A Fast and Shorter Path Finding Method for Maze Images by Image Processing Techniques and Graph Theory

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***Abstract*—There are a lot of studies about shortest path algorithms. In the previous study, we showed that an A* search algorithm outperformed Dijkstra's to solve maze in terms of a search time. In this paper, to solve maze more quickly, we propose a fast and shorter path finding method based on the image processing techniques and graph theory. The experimental results show that the proposed method is superior to an A* search algorithm. In particular, the proposed method is more effective when the maze image size is large.**

***Index Terms*—image processing techniques, maze images, shortest path algorithms, A* search algorithm, graph theory, maze image size**

I. Introduction

In general, a maze has a complicated path like a labyrinth. To solve a maze is a kind of a game or puzzle which connects a path between a start point and a goal point. There are a lot of studies about shortest path algorithms [1] [2]. It is important to find the shortest path and to solve as quickly as possible in a maze image using image processing techniques [3]. In the previous study [4], we showed that an A* search algorithm outperformed Dijkstra's to solve maze in terms of a search time. The A* search algorithm is based on the Dijkstra's method. The difference is to use a cost function of searching paths in the A* search algorithm. In order to solve maze more quickly, we also presented a method of applying a thinning image processing technique. The thinning technique reduced a search area in a maze image. As a result, the effectiveness of the thinning technique was shown. However, we excluded a thinning process time from overall search time. The thinning technique is one of time-consuming methods. To evaluate a search time fairly, the overall search time including a pre-process time should be measured. Therefore, we do evaluate the overall search time to find a shortest path in maze. In this paper, to solve maze more quickly, we propose a fast and shorter path finding method based on the image processing techniques and graph theory. The experimental results show that the proposed method is superior to an A* search algorithm. In particular, the proposed method is promising when the maze image size is large.

II. Proposed Method

In this paper, a maze has the following conditions.

- It is a general maze to avoid an obstacle.
- It is a binary image.
- A white pixel is a path.
- On the other hand, a black pixel is a wall or an obstacle.
- A start point always connects a goal point.

The proposed method is based on the image processing techniques and graph theory. Firstly, the proposed method roughly searches a shorter path in a maze image by the use of graph theory. It is expected to restrict search areas in maze. Secondly, the proposed method finds a shorter path in restricted search areas. This may lead to a quick search of the shorter path in maze. The proposed method is described below. Fig. 1 shows an outline of the proposed method. Fig. 2 shows a flow of the proposed method. First, we divide a maze image into n x n blocks. The value of n is given by a user. The value of n must be optimized to speed up solving a maze. Second, in each for a block, the areas are labeled by a labeling image processing technique. In Fig. 1 (b) with 4 x 4 blocks, the color areas show the labeled areas. The black areas are ignored. On the other hand, the white areas are taken into account of finding a shortest path. Here, we consider a labeled white area as a node in graph theory. Third, we investigate the connectivity all in the nodes, and make an undirected graph. Fourth, in the undirected graph, we search a shortest path between nodes including start and goal pixels. As a result, the undirected graph changes into the directed graph. The directed graph consists of a start node, a goal node, and their connected nodes. These nodes have the direction of the path. The unnecessary

