APPLIED AND ECONOMIC ASPECTS OF EFFICIENT MEASUREMENT OF DISTANCE BETWEEN NON-CONVEX OBJECTS

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Key words: convex polygon, algorithm complexity, algorithm speed, hierarchical tree, orthogonal tree.

Introduction (applied and economic aspects). In this article, an effective algorithm for measuring the distance between geometric objects and its economic significance will be studied.

Measuring the distance between objects is a very common problem.

The algorithm for measuring the distance between two objects has a wide range of applications. It can be used in many fields including:

1. *Geodesy* to measure distances between certain points on the earth's surface,
2. *Cartography* to measure distance on maps and plans.
3. *Navigation* to measure the distance between certain points on sea, air, and land.
4. *Computer graphics* to determine the distance between objects on a computer screen,
5. *Robotics* to determine the distance between robots and other objects in the process of navigation and control.
6. *Medicine* to measure distance on medical scan images,
7. *Architecture and Construction*: Accurate measurement of distances between objects in construction can be important to ensure proper placement of materials and avoid conflicts with other construction objects.
8. *Transport* for measuring the distance between vehicles on roads, railways, and in the airspace, as well as in the automotive industry, accurate distance measurement between vehicles can be important for road safety, as well as improving fuel economy and reducing brake weariness.
9. *Engineering design* to measure the distance between machines and elements of structures,
10. *Geology* to measure the distance between geologic features on the earth's surface.

In manufacturing processes, accurate measurement of the distance between two objects can ensure the correct placement and assembly of parts. Incorrect spacing can lead to product failure and rework, which wastes additional resources and reduces production efficiency.

Currently, measuring the distance between objects allows you to bypass obstacles and find optimal ways.

Methodology. Different methods and technologies can be used to measure the distance between non-convex objects. This paper includes a proprietary algorithm for measuring the distance between non-convex objects that is compared with other known approaches.

Our method is based on object fragmentation. We divide the object into a rectangle until the part of the polygon inside the rectangle of the object is not convex. The divide and conquer method is applied.

Afterwards, the distance between convex components is measured using the Gilbert-Johnson-Keerthi [E. G. Gilbert, D. W. Johnson, S. S. Keerthi, 1992, 193-203] distance algorithm.

Review of literature. The Gilbert-Johnson-Keerthi (GJK) algorithm can be used to measure the distance between two convex objects. The essence of the algorithm is that it observes the movement of one of the objects relative to the other and at the same time searches for the minimum distance between the two objects.

To do this, the GJK algorithm also represents two objects as polyhedra and finds their Minkowski difference point, which is the smallest point on the union surface of the two objects. Then the algorithm searches for the smallest distance between the objects in the direction of the norm of this point[E. G. Gilbert, D. W. Johnson, S. S. Keerthi, 1992, 193-203].

The Cultivation algorithm works by creating a series of spheres around one of the objects and then expanding these spheres until they touch the other object. The distance between the two objects is then computed as the radius of the last sphere that touches the other object[Quinlan, 2002].

R-tree is a spatial indexing data structure used for efficient nearest neighbor search in multi-dimensional space. To calculate the distance between two objects using R-tree, we perform a nearest neighbor search to find the closest point in one object to the other, and then calculate the distance between these points[Guttman, 1984, 47-57].

Scientific novelty. At present, the demands of the manufacturing market are increasing and along with it the demand for software provision is increasing.

The algorithm we have developed makes it possible to effectively measure the distance between objects. The algorithm we developed is 100% accurate, which is of great importance in calculations that require high accuracy. This algorithm enables us to provide 100% accuracy in a relatively short time.

Comparing the existing algorithms for calculating the distance between non-convex polygons to Quinlan's "Effective distance calculation between non-convex objects" [5], our algorithm is much easier to design. It is also more accessible in terms of complexity, because the branches of the trees are even less.

Unlike the algorithms developed by GJK, Lin and Canny, our algorithm works for arbitrary polygons.

The advantage of the proposed method over the rectangular tree (R-tree) is its accuracy. Distance measurement using a rectangular tree is done with some approximation, and this algorithm gives the exact distance between objects.

One of the advantages of the algorithm is its simplicity and easy presentation in a programming language.

