РАЗВОЈ 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 2Д мреже примјеном методе најмањих квадрата (класичан 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 брзу 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 GEODETIC 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 programing 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 programing 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 programing 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 (programing 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,

$$\mathbf{v}^{\mathrm{T}}\mathbf{P}\mathbf{v} = \min.$$

(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,

$$\mathbf{v} = \mathbf{A}\mathbf{x} + \mathbf{f}$$
$$\mathbf{L} = \mathbf{A}\mathbf{X} \quad .$$
$$\mathbf{L} = \mathbf{l} + \mathbf{v}$$

(2)

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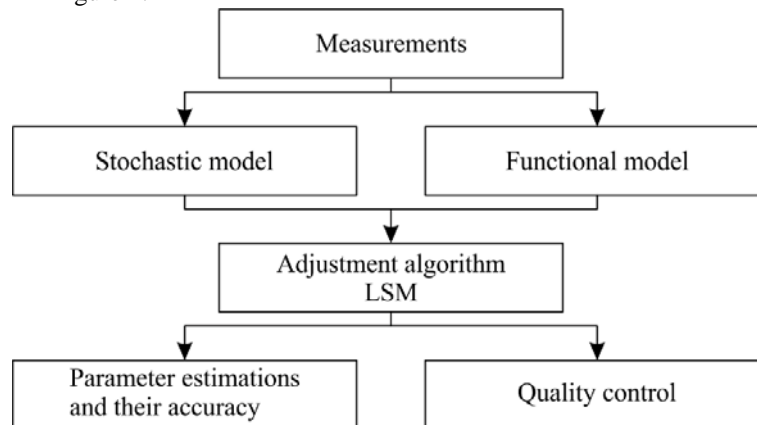
Figure 1. Components of LSM

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.

263
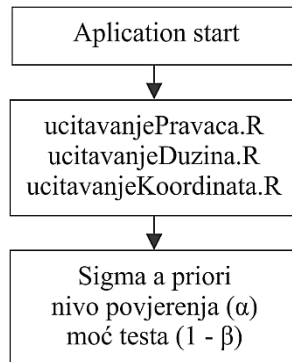
Figure 2. Software start

Figure 3 shows the main menu of the application. GUI is developed using the library gWidgetsRGtk2.a
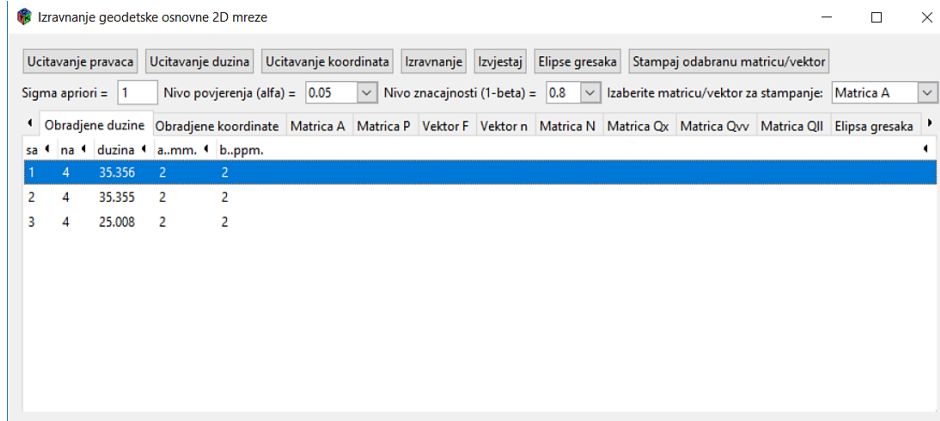
Figure 3. The main menu of application GUI (Software in R)

The first step, after starting the program, is to load measurement results and the points coordinates.

	A	B	C	D	E	F
1	1	4	0	0	53	3
2	1	6	44	4	11	3
3	1	5	90	18	4	3
4	2	3	0	0	12	3
5	2	6	44	50	29	3
6	2	4	90	45	23	3
7	3	2	0	0	10	3
8	3	5	267	49	24	3
9	3	6	313	34	47	3
10	4	2	0	0	10	3
11	4	6	46	44	32	3
12	4	1	89	32	58	3
13	5	3	0	0	25	3
14	5	1	182	46	9	3
15	5	6	269	39	36	3
16	6	2	0	0	29	3
17	6	3	88	44	45	3
18	6	5	132	38	34	3
19	6	1	179	30	58	3
20	6	4	272	39	34	3

Figure 4. Direction measurements input file

264

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.

