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THE FUNDAMENTAL PRINCIPLES OF IMPLEMENTING SOFTWARE FOR HIGHWAY TRACING USING THE FLEXIBLE BRACELET METHOD

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Abstract. *The article under consideration reveals the necessity of developing and implementing optimization algorithms for the automated laying of road axes. The state of the issue is reviewed, and the previously proposed computer-system approach in highway design is discussed, as well as the method of laying the road axis with maximum radii and the flexible bracelet method. The latter was created for the realization of the computer-system approach in highway design. The article is devoted to the basics of software implementation of the flexible bracelet method. The creation of a functional that facilitates the construction of a flexible bracelet of any complexity, with links that can be rotated relative to the joints, and the subsequent superimposition of this construction on a topographic map, is a key contribution of this article.*

Key words: *highway axis design, computer-aided design, flexible bracelet method.*

Introduction

In modern construction, the automated design of roads is becoming increasingly relevant. The use of CAD systems significantly improves the accuracy of calculations and optimizes design processes, leading to reduced costs and faster project implementation. Automation enables the modeling of various scenarios and the detailed analysis of road safety and efficiency. The application of modern information technologies allows projects to be adapted to real-world operating conditions. Thus, the optimization of road tracing through CAD represents a promising area in engineering design.

Analysis of publications

Since the mid-20th century, there has been a rapid development of computer technologies, with the dynamics of technological advancement exhibiting an exponential trend. In recent decades, the processing speed of computer technology has increased exponentially, as has its memory capacity. However, despite the evident influence of these technological advancements on various fields, including highway design, the prevailing scheme for automated highway design remains the tangential tracing method [1–4], which was first implemented over a century ago.

In relation to the aforementioned points, it is evident that there is a significant dearth of optimization algorithms within the domain of highway routing. While numerous software developers are engaged in this field [5–8], these software tools have not yet attained widespread utilization on a global scale. This underscores the significance of the research direction delineated in this paper.

The optimization algorithm can be found in [8]. In this case, an approach was implemented in which the user generated the tangential course of the road axis, and the radii were inscribed automatically. The geometric feasibility of inscribing maximum radii was subsequently checked [8]. The validation of this method entailed the development of specialized software, which incorporated a graphical window, an initial parameters window, and a calculation results window (fig. 1).

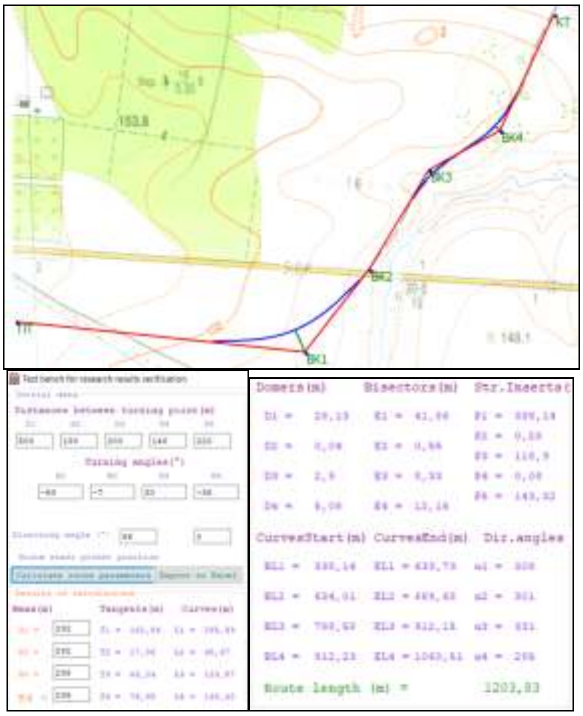

Fig. 1. The implementation of the highways tracing of using the maximum radius method in the program

The flexible bracelet method (FBM) was proposed in 2011 [9] as a special case of the general computer-systems approach in highway design (proposed in 2008), otherwise known as computer-systems highway design (CSHD) [10]. The computer-system approach posits the notion of a single, potential variant of a highway axis, predicated on a predetermined set of initial criteria. This methodology supplants the variant design, wherein numerous variants of the highway axis are cultivated, and one of them is subsequently identified as the optimal choice.

The utilization of tracing methods is known to afford designers a considerable degree of autonomy. While the automation of design processes entails a simplification of intricate mathematical calculations, it does not address the optimization of trace location. However, if the trace is systematized, ordered, and governed by a specific law, it can be more readily integrated into optimization algorithms, thereby expanding the scope of automatic design processes.

