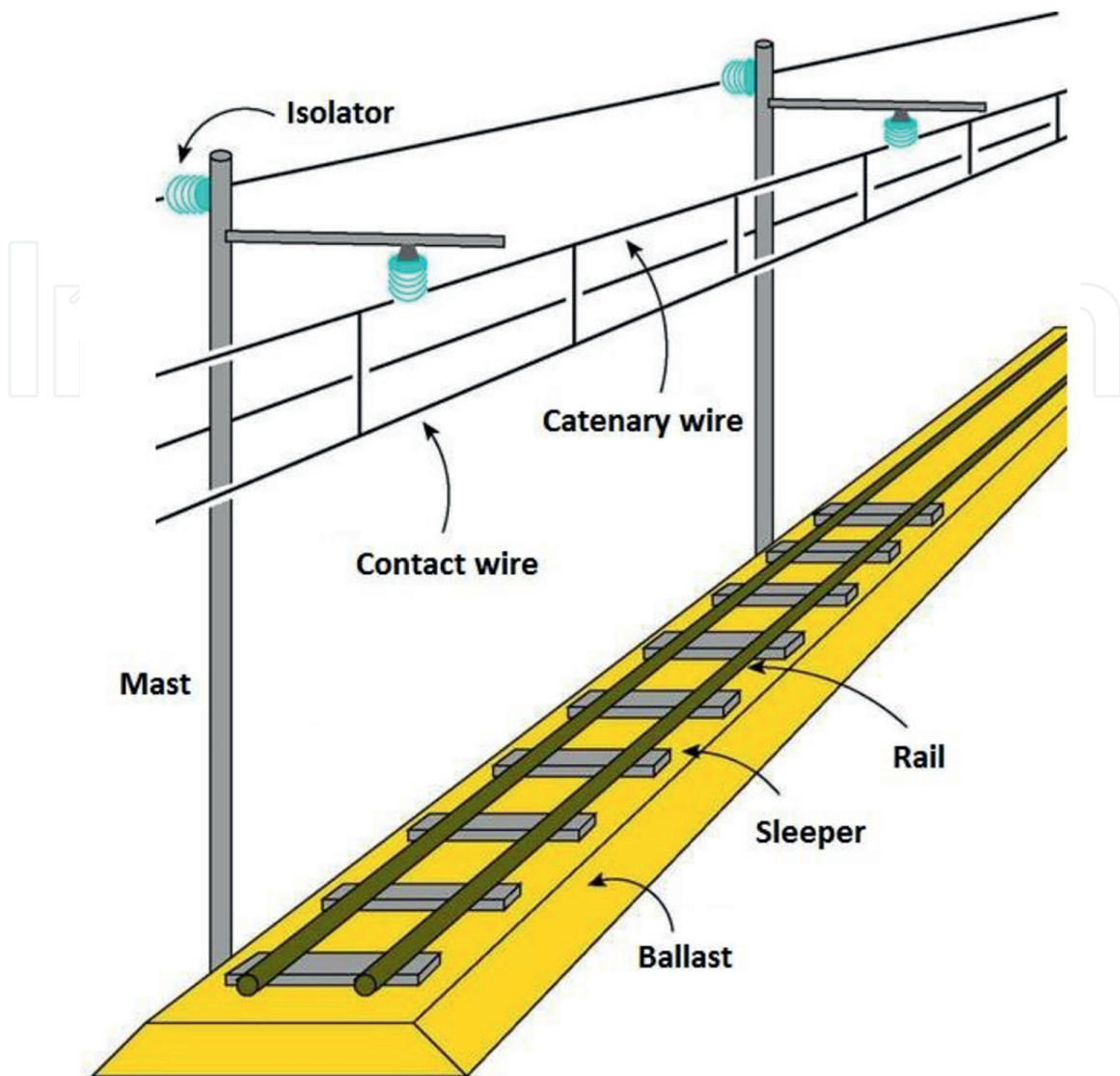
In Slovakia, various rail track segments are being rebuilt due to increased railroad speed and safety standards. Assembly wagons were fitted with an automated measurement device to assess the condition and geometry of the traction lines. The theory behind measuring fundamental traction line parameters like line height and stagger is discussed in this book chapter, along with the development of a measurement electronic device with appropriate sensors and a LabVIEW application for evaluating measured data and controlling and interacting with the electronic device. The Railways Research and Development Institute at Vrútky (Slovakia) is where the system was tested and put into use. This work also demonstrates effective and robust collaboration between the academic environment and praxis. The possibilities of using LabVIEW in industrial applications and its cooperation with the developed measuring device will be presented in this book chapter. The possibilities of communication of the device with the developed software and various methods of algorithm design using several structures found in the LabVIEW development environment will be presented.

**Keywords:** overhead traction line, LabVIEW application, automated measurement, measuring electronic device, railways, data acquisition

## 1. Introduction

Due to increase in the speed and also the safety of railway transport, many segments of railways are reconstructed and turned into electric in Slovakia. The overhead traction lines and supporting structures are crucial part of electrified railways and must achieve the strict and required geometrical parameters as seen in [1]. The simplified scheme of overhead traction line part is depicted in **Figure 1**.

Actually, there are many systems for measuring the parameters of overhead traction lines. The most often measured geometrical parameters are line height and stagger (horizontal position). Beside electrical parameters, other line parameters can be measured, such as contact wire thickness and vibrations and craters in the contact wire. As mentioned in an older study [2], the systems for measuring the overhead lines can be divided into the following categories: manual or automatic, contact (dynamic) or non-contact (static), and portable or vehicle-borne.



**Figure 1.**  
*Structure of railway overhead traction line.*

Naturally, non-contact methods are mainly based on usage of optical sensors, instruments, and computer vision algorithms [3–6]. We can also find other measurement approaches using more sophisticated methodologies: laser measurements operating in high-speed trains in Japan [7], LiDAR [8, 9], or radar [10] systems.

Contact methods use a series of sensors built in a locomotive pantograph. The measurements are based on contact forces between a pantograph and a contact wire [11]. The contact methods often measure the condition of a pantograph strip and the quality of interaction between the pantograph strip and the contact line [12, 13]. Many measuring systems are offered as commercial products (e.g., Tesmec or HBK).

