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Climbing pathfinding with the holds and a decision method of the difficulty level of the holds

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ABSTRACT

There are a variety of sizes and thicknesses of holds used in climbing, and the ease of holding them varies greatly. However, the difficulty of holding has not been considered in previous studies on route exploration. In this study, we improved the search algorithm A* used in previous studies and incorporated the difficulty of the hold into the fitness. We also used the improved A* as the evaluation function to estimate the difficulty of holds using a genetic algorithm. There was also no discussion on how many divisions of the hold should be divided by difficulty, so we assumed four divisions: 2, 4, 8, and 16 divisions. After adjusting the parameters during interviews with expert climbers, we compared the algorithm of the four divisions with that of previous studies using a questionnaire online. The results showed that the route of the algorithm, which considers the difficulty of the hold, was rated higher by expert climbers and that the 8-division algorithm was the best among the proposed methods.

Keywords: Pathfinding, Sport Climbing, A* Algorithm, Genetic Algorithm

1. INTRODUCTION

Climbing is a competition in which athletes select the best route from a given holds and climb it, taking into account his physique and performance [1]. The process of thinking about one's movements before climbing is called "observation". "Observations" are very important for improving climbing performance because most of the time the number of attempts to climb the course is also considered as the competition score [2]. The rules of the International Federation of Sport Climbing (IFSC), which runs world competitions such as the World Cup, state that both lead and non-rope-based bouldering competitions are required to take time for observations. Information technology has also been used to study pathfinding during route selection. Kourosh et al. graphically showed a CG animated climber climbing a given course [3]. On the other hand, this study did not consider the shape of the holds (means a manufactured climbing hold and attached to the Climbing Surface by means of screws or bolts). Holds are a very important element in climbing, and in a study to recreate a rock course on an indoor climbing wall [4], Whiting et al. proposed a method to recreate not only the position but also the shape and friction of the rock as a hold, which was highly reproducible. In our study, we proposed a route-finding method that more closely matches real-world climbing by adding hold difficulty to the A* algorithm used in the previous study [3]. Since there has been no research on hold difficulty, we divided hold difficulty into four partitions (2, 4, 8, and 16) and examined which partitions were appropriate. We used a genetic algorithm (GA) to estimate the difficulty of holding at each partition. In addition, the formula for calculating the cost of A* was modified from the interviews to experts in route selection. Based on the results, a web-based questionnaire was used to compare the results with previous studies. The training and evaluation of our study used data obtained from a 2017 model of a uniform standard climbing wall (MoonBoard) used in a study of route difficulty classification [5] and found in gyms around the world. The MoonBoard has two different slopes, 115 and 130 degrees, and data of 130 degrees was used to study hold difficulty and 115 degrees to evaluate the proposed method.

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2. RELATED WORK

Several studies have been conducted in relation to route selection. Jonas et al. conducted a study to aid in the design of climbing courses by visualizing climbing motions on a computer by a CG agent [6]. When a course designer selects the holds, the CG agent helps the course designer design by showing which route to select. Other studies have shown that CG agents assist course designers by showing movement; Kourosh et al. used a projector to illuminate a CG agent on a climbing wall and the agent showed movement between the selected holds [7]. It has been suggested that these studies can aid in course design as well as competition "observation" and understanding of how to climb. On the other hand, course design assistance has also been provided without route selection for climbers; Carlos et al. used an adversarial network to assist in course creation [8].

While these studies were developed to support route selection and course design and are supported by climbers through experimentation and interviews, they do not take the difficulty of holdings into account. The importance of holds in climbing has been mentioned in many studies and much research has been done on the effects of hold shape and friction on climbing [9][10]. Therefore, we propose a route selection method that takes the difficulty of the holds into account. We also propose a method for estimating the difficulty of a hold from the course.

