Autonomous Motion of Unmanned Ground Vehicles in General Environment

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Abstract: This paper deals with an optimal path-finding algorithm in a real general environment. This algorithm is designed for automatic motion and movement of unmanned ground vehicles. Importance of this problem solution is connected with the wide application of unmanned vehicles in modern armies. The article is divided into three basic parts and covers a general discussion of the problem, definition of basic principles of our optimal path-finding algorithm, an issue of optimum maneuver in a general environment on a local and global level, and a mathematical design for our algorithm.

Key words: optimal path-finding algorithm, unmanned vehicles, autonomous motion, area reconstruction

1 Introduction

The sense and utilization of unmanned vehicles is increasing steadily all the time; these vehicles are used in many various applications, both in the civil and military area. Unmanned aerial vehicles (UAV) are used most frequently; however, unmanned vehicles are also seen operating in a different type of media: unmanned space vehicles, unmanned ground vehicles (UGV), unmanned surface vehicles (SUV), or unmanned underwater vehicles (UUV, AUV).

Development of unmanned vehicles goes in two general directions; the development of hardware, electronic equipment, sensorial, weapon and communication systems, keeps up with software innovations, particularly in the area of decision processes automation. Vehicles, which had originally been controlled by the operator from a control center, gradually became semiautonomous and autonomous devices which are able to fulfill their tasks independently on their operators.

This paper results from the long-term research in the area of unmanned aerial and ground vehicles carried out at the University of Defence in the Czech Republic. The research priorities consist not only in developing unmanned systems but also in designing and implementing the algorithms for decision process automation support, optimizing tactical tasks, automatic searching and monitoring targets, etc. [4], [5].

2 Optimal path-finding task

The task of optimal movement of an unmanned vehicle in a general environment is not a trivial one. Although it cannot be classified as an entirely new and already unsolved issue, the only possibility how to achieve some progress in this area consists just in designing and creating mathematical models and algorithms of our own since there cannot be expected that somebody else is willing to provide us with his/her results. It is obvious that such know-how is carefully protected.

In general, there can be found several different attitudes and approaches how to solve this issue. The two most frequently used are as follows:

- Environment analysis in the infrared and visible light spectrum via passive sensorial devices (cameras).
- Environment analysis via laser scanning devices.

Our project considers implementing both above mentioned approaches in the future. Currently, however, our optimal path-finding algorithm applies just the second principle when a laser scanner for the environment reconstruction process is used. This device is able to scan surrounding environment at a visual angle of 360°. As a result of the scanning process, there is acquired a two-dimensional distance map serving as the input to our path-finding algorithm. During motion of the vehicle, the map is unceasingly elaborated and supplied with the missing parts of the environment.

Currently, this project is still in the making. We are working on the development of an experimental vehicle, which is supposed to move in a general environment autonomously. In the first stage of our research, a limiting condition was determined: the scanning process is conducted only in two-dimensional space. The reason of that condition does not consist in our algorithm but in the laser scanner providing the objects distances in one plane. In the future, the full three-dimensional environment reconstruction is expected.

There are wide application possibilities, particularly in the military area. Successful and sophisticated solution will be of great benefit to all modern armies since they use unmanned vehicles in order to fulfill their tasks. Practical utilization can be seen by using in foreign missions and operations (Afghanistan, Iraq, etc.) for automatic reconnaissance, target surveillance, following persons, transportation of wounded soldiers, etc. In addition, there are various further applications in the civil area as well.

3 Optimal path-finding algorithm

Design and implementation of a general optimal path-finding algorithm [3] is a fundamental prerequisite for a problem solution of this task.

Real time path optimization in a general environment is solved in two layers: a higher and a lower layer, where the high layer is independent of level of automation of local element control and determines rough (in terms of high model resolution) path configuration on the digital terrain model. Results of that algorithm are establishment of a motion vector configuration on the particular model in available resolution and based on general tactical and geographical information.

