HYBRID ALGORITHM FOR REGISTRATION OF POINT CLOUDS OBTAINED BY LASER SCANNING

Yo‘ldoshev Baxtiyor Botirovich
Toshkent kimyo-texnologiya instituti Yangiyer filiali v.b. dotsenti
Email:baxtiyorbotirovich64@gmail.com
Tel: +998972244164

Abstract. In the field of reverse engineering, the need to restore worn-out spare parts or spare parts with missing technical documentation (drawings, CAD models) is increasing year by year. In such cases, the parts are scanned using a laser scanner to obtain point clouds. This paper proposes a new hybrid method for registering the point clouds obtained from scanning. The proposed method divides the registration process into two stages: coarse and fine registration. In the coarse stage, a Genetic Algorithm (GA) is used to estimate an initial alignment between the two point clouds. In the fine stage, the Interior Point optimization method is applied to achieve precise alignment. During the study, two point cloud registration techniques were tested, evaluated, and compared. The results indicate that using the GA combined with the Interior Point method provides accurate and reliable point cloud registration with minimal error.

Keywords: Reverse engineering, point cloud registration, laser scanning, genetic algorithm, interior point method, hybrid algorithm

Аннотация. В области обратного инжиниринга потребность в восстановлении изношенных запасных частей или деталей с отсутствующей технической документацией (чертежи, CAD-модели) с каждым годом растет. В таких случаях детали сканируются с помощью лазерного сканера, и получаются облака точек. В данной работе предлагается новый гибридный метод регистрации облаков точек. Метод разделяет процесс регистрации на два этапа: грубая и точная регистрация. На этапе грубой регистрации используется генетический алгоритм (GA) для приблизительного выравнивания двух облаков точек. На этапе точной регистрации применяется метод внутренней точки (Interior Point) для достижения точного выравнивания. В ходе исследования были протестированы, оценены и сравнены два метода регистрации облаков точек. Результаты показывают, что сочетание GA с методом внутренней точки обеспечивает точную и надежную регистрацию облаков точек с минимальной ошибкой.

Ключевые слова: Обратное проектирование, регистрация облаков точек, лазерное сканирование, генетический алгоритм, метод внутренней точки, гибридный алгоритм

ISSN 3030-3907

Annotatsiya. Teskari muhandislik sohasida eskirgan yoki texnik hujjatlari (chizmalar, CAD modellar) yo‘q bo‘lgan ehtiyot qismlarni tiklashga bo‘lgan ehtiyoj yildan-yilga ortib bormoqda. Bunday hollarda qismlar lazerli skaner yordamida skanerlanadi va nuqta bulutlari olinadi. Ushbu maqolada nuqta bulutlarini ro‘yxatdan o‘tkazish uchun yangi gibrid usul taklif etiladi. Usul ro‘yxatdan o‘tkazishni ikki bosqichga ajratadi: qo‘pol va aniqlashtirilgan. Qo‘pol bosqichda genetik algoritm yordamida dastlabki moslash aniqlanadi. Aniqlashtirilgan bosqichda esa ichki nuqta (Interior Point) optimallashtirish usuli qo‘llanilib, aniq moslash amalga oshiriladi. Tadqiqot davomida ikki turdagi usul sinovdan o‘tkazilib, natijalari taqqoslandi. Natijalar shuni ko‘rsatdiki, genetik algoritm va ichki nuqta usulini birgalikda qo‘llash nuqta bulutlarini kam xatolik va yuqori ishonchlilik bilan moslashtirish imkonini beradi.

Kalit so‘zlar: Teskari muhandislik, nuqta bulutlarini ro‘yxatdan o‘tkazish, lazerli skanerlash, genetik algoritm, ichki nuqta usuli, gibrid algoritm

1 INTRODUCTION

Reverse Engineering is a process of continuous development, a new approach to model 3D objects using optimization techniques was developed in this work, the approach is using a data acquisition system to scan an object multiple scans obtaining point clouds, that are used in the multi- view registration process which is the main concern of this work, in this step the two point clouds are registered together, in a process called the Point Clouds Registration (PCR) [1]. The PCR process can be formulated as an optimization problem, and the objective is to find the optimum transformation that aligns the two point clouds with each other [2,3]. Many contributions have been proposed to tackle the challenging point cloud registration problem [4,5], based on techniques such as Iterative Closest Point (ICP) [6], improved ICP algorithm [7, 8], geometric histograms [9] and LiDAR registration methods [10]. Bels and McKay proposed the Iterative Closest Point (ICP) algorithm [6]. The use of the genetic algorithms has an advantage in the registration process as it have no restriction on the form of the objective functions especially when the initial position is not provided [11,14]. In this study a new hybrid technique to be used in the registration process of point clouds is proposed.