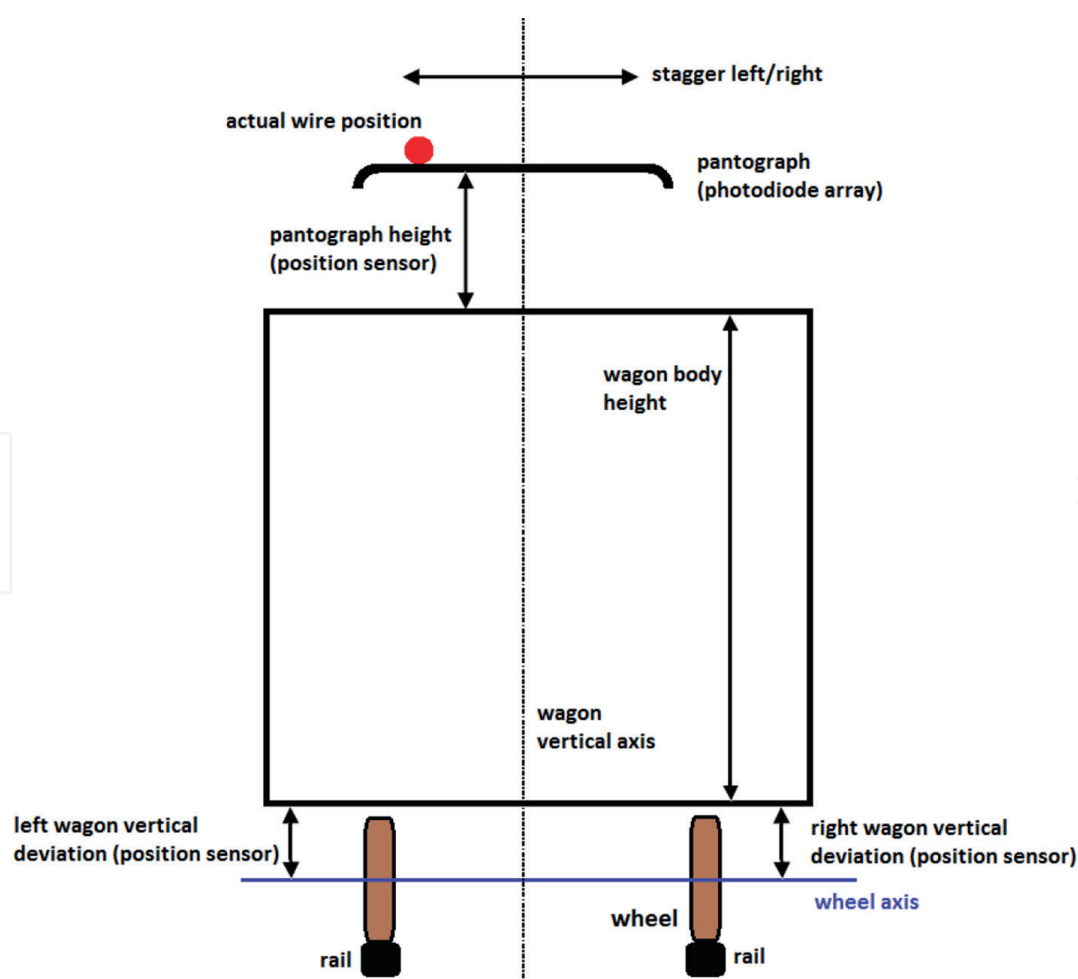
For continuous measuring and simplification and objectification of the height and stagger of overhead traction lines, we developed a sensor system built in the pantograph of an assembly wagon linked with the central electronic device. The entire system and measurement procedures may be controlled by the LabVIEW application. The advantage of this system is automatic data acquisition and storage in the system internal memory.

The proposed electronic device has two operating modes: autonomous mode and PC control via specialized service software (LabVIEW application). Evaluation

software can be used to analyze all measured data extracted from the internal device memory. When assessing the parameters of overhead traction lines, all the national technical standards are respected. The advantage of LabVIEW-based application design is that the measured data (tables and graphs) are presented in graphical user interfaces with a professional look. If some parameters exceed the defined tolerance, an overrun table is generated. The LabVIEW application also supports the printing of the measurement report.

## 2. The geometry of the measurement system

To measure the two basic parameters of overhead traction line geometry (contact wire height and stagger), the basic geometric properties and relations must be known. For measuring the heights, wire position sensors are used. For stagger computation, the photodiode array is implemented parallel to the pantograph strip. The simplified geometry of measurement is depicted in **Figure 2**. As shown in this figure, the resulting contact wire height is composed of several partial heights, and information from position sensors (measuring, e.g., the wagon vertical deviations) is dedicated to compute the corrected (perpendicular) height.



**Figure 2.** Geometry of system used for parameter computation (the schematic is not in a proper scale; it serves only for visualization of geometric relations).



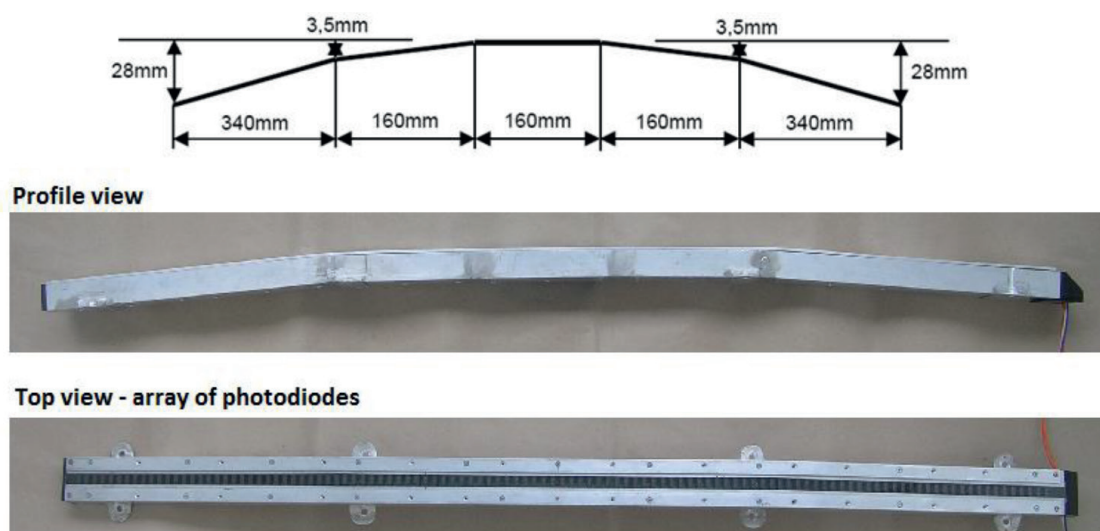
**Figure 3.**  
*The wire position sensor measuring the vertical deviation of the wagon body from the wheel axis.*

The following conditions are introduced in the measurement: the wagon body is hard, and in turn, the wagon vertical deviations are measured with wire position sensors (**Figure 3**). Also, the height of the pantograph (measured from the roof of the wagon) is measured with a wire position sensor.

Deviations are used for computing (correcting) the real height of the wire. The final height is a sum of partial (corrected) heights from the rails to the pantograph strip. Contact force between the pantograph and contact wire is kept as constant and controlled by an independent force sensor. The pantograph sensor for stagger measurement is shown in **Figure 4**.

The accuracy of height measurement is set under 1 cm, while other parameters are under 1 mm.

The last important part of the entire measurement system is the GPS module, which enables fusion of the measured overhead line data with the physical track. This data fusion is also possible due to the implemented trajectory increment sensor. The trajectory increment sensor is placed on the wheel and can measure one-hundredth of wheel turns. The wheel perimeter is approximately 2560 mm. The device can capture each data from this sensor, but the default increment is set to 4. It means that the device allows calculating track line parameters that are 10.24 cm each. This is a sufficient distance to calculate the parameters according to norms. The position of masts, as well as special events, is stored and aligned with the GPS position.