3. PROPOSED METHOD

3.1 A* with Holds

The formula for calculating the evaluation value of the A* algorithm for route search proposed in our previous study [3] is shown below.

$$c_n(\sigma_j) = h_{free}(\sigma_j) + h_{match}(\sigma_j) + h_{crossing}(\sigma_j) + h_{too-close}(\sigma_j) \tag{1}$$

σ_j refers to the following conditions, specifically the holds used by both hands and feet: $h_{free}(\sigma_j)$ when no holds are used by the hands and feet, $h_{match}(\sigma_j)$ when a single hold is used on both hands or feet, $h_{crossing}(\sigma_j)$ when the hands and feet are crossed and the hands are higher than the feet, $h_{too-close}(\sigma_j)$ when the hands and feet are in close proximity, giving a cost for each.

We added the hold difficulty factor $h_{hold}(\sigma_j)$ to $c_n(\sigma_j)$.

$$c_n(\sigma_j) = h_{free}(\sigma_j) + h_{match}(\sigma_j) + h_{crossing}(\sigma_j) + h_{too-close}(\sigma_j) + h_{hold}(\sigma_j) \tag{2}$$

$$h_{hold}(\sigma_j) = \{d_{hold-difficulty}(p_{right-hand}) + d_{hold-difficulty}(p_{left-hand})\} \times 10 \tag{3}$$

$d_{hold-difficulty}$ denotes the difficulty of the hold, and $p_{right-hand}$ and $p_{left-hand}$ denote the hold in the right and left hand positions, respectively.

3.2 A Decision of the Difficulty Level of the Holds

GA was used to estimate the difficulty of the holds used in the search algorithm. Data from seven difficulty categories of routes ranging from 6A+ to 7A+ at the 130-degree French grade of MooBoard 2017 were used for the estimation. The number of attachable holds on the MoonBoard is 198 at 11*18; the gene length of the GA individuals is the same length as 198 of the number of holds, and the genes have an integer value less than or equal to the number of divisions of difficulty. The search for the best combination was performed by a function in which the adaptability was evaluated with the smallest sum of the each standard deviations of the seven difficulty categories Elite selection was used for selection and two-point crossing was used for crossing. A table of hyperparameters and a model of GA training are shown below.

Table 1. GA Hyperparameters List

Hyperparameter name	Value
Population size	40
Generation size	1000
Mutation rate	0.1
Selection rate	0.2

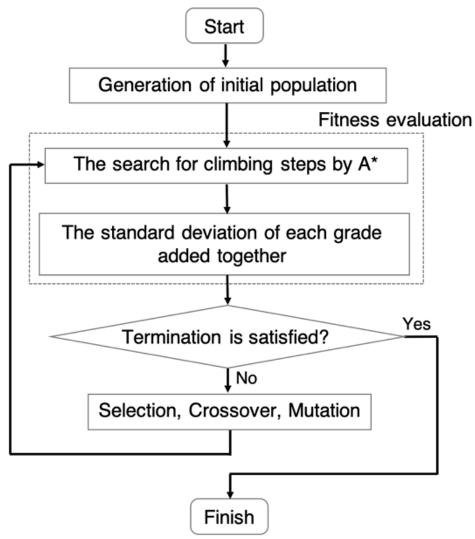

Figure 1. GA flow chart to estimate the difficulty of the hold

4. INTERVIEW AND ALGORITHM MODIFICATION

4.1 Interview

In a previous study [3], the proposed method was evaluated by interviews with expert climber. One expert climber (highest grade: 2-dan in Japanese grade) was interviewed to compare five different algorithms.

- A* without considering the holds (None)
- A* with holds classified in 2 levels of difficulty (2 splits)
- A* with holds classified in 4 levels of difficulty (4 splits)
- A* with holds classified in 8 levels of difficulty (8 splits)
- A* with holds classified in 16 levels of difficulty (16 splits)

The interviews were conducted in the following steps.