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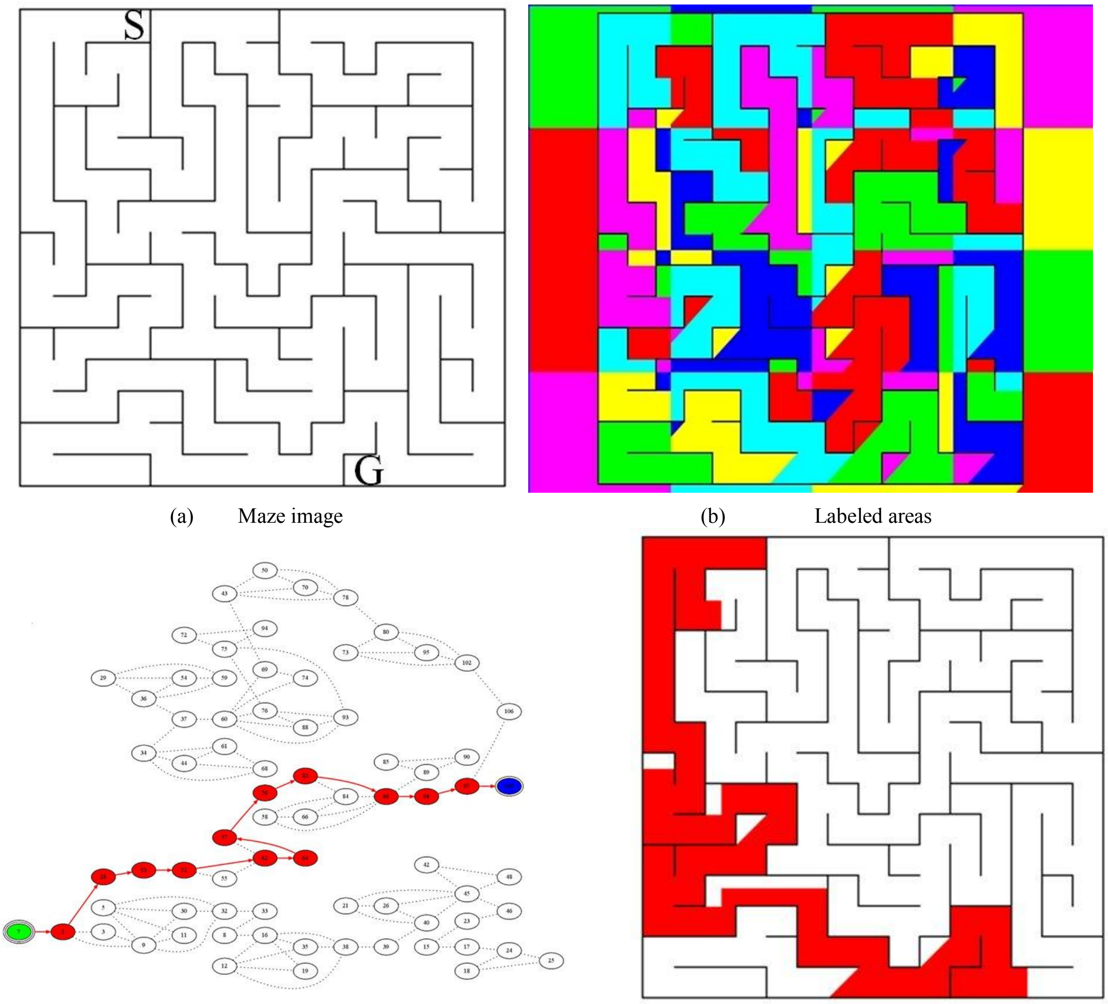
nodes are cut down. This means a search area gets smaller. Therefore, the proposed method is expected to speed up solving a maze. Fig. 1 (c) illustrates a search route on an undirected graph. Fifth, we reconsider the connected nodes as the search areas in maze. Hence, we have a restricted search area including start and goal points. Fig. 1 (d) shows the restricted search area. Finally, we run an A* search algorithm to the restricted search area, and find a shorter path in maze. The proposed method may be useful for a larger maze image size.



(a) Maze image (b) Labeled areas

(c) Undirected graph (d) Restricted search aMaze image

Figure 1. Outline of the proposed method

III. Experimental Results

In the experiments, we used a various type of 10 maze images (Maze01-Maze10) [4] and 5 maze images (MazeA - MazeE) with various image sizes. Fig. 3 shows MazeA and MazeE. We used QVGA, VGA, XGA, HD, UXGA, and FHD. Their image sizes are 320 x 240, 640 x 480, 1024 x 768, 1366 x 768, 1600 x 1200, and 1920 x 1080, respectively. We examined a search time of these maze images. As mentioned above, in order to evaluate a search time fairly, the overall search time including a pre-process time should be measured. The search time was measured on our personal computer (CPU: Intel Core i5, Memory size: 2GB). In each for a maze image, we repeated to measure a search time 10 times independently and calculated an average search time.

Firstly, the purpose of the experiment 1 is to compare the performance of the proposed method, the A* search algorithm, and the A* with thinning method. In the proposed method, we used n=4. Table I shows the comparison of the performance in terms of an average search time. From the result, the average search time of the proposed method outperforms those of the A* search algorithm and the A* search algorithm with a thinning technique. Especially, in the results of the Maze04, Maze08 and Maze09, the proposed method works well. The image size of these maze images is relatively high. On the other hand, the proposed method yields a poor result in the Maze05, compared to the result of the A* search algorithm. The original image of Maze05 is gray. Therefore, we must convert gray to binary. In Maze05, when applying thresholding the maze image, many noises seem to appear in the binary image. These noises may be exhausted terribly in a labeling process time. Furthermore, from the result, the effectiveness of the thinning technique is very low. The thinning technique seems a heavily time-consuming method. Fig. 4 shows the shortest paths in Maze04 and Maze05 images, respectively.