**Figure 4.** The pantograph sensor built in an aluminum skeleton: physical dimensions, profile view, top view—the array of photodiodes.

### 3. Acquisition device

An acquisition device is a complex electronic system developed for setting the measurement sensors, reading the data from sensors, and storing the measured data. The physical device is shown in **Figure 5** and block diagram in **Figure 6**. An acquisition electronic device is located in the cockpit of the wagon.

#### 3.1 Physical properties and parts of an acquisition device

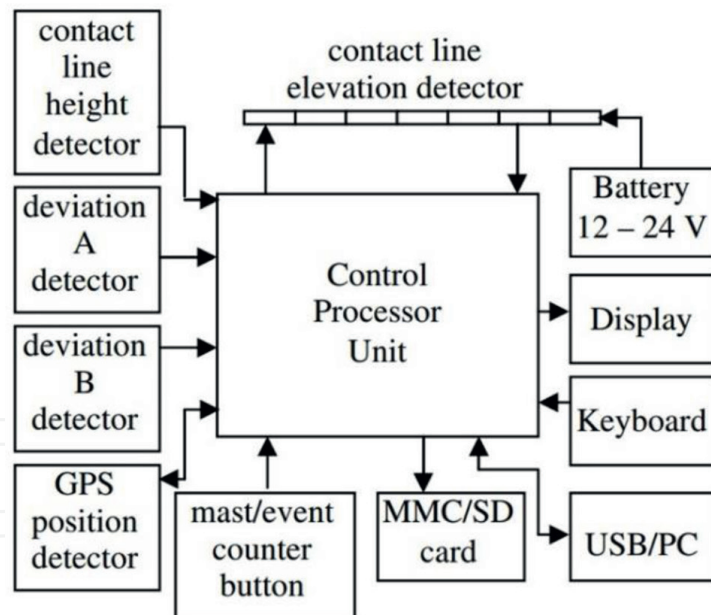
The main physical components of acquisition devices are:

- motherboard/microcontroller,
- detector of contact wire position on the pantograph strip,
- GPS signal detector,
- wagon deviation detector (right—A and left—B),
- trajectory incremental sensor,
- interconnection optical cables.

The 32-bit CPU used in the microcontroller core is from the NXP manufacturer. The microcontroller simultaneously interacts with other detectors and sensors as well as with the position of the overhead traction line on the pantograph strip detector using optical interconnection on a periodic basis. The display and keyboard are also connected via the ports. The PC is connected to the device via a USB port. The measured data can then be sent and analyzed on the PC with the LabVIEW application. Selecting measurement settings, starting, or terminating is possible from this connected PC.



**Figure 5.**  
*The physical appearance (front panel) of an acquisition device.*



**Figure 6.**  
*The block diagram of an acquisition device.*

### 3.2 Software features of an acquisition device

It is possible to immediately evaluate the parameters that were measured. The device and PC can communicate online. The software features of an acquisition device are:

- online numeric and graphic values displaying on the device's display,
- online numeric and graphic values displaying on the PC through the USB cable,

- measurement settings entered from the device keyboard,
- measurement settings entered from the PC through the USB cable,
- device settings entered from the device keyboard,
- the measurement can be started from the device keyboard or from a PC through the USB cable,
- measurement overview on the device,
- measured parameter recording,
- saving the record to the MMC/SD card,
- list of last 20 measurements,
- password-oriented access to the device (tree level),
- the automatic actual time and date setting,
- measured data evaluation on PC.

### **3.3 Acquisition device motherboard**

Dual-layer board is how the motherboard is implemented (1.5 mm). The following building blocks are included: the processor unit, the 16-bit converter with analog multiplex, the power supply component, the binary signal inputs, the MMC/SD card, the USB controller, the serial optical interface for the position of the overhead traction line on the pantograph strip detector, the GPS module, and the RTC controller.

On the motherboard is the 32-bit LPC2214 with the ARM7TDMI core [14]. The frequency of operation is 55 MHz. For programs and other peripheral controllers, this CPU has 256 kB flash memory in addition to 16 kB RAM. The CY62167DV30 external 16 Mbit integrated RAM is added to the processor. The operating system uses this memory.

For storing measured data, an external NAND memory with a 1 Gbit capacity is used. The entire recording capacity is between 200 and 240 km. This amount depends on the measurement precision you've set. The increment count from the trajectory incremental detector determines the measurement precision.

A common 16-bit bus connects each circuit. The programmable logical field XC2C64A and the processor work together. With the help of this logical field, the following interfaces can be realized: keyboard, binary inputs, serial controller, and PC connections.

### **3.4 Position sensor of the contact wire**

The sensor is designed as a non-contact sensor (photodiode) working on the principle of reflection of infrared radiation from an obstacle (overhead traction line) (**Figure 4**). An integrated photodiode OPB732 is used, which emits infrared light with a wavelength of 850 nm [15]. The sensitivity indicated by the manufacturer is a maximum of 5.5 cm, but 2.54 cm is recommended.



The sensor works in the dynamic (impulse) mode. There are 16 integrated gates on one module at distances of 1 cm. The position sensor consists of seven modules. The number of modules is optional—it is set in the menu of the control unit.

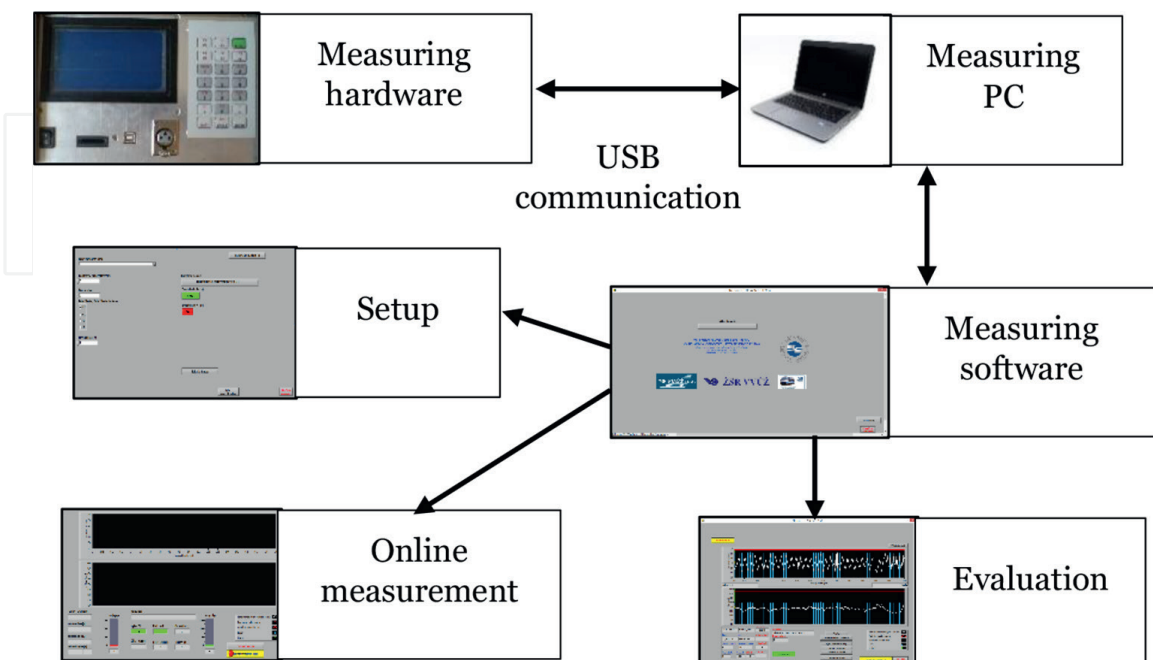
#### 4. The PC's software description

The software solution for measuring overhead traction line parameters is created in the LabVIEW development system. The application was created for a more user-friendly environment for communication with the hardware part (Figure 7). With the help of the created software, it is possible to perform three basic modes when measuring parameters:

