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The Method to Navigate the Forward and Backward Path of a Towing Tractor for Transporting Aircraft

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ABSTRACT

Aircraft carriers are the backbone of the Navy. They are equipped with aircraft, and their ability to take off and land aircraft quickly and efficiently determines their performance. Therefore, the number of aircraft is a key consideration in the design of an aircraft carrier and ensuring that they can be operated in the space of the aircraft carrier is an important factor in the arrangement design as well. On the other hands, towing tractors are used to move aircraft around. Towing tractors must safely move aircraft in open spaces while avoiding multiple obstacles, which requires skilled operators. In this study, we propose a method to automate the path of a towing tractor and then follow it. First, we studied the kinematics of the towing tractor and aircraft carrier, considering the wheel movement and steering angle. Then, we calculated the optimal path of the tractor and aircraft considering both forward and backward motion. Finally, we applied dynamics to verify that the towing tractor and aircraft carrier could follow the calculated path. We tested the proposed method in a field with various obstacles and in a narrow area such as a parking lot and confirmed that it was effective.

KEY WORDS

Aircraft carrier; Towing tractor; Navigation; Optimal path; Dynamics.

INTRODUCTION

Traditionally, aircraft carriers are the main power of major powers as well as the navy. (Ryan et al., 2011) Aircraft are typically equipped in aircraft carriers, and how many and how fast they can take-off and land determine the performance of aircraft carriers. In general, for preparing the take-off and landing sequence of aircraft, a towing tractor is used. On land, this work can be carried out smoothly like airplane at general airports along guidance lines and work instructions. However, as described above, since this process must be performed in limited space in an aircraft carrier lined with many aircraft and equipment, the time and efficiency of moving aircraft depend on the proficiency of the towing tractor operator. Therefore, it is necessary to automate the path of the towing tractor and follow it. this study proposes a method of optimizing and following the path of the towing tractor in the aircraft carrier.

Various methods have been proposed for utilizing towing tractors to determine and track the optimal path for aircraft carriers. Gomez-Brabo et al. (2005) proposed a method for planning the path of a tractor-trailer, predicting the path based on the kinematics and restricted maneuvering modeling of the tractor-trailer's motion. They then utilized fuzzy system inverse mapping to generate the optimal path for movement. Similarly, Elhassan (2015) performed modeling to predict the path of the connected vehicle and then used the rapidly exploring random tree (RRT) method to generate the optimal path. This was then applied to the docking task. In addition to the aforementioned studies, our research has explored various methods for generating and tracking the optimal path for aircraft and towing tractors.

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KINEMATICS

When moving aircraft in a hanger or deck on aircraft carrier, it does not move by itself with propulsion, but uses a tractor to tow the ship. Therefore, the tractor fixes the nose wheel and then tow it to move aircraft. This movement becomes very similar to the movement of a general tractor-trailer, which is expressed in figure 1. And if kinematics is derived for this, it can be expressed as equation 1.

$$\frac{d}{dt}\begin{bmatrix} x_1 \\ y_1 \\ \theta_{CA} \\ \theta_T \end{bmatrix} = \begin{bmatrix} v_T \cos\beta_{CA} \cos\theta_{CA} \\ v_T \cos\beta_{CA} \sin\theta_{CA} \\ \dfrac{v_T \cos\beta_{CA} \tan\beta_{CA}}{L_{CA}} \\ \dfrac{v_T \tan\beta_T}{L_T} \end{bmatrix} \quad [1]$$

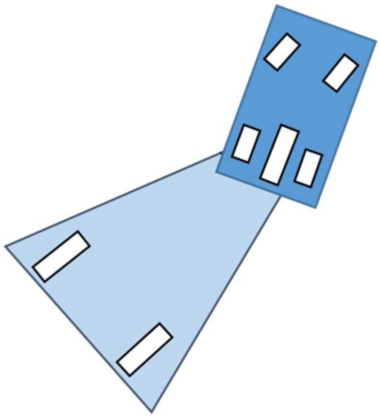

Figure 1. Schematic of towing tractor and aircraft

There are two wheels, an axis, and a nose wheel in front of the rear wheel. And the distance between the axes of the loader is called L_{CA}, and θ_{CA} is the angle of the loader based on the fixed coordinate system. And β_{CA} is the angle between the nose wheel and the central axis of the loader, and x_1 and y_1 are the absolute coordinates of the center of the rear wheel shaft of the loader. The distance between the axes of the turning tractor is L_T, and the rotation angle and steering angle of the tractor are θ_T and β_T, respectively. And the speed of the tractor is set to be v_T.