	A	B	C	D	E
1	2	5	224.523	2	2
2	3	4	282.051	2	2

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.

	A	B	C	D	E
1	1	100.0000	100.0000	1	1
2	2	300.0000	300.0000	1	1
3	3	298.5985	101.2651	0	0
4	4	102.4875	303.9821	0	0
5	5	201.4561	98.2547	0	0
6	6	197.7365	198.5932	0	0

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 (α), 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.
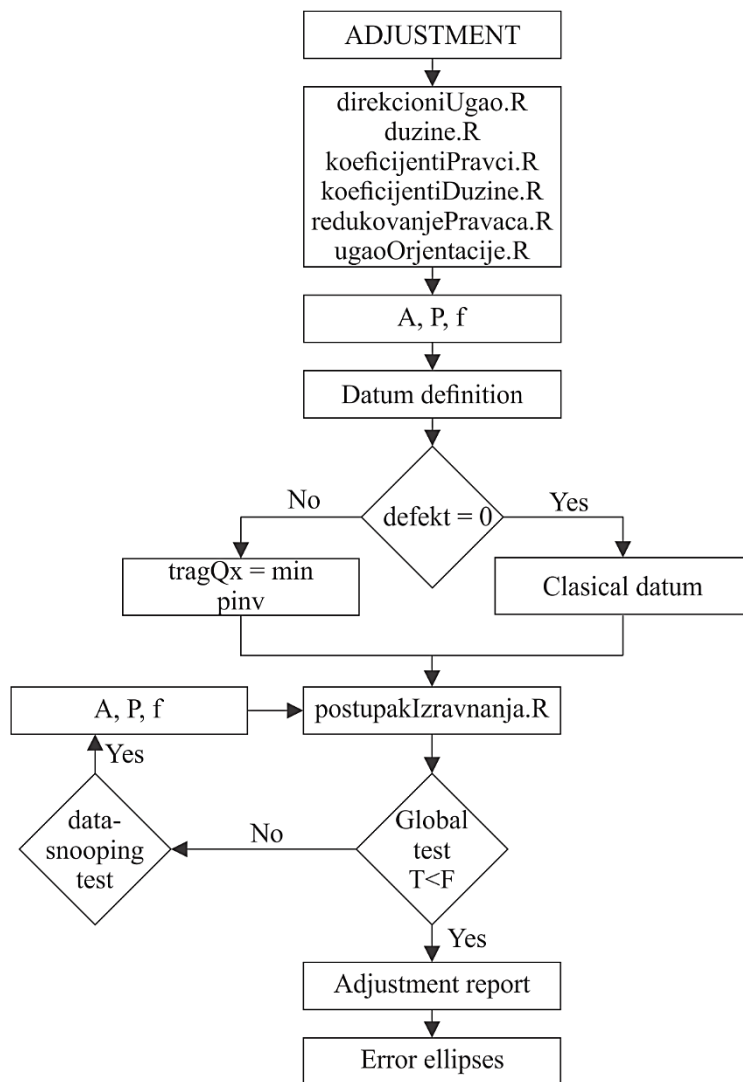
```
                    ┌─────────────────────────┐
                    │       ADJUSTMENT        │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │    direkcioniUgao.R     │
                    │        duzine.R         │
                    │    koeficijentiPravci.R │
                    │    koeficijentiDuzine.R │
                    │   redukovanjePravaca.R  │
                    │     ugaoOrjentacije.R   │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │         A, P, f         │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │     Datum definition    │
                    └─────────────────────────┘
                                 │
                                 ▼
            No                 ◇ defekt = 0 ◇            Yes
    ┌─────────────────┐                         ┌─────────────────┐
    │  tragQx = min   │                         │  Clasical datum │
    │      pinv       │                         │                 │
    └─────────────────┘                         └─────────────────┘
                                 │
                                 ▼
  ┌─────────────┐        ┌─────────────────────────┐
  │    A, P, f  │ ─────▶ │   postupakIzravnanja.R  │
  └─────────────┘        └─────────────────────────┘
         ▲ Yes                      │
         │                          ▼
  ◇ data-snooping ◇  ◀── No ── ◇ Global test T<F ◇
      test                          │
                                   Yes
                                    ▼
                    ┌─────────────────────────┐
                    │     Adjustment report   │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │      Error ellipses     │
                    └─────────────────────────┘
```