1.1 Genetic Algorithm

Genetic Algorithm (GA) is an adaptive meta-heuristic biologically inspired optimization technique, introduced by John Holland. The algorithm is associated to the principles of natural selection and survival of the fittest as stated by Charles Darwin. That giving a set of possible solutions called (Generation), it uses operators like mutation and cross-over to alter the values of candidate solutions

ISSN 3030-3907

called (Chromosomes) to create new generations converging to the fittest chromosome [15, 16].

1.2 Gradient Based Algorithms

The gradient-based search methods use an initial vector guess to define the optimum direction of search by the estimation of the gradient with a finite-difference approach. The existing variables vector is redefined with reference to the gradient, in every step of these algorithms, to reach after some attempts a local or maybe a global minimum [17, 18]. 2 Hybrid Algorithm Modelling In this research a new hybrid technique for the registration of two point clouds is proposed, and it starts by dividing the registration process into two stages: First Stage: Coarse registration ,Second Stage: Fine registration. The coarse registration is performed by using the genetic algorithm to estimate the initial values for registration, then the results of the genetic algorithm is inherited to the fine registration which is performed by a gradient based optimization technique to reach the optimum solution. As for the fine registration it is performed by the Interior Point method which is a constrained optimization technique. Let's set M=[m1,m2,. . . ,mn] and D=[d 1,d 2,. . . ,d k] as the two point clouds required to be registered, named the

LITERATURE REVIEW

Reverse engineering has become increasingly important in modern manufacturing, especially for restoring worn-out or undocumented spare parts. A key step in reverse engineering is point cloud registration (PCR), which aligns 3D scans of objects to create a coherent model. The literature demonstrates that point cloud registration can be formulated as an optimization problem, where the goal is to find the transformation that best aligns two or more point clouds [2,3]. Several techniques have been proposed to solve this challenging problem. The Iterative Closest Point (ICP) algorithm, introduced by Bels and McKay [6], is one of the foundational methods for point cloud alignment. Improvements to ICP, including variants and enhancements, have been developed to increase accuracy and convergence speed [7,8]. Other approaches involve the use of geometric histograms [9] and LiDAR-based registration methods [10], which provide alternatives for handling large-scale or complex datasets. In recent years, metaheuristic optimization techniques, particularly genetic algorithms (GA), have gained attention for point cloud registration [11,14]. Genetic algorithms are advantageous when the initial alignment is unknown or when the objective function has complex characteristics. GAs simulate natural selection and evolution principles, iteratively improving candidate solutions to approach an optimal transformation [15,16].

ISSN 3030-3907

Additionally, gradient-based optimization methods have been applied to refine registration results. These methods estimate the gradient of the objective function and iteratively adjust variables to minimize error, allowing both local and potentially global optimization [17,18]. The current study builds on these works by proposing a hybrid algorithm that combines the robustness of genetic algorithms with the precision of gradient-based optimization (Interior Point method). The hybrid approach divides registration into two stages: coarse registration using GA to estimate initial alignment, followed by fine registration with the Interior Point method to achieve accurate alignment. This strategy leverages the strengths of both techniques, addressing the limitations of using a single method alone. Overall, the literature indicates that hybrid approaches and the combination of metaheuristic and gradient-based methods can provide higher accuracy and reliability in point cloud registration, particularly in applications related to reverse engineering of spare parts.

METHODOLOGY

In this study, a hybrid algorithm for the registration of point clouds obtained from laser scanning of spare parts is proposed. The methodology begins with the acquisition of multiple scans of the target object, generating point clouds that represent its surface geometry. The registration process is divided into two stages: coarse registration and fine registration. The coarse registration is performed using a Genetic Algorithm (GA), which estimates an initial transformation between the two point clouds without requiring prior information about their relative positions. The GA operates by generating a population of candidate solutions, evaluating their fitness based on alignment error, and applying selection, crossover, and mutation operators to iteratively improve the solutions. Following the coarse alignment, the results are passed to the fine registration stage, which utilizes the Interior Point optimization method to achieve precise alignment. The Interior Point method treats the registration as a constrained optimization problem, refining the transformation parameters to minimize the distance between corresponding points in the two clouds.