The key point of solution consists in particular ability of parallel execution of that solution and implementation of the GPGPU concept to element processing (NVIDIA-CUDA, AMD-Stream). In these areas, there are certain possibilities that there is not possible to avoid serialization of particular phases since iteration steps of algorithm is previous result dependent; nevertheless, process solution of each phase is possible to parallelize. Here is another small complication of global memory share of particular threads of phase solution resulting in small latency in the final solution. General effectiveness is dependent on parallel process count, which can be executed in each phase of the iteration process; this number is variable to calculation process and in general point of view it is trapezoid or triangle trend, as illustrated in figure 1.

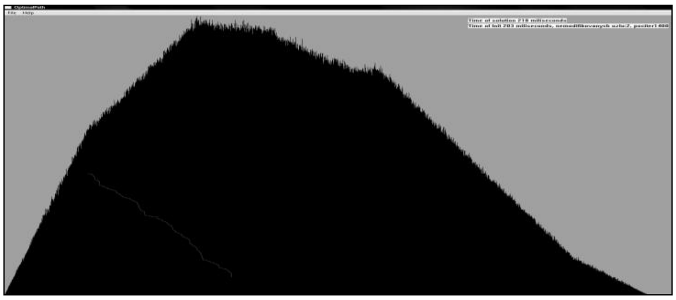


Fig. 1 Graph of number of executed threads in each phase of solution

There is an example of model containing 1 million elements and 4 millions connections, where final solution was achieved in 1,400 iterations phases, where in each phase it was possible to execute 1 to 1,286 parallel threads operating over elements as shown on a graph. Parallel solution in that case could speed up the final solution more than 100 times.

Regarding the fact that a detailed description of the algorithm or extract of its program code would exceed the scope of this article, bellow there is outlined a sequence of individual steps aggregating individual processes ensuring implementation of mainly trivial and routine sub-processes:

1. Input or creation of initiatory data mode (chart) of a traffic network, especially initiation of weight coefficients, for links of individual nodes.
2. Initiation of starting positions of individual elements and determination of destinations for each of the elements.
3. Sequencing elements in the queue for solution.
4. Calculation of an optimum path for the first element to its destination.
5. Extrapolation of timetable of the path being solved and determination of probability coefficients for a given element in given time and given segment.
6. Inserting this calculation in a table of paths and inclusion of an indicator in transit segments of the chart for this item of the table of paths.
7. Solution of path optimization for the next element (in the queue). Prior to partial summation of individual links starting from the given node, expected time of arrival to the node (and middle of the link) is being calculated as well as spatiotemporal component of each link from the table of paths colliding with anticipated time of (the center of) the link is being integrated (separate algorithm).
8. Until the end of the queue of elements is reached, the algorithm continues with the step 5, after that it continues with step 9.
9. Should any of the elements reach its destination, it is excluded from the queue; should there be a requirement to add a new element, it is included at the end of the queue.
10. Update of positions of all elements in the model, setting of given element indicator at the beginning of the queue and continuation with the step 4.

4 Mathematical model

There is a flow diagram presenting a fundamental work scheme of our algorithm in figure 1. At the beginning, we are in the initial point whose exact position we know. The goal is to reach the target point; again we know its exact position. All blocks of the diagram are described in the following chapters in detail.