Analysis**.** Measuring the distance between objects. Gilbert-Johnson-Keerthi (GJK)[2], Canny Lin [Lin, Canny, 1991, 1008-1014], and Bobrov developed an algorithm that calculates the distance between convex objects using the features of convex polygons.

This article presents the algorithm we have developed, which, at each iteration, divides the object into four parts and takes the closest one.

A question arises, how to divide the geometric object into four parts? To split an object into four components, we take the object's largest and smallest coordinates (X_{min}, X_{max}, Y_{min}, Y_{max}) and enclose the object in a rectangle. After all this, the object is divided into four parts by calculating the average of the coordinates of the object and fragmented.

Consider we are given the following object ABCDE. The following object is taken in the rectangle HFDG. With the midpoints of the coordinates, the object is divided into four equal rectangles: FKMI, KDJM, IMLH, and MJGL (Fig. 1). To measure the distance between objects, we can measure the distance between their components and take the smallest one.

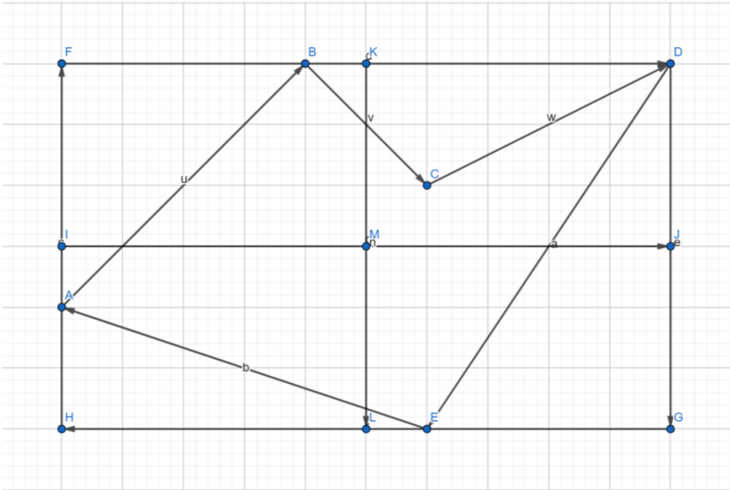

Figure 1. Object fragmentation

The main function implementing the algorithm, receiving 2 objects, divides these objects into four parts and recursively calls the same function with the closest components.

To measure the distance between the components of objects, we can take these components in circles because measuring the distance between circles is incomparably easier than between rectangles.

By having the minimum and maximum coordinates of two objects, two of the four components of the object can be excluded, making the computer easier to work with. Then the rectangle is taken into the circle, calculating the average of the coordinates of the rectangle.

To measure the distance between two circles, we need to know the coordinates of their centers and their radii.

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} - (r_1 + r_2) \qquad (2)$$

In formula (2), if D<0, the circles intersect, otherwise they don't.

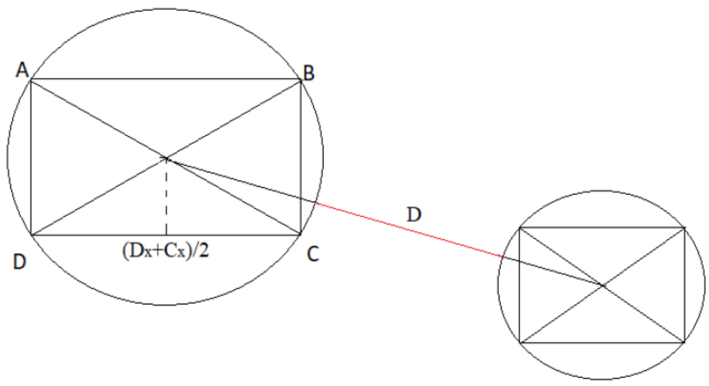

Figure 2 Measuring distance using a circle.

If the circle intersects with two circles of the other object (Fig. 3), the operation continues with the two circles drawn on the segment of the given object, until the circles do not intersect in one of the rectangles drawn on those circles.