In light of these considerations, a novel method of tracing was devised: the flexible bracelet method (FBM) [9]. The fundamental principle of this method entails the utilization of a complex geometric figure comprising a consistent system of indivisible elements and interconnecting links (see figure 2, which illustrates the physical model consisting of a rectangle).

Fig. 2. The physical model of flexible bracelet method consisting of a rectangle

The concept and fundamental mathematical approaches to the flexible bracelet method have been developed thus far [9]. The subsequent stage is software development and parallel mathematical detailing of this method. The present article is devoted to the initiation of this stage.

Purpose and mission statement

The objective of the present study is twofold: firstly, to implement the extant developments of the flexible bracelet method, and secondly, to develop software to realize this method in practice. In order to achieve the aforementioned objective, the following tasks must be accomplished:

– development of the algorithm;

– development of the block diagram;

– development of code in C#;

– development of the program interface.

The initial functionality should include:

– creation of a chain of bracelet elements of any number and size;

– ability to move the bracelet, rotate any element in relation to the link;

– loading of a topographic map and lining up the bracelet in any direction on the map.

Basic Outline

The initiation of the implementation process for highway tracing by means of the flexible bracelet method consists of the following items:

1) creation of the main window structure;

2) drawing a single golden ratio rectangle;

3) implementation of the flexible bracelet (chain of segments);

4) implementation of dragging the entire chain;

5) implementation of selection and rotation of individual segments;

6) integration of all functionalities.

Creation of the main window structure was performed as follows. A Windows Forms project was created in C#. The main window was divided into two areas:

– the Parameter Panel (approximately 1/5 of the window’s width) is used for entering the model parameters via text boxes (e.g., short side, link size, and number of segments);

– the Graphics Panel is used for drawing the model (fig. 3).

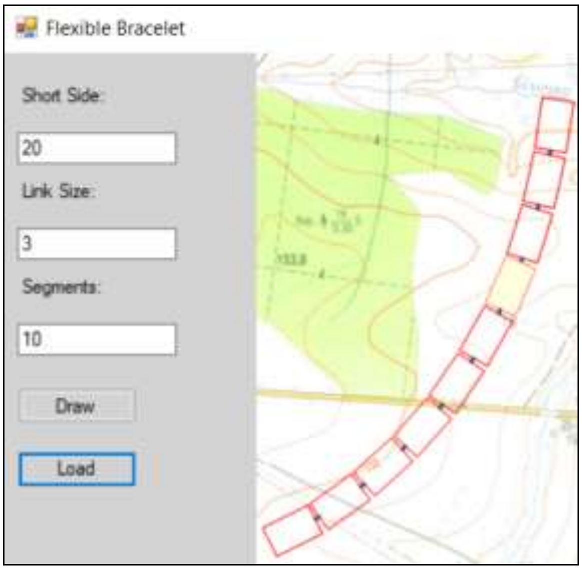

Fig. 3. Interface of the program for implementing the flexible bracelet method

Drawing a single golden ratio rectangle was performed as follows. A module for drawing a single rectangle was implemented. In this module:

– the short side *s* is provided by the user;

– the long side is calculated using the golden ratio formula:

$$L = s \cdot \varphi , \tag{1}$$

where, $\varphi = 1.618$ – is the golden ratio.

– the rectangle is drawn in red using the “Graphics.DrawRectangle” method.

Implementation of the flexible bracelet (chain of segments) was performed as follows. Functionality was extended by constructing a chain of segments, where:

– each segment is represented by a rectangle with dimensions *s* (short side) and *L* (long side);

– a blue link of length *l* (user-defined parameter) is drawn between adjacent segments.

– the total width of the chain is calculated as:

$$W_{total} = (N-1)\cdot(L+l)+L , \tag{2}$$

where, *N* – is the number of segments.

Block diagram of the algorithm for FBM implementing is shown in fig. 4.

Implementation of dragging the entire chain was performed as follows. Mouse event handlers (MouseDown, MouseMove, MouseUp) were added to allow the entire chain to be dragged. In this process:

– the displacements Δx and Δy are calculated relative to the initial click point;

– the global variable “offset” is updated, and the “Invalidate()” method triggers a redraw of the graphics panel with the new offset.

