UDC 004.432 + 528.2/.3

EVALUATION OF THE POSSIBILITIES OF THE PYTHON PROGRAMMING LANGUAGE FOR SOLVING GEODETIC TASKS

PAVEL DOLHI, GALINA SHAROGLAZOVA
Polotsk State University, Belarus

There are tasks in geodesy and related sciences that require a significant amounts of computational work involving the mathematical apparatus of Ordinary Least Squares. In this paper, we consider a problem of solving the system of normal equations that are composed from the results of re-leveling of the geodynamic polygon. The system of normal equations is solved by the formula (1) [1].

$$X = (A^T PA)^{-1} A^T PL \quad (1)$$

where X – vector of unknown parameters; A – matrix of coefficients of the error equations; P – matrix of the weights of measures, where the i-th diagonal element is calculated by the formula $p_i = \frac{c}{s_i}$, where C – weight coefficient, S_i – length of the i-th measured line; L – vector of free terms of the error equations.

Matrices used as data source may have considerable dimensions. For each leveling point as many error equations are composed as many cycles of leveling was made.

The algorithm used for solving the system of normal equations includes matrix operations. Matrix multiplication is an operation with computational complexity about $O(n^3)$. The description of methods for optimization of this algorithm is beyond the scope of this paper.

The most popular software products for operating with matrices among explorers in the field of geodesy are Microsoft Office Excel and Matlab.

According to the author, operating with matrices in Microsoft Excel requires increased concentration of attention and takes much time. Displaying big matrices is difficult.

Matlab provides a large number of functions for matrix operations, but this environment isn't suitable for developing big programs, functions of integration with other software products are limited. Matlab programming language is weakly typed, the speed of execution of cyclic algorithm is low, the support for sparse matrices is incomplete, object-oriented programming in Matlab is difficult. The installation package has a size of about 10 Gb [3].

Python programming language first appeared in 1991, nowadays it is included in the worlds' top-five programming languages (according to PYPL and TIOBE indices, that are based on queries in search engines, independent researches of such popular IT-portals as Stack Overflow and GitHub) [2, 5, 8, 9].

Python is a multiparadigmal language (it supports different styles of programming: structural, object-oriented, functional, reflective, imperative, aspect-oriented etc.). In its reference implementation – CPython – the language is interpreted or compiled into byte code. Other implementations have the possibility of compilation into MSIL (IronPython), Java byte code (Jython). Unlike the previously mentioned Matlab and Microsoft Excel, Python interpreter is distributed under the terms of permissive license. In fact, it doesn't limit the freedom of users' and developers' action. The installation package of Python interpreter has the size of about 35 Mb. Additional packages and libraries are installed by standard utilities if the Internet connection is available.

The following Python libraries seem the most useful for solving geodetic and geodynamic tasks:

- NumPy – tools for big data, including matrices and arrays processing.
- SciPy – tools for scientific and engineer calculations, e. g. maxima and minima of the function, integral calculations, solution of ordinary differential equations, polynomial approximation etc.
- Matplotlib – library for graphical representation of numeric data, charts plotting.
- Networkx – library for networks and graphs processing. It seems to be promising to use in geodesy and related sciences, because any network can be represented as a graph for solution of different tasks, as, for example in research [4]. There is the function of importing networks from formats supported by all modern geoinformational systems (for example ESRI shapefile), so the library is also useful for solving tasks of routing and allocation.

In our research the Numpy library was chosen for geodetic and geodynamic solutions. It isn't included into the standard library, but can be installed without any trouble by PIP utility. Algorithms included into the library were implemented in C and optimized for big data operations. There is the possibility to integrate Python

programs with C/C++ programs. According to a number of studies programs with Numpy run faster than those on pure Python and even faster than on C [6].