Figure 7. Diagram of the adjustment procedure in the software
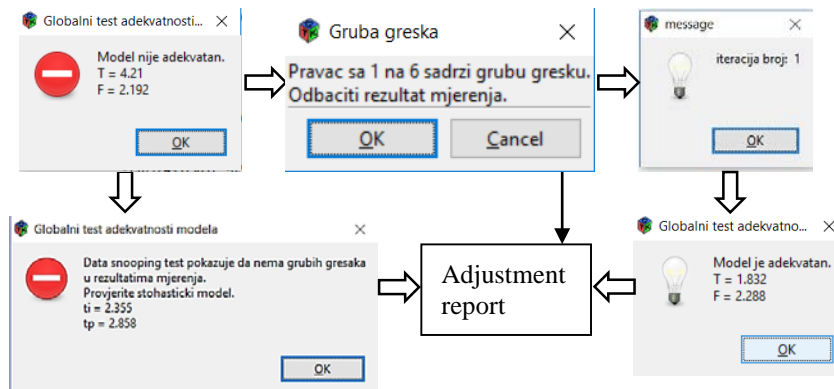
266

Figure 8. Global test 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.

```
elipseGresaka <-
  data.frame(row.names = c("lambda 1", "lambda 2", "a", "b", "teta", "odnos"))
matricaKx <- sigma0 * matricaQx
k <- 0
for (i in seq(1:nrow(a))) {
  (a[i, 1] == 0)
  k <- k + 1
  naziv <- row.names(a)[i]
  elipseGresaka[1, k] <- 0
  colnames(elipseGresaka)[k] <- naziv
  segmentKx <-
    matricaKx[c(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]
  aElipsa <- sqrt(lambda1)
  bElipsa <- sqrt(lambda2)
  tetaElipsa <-
    atan2(lambda1 - segmentKx[1, 1], segmentKx[1, 2]) * 180 / pi -
                floor((atan2(lambda1 - segmentKx[1, 1], segmentKx[1, 2]) *
                                                   180 / pi) / 360) * 360
  elipseGresaka["lambda 1", naziv] <- lambda1
  elipseGresaka["lambda 2", naziv] <- lambda2
  elipseGresaka["a", naziv] <- aElipsa
  elipseGresaka["b", naziv] <- bElipsa
  elipseGresaka["teta", naziv] <- tetaElipsa
  elipseGresaka["odnos", naziv] <- aElipsa / bElipsa
}
```

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).