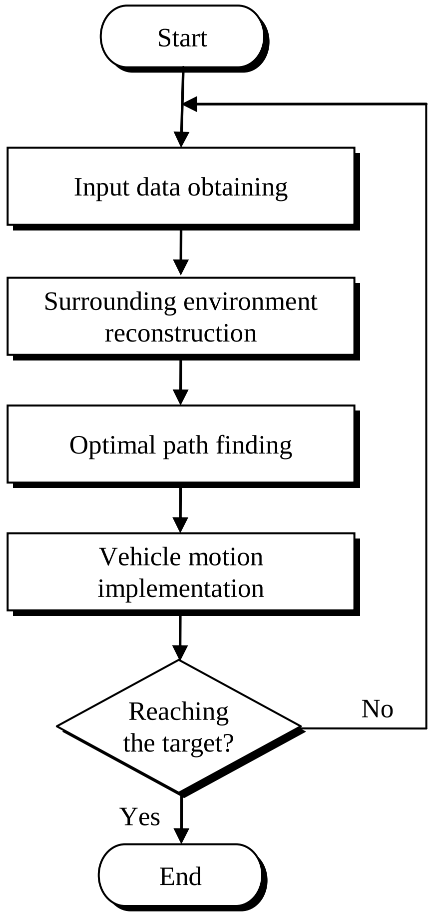


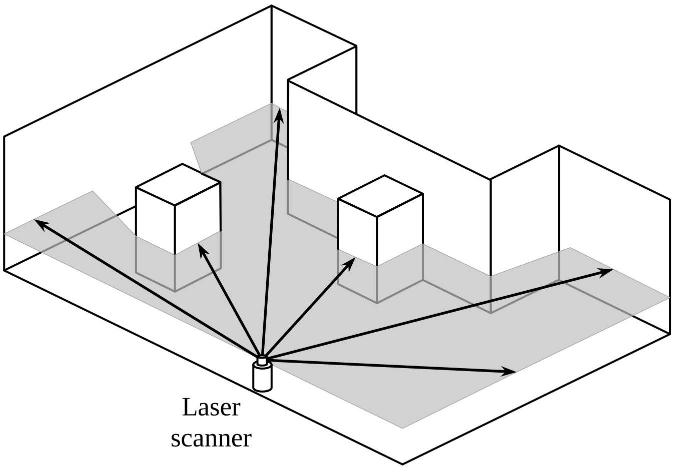
Fig. 2 Flow diagram of our algorithm of unmanned vehicle autonomous motion

4.1 Input data obtaining

We use a laser scanning device LD-LRS1000 made by Sick company in order to obtain input data (see figure 3). This device can scan the surrounding area at the visual angle of 360° at speed up to 10 Hz with precision 0.25° Operational range of measured distances is from 0.5 m to 250 m [6].

Fig. 3 Laser scanning device LD-LSR1000

As a result of the scanning process within one revolution of the rotation head, we acquire the distance map of the area which is composed of a data set of distances from the rotation head to the nearest object within a particular angle. The whole process is graphically presented in figure 4. The gray surface in the picture expresses the scanned area in the horizontal plane.



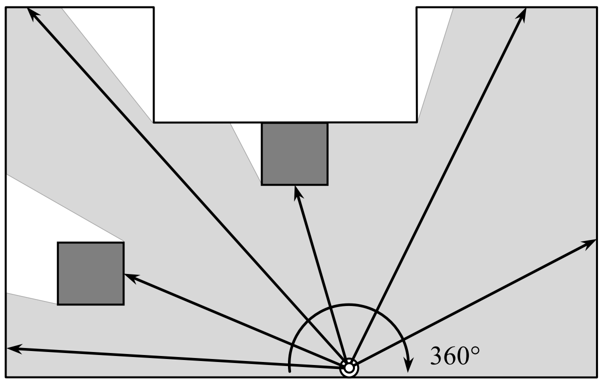


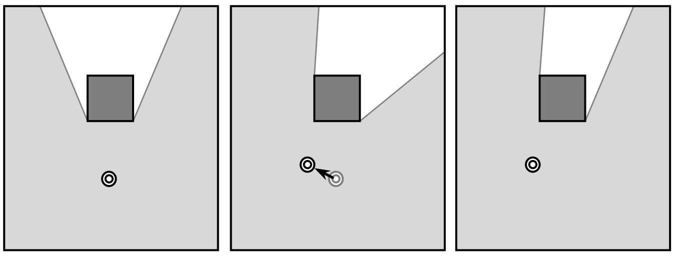
Fig. 4 Principle of the laser scanner LD-LRS1000

4.2 Surrounding environment reconstruction

Within each turn of the rotation head of the laser scanner, we gain the preview of the surrounding area. In many cases, the whole configuration of the area is not known since objects in the area restrain from direct visibility; hence the laser scanner is not able to scan the area which is located behind those objects (see figure 4).

