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Industrial Artificial Intelligence and Digital Technologies for Intralogistics Tasks

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Abstract: In Industry 4.0, logistics is becoming an integral part of production. Intralogistics connects two specific points, optimally transferring materials, finished goods, and dataflows between various hubs within one enterprise. Therefore, path planning tasks occupy a substantial part in the intralogistics problem. The path can be represented on the map as a large polygonal chain with an excessive number of peaks. These problems require algorithms that reduce the number of line points. The database is represented by the proceedings of Russian and foreign scientists; Psimpl, NumPy, Matplotlib libraries. The methodological base is represented by the Ramer-Douglas-Peucker, Lang, Opheim algorithms. The article presents generalized data of comparison of the RDP, Lang, Opheim algorithms depending on the number of input path peaks for solving intralogistics problems. The RDP, Lang and Opheim algorithms from Psimpl were used to reduce the number of line points approximating the path. This allowed to conduct a comparative analysis of these algorithms for solving "path planning" problem. Python using NumPy and Matplotlib allowed to obtain the data. Research has shown there are no universal methods for solving "path planning" problem. This task requires choosing an optimal algorithm with subsequent digital method application.

1 INTRODUCTION

In the age of Industry 4.0, artificial intelligence (AI) technologies are changing industrial processes, planning methods, and production of goods and services. Industrial AI is needed to solve production problems: increasing productivity, reducing costs, optimizing production, forecasting and analyzing, etc. Logistics has become an integral part of production, and intralogistics covers the internal processes of warehouse logistics. It optimizes systems for transferring materials, finished goods, and data flows between tracking points of one enterprise, be it a warehouse, air or sea terminal. (Anikin, 2019; Sanjay, 2020)

Rapid growth of the company, lack of a clear development plan, management of external and internal business processes, in particular, uneven shipment / loading of products, are some of the logistic challenges. An industrial AI will help to predict various challenges (Skhirtladze, 2018). The concentration of data flows and the creation of a single information space will allow tracking production and the state of warehouses, optimizing logistics processes, such as product movement, inventory management. (Alexandrov, 2018; Freitag, 2018; Sekerin, 2019)

It is necessary to choose the optimal cargo shipping procedure to various points to cut costs of a company engaged in cargo transportation. In this regard, the problem of the most efficient use of transport, the correct direction of cargo transportation with minimal transportation costs arises (Efromeeva, 2018).

For simple spatial route planning, the "path planning" method is used. However, the amount of computation required to narrow the uncertainty interval in a multidimensional space is a power function whose exponent is equal to the space dimension (Buzer, 2009).

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The found path represents a larger number of points, the number of which is redundant. The Ramer-Douglas-Peucker (RDP), Lang, and Opheim algorithms are investigated to reduce the number of line points approximating the path to satisfy differential and dynamic constraints. (Agarwal, 2000)

Path planning problems in known environments are actively studied. They provide a basis for more complex cases where the environment is not known in advance (Cormen, 2022). A special case of solving a path planning problem is the navigation of an agent (e.g., a mobile wheeled platform) in a dynamic environment, in which the probability of some obstacle appearing may arise over time. The solution to this problem is relevant, in particular, for service robotics, to ensure safe movement and effective interaction between a person and a mobile wheeled platform (Kazakov, 2016). The main complexity in this problem solving is to ensure a sufficiently high frequency of path rebuilding, necessary to respond to dynamic obstacles. At the same time, considering dynamic obstacles is necessary to avoid unexpected collisions with objects not provided for by the static map (Efromeeva, 2018, 2020). The constructed path will be represented by an excessive number of points. The task of reducing the number of line points approximating the path will be the aim of our study.

2 MATERIALS AND METHODS

Many Russian and foreign scientists have studied this problem. The Ramer-Douglas-Peucker (RDP) algorithms and their modifications, additions (the Opheim, Lang, etc. algorithms) are traditionally used to solve problems of removing unnecessary points and simplifying a polyline described by a vector (Douglas, 1973; Ramer, 1972). However, the Ramer-Douglas-Peucker algorithm is not optimal in terms of the number of points obtained and execution speed (Cormen, 2022; Efromeeva, 2018; Prasad, 2012). Therefore, these algorithms have received numerous improvements in various areas. Thus, A.S. Asanov, Yu.D. Vybornova, V.A. Fedoseev (Asanov, 2022) and others used descriptors in their proceedings to protect vector maps; A. Kolesnikov, P. Fränti (Kolesnikov, 2020) and others were engaged in the reduction of vector graphics data; J. Sklansky, V. Gonzalez (Sklansky, 1980); A. Masood, S.A. Haq (Masood, 2007) and others performed the approximation of digitized curves; D. Brunner, P. Soille (Brunner, 2007) and others were engaged in the filtering of areas of multichannel images; T. Tienaah, E. Stefanakis, D. Coleman (Tienaah, 2015) and others studied the computer graphics; A.G. Kurochkin, E.A. Titenko (Kurochkin, 2016) and others studied the robotics; I.M. Vanchugov, R.A. Shestakov (Vanchugov, 2023) and others made the geological and technological researches; I.V. Anikin, R.F. Minnikhanov (Anikin, 2021) and others were in the processing the vehicle trajectories from video cameras.