1. Randomly pick out one course for each of the seven categories from 6A+ to 7A+
2. For the 7 routes 1) to calculate the procedure with the following 5 different algorithms
3. The expert climber rank those routes
4. The expert climber choose the most preferred procedure algorithm
5. The expert climber talk freely about the differences between expert climbs and presented climbs

The most preferred A* chosen by the expert climber was the A* where the holds were divided into 4 levels of difficulty. On the other hand, it was noted that the feet positions were too often in high places than the hands positions in all algorithms.

4.2 Algorithm modification

Based on the results of the interviews, we modified the costs to be added if the feet position was above the hands position. Previous research added $c_{crossing} = 100$ for $h_{crossing}(\sigma_j)$ when the feet are elevated higher than the hands and when the hands and feet are crossed. However, according to expert climbers, it should be more costly to have the feet position is above the hands position compared to the crossings of the hands and feet. Therefore, we added $c_{too-high-step} = 1000$ if the hands level was below the feet level.

4.3 Web Questionnaire

We conducted a web-based questionnaire with the aim of evaluating five different algorithms (None, 2 splits, 4 splits, 8 splits and 16 splits) using a modified A* as well as interviews with expert climbers.
Because we used Japanese grades tailored to the target climbers, the categories of difficulty we used were 6A+ (3-kyu), 6B+ (2-kyu), 6C+ (1-kyu), and 7A+ (1-dan). A total of four courses were used, with one course randomly selected from each difficulty category with five different algorithmic ascents. The web questionnaire was administered by Google Form.

1. For each difficulty category, show a video of the route for solving each algorithm.
2. After each video, present the questions to evaluate on a Likert 7-point scale (1: completely disagree, 7: completely agree)
   - This movement is close to expert climbers. (“Close to experts”)
   - I think this move is appropriate for this course. (“For this course”)
   - I think this move is reasonable for this level of difficulty. (“For this level”)
3. After all the difficulty categories, the video shows the route solved with each algorithm for one more 6A+ (3-kyu) course
4. After each video, present free description questions
   - Please let us know if there is a good part of this movement.
   - Please let us know if there is any part of this movement.
   - Please let us know if you have any suggestions for improving this movement.
5. Finally, as an overall questionnaire, the following questions are presented
   - If you were to divide all the holds of a MoonBoard by the difficulty of holding it, which options do you think would be most appropriate?
     - 2 splits / 4 splits / 8 splits / 16 splits
   - Please tell us what you felt throughout the questionnaire.

4.4 Questionnaire result

There were 18 participants in the survey and the mean age was 23.7 years (standard deviation: 3.2, 17 males and 1 female). All were expert climbers and the median grade was 2-dan in Japanese grade. They were given generic prepaid card calculated at 1,000 yen per hour.

Three conditions of the survey (“Close to experts”, “For this course”, and “For this level”) are shown in Figure 3. Kruskal-Wallis tests were performed for each question at each difficulty level, and if significant differences ($p < 0.05$) were found, multiple comparisons (corrected for p-values by the Benjamini & Hochberg method) were performed. For the “Close to experts” question, 6C+: “None” – “8 splits”, “None” – “16 splits” and “2 splits” – “16 splits”; 7A+: “None” – “4 splits”, “None” – “8 splits”, “None” – “16 splits” and “2 splits” – “16splits” we found a significant difference ($p < 0.05$). In “For this course,” we found significant differences ($p < 0.05$) for 6A+: “None”-“2 splits”, “None”-“4 splits” and “None”-“16splits”; 6B+: “None”-“8 splits”; 6C+: “None”-“4 splits”, “None”-“8splits”, “None”-“16splits” confirmed significant differences. “For this level”, significant differences were found for 6B+: “None” – “8 splits” and 6C+: “None “-“4 splits”. All items where significant differences were found were rated lower for “None” or “2 splits” (lower for “None” in the case of the “None”-“2 splits” comparison).

The most common answer to the question about the number of holds divided by difficulty to hold was “8 splits” (9 people), followed by “4 splits” (5 people), “16 split” (3 people), and “2 splits” (1 person).