TABLE I. COMPARISON OF THE PERFORMANCE IN TERMS OF AN AVERAGE SEARCH TIME (MSEC.).

Images (Image sizes)	Proposed	A*	A* with thinning
Maze01 (570x820)	34.4	34.1	11334.6
Maze02 (420x300)	10.3	11.0	697.2
Maze03 (550x670)	32.4	44.6	1731.1
Maze04 (1540x670)	210.0	1257.8	8365.6
Maze05 (500x370)	21.9	11.1	4293.4
Maze06 (590x820)	42.4	44.3	7230.9
Maze07 (590x800)	33.8	43.7	3706.2
Maze08 (560x760)	35.6	75.9	4550.4
Maze09 (670x940)	60.4	136.7	5910.4
Maze10 (400x400)	48.7	45.1	4053.1
Average	53.0	172.2	5187.3

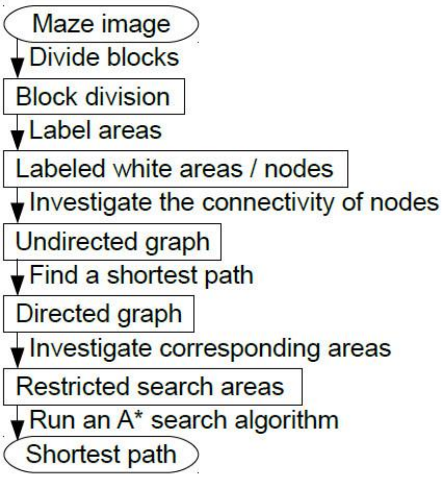
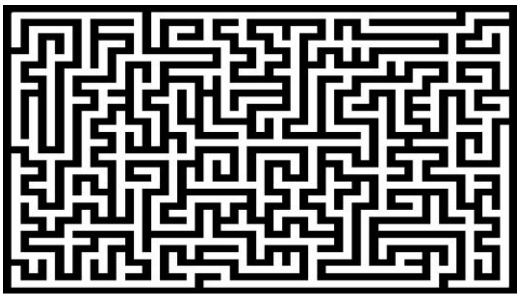
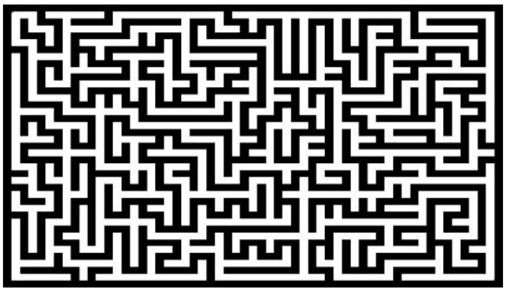


Figure 2. Flow of the proposed method.



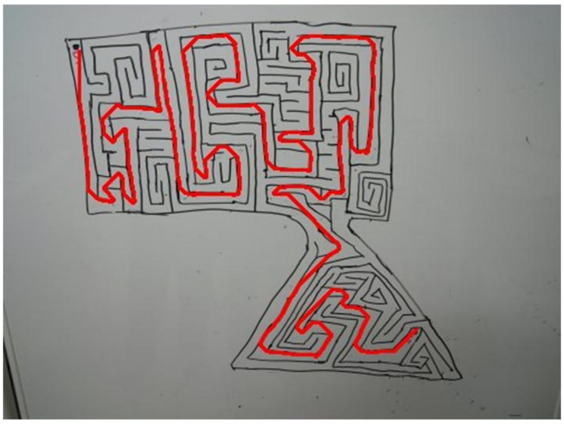
(a) MazeA



(b) MazeE

Figure 3. Maze images we used.

(a) Maze04



(b) Maze05

Figure 4. A shortest path in maze images.

Secondly, from a previous result, the proposed method gives a favorable performance particularly when the image size is large. In the experiment 2, we investigate the influence of the image size, compared to the A* search method. Here, the block division size is fixed. We used it 12 x 12. Table II shows the influence of the image size in terms of an average search time. The larger the image size is, the more the performance of the proposed method rises, compared to the A* search method. From the result of QVGA, the difference of the average search time between the proposed method and the A* method is 2.0 msec. On the other hand, in the FHD, its difference is 843.4 msec. We recommend to using the proposed method, particularly when the size of a maze image is large.

TABLE II. INFLUENCE OF THE IMAGE SIZE IN TERMS OF AN AVERAGE SEARCH TIME (MSEC.).