Implementation of selection and rotation of individual segments was performed as follows. Functionality was added to enable selection and rotation of individual segments:

– when a click occurs in the "handle" area (upper-left or lower-left corner) of a segment, the segment is highlighted with a semi-transparent red fill;

– the pivot point for rotation is defined as the connection point with the previous segment (the right center of the previous segment plus a horizontal offset equal to the link size);

– when rotating, the new angle θ_{new} is computed using the formula:

$$\theta_{new} = \theta_{startSegment} + (\theta_{current} - \theta_{start}) , \tag{3}$$

where, θ_{start} – is the initial angle between the pivot and the click point;

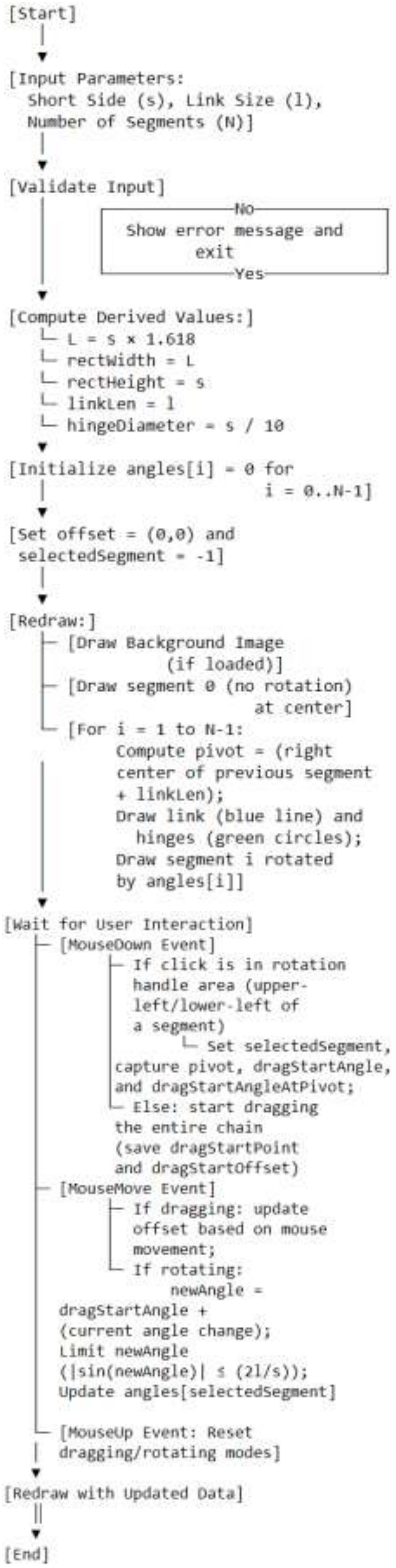

Fig. 4. Block diagram of the algorithm for implementing the flexible bracelet method

$\theta_{current}$ – is the current angle between the pivot and the mouse position;

– to prevent overlapping of segments, a constraint is applied:

$$|\sin\theta| \le \frac{2 \cdot l}{s}, \quad (4)$$

yielding a maximum allowed angle:

$$\theta_{\max} = \arcsin\left(\frac{2 \cdot l}{s}\right). \quad (5)$$

Integration of all functionalities was performed as follows. Finally, the following features were integrated:

– drawing the chain: each segment is drawn according to its relative angle, with blue links and green joints drawn between segments;

– dragging: the entire chain can be moved by updating the global offset variable;

– selection & rotation: upon clicking the rotation handle of a segment, that segment is selected and its orientation is adjusted, subject to the mathematical constraint.

Results

Consequently, a functional version of the software has been developed for the practical implementation of the method of laying the axis of the highway using the flexible bracelet method. Figure 5 presents the example of axis laying on the training map at the scale of 1:10000, while Figure 6 presents the example of axis laying on the map at the scale of 1:25000 near Izmir city (Turkey).

Fig. 5. The example of FBM implementation on the training map at the scale of 1:10000

Conclusions

The present paper demonstrates the initial phase of a protracted endeavor: the digital implementation of the method for laying out the axis of a highway utilizing the flexible bracelet technique.

Fig. 6. The example of FBM implementation on the map at the scale of 1:25000 near Izmir city (Turkey)

The development of an algorithm, a block diagram, code, and an initial interface has been accomplished. At this stage, the tool exhibits notable similarities to the well-established flexible ruler method (see Figure 7).

Notably, it is virtual, and the flexibility of the "ruler" can be tailored to specific requirements.