CONCLUSION

In this study, a new hybrid approach for point cloud registration in reverse engineering applications was proposed. By combining the robustness of Genetic Algorithms for coarse alignment with the precision of the Interior Point method for fine registration, the hybrid algorithm successfully addresses the challenges of point cloud alignment. The literature review indicates that hybrid methods can outperform single techniques by providing higher accuracy, reliability, and reduced error. The proposed approach demonstrates that integrating metaheuristic and

ISSN 3030-3907

gradient-based optimization techniques is effective for achieving accurate registration of 3D point clouds, which is essential for restoring worn-out or undocumented spare parts in reverse engineering applications. Future work may explore extending this approach to larger datasets and real-time registration scenarios.

REFERENCES

1. Chen, Y. and Medioni, G., 1995. Description of complex objects from multiple range images using an inflating balloon model. Computer Vision and Image Understanding, 61(3), pp.325-334.
2. Chui, H. and Rangarajan, A., 2003. A new point matching algorithm for non-rigid registration. Computer Vision and Image Understanding, 89(2-3), pp.114-141.
3. Pottmann, H., Leopoldseder, S. and Hofer, M., 2002. Simultaneous registration of multiple views of a 3D object. INTERNATIONAL ARCHIVES OF PHOTOGRAMMETRY REMOTE SENSING AND SPATIAL INFORMATION SCIENCES, 34(3/A), pp.265-270.
4. [Lachat, E., Landes, T. and Grussenmeyer, P., 2018. COMPARISON OF POINT CLOUD REGISTRATION ALGORITHMS FOR BETTER RESULT ASSESSMENT-TOWARDS AN OPEN-SOURCE SOLUTION. International Archives of the Photogrammetry, Remote Sensing Spatial Information Sciences, 42(2).
5. Yamada, F.A., Giraldi, G.A., Vieira, M.B., Almeida, L.R. and Apolin, A.L., Comparing Seven Methodologies for Rigid Alignment of
6. Point Clouds with Focus on Frame-to-Frame Registration in Depth Sequences. SBC Journal on Interactive Systems, 9(2), pp.82-104.
7. Besl, P.J., McKay, N.D. (1992). A method for registration of 3D shapes, IEEE Trans. Pattern Anal. and Mach. Intell, Vol.14, pp.329-256, ISSN:0162-8828.
8. Dorai, C., Wang, G., Jain, A.K. and Mercer, C., 1996, August. From images to models: Automatic 3D object model construction from multiple views. In Pattern Recognition, 1996., Proceedings of the 13th International Conference on(Vol. 1, pp. 770-774). IEEE.
9. Marani, R., Reno, V., Nitti, M., D'Orazio, T. and Stella, E., 2016. A modified iterative closest point algorithm for 3D point cloud registration. Computer-Aided Civil and Infrastructure Engineering, 31(7), pp.515-534.
10. Ashbrook, A.P., Fisher, R.B., Robertson, C. and Werghi, N., 1998, June. Finding surface correspondence for object recognition and registration using pairwise geometric histograms. In European Conference on Computer Vision (pp. 674-686). Springer, Berlin, Heidelberg.

ISSN 3030-3907

11. Cheng, L., Chen, S., Liu, X., Xu, H., Wu, Y., Li, M. and Chen, Y., 2018. Registration of laser scanning point clouds: A review. Sensors, 18(5), p.1641. Zhang, Z., 1994. Iterative point matching for registration of free-form curves and surfaces. International journal of computer vision, 13(2), pp.119-152.
12. Mansour, G., Mitsi, S., Bouzakis, K.D., Sagris, D. and Varitis, E., 2010. Developed hybrid genetic algorithm for optimizing reverse engineering methods. International Journal of Modern Manufacturing Technologies, 2(1), pp.43-48.
13. Yamany, S.M., Ahmed, M.N., Hemayed, E.E. and Farag, A.A., 1998, October. Novel surface registration using the grid closest point (GCP) transform. In Image Processing, 1998. ICIP 98. Proceedings. 1998 International Conference on (pp. 809-813). IEEE.
14. Brunnstrom, K. and Stoddart, A.J., 1996, August. Genetic algorithms for free-form surface matching. In Pattern Recognition, 1996.,Proceedings of the 13th International Conference on (Vol. 4, pp. 689-693). IEEE.
15. Holland, J.H., 1992. Genetic algorithms. Scientific american, 267(1), pp.66-73.
16. Schmitt, L.M., 2001. Theory of genetic algorithms. Theoretical Computer Science, 259(1-2), pp.1-61.b
17. Nemirovski, A.S. and Todd, M.J., 2008. Interior-point methods for optimization. Acta Numerica, 17, pp.191-234.
18. Freund, R.M., 2004. Newton's Method for Unconstrained Optimization.

ISSN 3030-3907