HYBRID A*

In general, Dijkstra's method (Dijkstra, 1959) or A* method (Russell, 2018) is used for path search. However, in the case of this method, as a method designed for graph search, a graph is generally constructed based on grid and used to find a path. Therefore, there is a great disadvantage that the search area is limited due to grid. Hybrid A* method was designed to apply dynamics or kinematic to the A* method. If the existing A* method moved within a predefined grid, the hybrid A* method is a big difference in that the node for search is not the center of the grid or a point based on the grid, but a point considering the kinematic model at the current node. Therefore, it is possible to construct a node in consideration of dynamics that could not be considered in the existing grid-based method. Path search scheme using hybrid A* for towing tractor and aircraft can be expressed as figure2.

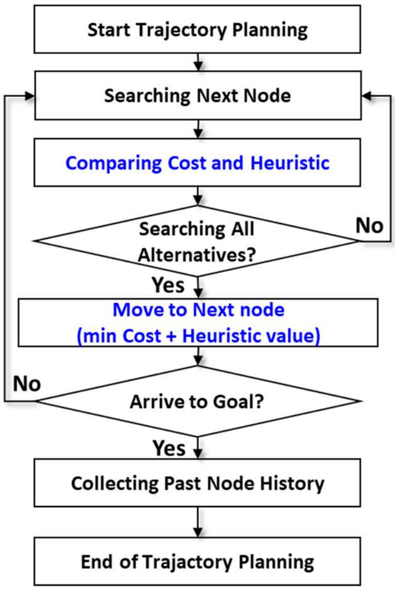

Figure 2. Path search scheme for towing tractor and aircraft using Hybrid A*

The cost function is a function representing the cost required to proceed to the node, and in general, the distance is often used as a cost value for the shortest distance search. In the case of our problem, the distance between the two nodes was considered as a cost because the shortest distance had to be considered basically. And in the case of backward movement, an additional cost was added because it is a relatively more difficult path than forward movement. In addition, in the same way, an additional cost was added when the direction was changed from forward to backward or from backward to forward. Here, the additional cost was selected in consideration of the interval between nodes and configured to be changed according to the needs of the user.

APPLICATION

In this study, a user program based on the kinematics and hybrid A* described above was implemented. The program can generate simple fields and examples for the towing tractor and aircraft. The program was developed in a .Net environment using the C# language, and a GUI was implemented using the MVVM pattern. The GUI configuration is shown in figure 3.

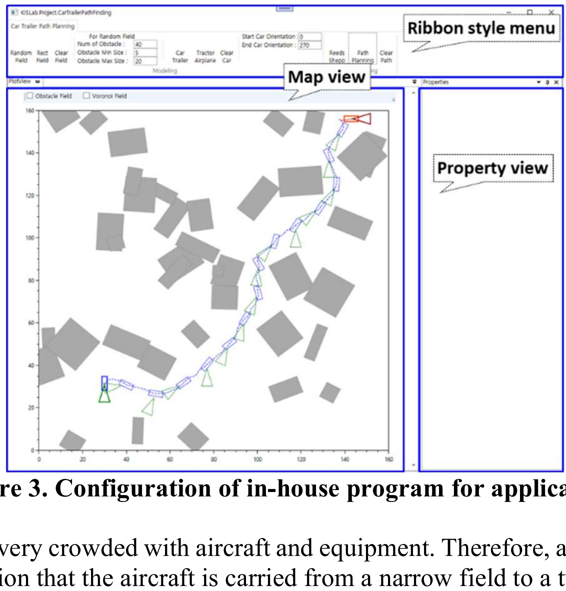

Figure 3. Configuration of in-house program for applications

The hangar of the aircraft carrier is very crowded with aircraft and equipment. Therefore, assuming the situation, two examples were carried out under the assumption that the aircraft is carried from a narrow field to a tuning tractor as follows.
The first example is how to get the aircraft back to its destination after the turning of the towing tractor. This requires very precise transportation, and of course, the backward movement must be carefully performed in consideration of the jack-knifing.