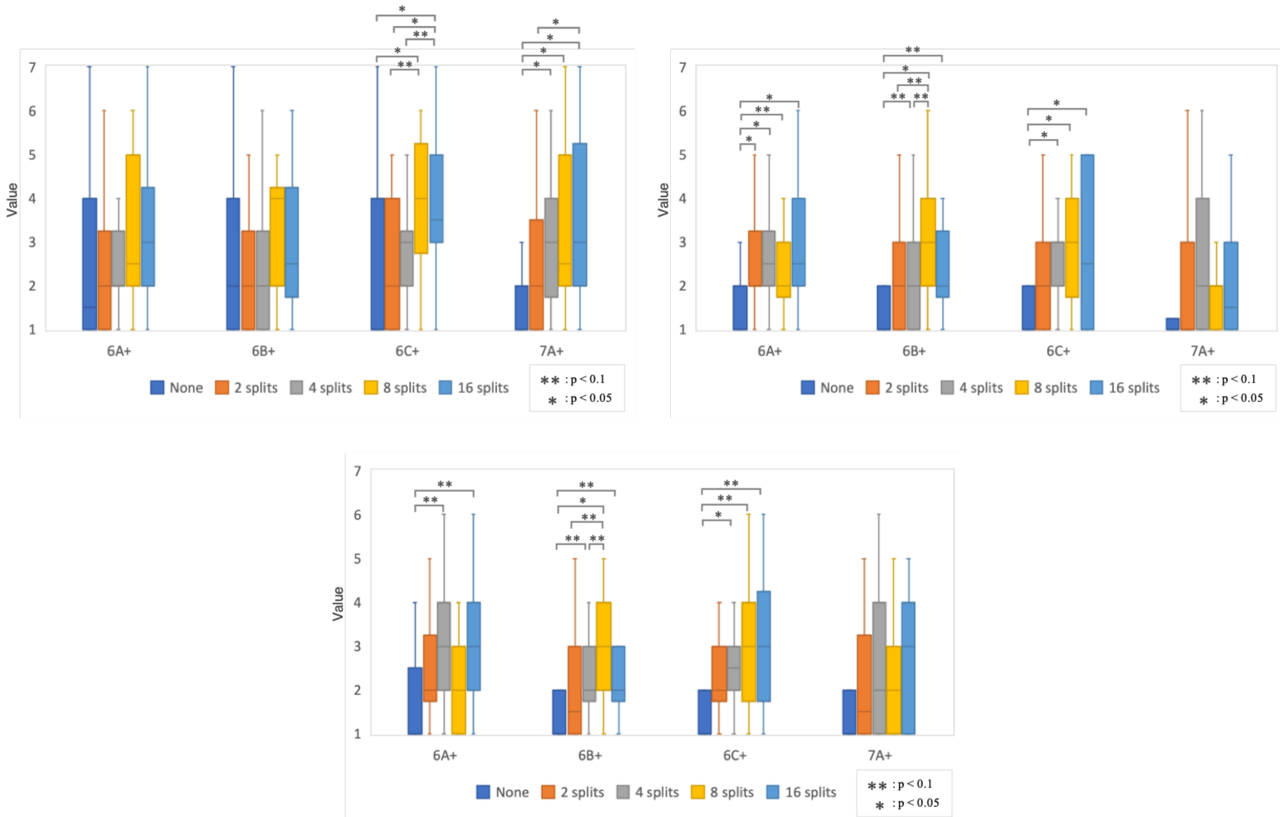

Figure 2. Top left: “Close to experts”, top right: “For this course”, below: “For this level”