Therefore during motion of a vehicle, it is necessary to supply and update the digital image of the surrounding environment. At the moment of a small change of a vehicle position in the area, we obtain new information about distribution of the obstructions there. A different angle of view ensures exposing of the areas that were so far hidden behind objects. The new information is integrated into the whole map of the area.

The described principle is presented in figure 5. In figures 5a and 5b, there are two independent maps of the same area, however, they are taken from a different position of the scanner. Figure 5c shows the principle of the surrounding area reconstruction which is conducted by unification of the both distance maps. Supplying of missing parts of the digital image of the area is carried out continuously during the whole vehicle motion.



a) b) c)

Fig. 5 Principle of surrounding area reconstruction

We need to know the precise position of the laser scanner at the moment of measurement to be able to unify two different distance maps. However, it is not a simple task. The precise vehicle position is known only at the beginning.

There are several approaches how to compute the vehicle position during its movement:

- Application a software analysis to every new distance map and determination of its best position in the reconstructed area. There is a drawback of this method – relatively significant computational requirement and higher probability of an error in case of substantial dynamic changes in an obstacles configuration.
- Keeping an estimated vehicle position via motion measurement of its motive parts (e.g. measurement of driving wheels revolution and their steer angle) and using the software analysis only to elaborate the position. There is also drawback – necessity for creation of a corresponding conversion model of input data into a new vehicle position and also relatively significant inaccuracy of the result.
- Keeping an estimated vehicle position via a digital magnetometer and accelerometer and using the software analysis only to elaborate the position slightly.

In our project, we take advantage of the last method which is very precise and implementable. We acquire the new coordinates of a vehicle from a digital accelerometer and a turning angle from a digital magnetometer. Then, we launch the software analysis to elaborate the position of a vehicle – but only in a small range.

4.3 Optimal path finding

At the moment of a surrounding environment update, the optimal path-finding algorithm is accomplished (see chapter 3); hence there is a new route from a current point to a target point. Our algorithm sets corresponding weights to all points of the reconstructed area.

Small weights are set to points through which the transport can be conducted. Vice versa, very high weights are set to points representing known obstacles; it is so because we need to omit those points as possible variants. The area which is still hidden deserves a special attention. All points in this area are set to middle weights; our algorithm tries to find the route through free known space firstly, and only in case when it is not possible, through unknown space. In case of uncovering new information, the route update takes place again.

The above mentioned principle is shown in figure 6. On the left, there is a reconstructed area; the right picture presents weights as an input to our algorithm. The value of weights corresponds to the gray color scale. We can see that the solid object is encapsulated in gradually decreasing weights of high values in order to respect the size of the vehicle and its turning radius.

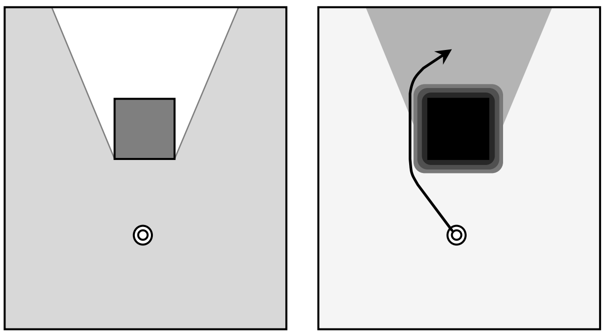


Fig. 6 Principle of assigning weights to the area

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4.4 Vehicle motion implementation

Motion of a vehicle is conducted immediately after a new trajectory (route) is found (provided it exists). The whole process of the environment reconstruction and optimal path finding is repeated unceasingly during the vehicle motion. In case of dynamic changes in the environment, the instantaneous update of the route takes place. The algorithm ends at the moment of reaching the target point.

