Design of Human-machine Interface for GNSS Device

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***Abstract*—The design of human-machine interface for devices that determine possible positions using Global Navigation Satellite Systems (GNSS) is the topic of this paper. The aim of this work is to simplify the existing complicated mechanism of setting of these devices and to allow their full utilization for naive users as well. The mathematical model of surveying process was developed within an analysis. The design of interface is based on the theory of state machine with hierarchical states. The proposal is implemented by a system top-down analysis and links between the functional sub-components are described using a sequential scheme. The specific application for communication of the user with the interface was developed in this project. The application works in the off-line mode. That means all values of the parameters are imported into the device manually. The application works with the support of geographical information system that evaluates all spatial parameters and simulates the measurement conditions in the given locality. The design of interface was verified on the specific GNSS device, GRS-1 by Topcon Company.**

***Index Terms*—Human-machine interface, hierarchical state machine, GNSS device**

I. Introduction

The devices for determining of geographic location by the satellite methods (GNSS) are over time constantly improved and they expand their functional repertoire. On the other hand, their operation is increasingly complex and the serviceability of these devices is very difficult for naive users without special training. The aim of the project is to design a user interface that allows easy setting of parameters of apparatus for GNSS positioning methods. This will greatly extend the range of users of these devices and it will simplify their operations. The idea of human-machine interface is not entirely original. Works that deal with this issue can be divided into the following categories:

1. The general issue of human-machine interface, a conceptual view in terms of mathematics, logic, formal languages, predicate calculus and artificial intelligence [1], [2], [3]
2. The interface for large-scale control of industrial systems [4], [5], [6]
3. The application of human-machine interface in physiology and medicine [7], [8], [9]
4. The human-machine interface for mobile devices [10], [11]
5. Special methods and applications [12], [13], [14]
6. Control system design and implementation for a virtual terminal for agricultural vehicles based on standard ISO 11783 [15], [16].

The benefit of the solution that is described in this article is a system approach. This means that the human-machine interface is extended about the neighborhood of system, i.e. about the environment (terrain in our case), in which the measurement is realized. In this case, GIS is the integrative element between the user, device and the environment.

The GIS is needed for spatial analysis of planning of GNSS measurement. The similar applications like the application designed by authors were developed in ArcGIS environment for GNSS planning. These applications include functional tools working with digital elevation model. For example, the dissertation [17] deals with the mapping of utilities and a tool called Urban Canyon GNSS Simulation was created as part of this thesis. In the paper [18] is described Satellite Viewsheds tool which has been programmed using VBA and serves also for GNSS planning in GIS.

Currently, the first phase of the project is finished. This solution is off-line, when calculated values of the parameters are overwritten into the device manually. The goal of the next step of the project is on-line solution. In this case, the device will be direct connected with PC and the values of the parameters will be imported into the GNSS device direct through communication interface.

II. Motivation

The most common use of GNSS device in practice is:

- navigation,
- position setting,

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- surveying in field.

There is a problem: the usage of GNSS device is very complicated especially for naive users (laymen). Even experienced experts have problems.

In order to demonstrate the complexity of input parameters presetting, we present the number of pages that the users have to set in various modes:

- Static method – 8 pages
- GNSS without corrections – 13 pages
- Configuration of CZEPOS (set of permanent reference stations in the Czech Republic) – 14 pages
- Configuration of TopNet (set of permanent reference stations of Geodis Company) – 14 pages.

The effective solution of this problem is human-machine interface. Authors were inspired by publications [10], [11], where the human-machine interface for mobile devices is being discussed. The new approach that is used in this project is the usage of reduced set of input alphabet of state machine that represents the GNSS device.

The goal of this project is to create design of human-machine interface for GNSS device. There are two types of inputs:

- Subjective – parameters of required accuracy
- Objective – parameters expressing environmental and geographical conditions (supported by GIS).

Outputs of this project occur in these variants:

- Off – line: list of parameters values,
- On – line: settings of parameters direct in the device.

III. Analysis Of The Gnss Device

The device for determining a position is necessary to be set before the measurement so as the conditions required by the user can be accomplished. From this perspective, the input parameters can be divided into three groups:

1. Device parameters
    - antenna height
    - parameters of the communication equipment (a modem)
    - internet connection parameters (user name, password, dial number)
    - battery status
2. Environmental parameters
    - availability of data services in the given locality
    - state of coverage of mobile networks
    - local terrain parameters
3. Parameters that express the user requirements
    - selection of locality
    - accuracy of measurement
    - purpose of measurement (GIS, cadastre of real estates)
    - form of output (coordinate and vertical systems, format of coordinate list, measurement of position and/or height).