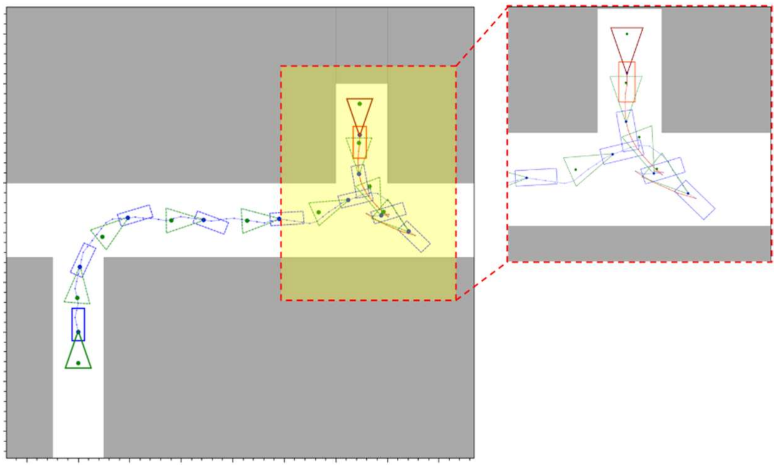

Figure 4. Path planning for backward movement

As can be seen in figure 4, while considering kinematics, it is important to pay attention to collisions with the surrounding environment when reversing. The blue path is forward movement and red path is backward movement. The following path was shown that forward and backward movement were harmonically used as a skilled operator and it can be seen that the path is found smoothly.
The second example is for parallel parking. Since the aircraft acts like a cargo of a truck, parallel parking is a much more difficult maneuver than normal parking. Figure 5 shows a path of parallel parking of an aircraft in a very narrow environment. As can be seen in figure 5, the towing tractor is rotated, and parallel parking is performed smoothly as operators driving pattern.

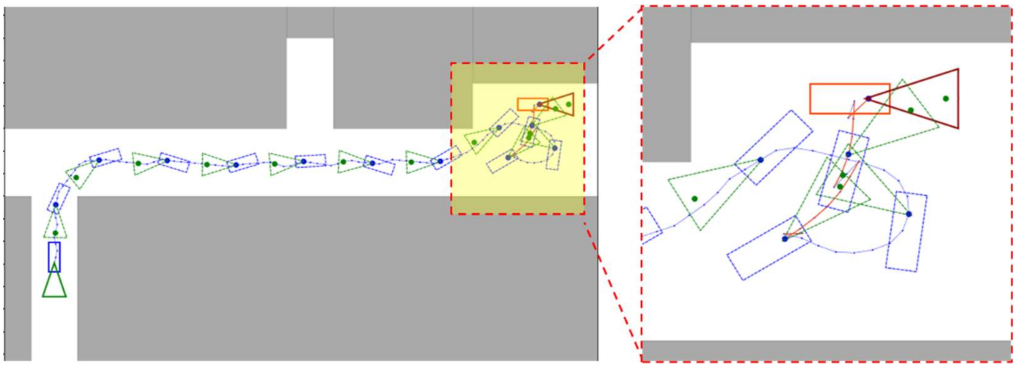

Figure 5. Path planning for parallel parking

CONCLUSIONS AND FUTURE WORKS

In this study, we proposed a method to find a path that can effectively transport an aircraft in the aircraft carrier, which is a limited space for the towing tractor. This method is based on the kinematics for the towing tractor and aircraft. And using this, hybrid A* method was used to find the path considering forward and backward movement. For implementing this, in-house program was developed and applied to two cases. Two cases were modeled after frequently performed operations in aircraft carriers. The results show that generated path for towing was acceptable and similar to real operations.
The proposed method in this study is a path planning method that considers the connection between a aircraft and a tractor. However, it can also be applied to path planning for large ships being towed by tugboats in narrow coastal waters. Therefore, in the future, we plan to expand this method to towing problems for large ships in coastal area. In this case, the ship's equations of motion will be mainly used, and the ship's optimal fuel consumption and time will be considered accordingly.

CONTRIBUTION STATEMENT

Ki-Su Kim[1]: conceptualization; methodology; implementation; writing – original draft, **Kwang-Phil Park**[2,*]**:** conceptualization; supervision; writing – review and editing **and Sang-Hun Kang**[3]**:** research assistance.

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