RAZVOJ ПРОГРАМА ЗА ИЗРАВНАЊЕ ГЕОДЕТСКИХ МРЕЖА У OPEN-SOURCE РЈЕШЕЊУ

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Резиме:
У раду је представљена могућност примјене програмског пакета R за аутоматизацију поступка изравнања геодетске основне 2D мреже примјеном методе најмањих квадрата (классичан датум и минималан траг кофакторске матрице). Обрађена је и примјена програмских библиотека, којима се проширују могућности за израду погодног графичког корисничког интерфејса у R. Програмски пакет R омогућава бру статистичку обраду велике количине података и због тога има све већу примјену у многобројним научним областима. Аутоматизација изравнања геодетских мрежа обухваћена је у многим комерцијалним програмским рјешењима за обраду података геодетских мјерења, због чега примјена open-source рјешења може имати посебан значај за научну и стручну јавност.

Кључне ријечи: програмски пакет R, изравнање геодетских мрежа.

DEVELOPMENT OF SOFTWARE FOR GEODETC NETWORK ADJUSTMENT IN OPEN-SOURCE ENVIRONMENT

Abstract:
The paper presents the possibility of using the software R for the automatization of the procedure for geodetic 2D network adjustment with the least squares method (classical geodetic datum and min. trace of the cofactor matrix). Software libraries have also been processed, which expand the possibilities for creating a suitable graphical user interface in R. The R packages enables fast statistical processing of large amounts of data and therefore has a growing application in many scientific fields. Automatization of the geodetic network adjustment is encompassed in many commercial software solutions for data processing of the geodetic measurements, which makes application of open-source solutions have special significance for the scientific and professional public.

Keywords: software R, geodetic network adjustment.
1. INTRODUCTION

R is advanced open-source programe language for statistical analysis and data manipulation. R is integrated suite of software facilities for data manipulation, calculation and graphical display. Among other things it has [1]:

- an effective data handling and storage facility,
- a suite of operators for calculations on arrays, in particular, matrices,
- a large, coherent, integrated collection of intermediate tools for data analysis,
- graphical facilities for data analysis and display either directly at the computer or as a hard copy, and
- a well-developed, simple and effective programming language which includes conditionals, loops, user defined recursive functions and input and output facilities.

The main lack of programming language R is the lack of adequate graphical support. All commands need to be typed in the console, as opposed to some other programming languages, but this approach, on the other hand, allows the processing and monitoring of the processing of a large amount of data in short period of time. Another huge advantage of R compared to other programming language is a possibility to allocate the names to the rows and columns, as well as the possibility to perform various operations with these names [2].

The mathematical model used for geodetic network adjustment, which best describes the state of such system is the Gauss-Markov model (GMM). The system should be linear or linearized. GMM consists of the functional and stochastic part and defines the relations between stochastic observations and unknown parameters of the geodetic network.

In the linear and linearized measurement models adjustment is performed using the Least Squares Method (LSM). The mathematical model implies a mathematical description of assumptions about measurements and their functional relations with unknown parameters [3].

The problem of geodetic network adjustment has been addressed in domestic and International literature in the areas of processing and analysis of geodetic measurements. References for the development of, general purpose, software in the programming language R, is available on the official website r-project [4]. Kilibarda and Pejović in their paper, entitled "Application of open source/free software (R + Google Earth) in designing 2D geodetic control network" [5], presents the possibility of using R when designing the geodetic networks and the possibility of its connection with Google Earth. The same problem is addressed by Sekulić and others, in the paper entitled, "Development of Interactive 1D/2D Geodetic Control Network Design and Adjustment Software in Open Source/Free Environment (R + Google Earth + Google Maps)" [6]. These papers are the first research in this field, in our area.

Geodetic network adjustment, with a large number of measurements, was a challenge for geodetic experts, until the commercial software intended for this purpose has emerged. Software development process with graphical support in the open-source environment (programming language R) is presented in this paper. Based on the input measurement data (directions and lengths) and the approximate points coordinates, the program determines the most probable values of unknown parameters based on LSM, and after that creates the adjustment report and graphical representation of the error ellipses.
2. LIBRARIES AND FUNCTIONS

Programming language disposes of a numerous of basic functions, that are adequately explained in the publicly accessible literature. On the other hand, it turned out that these functions are not enough to cover the needs of all users, so the additional libraries are developed for certain areas, that serve as a complement to the basic functions and extend the possibilities of the programming language R. These libraries can be downloaded from especially developed R internet services.