The authors of this study used the Ramer-Douglas-Peucker (RDP), Lang, and Opheim algorithms. These algorithms were implemented using Psimpl (a C++ polyline simplification library). The analysis of the obtained output data was carried out using the NumPy and Matplotlib libraries of the Python programming language (NumPy is a library for the Python language that adds support for large multidimensional arrays and matrices, a large collection of high-level mathematical functions to operate on these arrays; Matplotlib is a library for plotting graphs for the Python language and its numerical mathematical plugin NumPy).

The authors proposed to conduct a comparative analysis of the Ramer-Douglas-Peucker (RDP), Lang, and Opheim algorithms using digital technologies to solve the problem of optimal "path planning", for example, to optimize the movement of transport in a warehouse and ensure their interoperability.

3 RESULTS

Problem statement: when a mobile wheeled platform, for example, moves from one object to another, its route is constructed in the form of a certain line, where the number of points is excessive (Efromeeva, 2016). It is necessary to minimize the trajectory of movement, i.e. to reduce the number of points on the path.

This task can be divided into two subtasks:

1. Path construction (movement by points).
2. Approximation of the number of points (path reduction).

For example, a drone aircraft flying around warehouse racks along different routes to identify empty or loaded shelves, etc. At the same time, it should fly around the entire warehouse in a minimum amount of time without losing efficiency. (Hammerschmidt, 2020)

We will conduct a comparative analysis of the RDP, Lang and Opheim algorithms in order to address the challenge. A number of tests were made to compare the efficiency of the RDP, Lang and Opheim algorithms. The input data of the tests are polygonal chains with a number of peaks from 10 to

1000. These polygonal chains are an interpolation of a section of a smooth sinusoid.

The key parameters for evaluating and comparing the efficiency of these algorithms were chosen: 1) the algorithm running time; 2) the ratio of the number of peaks of the interpolated path to the number of peaks of the original path; 3) the normalized total deviation of the interpolated path from the original.

The normalized total deviation of the interpolated path from the original can be formally represented by the formula (1):

$$S = \int_{x_0}^{x_n} |f(x) - g(x)| dx \qquad (1)$$

where $f(x)$ is the original function, $g(x)$ is the interpolated function, x_0 is the coordinate of the start point, x_n is the coordinate of the last point, S is the normalized total deviation of the interpolated path from the original

The RDP, Lang and Opheim algorithms were executed in the Python language using the above libraries. As a result, the data was obtained for comparing tests of processing polygonal chains with different number of peaks. We will plot graphs of the algorithm comparison to visualize the obtained data.

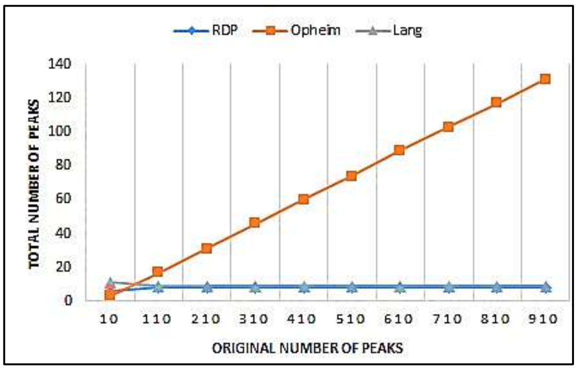

Figure 1 (a): Graphs comparing the dependence of the running time of algorithms on the number of peaks in the input path. Source: created by the authors.

Figure 1(a) shows comparative graphs of the dependence of the running time of the RDP, Lang and Opheim algorithms versus the number of peaks in the input path. The running time (1000 runs) was recorded and the arithmetic mean was calculated for each algorithm and each number of peaks considered. As can be seen from the graphs, all three algorithms have a dependence close to linear within the considered area. Despite the fact that the Ramer-Douglas-Peucker algorithm is on average at least 3 times more efficient than the others in terms of time, the running time allows all three algorithms to process more than 100 times per second even in the worst case, which is acceptable.

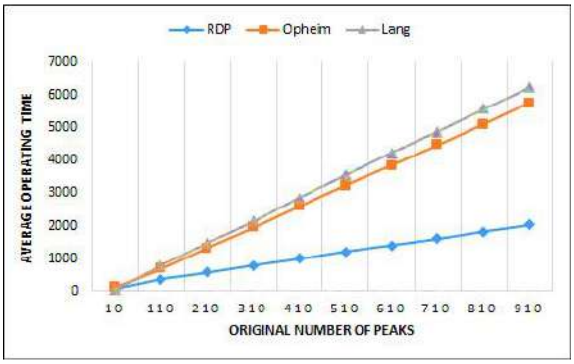

Figure 1 (b): Graphs comparing the dependence of the number of peaks in the resulting path on the original number of peaks. Source: created by the authors.