The set of parameters which accomplish the user requirements is given by (1) where D are parameters that dependent on the specific device and E are parameters that dependent on the given location (geographical conditions, available services, satellite configuration, temperature, etc.):

$$U \subseteq D \cap E. \tag{1}$$

Accuracy marked A is a function of two variables by *(2)* where U is utilization and T is the period of observation, i.e. the period during which the device must be used to achieve the required accuracy:

$$A = f(U, T). \tag{2}$$

IV. Method Of Solution

In our case the fuzzy set theory and application of state machine with hierarchical states are used. The system approach using top-down method was used to design the human-machine interface. The core of the problem is that the surveying process takes place in a system which is consisted of the following basic components:

- mobile measuring instrument
- locality where measurement is realized
- users, who carry out the whole process of measurement.

GIS is a supportive tool of this system and its main function is an analysis of the geographical parameters of the locality. Figure 1 provides a simplified variant of the whole system.

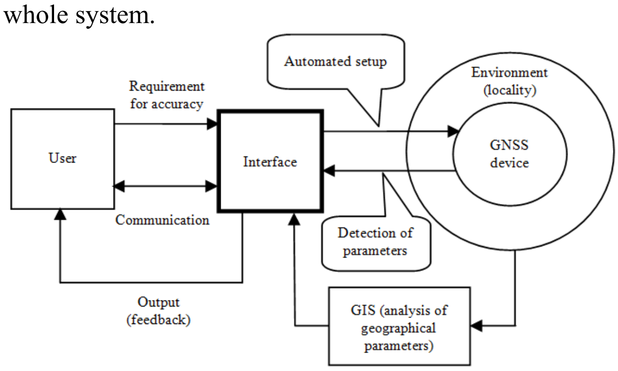

Figure 1. The scheme of measuring system using GNSS method with proposed interface

As mentioned above, interface is designed by top-down system method. The interface in this case is considered as a system that has inputs, outputs and internal states. The input is the requirement for measuring accuracy with a given device in a selected locality by given formula (2).

The output is *A* predicate that determines to what degree it is possible to achieve a given aim. The *A* predicate is fuzzy number that characterizes the entire process of measurements. This fuzzy number indicates the degree of fulfillment of the initial request (accuracy of measurement). The basic scheme is in Figure 2.

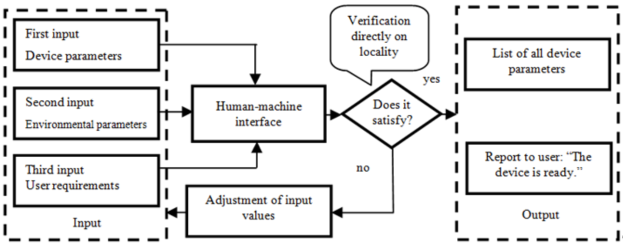

Figure 2. The process of setup of GNSS instrument before measurement

The interface is designed for GRS-1 instrument by Topcon Company. The method of hierarchical state machine is applied. The GRS-1 device has three parallel states (1., 2., 3.) and one exclusive state (4.):

1. detection of battery status of instrument
2. the setting of the device
3. the testing of environmental conditions
4. evaluation of parameters.

States marked (2.) and (3.) have additional parallel states of lower level.

Inputs of the system:

1. Required accuracy
   - I. Particular accuracy (approximately to 1.5 cm in position): this is typical for static method of measurements.
   - II. Accuracy (about 1.5 - 3 cm in position): typical for RTK method of measurement.
   - III. Sub-meter accuracy (approximately to 0.5 m in position): typical for GIS applications.
   - IV. Accuracy above 1 m in position: typical for autonomous mode of measurements.
2. Locality of measurement.

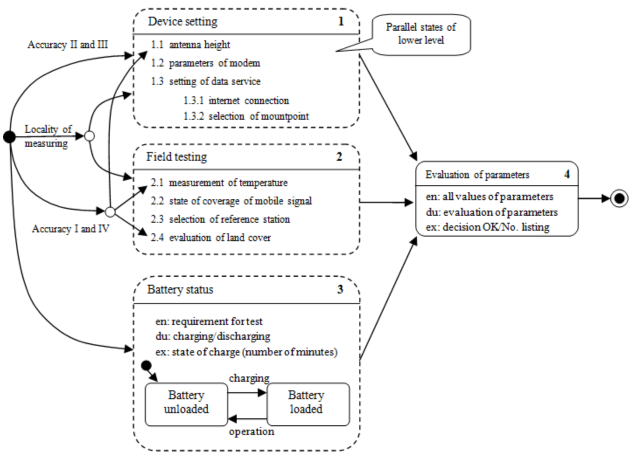

Figure 3. The state diagram of the system with GRS-1

Figure 3 shows a hierarchical state diagram in simplified form. There are obvious individual activities in settings of GRS-1. The input is desired accuracy and the output is a list of all set values and the report that gives information to what degree the system is able to ensure the given accuracy.