Mjerenje	Od	Do	v̂	Q v̂ v̂		Î		Q Î Î	rii	Gi	u-v
pravac	1	4	2,0223	2,6221	0	00	02,022	6,3779	0,2913	15,5711	0,0000
pravac	1	5	-2,0223	2,6221	90	17	08,978	6,3779	0,2913	15,5711	0,0000
pravac	1	6					gruba greska				
pravac	2	3	-0,0243	3,0564	-1	59	59,976	5,9436	0,3396	14,4225	0,0000
pravac	2	6	1,3386	3,6629	44	50	18,339	5,3371	0,4070	13,1745	0,0000
pravac	2	4	-1,3143	3,4519	90	45	09,686	5,5481	0,3835	13,5712	0,0000
pravac	3	2	0,0262	3,0352	0	00	00,026	5,9648	0,3372	14,4729	0,0000
pravac	3	5	0,8387	2,7953	267	49	14,839	6,2047	0,3106	15,0812	0,0000
pravac	3	6	-0,8649	3,4701	313	34	36,135	5,5299	0,3856	13,5356	0,0000
pravac	4	2	3,5374	3,3860	0	00	03,537	5,6140	0,3762	13,7027	0,0000
pravac	4	6	-2,4080	4,2318	46	44	19,592	4,7682	0,4702	12,2570	0,0000
pravac	4	1	-1,1293	3,1490	89	32	46,871	5,8510	0,3499	14,2088	0,0000
pravac	5	3	-0,1295	2,1877	-1	59	59,871	6,8123	0,2431	17,0472	0,0000
pravac	5	1	1,0569	2,1371	182	45	45,057	6,8629	0,2375	17,2477	0,0000
pravac	5	6	-0,9274	2,8215	269	39	10,073	6,1785	0,3135	15,0110	0,0000
pravac	6	2	-1,5705	2,5168	-1	59	58,430	6,4832	0,2796	15,8935	0,0000
pravac	6	3	0,1755	2,4103	88	44	16,175	6,5897	0,2678	16,2410	0,0000
pravac	6	5	0,0810	3,2525	132	38	05,081	5,7475	0,3614	13,9811	0,0000
pravac	6	1	0,4828	1,7203	179	30	29,483	7,2797	0,1911	19,2241	0,0000
pravac	6	4	0,8312	2,3248	272	39	05,831	6,6752	0,2583	16,5368	0,0000
duzina	1	2	1,8345	2,2980		224,5248		1,9037	0,5469	7,7652	0,0000
duzina	3	4	-0,5169	1,5470		282,0505		2,7713	0,3582	9,7268	0,0000

Opsti test adekvatnosti modela				
σ̂₀ =	0,853802		f1 =	7
σ₀ =	1		f2 =	1E+10
	T =	1,371784		
	F =	4,142332		
	prihvata se nulta hipoteza			

Ocjene nepoznatih parametara						
	y [mm]	x [mm]	Y [m]	X[m]	σ_Y [mm]	σ_X [mm]	σ_POL [mm]
3	4,4977	1,3673	298,6030	101,2665	2,3755	1,8441	3,0073
4	7,6834	1,4119	102,4952	303,9835	2,4673	2,1406	3,2664
5	5,5804	-1,0777	201,4617	98,2536	1,9483	1,1656	2,2704
6	4,2759	4,9034	197,7408	198,5981	1,4902	1,5455	2,1469

Elipse gresaka				
	a [mm]	b [mm]		teta
3	2,4070	1,8028	75	54	58,11
4	2,5535	2,0369	64	42	7,68
5	1,9493	1,1640	87	45	19,27
6	1,7182	1,2873	41	16	46,72

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.

```
Izravnanje geodetske 2D mreze
Autori: Zoran Kokeza, Miroslav Vujasinovic
===========================================================================
Izbor datuma: datum definisan koordinatama tacaka
Datum definisu: Y1, X1, Y2, X2
Broj merenih velicina je n = 22
Broj tacaka geodetske mreze je: 6
Broj stanica sa kojih su mereni pravci je: 6
Broj merenih pravaca je: 20
Broj merenih duzina je: 2
Broj nepoznatih parametara je u = 10
Sigma apriori = 1.0000
Sigma aposteriori = 0.8538
===========================================================================
Nakon izravnanja
===========================================================================
broj iteracija = 2
broj grubih gresaka = 1
Broj merenih velicina je n = 21
Broj stanica sa kojih su mereni pravci je: 6
Broj merenih pravaca je: 19
Broj merenih duzina je: 2
===========================================================================
Ocjene dobijene iz izravnanja i kriterijumi kvaliteta i tacnosti
===========================================================================
```