In figure 7, there is an example of the key fragments of the vehicle motion on our designed simulator which we had developed in order to verify our theoretical designs and conclusions. The top left picture shows the configuration of the environment including initial and target points. The successive pictures present the progress of the vehicle motion. The red line shows the optimal path from the current point; the blue line preserves the path through which the vehicle moved.

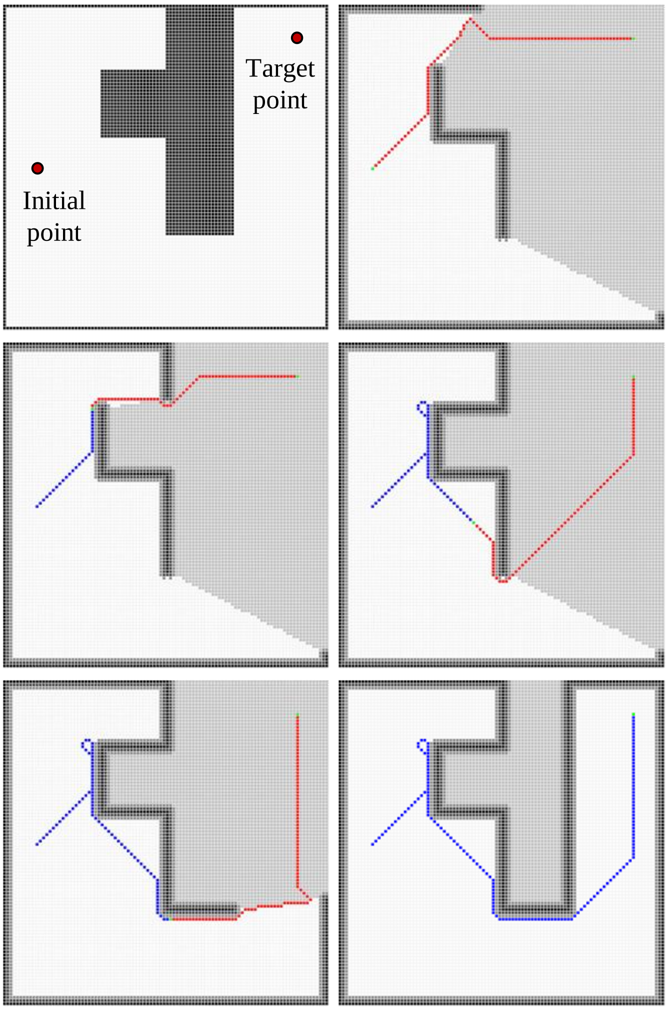

Fig. 7 Verification of our designed model on the simulator

We verified the process of autonomous vehicle motion also in practice on a simple example via our designed experimental vehicle. In figure 8, there is, analogously as in the previous case, the succession of the vehicle motion in the real environment.