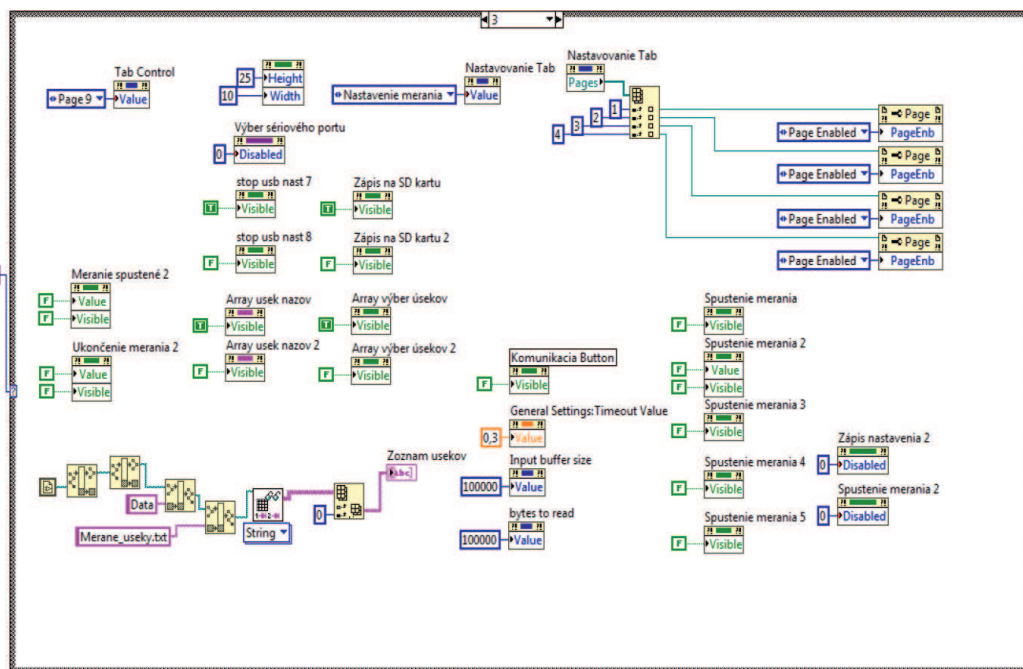
1. setup
2. online measurement
3. evaluation

For the first two modes, it is necessary that the PC with the software is connected to the hardware part using a USB connection. The third mode is used without the need to connect to the device. It should be noted that the first two modes can also be implemented directly in the device using the keyboard without the need to connect to a PC.

The selection of the application mode is realized as a state machine. When the mode is selected, appropriate tabs must be displayed (Figure 8). The user interface contains the "Tab control," and for different modes, different tabs must be displayed. The state is transferred through the local variable to the next parts of the block diagram.



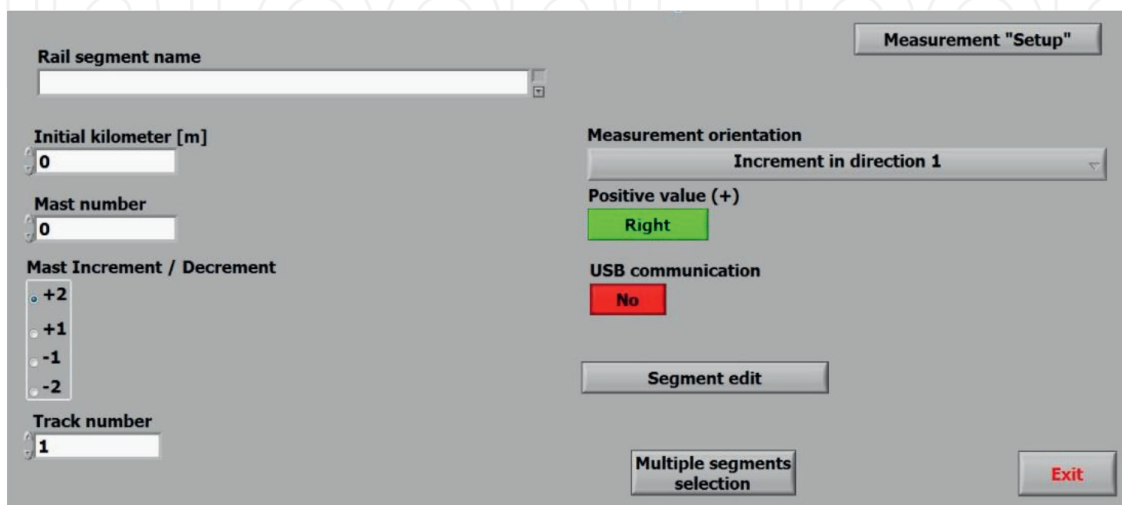
**Figure 7.** Hardware (device and PC) and software (setup, measurement, and evaluation) blocks that are needed for the right functionality of the device.



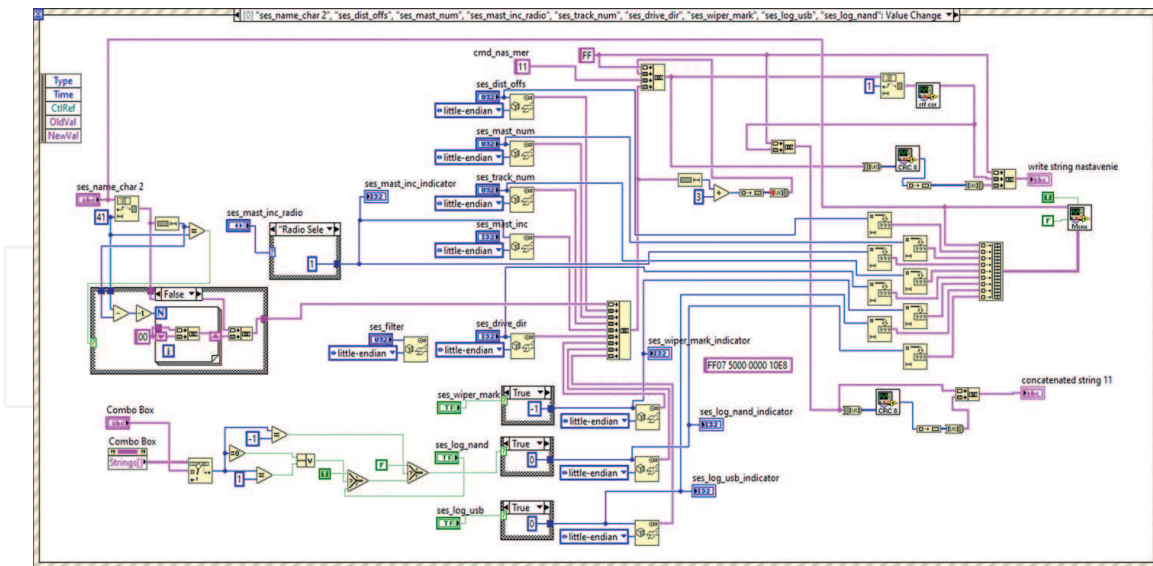
**Figure 8.**  
 The block diagram for mode selection.