Mjerenje	Od	Do	v	Qvii	loc	Qlii	rii	Gi	u-v
Pravac	1	4	2.022	2.622	0 00 02.022	6.378	0.29	21.52	0.00
Pravac	1	6			gruba greska				
Pravac	1	5	-2.022	2.622	90 17 08.978	6.378	0.29	21.52	0.00
Pravac	2	3	-0.024	3.056	359 59 59.976	5.944	0.34	19.93	0.00
Pravac	2	6	1.339	3.663	44 50 18.339	5.337	0.41	18.21	0.00
Pravac	2	4	-1.314	3.452	90 45 09.686	5.548	0.38	18.76	0.00
Pravac	3	2	0.026	3.035	0 00 00.026	5.965	0.34	20.00	0.00
Pravac	3	5	0.839	2.795	267 49 14.839	6.205	0.31	20.85	0.00
Pravac	3	6	-0.865	3.470	313 34 36.135	5.530	0.39	18.71	0.00
Pravac	4	2	3.537	3.386	0 00 03.537	5.614	0.38	18.94	0.00
Pravac	4	6	-2.408	4.232	46 44 19.592	4.768	0.47	16.94	0.00
Pravac	4	1	-1.129	3.149	89 32 46.871	5.851	0.35	19.64	0.00
Pravac	5	3	-0.129	2.188	359 59 59.871	6.812	0.24	23.56	0.00
Pravac	5	1	1.057	2.137	182 45 45.057	6.863	0.24	23.84	0.00
Pravac	5	6	-0.927	2.821	269 39 10.073	6.179	0.31	20.75	0.00
Pravac	6	2	-1.570	2.517	359 59 58.430	6.483	0.28	21.97	0.00
Pravac	6	3	0.175	2.410	88 44 16.175	6.590	0.27	22.45	0.00
Pravac	6	5	0.081	3.252	132 38 05.081	5.748	0.36	19.32	0.00
Pravac	6	1	0.483	1.720	179 30 29.483	7.280	0.19	26.57	0.00
Pravac	6	4	0.831	2.325	272 39 05.831	6.675	0.26	22.86	0.00
Duzina	2	5	1.835	2.298	224.52483	1.904	0.55	10.73	0.00
Duzina	3	4	-0.517	1.547	282.05048	2.771	0.36	13.44	0.00

```
===========================================================================
Usvojeni nivo znacajnosti je: 0.05
Globalni test adekvatnosti modela
Vrednost testa nulte hipoteze je: 1.3718
Dozvoljena vrednost je: 4.1423
Suma rii = : 7.0000
===========================================================================
OCJENE NEPOZNATIH PARAMETARA SA OCJENOM TACNOSTI
===========================================================================
```

oznaka tacke	y[mm]	x[mm]	Y[m]	X[m]	my[mm]	mx[mm]	mp[mm]
1	0.0000	0.0000	100.0000	100.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	300.0000	300.0000	0.0000	0.0000	0.0000
3	4.4977	1.3673	298.6030	101.2665	2.3755	1.8441	3.0073
4	7.6834	1.4119	102.4952	303.9835	2.4673	2.1406	3.2665
5	5.5804	-1.0777	201.4617	98.2536	1.9483	1.1656	2.2704
6	4.2759	4.9034	197.7408	198.5981	1.4902	1.5455	2.1469

```
===========================================================================
Elementi elipse gresaka
```

oznaka tacke	A[mm]	B[mm]	teta
3	2.4070	1.8028	75 54 58.1
4	2.5535	2.0369	64 42 07.7
5	1.9493	1.1640	87 45 19.3
6	1.7182	1.2873	41 16 46.7

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).
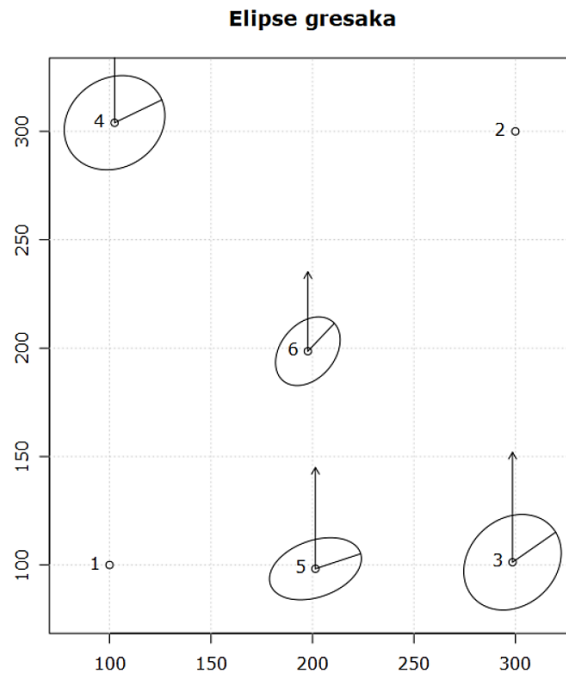

Figure 12. Error ellipses (software in R)

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).

270

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