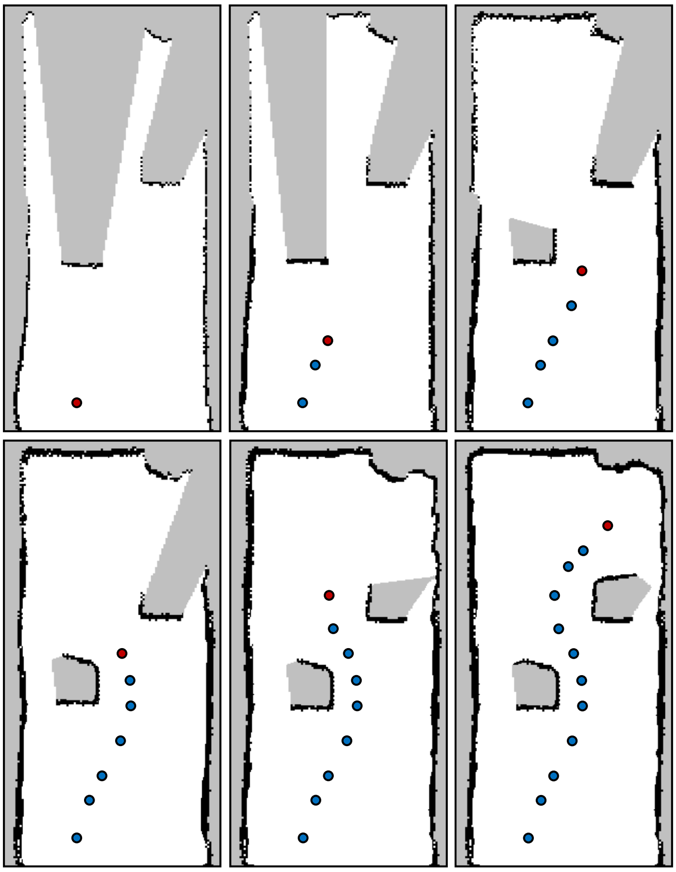

Fig. 8 Verification of our designed model in the real environment

5 Conclusion

As already mentioned, the paper was created within the research at University of Defence in the Czech Republic. We deal with development of autonomous unmanned systems and also with development of the software equipment for the system of the soldier of the 21st century. Figures 9 and 10 present some results of our research.

Our key project remains in the development of the autonomous unmanned ground vehicle (see figure 9). This vehicle is used especially for reconnaissance purposes offering the possibility of targets destruction. The vehicle is based on the chassis of a four-wheeled vehicle YAMAHA YFM400. On the top of the chassis, there is a robotic platform fitted with the sensorial, communication and weapon system.

Fig. 9 Unmanned ground vehicle

Nowadays, we are developing control software, particularly units for decision process automation support. In the future, we are planning to implement the described optimal path-finding algorithm into this vehicle. We are also working on the system of automatic searching and monitoring targets.

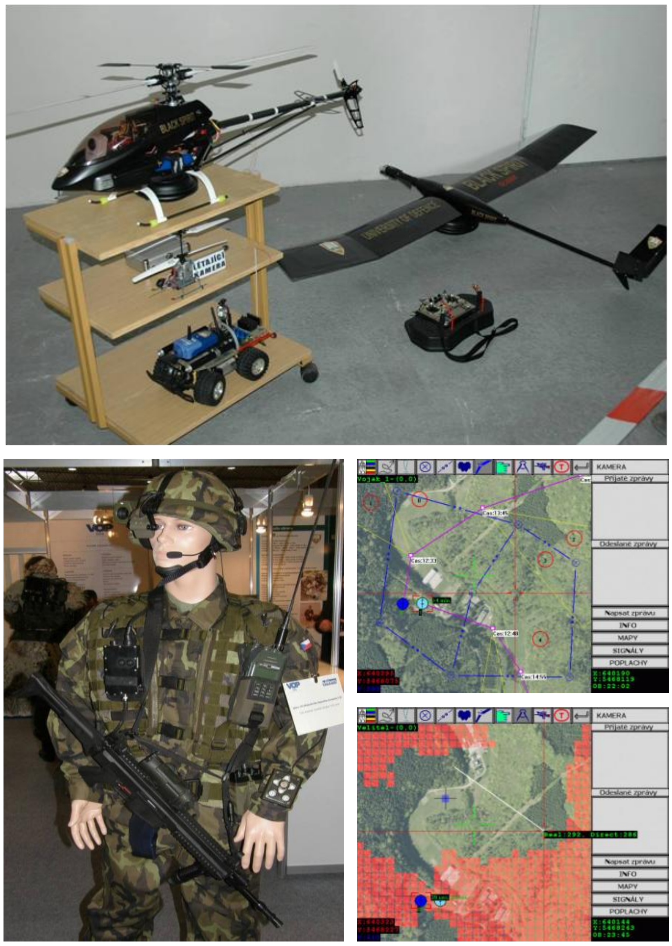

Fig. 10 Further results of our research

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