Some of the additional libraries used for the development of the software, in the R, are:

- gWidgetsRGtk2, a library that enables the creation of Graphical User Interface (GUI) content,
- plotrix,
- pracma, pseudo-inversion of the matrix, and
- knitr, a package for the dynamic creation of the reports in R.

2.1. Library „gWidgetsRGtk2“

The library enables the creation of the GUI, which simplifies the use of the program and its application in everyday work. It represents the implementation of the gWidgets library for the RGtk2 environment, which provides a link between gWidgets and Gimp Tool Kit (GTK) libraries [7].

2.2. Library „plotrix“

The plotrix package is intended to provide a method for getting many sorts of specialized plots quickly yet allow easy customization of those plots without learning a great deal of specialized syntax. The library is developed and maintained by Jim Lemon [8].

2.3. Library „pracma“

This package provides R implementations of more advanced functions in numerical analysis, with a special view on optimization and time series routines. Uses Matlab function names where appropriate to simplify porting. The library is developed and maintained by Hans Werner Borchers. One of the functions in this library is "pinv" which enables the finding the pseudo-inverse matrix (G inversion or Moore-Penrose inversion). This function is used for a geodetic network adjustment with a datum defined as a minimum trace on all points [9].

2.4. Library „knitr“

The knitr package was designed to be a transparent engine for dynamic report generation with R. It has solved some long-standing problems with package Sweave. The design of knitr allows any input languages (e.g. R, Python and awk) and any output markup languages (e.g. LaTeX, HTML, Markdown and so on). This library is available in some other programming languages besides R, such as C++ and Python. The main advantage of this library is that the user has the control over the output, from the beginning to the end [10] [11].
3. DEVELOPMENT OF THE SOFTWARE FOR AN ADJUSTMENT

There are two basic types of geodetic network adjustment,
- adjustment based on observation equations, and
- adjustment based on condition equations.

In a parametric adjustment, observations are expressed in terms of unknown parameters that were never observed directly. This generally leads to larger systems of equations, but the adjustment is straightforward in its development and solution and, as a result, is well suited to computers. In complicated networks, it is often difficult and time-consuming to write equations to express all conditions that must be met for a conditional adjustment, so it is harder to program it. The lack of adjustment based on observation equations is that datum parameters must be defined. This is solved by finding the inverse of a matrix [12] [13].

LSM can be expressed in mathematical notation as,
\[ v^T P v = \min. \]  
(1)

A functional model in adjustment computations establishes the relation between measurements and unknown parameters, should be linear or linearized and in matrix form can be represented as,
\[ v = Ax + f \]
\[ L = AX . \]
\[ L = I + v \]  
(2)

Bearing in mind the scope of the adjustment procedure, it can be briefly shown as the algorithm in Figure 1.

3.1. Overview of the functionality of the software for the adjustment

Figure 2 shows a diagram with steps that need to be performed before running the adjustment, in order to make it possible.
Figure 2. Software start

Figure 3. The main menu of application GUI (Software in R)

The first step, after starting the program, is to load measurement results and the points coordinates.
Figure 4 shows the file that is used to load direction measurement values, in column A there is a label of station point, in column B the label of the sight point, in column C, D and E the values of the measured directions (degrees, minutes and seconds, respectively), and the value of standard deviation of the measured direction is in column F.

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<th>C</th>
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<th>E</th>
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</table>

*Figure 5. Distance measurements input file*

Figure 5 shows the file that is used to load distance measurement values, in column A there is a label of station point, in column B the sight point, in column C the value of the distance measurements and the value of standard deviation \((a[\text{mm}] + b[\text{ppm}])\) of distance measurements in columns D and E.

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</tbody>
</table>

*Figure 6. Points coordinate input file*

Figure 6 shows the file that is used to load the points coordinates, in column A there is label of the point, Y and X coordinate of a point are in the columns B and C. Columns D and E serve for datum definition, ones in these columns means that the specific coordinate of that point defines the datum. Depending on the number of datum parameters, the program selects and defines the datum.

In addition to above-mentioned data, it is necessary, in the software, to specify the values of the a priori dispersion factor, the risk level \((\alpha)\), and the statistical power \((1 - \beta)\).

After completion of data entry, the adjustment procedure can be started. In Figure 7, a diagram of the adjustment procedure is shown, which is in accordance with the adjustment procedure shown in the previous section.
Figure 7. Diagram of the adjustment procedure in the software
As shown in the diagram (Figure 7), the data-snooping is repeated while the global test of the model shows contradictions or until the data-snooping show that there are no outliers in measurement results (Figure 8).