In pure Python matrices are represented as a two-dimensional list. This format is convenient for calculations, because there is the possibility to take arbitrary elements, add, remove, edit them. In Numpy library matrices are represented as an instance of **numpy.matrixlib.defmatrix.matrix** class, that can be initialized by numpy.matrix() method with a list as an argument. Inverse transformation is performed by **.tolist()** method. Matrix multiplication and addition are performed by binary operators ***** and **+** respectively. Transposition is performed by .transpose() method, inversion of the matrix – by .I property. Here is a fragment of a source code of software developed in our research, in that solution of normal equations with Numpy is performed [7].

```
# вычисление неизвестных методом линейной аппроксимации
self.N_linear = self.A_linear.transpose()*self.P*self.A_linear
self.Q_linear = self.N_linear.I
self.free_members_vector_linear = self.A_linear.transpose()*self.P*self.L_np
self.vector_of_solutions_linear = self.Q_linear*self.free_members_vector_linear
solutions_list_linear = self.vector_of_solutions_linear.tolist()
```

Matplotlib library allows to plot such images as line plots, histograms, three-dimensional plots, streamplots and others. Different coordinate systems are supported. Matplotlib allows to create interactive images, that refresh operatively in time, embedding plots into windows of other software developed in Python. Navigation toolbar allows to scale and scroll the plots.

The possibility of plotting contour maps, e.g. spatiotemporal charts of movement of the leveling points is of interest for geodynamics. The result is below (fig. 1). This chart was made on the basis of re-leveling on Polotsk geodynamic polygon from 2004 till 2015. The function of plotting such charts is planned to be embedded into the developed software.

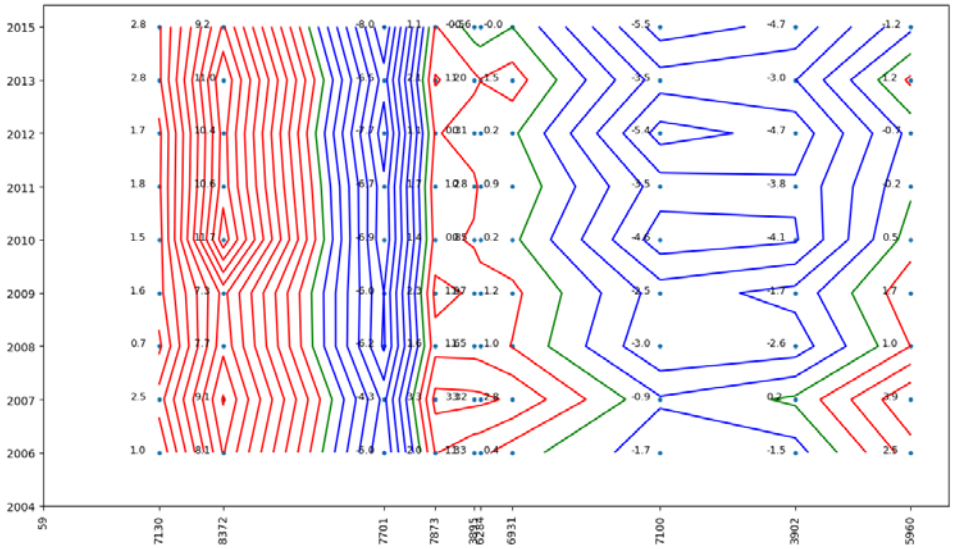

Fig. 1. Spatiotemporal chart of movement of the leveling points on Polotsk geodynamic profile

We made an attempt to represent the leveling network graphically by Networkx library. The problem is complicated by the fact that the horizontal coordinates of the leveling points are unknown. Networkx library offers several methods of graph visualization. In our case the closest to the real view of the network was obtained by the spectral method. The function of network visualization is planned to be embedded into the developed software to give the user an opportunity to get an idea about the network topology.

Developed software product is based on PyQt5 framework, which allows the developer to create a simple and user-friendly interface (fig. 2).

We shouldn't forget about the entry threshold. The lower it is, the less difficulties in studying the language a beginner has. Python has one of the lowest entry thresholds. This fact combined with the variety of

functions of standard and additional libraries makes Python the most perspective language for data analysis, scientific and engineering calculations, development of scientific and applied software. Furthermore, as practice shows, professional geodesists who studied programming independently develop higher quality software then professional programmers. As an example we can name the programs of professor V. I. Mitskevitch. His software was developed in FORTRAN but didn't lose its relevance even nowadays.