#### 4.1 Setup

In the case of selecting the "Setup" mode, the PC must be connected to the hardware part. In this mode, the device operator can set the input data for measuring the overhead traction line parameters (Figure 9). If the measurement in the given section has not yet been carried out, it is necessary to enter all the necessary data for the measurement of this section. The name of the measured section can be considered the basic data. This name is important as it is subsequently used in the evaluation of data from this section. The name of the measured section is used when creating the names of the evaluated files. It is also used when comparing the results of measuring parameters for multiple measurements of the same section.



**Figure 9.**  
 The front panel of the "Setup" mode.



**Figure 10.**  
The parameters are written in the "Event" structure.

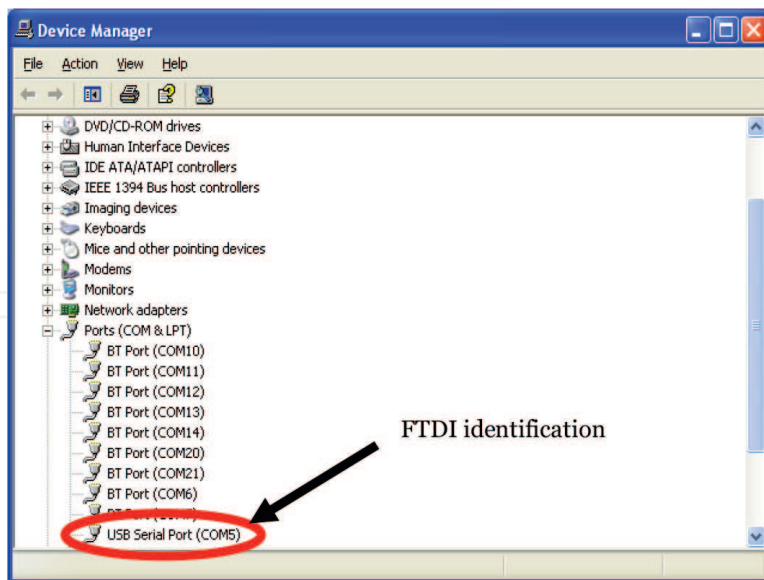
Users can type all measurement parameters at once, and these parameters will be written to the variables after the corresponding button is pressed. The "Event" structure in the block diagram is used to provide this functionality (the example is given in **Figure 10**).

Other data that are set in this mode are the initial mast, initial kilometer, and track number. The entered data serve as initial values when the parameters are measured. With the initial mast, it is also necessary to set if the number of mast will be increased or decreased. This data is used for manual marking of masts located on the measured section. When measuring, the location of the masts is marked with a joystick button. Since the information about the initial mast is entered as numerical information, it is possible to increase or decrease the number of the measured mast by the set constant. In many cases, however, in the measured sections, the masts are marked not only with a numerical value but also with a letter. After the first measurement of the section, these masts can be edited during the evaluation (more information is given in Section 4.3). If a list of masts is available for the measured section, the mast designation is read from this file. In this case, it is important that the name of the measured section and the name of the file with the designation of the masts are the same.

When entering the initial kilometer, the value corresponding to the railway line kilometer at the first measured mast is entered. When measuring the section, the crossed distance is then increased or decreased based on the orientation of the measuring wagon and the setting of the trajectory increment sensor. The last important input data is the stagger value at the first measuring mast. The exact value is not entered, but it is only mentioned whether it is positive or negative from the point of view of measurement. The exact value is determined based on the position of the overhead traction line above the sensor in the pantograph.

## 4.2 Online measurement

The "online measurement" mode is used to display currently measured parameters. To use this mode, it is necessary that the PC is connected to the hardware via a USB. At the same time, data transfer via USB must be enabled in the "Setup" mode.



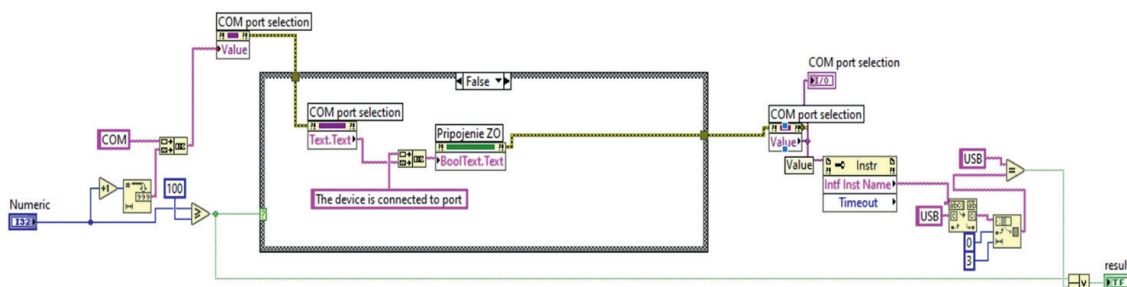
**Figure 11.**  
Viewing the device in the "Device Manager" in the Windows operating system.

The acquisition device implements an FTDI chip FT2XX that can provide serial communication. The acquisition device is presented in Windows "Device manager" as an additional COM port (**Figure 11**). The application checks the connected COM devices and tries to find the device with the FTDI description. The application increments the COM port number in the while loop and searches the string "USB," which is typical for a connected FTDI chip. The subVI for searching for a connected COM port is given in **Figure 12**.