Part of the code used for the computation of error-ellipses is shown in Figure 9, which is according to the diagram (Figure 7) the last step in the geodetic network adjustment in the software.

```r
ellipseGresaka <-
data.frame(row.names = c("lambda 1", "lambda 2", "a", "b", "teta", "odnos"))
matricaKx <- sigma0 * matricaOx
k <- 0
for (i in seq(1:nrow(a))) {
  (ai, i) == 0
  k <- k + 1
  naziv <- row.names(a)[i]
  ellipseGresaka[1, k] <- 0
  colnames(ellipseGresaka)[k] <- naziv
  segmentKx <-
    matricaKxc(paste("y", row.names(a)[i], sep = ""),
              paste("x", row.names(a)[i], sep = ""),
              c(paste("y", row.names(a)[i], sep = ""),
              paste("x", row.names(a)[i], sep = ""))
  val <- eigen(segmentKx)$values
  lambda1 <- val[1]
  lambda2 <- val[2]
  aellipsa <- sqrt(lambda1)
  bellipsa <- sqrt(lambda2)
  tetaeiplsa <-
    atan2(lambda1 - segmentKx[1, 1], segmentKx[1, 2]) * 180 / pi -
    floor((atan2(lambda1 - segmentKx[1, 1], segmentKx[1, 2]) * 180 / pi) / 360) * 360
  ellipseGresaka["lambda 1", naziv] <- lambda1
  ellipseGresaka["lambda 2", naziv] <- lambda2
  ellipseGresaka["a", naziv] <- aellipsa
  ellipseGresaka["b", naziv] <- bellipsa
  ellipseGresaka["teta", naziv] <- tetaeiplsa
  ellipseGresaka["odnos", naziv] <- aellipsa / bellipsa
  }
```

**Figure 8. Global test in the software**

**Figure 9. Part of code, used for error-ellipses computation**
3.2. Practical examples

Adjustment of the measurement results in the geodetic 2D network was performed in the MS Office (Excel) software package, and the following results are obtained (Figure 10).

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<th>Q*Q</th>
<th>i</th>
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</tbody>
</table>

Figure 10. Adjustment report (Excel)

The results obtained by geodetic network adjustment performed in the software developed in R, are shown in the report in Figure 11.
Izravnjenje geodetske 3D mreže

Autori: Goran Manić, Nikola Vršački

Izbor datuma: datum definisan koordinatnim tacaka
Datum definiran: Y1, X1, X2, X3
Broj reznih tacaka 3D mreže je: N = 22
Broj reznih tacaka geodetske mreže je: 3
Broj stacionara kojih su rezni pravci: 6
Broj reznih pravaca je: 20
Broj reznih dužina je: 2
Broj nepoznatih parametara je u = 10
Sigma apsolutni = 0.0000
Sigma apsolutni = 0.0533

Nakon izravnjene

broj iteracije = 2
broj globalnih uzakta = 1
broj reznih veličina je n = 21
Broj stacionara kojih su rezni pravci: 6
Broj reznih pravaca je: 19
Broj reznih dužina je: 2

Ovleće dobijene la izravnjani i kriterijuma kvalitete i tačnosti

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Nepovoljni dio šakaznja je: 0.05
Globalni težak adaptivne modela
Vrednosti težaka solusi hipoteze je: 1.3718
Dobitak na vrednosti je: 1.1423
Suma zii = : 7.0000

Ovjehe nepoznatih parametara sa ovjenom tačnosti

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Figure 11. Adjustment report (software in R)
Adjustment results check between Excel and software, shows that the same results are obtained in both ways. The advantage of the software over the Excel is reflected in the speed of adjustment, during which the possibility of human error is reduced to a minimum. Figure 12 shows the drawing of the points, with error ellipses, whose parameters are shown in the adjustment reports (Figure 10 and Figure 11).

4. DISCUSSION AND CONCLUSION

R in practical application for processing and analysis of geodetic measurements proved to be quality program because it is based on a simple syntax for manipulating with a large amount of data. In the matrix computations, it shows the improvement in relation to other software solutions, where this programming language allows the allocation of the names to the rows and columns, as well as management of these names.

The disadvantage of this solution is lack of the support for GUI application programming. This lack has been recognized by experts, and the library called gWidgets has been developed, that has expanded the possibilities of programming language R. There are some other solutions, which are also open source, but they are primarily used for displaying the content within the Internet environment.

The standard way of managing software solutions in programming language R is to monitor the flow of the program execution in the console, which makes data entry more difficult. Unlike this approach, the gWidgets library enables the development of software with graphical support for simple management of complex software solutions (data entry, processing and presentations).
LITERATURE