V. Algorithm For Human-machine Interface

Parameters that affect the use of devices for GNSS positioning can be divided into the following groups:

1. Technical possibilities of the concrete instrument (height of the antenna, battery status, parameters of modem, parameters of internet connection, etc.)
2. Geographical conditions of the environment in which the device will be used (landforms, number of satellites, the status of coverage of the mobile operator)
3. Environmental conditions (weather, temperature, day time).

The behavior of the interface of device can be described by the state machine:

$$A = (\Sigma, Q, \sigma, q_0, F), \qquad (3)$$

where Σ is a finite non-empty set of symbols (input alphabet of device),
Q is a finite non-empty set of states,
σ is the transition function σ: $Q \times \Sigma \rightarrow Q$,
$q_0 \in Q$ is the initial state,
$F \subseteq Q$ is the set of final states.

The proposed human-machine interface implements the display: $\Sigma_I \rightarrow \Sigma$, where $\Sigma_I \subseteq \Sigma$. The input alphabet of device called Σ can be expressed as:

$$\Sigma = T \times B \times H \times S \times I \times A \times E \times D \times M \times C \times DS, \qquad (4)$$

where individual sets have these meanings:

T - local conditions in the terrain
E - environmental conditions (temperature, weather)
B - state of battery charge
D - the type of device and its technical options
H - shading of horizon
M - coverage of the signal of mobile operator
S - antennal sensitivity of modem
C - number of satellites and their configuration
I - parameters of internet connection
DS - data services
A - the type and accuracy of the GNSS antenna.

The human-machine interface works on the principle of functional dependencies of input parameters. Due to these dependencies, the set (Σ) can be reduced to the set (Σ_I). The mutual functional dependence of the input parameters of the apparatus is demonstrated in Figure 4.

The design of algorithms of the human-machine interface for GNSS device is based on the functional dependence of the input parameters. From Figure 4 it is obvious that for example shading of the horizon (*H*) is dependent on local conditions in the terrain or the antennal sensitivity of the modem (*S*) is given by the type of equipment and its technical options, etc. This means if the certain value of independent parameter is set, other parameter, that is dependent on this parameter, it cannot have any random value from its domain. This dependence allows constructing an interface, where using a few independent parameters can control relatively complex device with many parameters.

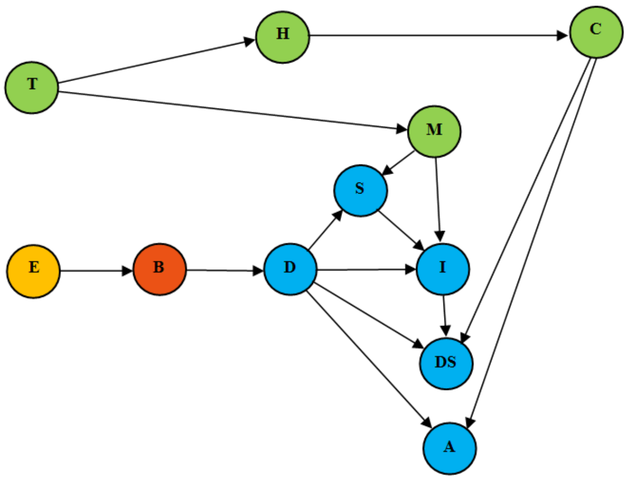

Figure 4. The functional dependence of device parameters (Σ)

The flowchart of the proposed interface is in Figure 5. The core of application is a block called *Evaluation in GIS*, which operates on the base of ArcGIS. This block evaluates device parameters that are dependent on the geographical conditions in which the measurement is realized. The user inputs are: locality of measurement and accuracy.

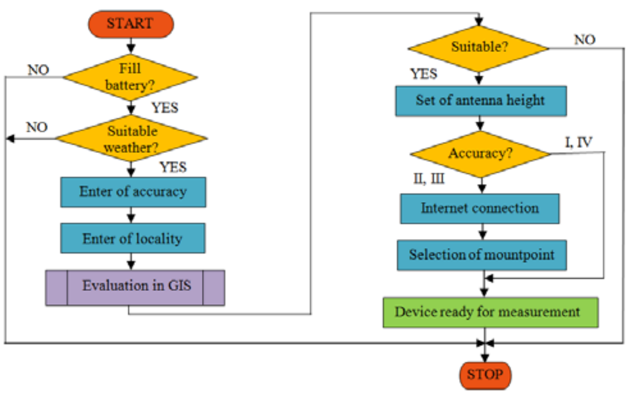

Figure 5. Flow chart of the human-machine interface

VII. Experimental Results

The proposed interface was implemented in Delphi. In the current state, the application works in off-line mode, i.e. it is independent of GNSS device. The application is called HMI – GRS-1 (Human-Machine Interface for GRS-1) and its operation is very simple. There is the main form of the application after its starting. This form contains only four components: combo boxes to select of purpose of measurement and the desired accuracy, the button to select the locality and the button for processing (see Figure 6).