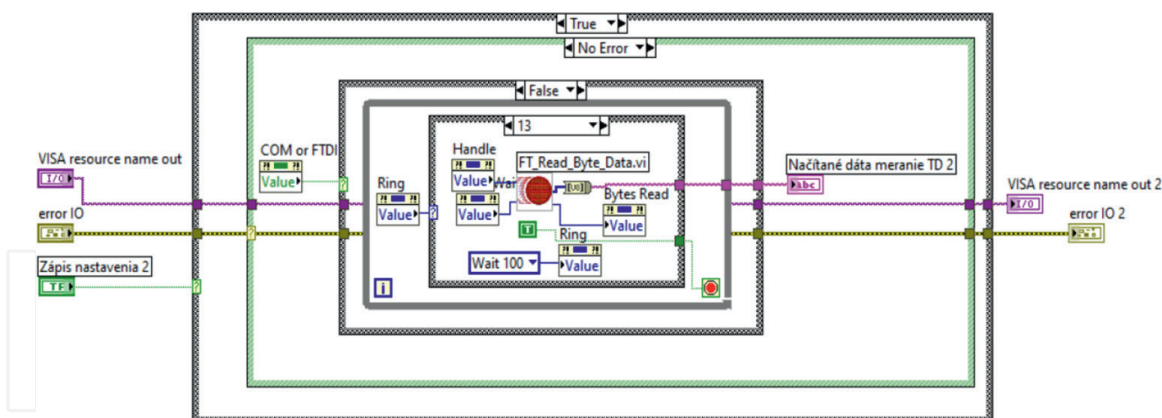
After the device is found, communication can be established between the device and the PC in two ways. The VISA functions can be used, and these functions are implemented in the LabVIEW environment, or the FTDI D2XX function library for LabVIEW can be used, but this library must be downloaded and incorporated into the environment. An example of communication between the PC and the device through implemented FTDI functions is shown in **Figure 13**.

When FTDI functions are used, the state machine is mainly designed for writing and reading data. The individual steps of communication setup are designed as separate states. After starting the communication via FTDI, it is then sufficient to refer to the reading or writing state. The implementation of the state machine therefore makes the block diagram more transparent and simplifies it.

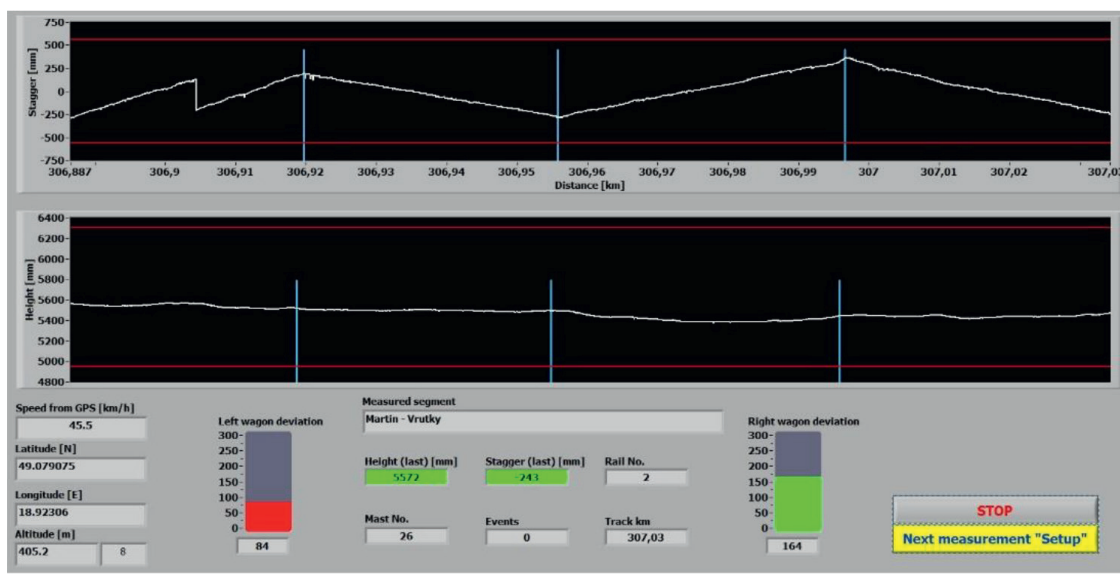
By selecting this mode, after synchronization, the data on the measured parameters will be displayed on the PC screen in both graphic and numerical



**Figure 12.**  
The code for searching for a connected COM port.



**Figure 13.**  
The state machine with FTDI subVIs is used for the creation of the USB connection.



**Figure 14.**  
The front panel of the “Online measurement” mode.

forms (Figure 14). Individual indicator elements are used not only to display the status of the measured parameters of contact line height and stagger but also to indicate the status of auxiliary data from the sensors. Auxiliary data includes, for example, information about the deviation of the measuring wagon. This parameter is important in terms of contact line height and stagger correction. Along with data on currently measured values, data on the measured section is also displayed on the screen. There is information about the crossed distance, the current mast field, and the number of the measured railway track.

Only the last 100 m of the measured data for height and stagger measurement are displayed on the graphic indicators. The coloring of the numerical indicators indicates if the limit values have been exceeded (red—exceeded, green—within the limit). The next displayed information is information obtained from the GPS module—actual speed, latitude and longitude, and altitude.

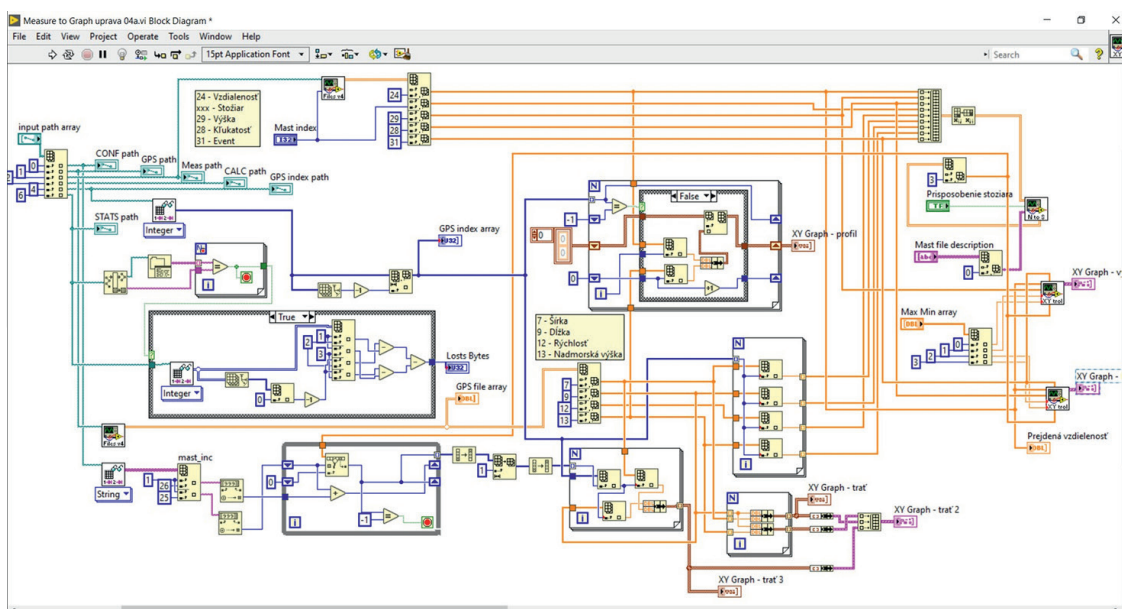
### 4.3 Evaluation

This mode is used if the measured data about the overhead traction line is saved on the SD/MMC card. During the first processing of the measured data files, the evaluated data are written into table files that can be viewed with table editors. When the data file is subsequently loaded, the preprocessed data stored in the table files are loaded directly from this table file.