Images	QVGA		VGA		XGA		HD		UXGA		FHD	
	Proposed	A*	Proposed	A*	Proposed	A*	Proposed	A*	Proposed	A*	Proposed	A*
MazeA	8.0	10.5	34.9	71.0	93.7	260.6	129.5	393.9	265.0	871.4	292.1	1061.2
MazeB	7.0	10.3	28.5	70.4	77.6	271.2	108.6	466.2	214.3	969.5	241.6	1235.7
MazeC	8.5	10.6	35.7	100.7	103.7	394.0	148.8	578.1	295.8	1327.8	349.2	1511.5
MazeD	7.1	5.6	27.0	33.4	72.3	147.8	101.9	181.9	200.5	474.6	244.2	488.1
MazeE	7.0	10.6	35.5	89.3	91.9	353.8	124.9	501.0	248.5	1251.5	311.3	1359.0
Average	7.5	9.5	32.3	73.0	87.8	285.5	122.7	424.2	244.8	979.0	287.7	1131.1

TABLE III. INFLUENCE OF THE BLOCK DIVISION SIZE IN TERMS OF AN AVERAGE SEARCH TIME (MSEC.).

Image size	Images	Block division size						
		1x1	2x2	4x4	8x8	16x16	32x32	64x64
QVGA	MazeA	10.2	9.1	8.7	8.1	8.5	11.0	22.1
	MazeB	8.6	8.2	7.3	7.1	7.8	8.6	14.5
	MazeC	10.9	9.7	8.8	8.7	8.7	11.5	42.1
	MazeD	8.7	7.5	7.9	7.9	7.6	8.0	11.9
	MazeE	9.2	9.5	7.6	7.2	7.1	9.2	15.6
	Average	9.5	8.8	8.1	7.8	7.9	9.7	21.2
VGA	MazeA	54.3	51.8	42.7	37.4	30.6	33.9	56.9
	MazeB	49.6	45.7	36.3	32.7	30.0	30.7	37.9
	MazeC	59.7	57.4	45.5	42.5	36.3	37.1	77.5
	MazeD	45.4	38.3	32.8	31.4	27.5	29.9	42.2
	MazeE	47.6	46.2	36.6	31.7	29.1	31.5	39.4
	Average	51.3	47.9	38.8	35.1	30.7	32.6	50.8
XGA	MazeA	163.6	144.1	118.7	103.4	80.6	77.4	96.8
	MazeB	152.4	145.0	107.4	88.0	76.5	72.3	77.5
	MazeC	185.0	170.7	137.6	123.7	103.5	91.3	120.8
	MazeD	134.3	106.6	92.4	80.5	70.4	70.4	83.2
	MazeE	142.8	152.6	111.8	87.9	71.6	72.5	82.5
	Average	155.6	143.8	113.6	96.7	80.5	76.8	92.2
UXGA	MazeA	523.3	415.1	358.8	299.6	224.3	207.1	209.5
	MazeB	461.0	405.7	321.3	256.4	213.9	184.7	174.6
	MazeC	572.0	517.8	422.4	372.5	315.0	237.7	245.7
	MazeD	401.6	302.4	268.2	228.0	204.4	189.9	179.2
	MazeE	432.8	471.3	321.5	243.4	194.2	195.0	196.4
	Average	478.1	422.5	338.4	280.0	230.4	202.9	201.1

Finally, we examine the relationship between the block division size and the image size. The purpose of the experiment 3 is to investigate the influence of the block division size for an image size. In the experiment, the block division size n x n was ranged among $\{n=2^m \mid m=0,1, \dots ,6\}$. The image sizes were QVGA, VGA, XGA, and UXGA. Table III is the influence of the block division size in terms of an average search time. Due to an image size, there may exist an optimal block division size in terms of an average search time. From the result, the optimal block sizes of QVGA, VGA, XGA, and UXGA are 8 x 8, 16 x 16, 32 x 32, and 64 x 64, respectively. Each of these block sizes gives a minimum average search time. In terms of the average search time, there seems a peaking-phenomenon of the block division size. It is important to determine an appropriate block division size, due to an image size.

IV. CONCLUSIONS

In this paper, to solve maze more quickly, we have proposed a fast and shorter path finding method based on the image processing techniques and graph theory. The experimental results show that the proposed method beats the A* search algorithm in terms of an average search time. In particular, the proposed method is promising when the maze image size is large. The points of interest of the proposed method are to use both of the image processing technique and graph theory. By using not only the image processing technique but also graph theory, the proposed method achieves a high performance. In the future, the optimization of the block division size for a maze image should be considered.

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