The user can select one of these options by purpose:

• Applications in geodesy and cadastre
• Use in GIS
• Navigation purposes
• Unspecified.

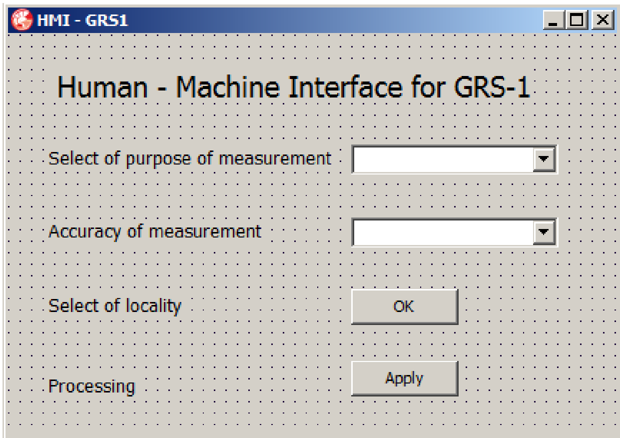

Figure 6. Application form of Human-Machine Interface for GRS-1

The program offers adequate opportunities of accuracy according to the chosen purpose of measurement. The user can choose one of the options. The user is switched after pressing the button to “Select the locality” into the ArcGIS environment in which enters the area of measurement by polygon. The last element on the form is the "Processing". The assignment is confirmed by pressing this key and the calculation of the optimal values of parameters for the GRS-1 device is started. After this, the application is switched into ArcGIS environment.

The spatial analysis is performed in GIS environment and the optimal parameters for the GRS-1 device are generated on the basis of this analysis. These input layers are needed for correct function of analysis in GIS (see Figure 7):

- Meteorological data
- Layout of permanent reference stations
- Map of coverage of mobile networks
- Land cover
- Orthophoto map
- Digital elevation model.
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The module to calculate the optimal parameters of settings of the GRS-1 device was created in the scripting language Python. The module evaluates primarily digital terrain model in a given location and map coverage of mobile signal by the operator. It also works with the expert system, where the experiences with GNSS measurement are stored. Based on this information, the application considers whether required accuracy is achievable in a given locality. If it is not able to achieve the desired accuracy, the application submits report and the user is prompted to re-enter.

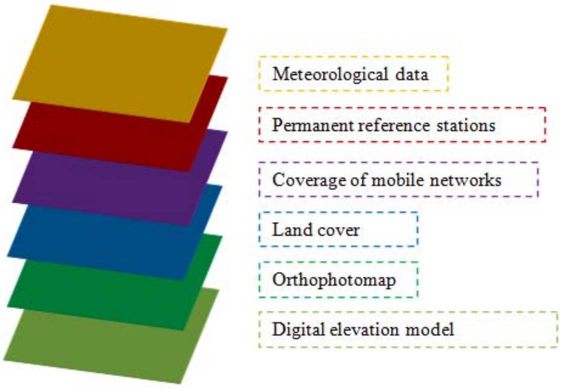

Figure 7. Input datasets for GIS

The application generates a report after processing of spatial analysis that contents the optimal parameters of settings for the GRS-1 device. At present, the application works off-line. Optimized values of parameters are set manually by inserting into the device. On-line mode will be handled the next phase when the device will be connected to the PC via the Windows Mobile communication interface. The aim is to achieve a state when the device sets parameters automatically using application according to the final report.

Practical experiences have confirmed the assumptions of the authors. The designed application makes the GRS-1 device easy to handle and allows its use for naive users. The device is permanently used in several projects and in many of bachelor's, master's and doctoral theses. The benefit of the solution is fact that the handling with GRS-1 device does not require complex training as it was before without the application of Human - Machine Interface.

VI. CONCLUSIONS

The user interface for setting parameters of GNSS device using method of hierarchical state machine was designed in this paper. The core of system is a state in which the values of the set and detected parameters are evaluated. This state is implemented in ArcGIS environment. The proposed system will greatly simplify the operation of devices to determine possible positions using GNSS methods and will allow the use of these devices also for naive users.

Outputs of the project are in two phases:

1st phase: Off – line solution - application in ArcGIS (ESRI) in Python script. Output is list of values of parameters and manual presetting of parameters of the GNSS device.

2nd phase: On – line solution - application in ArcGIS (ESRI) in Python script. Output is list of values of parameters and automatic presetting of parameters of the GNSS device through communication program PC – GNSS device.

The next stage of the project will solve the on-line connection between GNSS device and PC. The application will compute the required values of the parameters and will set the device ready for the measurement.

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