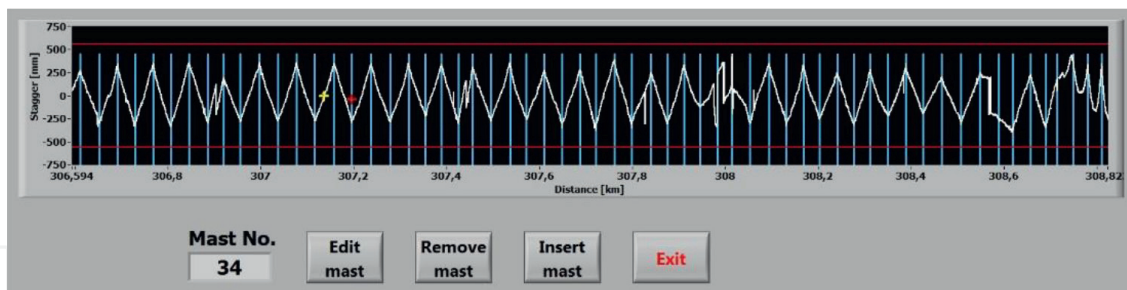
The measured data are written in a binary data file. The data from sensors are written directly to the file in the raw form as U32 data type. Therefore, it is necessary to convert these data into real values. Real values in the DBL data type are achieved by incorporating the entered constants and the position of the contact wire. An example of conversion of binary data from sensors to real values is shown in **Figure 15**.

During the first evaluation of the measured section, it is possible to edit some measured data (**Figure 16**). These data need to be adjusted because they will be used as a reference when measuring the same section repeatedly. When editing the data, a new window will appear. In this window, masts of overhead traction line can be edited. The user can insert or delete a mast. This situation occurs if the operator incorrectly marked the location of individual masts during the first measurement. The place of insertion or deletion of the mast is indicated by moving the cursor to the place where the user wants to insert the location of the mast. Mast editing also serves to change the generated mast number. This option is possible if the list of traction masts for the measured section is not known in advance.

When measuring the same section repeatedly, this option will no longer be available. Masts will be automatically added to the evaluated data based on the first accurate measurement.



**Figure 15.** The block diagram of the "Evaluation" mode where the binary stored raw U32 data are transformed to readable numbers DBL.



**Figure 16.**  
The front panel of the mast adjustment for initial evaluation.



**Figure 17.**  
The front panel of “Evaluation” mode.

Browsing the measured data in the displayed graphs can be done only after evaluating all the measured data (**Figure 17**). After displaying the measured data, it is possible to find out the height and stagger data using the cursors located in the graphs. At the same time, data corresponding to the position of the cursor in the graph is displayed in the numerical indicators. The displayed data are:

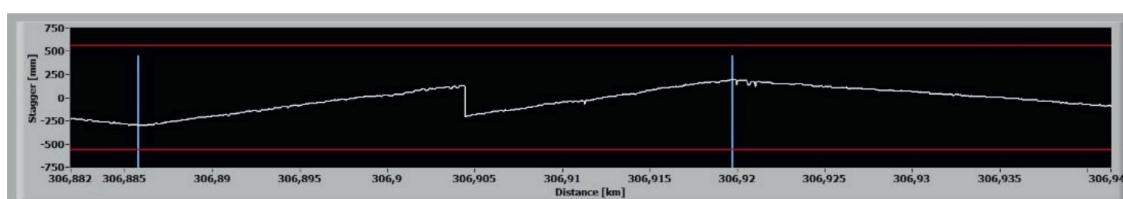
- distance—the value is given in km,
- stagger—the value is given in mm,
- height—the value is given in mm,
- mast number,
- GPS data:
  - date of measurement,
  - measurement time,

- latitude,
- longitude,
- actual speed during measurement,
- altitude,
- number of satellites,
- accuracy of measuring the position of the measuring device (wagon).

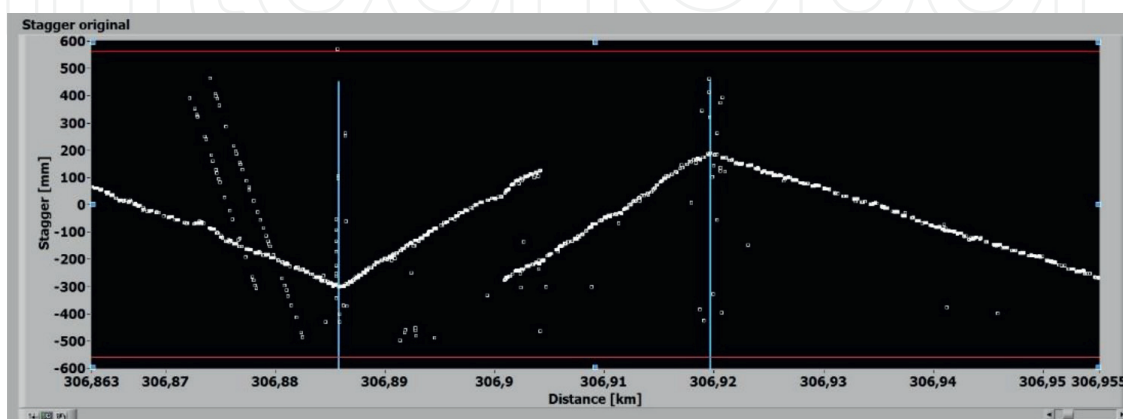
In this graphic display, it is possible to view the measured data for the entire measured section, or it is also possible to choose a detailed display of the measured data. After selecting the detailed display, it is possible to display individual measured sections either according to the crossed path or as sections between individual masts (**Figure 18**).

When evaluating the data, there may be inaccuracy in determining the parameters. These cases often occur when overhead traction lines are crossed. It happens when one overhead traction line ends and the other starts. Such a crossing will be reflected in the different heights of the overhead traction line. Therefore, it is possible to display the original data obtained from the sensors to accurately determine the parameters (**Figure 19**).

Since the measuring system is primarily intended for determining the parameters of height and stagger, it is necessary to detect the exceeding limit values of these parameters. The software allows the user to enter the values of the limit parameters.