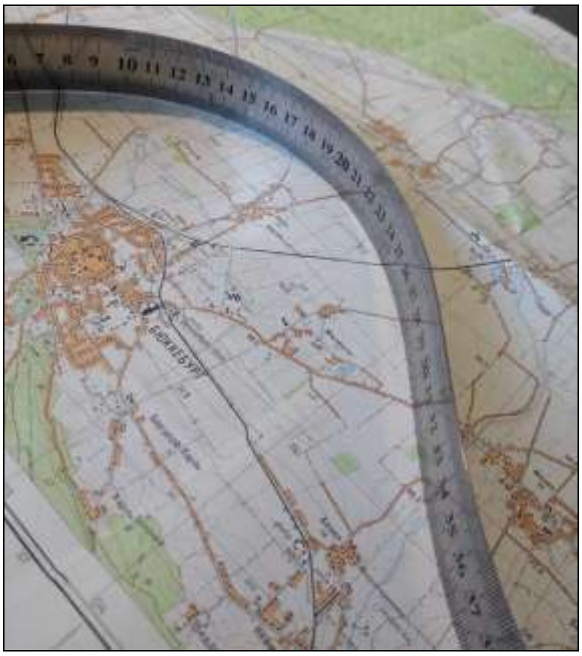

Fig. 7. The example of flexible ruler method of laying the axis of the highway

The subsequent phases of research should prioritize the following:

1) the first problem to be addressed is the harmonization of the scale of the map and the elements of the flexible bracelet;

2) the second problem to be addressed is the harmonization of the geometry of the flexible bracelet with the geometric constraints of highway design regulations;

3) the third problem to be addressed is the harmonization of the flexible bracelet geometry with geometric constraints based on the latest research of scientists.

Only after solving the above problems, we can proceed to solving optimization problems and implementing the computer-system approach.

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Основи програмної реалізації трасування автомобільних доріг за допомогою методу гнучкого браслета

Анотація. Проблема. *Останні роки швидкість обчислювальних операцій комп'ютерної техніки збільшилась у декілька разів. Це саме стосується й обсягів пам'яті перероблюваної інформації. Здавалося б, вищезазначені факти мали б вплинути і на ідеологію проєктування автомобільних доріг, але за фактом у системах автоматизованого проєктування автомобільних доріг найчастіше використовують схему тангенціального трасування. Ми маємо недостатню кількість оптимізаційних алгоритмів у галузі трасування автомобільних доріг. Це зумовлює актуальність напряму досліджень цієї статті.* ***Мета.*** *Метою дослідження є розроблення алгоритму, коду й інтерфейсу програми для початкової реалізації трасування осі автомобільної дороги за допомогою методу «гнучкого браслета» (Flexible Bracelet Method, FBM). Завдання дослідження полягає у створенні програмного забезпечення, що реалізує FBM із можливістю підвантаження топографічних зображень як підкладки.* ***Методологія****. В основі аналітичних розрахунків складових методу гнучкого браслета лежать методи окремих розділів алгебри, геометрії і планіметрії. В основі написання коду було об’єктно-орієнтоване програмування. Створення інтерфейсу та графічного вікна базувалося на принципах найпростішої конструкції і графічної візуалізації.* ***Результати.*** *Був розроблений функціональний прототип програмного забезпечення, який демонструє побудову гнучкого браслета з можливістю переміщення та обертання окремих сегментів. Прототип дозволяє завантажувати топографічні зображення у форматі JPEG, які використовуються як підкладка в процесі трасування осі дороги. Експериментальні випробування демонструють, що запропонований підхід забезпечує точне відтворення потрібної траєкторії та відповідає визначеним геометричним обмеженням.* ***Оригінальність****. Вперше ідею методу реалізовано програмно з можливістю створюва-*

ти ланцюги гнучкого браслета як ескізну лінію осі автомобільної дороги на топографічній карті. ***Практична цінність.*** *На цьому етапі розроблений алгоритм має потенціал для впровадження в сучасні CAD-системи проєктування доріг, що дозволить отримувати ескізні лінії траси змінної гнучкості, але головна перевага використання методу гнучкого браслета полягає в подальшій імплементації комп'ютеро-системного проєктування автомобільних доріг.*

Ключові слова: *гнучкий браслет, трасування доріг, автоматизоване проєктування, CAD, оптимізація, геометричні обмеження*.

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