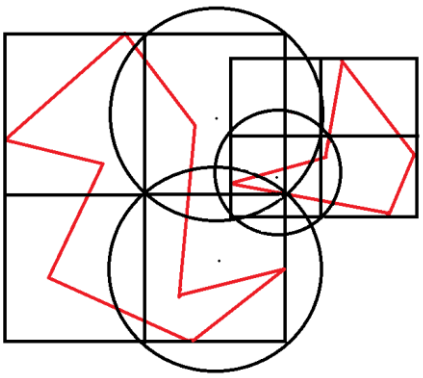

Figure 3. Intersection with two circles

Dividing the object into four parts, it is necessary to check if there is a point in the rectangle belonging to the original object. For that, the midpoint of the coordinates should be moved from X_{max} and X_{min} of the given rectangle to check if there is a point belonging to that rectangle. The same operation is performed with the Y coordinate. The set of these points is separated from all the points belonging to the object because further operations will be performed with those points.

Using this algorithm, the following steps are performed to measure the distance (Fig. 4):

1. the objects in the rectangle are taken in the foregoing way,

2. the resulting rectangles are accordingly divided into four equal rectangles,

3. from those rectangles, the closest ones are taken, in which there is a point belonging to the object,

4. the convexity of the object inside the rectangle is checked,

5. the Gilbert-Johnson-Keerthi algorithm is applied.

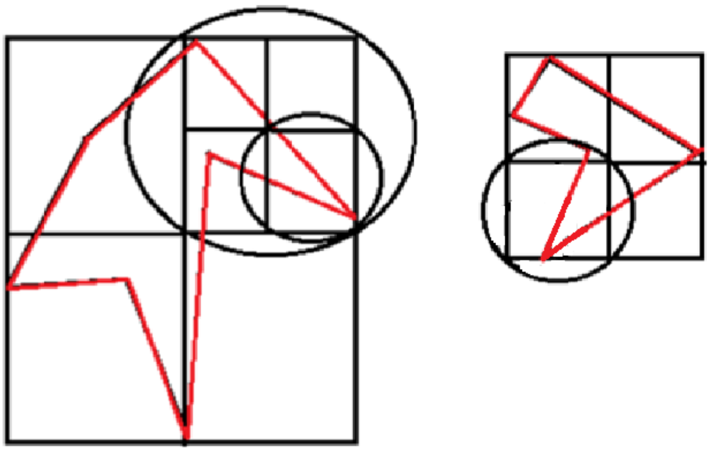

Figure 4. Sequence of steps

Points 1-3 are performed until the component of the polygon inside the rectangle is not convex.

If the number of objects exceeds two, applying the above mentioned algorithm, we can build a rectangular tree whose leaves are convex polygons and use the tree to measure the distance between all objects.

To check the convexity of an object, we need to check if all interior angles are less than 180°.

Effective distance measurement between non-convex objects can be used in the economy in many ways. One potential application is supplying chain management, which can help optimize logistics and reduce transportation costs.

For example, in the manufacturing industry, parts and components may need to be moved between different facilities or suppliers. By measuring the distance between non-convex facilities, such as warehouses or manufacturing plants, companies can identify the most efficient transportation routes, reducing costs and improving delivery times.

Similarly, in the retail industry, measuring the distance between non-convex objects can help optimize product distribution. By identifying the most efficient routes for delivery vehicles, companies can reduce transportation costs and improve the speed and accuracy of deliveries.

Effective distance measurement between non-convex objects can also be applied to location-based marketing strategies. By identifying the location of potential customers and measuring the distance between non-convex objects, companies can target their marketing efforts more effectively and increase return on investment.

Conclusion: Thus, the algorithm developed in the article divides the object into 4 parts using the bounding rectangle and takes the closest one. This operation is performed as long as the inner part of the rectangle bounding the object is not convex. later applies the GJK algorithm between the convex components.

Accurate and efficient measurement of distances between non-convex objects is of great importance in various fields and can contribute to economic growth and productivity.

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Applied and economic aspects of effective measurement of distance between non-convex objects

Key words: Convex polygon, algorithm complexity, algorithm speed, hierarchical tree, rectangular tree.

In this article, an effective algorithm for measuring the distance between geometric objects is studied. Effective distance measurement between non-convex objects is of great economic importance in various fields. It can be used in many fields. Currently, measuring the distance between objects allows you to bypass obstacles and find optimal paths. The diversity of the field of application results in an increase in the demand for the software, as well as the saved funds. The algorithm developed in this article divides the object into four parts using rectangles and measures the distance using a circle. The segmentation continues until the part of the object inside those rectangles is not convex.
A hierarch is built, a tree whose leaves are convex polygons covering the surface of the object, and whose root is the original object. The advantage of our algorithm is accuracy, and the disadvantage is speed.