Thus, having considered the possibilities and features of Python programming language, we can highlight the following advantages of this programming language in solving problems of geodesy and related sciences:

- Interpreter, additional packages and libraries are distributed under terms of free license, installation and extension of the interpreter is performed by simple actions;
- The language has a good functionality and performance to solve most problems that arise in geodesy and related sciences;
- The language is easy to learn, may be learned in a short time by a non-professional programmer without losing its relevance and popularity in the world.

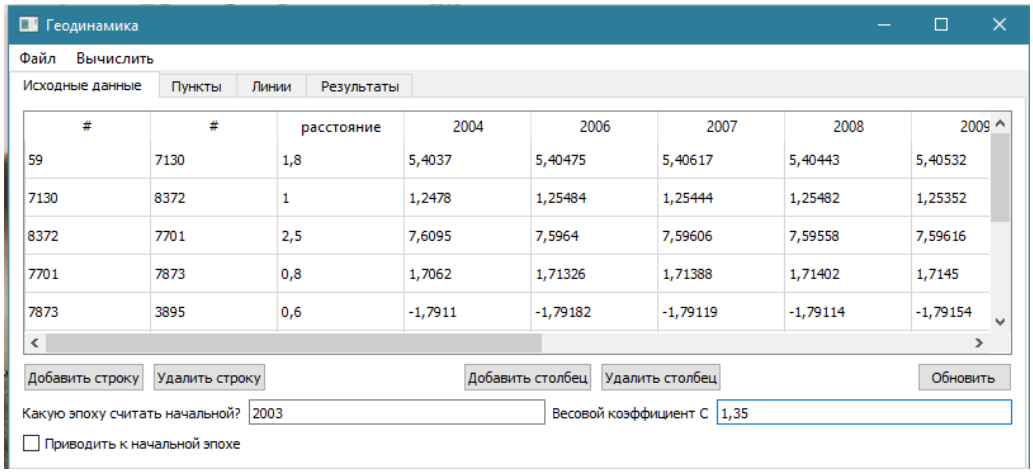

Fig. 2. Main window of the developed software product

REFERENCES

1. Дегтярев, А.М. Теория математической обработки геодезических измерений для студентов 2 курса геодезического факультета / А. М. Дегтярев. – Новополоцк, 2015. – 28 с.
2. Исследование Stack Overflow: JavaScript — самый популярный язык программирования | Dev.by // ИТ в Беларуси | Dev.by [Электронный ресурс]. – Режим доступа: https://dev.by/lenta/main/stack-overflow-2017. – Дата доступа: 02.02.2018.
3. Как мы использовали MATLAB. История одного фейла [Электронный ресурс] / Хабрахабр // Лучшие публикации за сутки. – Режим доступа: https://habrahabr.ru/post/199142/. – Дата доступа: 02.02.2018.
4. Коробков, С.А. Обобщенные узлы геодезических сетей в реализации гиперграфами / С.А. Коробков, Э.А. Паршялюнас, В.И. Самохвалов. – Вильнюс, 1994. – 8 с.
5. Топ-10 языков программирования в 2017 году по версии GitHub [Электронный ресурс] // Tproger – создано программистами для программистов. – Режим доступа: https://tproger.ru/articles/github-top-10-languages-2017/. – Дата доступа: 01.02.2018.
6. C - Почему матричное умножение происходит быстрее с numpy, чем с ctypes в Python? – Quaru [Электронный ресурс] // Поиск вопросов и ответов по программированию – Quaru. – Режим доступа: http://qaru.site/questions/110752/why-is-matrix-multiplication-faster-with-numpy-than-with-ctypes-in-python. – Дата доступа: 10.02.2018.
7. NumPy – NumPy // NumPy – NumPy [Electronic resource]. – Mode of access: http://www.numpy.org/. – Date of access: 03.02.2018.
8. PYPL PopularitY of Programming Language [Electronic resource] // PYPL PopularitY of Programming Language. – Mode of access: http://pypl.github.io/PYPL.html. – Date of access: 01.02.2018.
9. TIOBE Index | TIOBE – The Software Quality Company // TIOBE Index | TIOBE – The Software Quality Company [Electronic resource]. – Mode of access: https://www.tiobe.com/tiobe-index/. – Date of access: 01.02.2018.