Figure 1(b) shows a graph comparing the dependence of the number of peaks in the resulting path on the number of peaks in the original path. Here can be seen the Ramer-Douglas-Peucker algorithm and the Lang algorithm, with the constant parameters of path simplification accuracy and with a sufficient number of peaks (in this case, more than 10) in the original path have a constant number of peaks in the resulting path. The Opheim algorithm has a close to linear dependence of the resulting path length on the original. That is, if the number of peaks is much larger, the loss in comparison with the other two algorithms is quite considerable, which is a significant drawback.

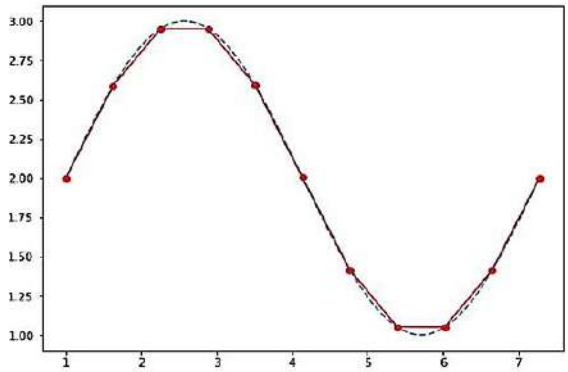

Figure 2 (a): Lang line simplification algorithm (--- the original path; –·– the simplification path). Source: created by the authors.

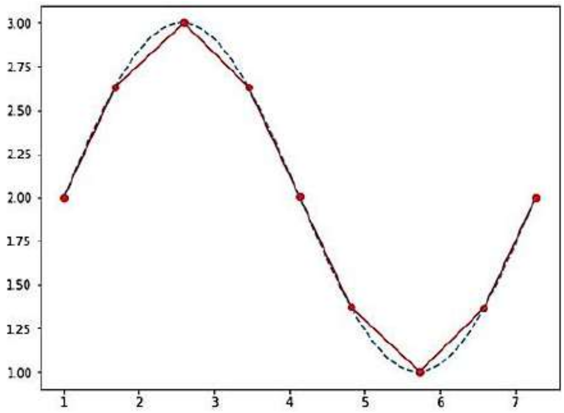

Figure 2 (b): Opheim line simplification algorithm (--- the original path; –·– the simplification path). Source: created by the authors.

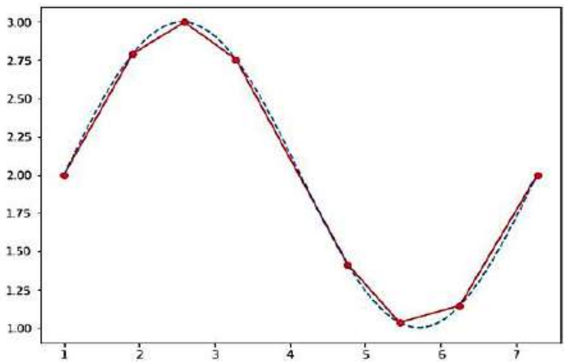

Figure 2 (c): Ramer-Douglas-Peucker line simplification algorithm. (--- the original path; –·– the simplification path). Source: created by the authors.

Figure 2 (a, b, c) shows the results of simplifications of the same original path using the Lang, Opheim and Ramer-Douglas-Peucker algorithms, where the dotted line (---) represents the original path, and the polygonal (–·–) line represents the result obtained by applying these algorithms.

Thus, following the results of the analysis, it can be concluded that the Ramer-Douglas-Peucker algorithm is the most effective algorithm for this applied problem. It provides the necessary and sufficient efficiency for all the parameters considered.

3. CONCLUSION

A large number of production problems can be formulated and solved as network models. These are tasks such as: designing a gas pipeline connecting boreholes with a receiving terminal; searching the shortest path between two objects along an existing transport system; determining the maximum capacity; finding a scheme for crude transmission with minimum cost; drawing up a construction timeline, etc.

The comparative analysis of Lang, Opheim and Ramer-Douglas-Peucker algorithms for reducing the number of line points approximating the path is important for solving production problems, such as intralogistics. Intralogistics is necessary for organizing warehouses, normalizing supplies, establishing of logistics chains, in order to ensure the growth of the company. However, all the pros and cons of the algorithms for each production should be studied. They should work to reduce the number of line points approximating the path for differential and dynamic constraints.

For example, when the process of controlling the autonomous movement of a mobile wheeled platform is considered, the object of the study becomes the process of constructing its route, adjusted for dynamically changing obstacles.

The research has shown that there are no universal solution methods for "path planning" problems. The given task, with a certain set of peaks, requires the selection of an optimal algorithm with its subsequent programming, for example, in Python with the necessary libraries.

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