**Figure 18.**  
*Detailed display of stagger between two masts.*



**Figure 19.**  
*Original data from sensors.*



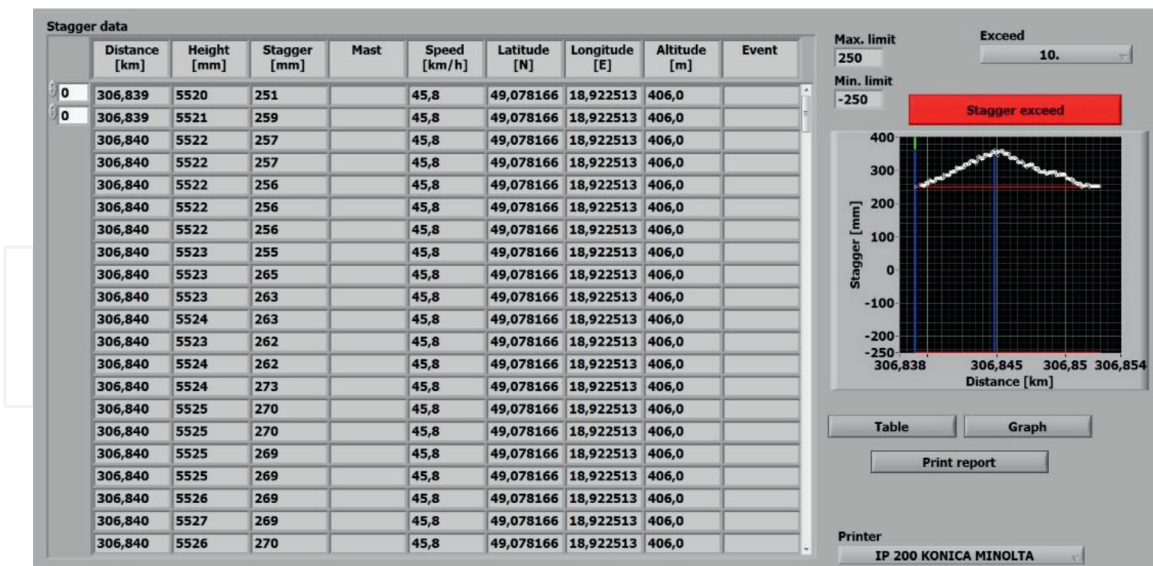


Figure 20. Exceeding the maximum values.

Subsequently, all values that are greater than the specified limit values are automatically searched. These values can be displayed in a tabular or graphical form (Figure 20). Since it is very often not just individual values but a series of values, it is possible to select an individual series of values based on the analysis. The evaluated data can then be exported to a file or printed as a report.

Report creation is also possible for other measured parameters than just height and stagger exceedances. It is also possible to create a report containing data only on the value of height and stagger for specific masts. This report is important for checking the correctness of the overhead traction line placement.

The "Report Generation" toolkit is used to create the report. The user can select the choices on the application front panel, and based on their choices, the functions like "Append Image to Report" or "Append List to Report" are applied in the result. These functions are placed in the "Case" structure, and the user choice switches the "True" or "False" state (Figure 21).

When measuring the same section repeatedly, it is possible to compare the parameters measured during individual measurements (Figure 22). Sections must be selected from already evaluated files. For a correct evaluation, it is necessary to select the same measured sections. Synchronization of data for comparison is done based

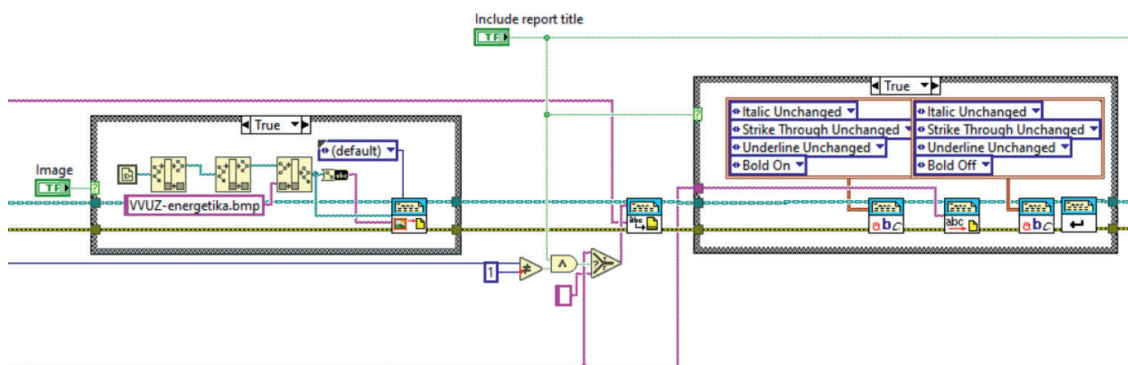


Figure 21. The part of a block diagram for report generation.

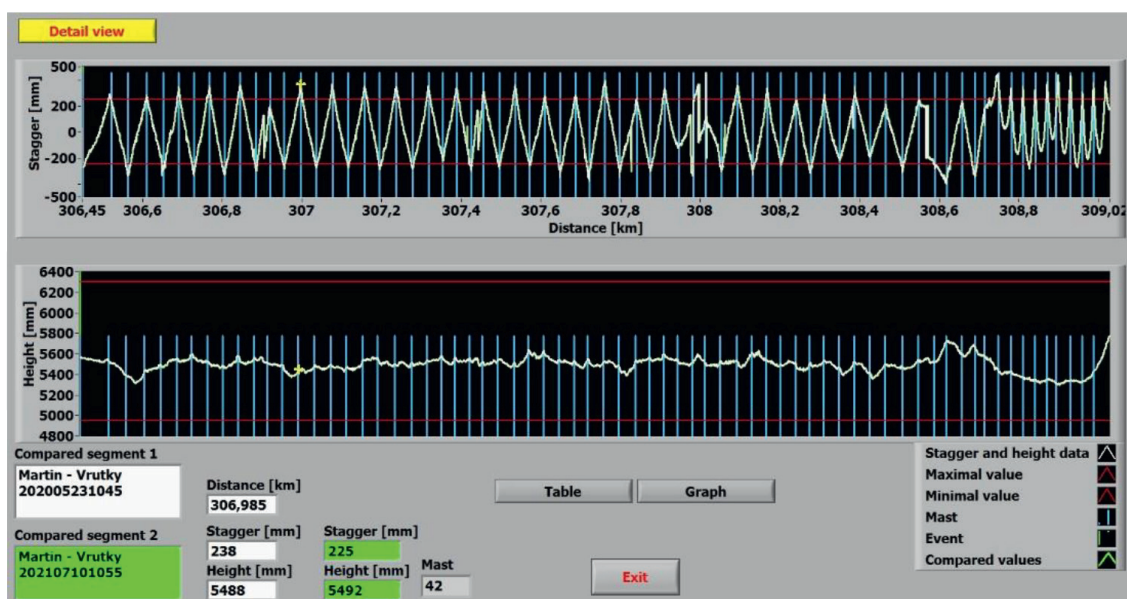


Figure 22. Comparison of measured parameters for two measurements for the same section.

on the coordinates from the GPS module. In the basic graphic display, it is possible to view the measured data for the entire measured section, or it is also possible to choose a detailed display of the measured data. Measured data of height and stagger can also be determined using cursors located in graphs, while data from individual measurements are also represented numerically.

## 5. Conclusion

The presented device and developed software for overhead traction line height and stagger measurement are determined for continuous measurement of statistical parameters. The automatic data acquisition is the device's advantage, while the distance of measurement can be set by the user. The setting of measurement can be realized in the device through a keyboard or in a graphical user interface through a PC.

The device's internal memory is organized as a ring buffer, and measured data are recorded here. The recorded data must be evaluated through the developed software. This software enables evaluation based on limits set by technical norms.

Then, the measured parameters can be evaluated objectively because not only the absolute values of line height or stagger are presented but also the corrected values are displayed as real values.

The developed software can be extended by the possibility of an automated section measurement in the future. This would be possible based on the data from the GPS sensor, while the knowledge of the position of the masts at the beginning and end of the measured sections would be used.

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### **Conflict of interest**

There is no conflict of interest.


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