5. DISCUSSION

5.1 Number of the hold division

Within all grades (6A+, 6B+, 6C+, 7A+) in one of the three question items, “4 splits”, “8 splits”, “16 splits” were rated higher than “None” with a significant difference ($p < 0.05$) and a significant trend ($p < 0.1$). When asked about the number of splits, “2 splits” was selected by only one participant and it was considered to be an inappropriate number of splits. It was also pointed out that “more of the specified holds should be used” (ID: 9) and “more holds should be used by hands” (ID: 3) in the “16 splits” interview. In the computation of our proposed method, the cost per move increases with the number of splits, so the “16 splits” route selection algorithm skipped holds to be used in order to reduce the number of moves. While this can be an advantage, the MoonBoard has a smaller impact because the starting and finishing holds heights are limited to some extent and do not differ significantly in length of the course. Other climbing walls are taller and wider and are expected to have a bigger impact. On the other hand, There was no comment that “8 splits” used few holds. Therefore, we found that our proposed method calculates the evaluated value well in the case of “8 split”, which is the optimal number of splits.

5.2 Difference in Results by Questionnaire

Some items were not identified as significant. Based on the interviews conducted with 6A+, the discussion will focus on the 6A+ of “Close to experts”. The difficulty grades used in this study were 6A+ to 7A+. At the easier grades (6A+), hard-to-hold holds are used less frequently, and it is expected that there is little difference between the routes chosen by our proposed method and the method that does not consider the difficulty of the holds. This is true not only between previous studies and our proposed method but also between the algorithms by number of splits. Many participants (ID: 4,6,9,14,17,18) cited the use of climbing techniques such as “diagonals” and “counterbalance” for routes chosen with the hold consideration algorithm as a good point. The climbing technique allows one to move from one position to the next in a stable position without strain [1]. This seems to have contribution to the good ratings for “Close to experts” and “For this course”. On the other hand, it was pointed out that “I think I'm closer to being an expert climber if I do movements of higher intensity” (ID: 5). In addition, some participants mentioned that in the lower grades, a simple way of climbing rather than technique is closer to expert climbers. “3-kyu (6A+) should be simpler” (ID: 11). It was suggested that a reasonable ascent for a grade or course did not necessarily equate to an ascent closer to an expert climber.

6. CONCLUSION

We proposed a route search that considered holds in climbing. We also used GA to estimate four types of hold difficulty, which have not been done before, in “2 splits”, “4 splits”, “8 splits”, and “16 splits” route-finding. In addition, a web-based questionnaire was used to compare the four estimated hold difficulty levels with five algorithms that did not take into account the hold difficulty of previous studies. We posed three questions to participants: the proximity of the route presented to the expert climber, the validity of the route to the course, and the validity of the difficulty to the course. In all grades (6A+, 6B+, 6C+, 7A+) of one of the three question items, “4 splits”, “8 splits”, “16 splits” were rated higher than “None” with a significant difference ($p < 0.05$) or a significant trend ($p < 0.1$). In addition, the results of the questionnaire and the open-ended comments indicated that “8 splits” was the best number of splits in the proposed method.

REFERENCES

[1] M. Kawasaki, “Practice Guide of Indoor Bouldering” Yama-kei Publishers co. Ltd., Japan, 2014.

[2] M. Boschker, F. Bakker, C. Michaels, “Memory for the functional characteristics of climbing walls: perceiving affordances” Journal of Motor Behavior 34.1, pp. 25-36, April 2002.

[3] N. Kourosh, J. Rajamäki, P. Hämäläinen, “Discovering and synthesizing humanoid climbing movements” ACM Transactions on Graphics, pp. 1-11, July 2017.

[4] E. Whiting, N. Ouf, L. Makatura, C. Mousas, Z. Shu, L. Kavan, “Environment-scale fabrication: Replicating outdoor climbing experiences” The ACM CHI Conference on Human Factors in Computing Systems, pp. 1794-1804, May 2017.

[5] D. Alejandro, J. Sarmiento, P. Satterthwaite, “Machine Learning Methods for Climbing Route Classification” Web link: http://cs229.stanford.edu/proj2017/final-reports/5232206.pdf.

[6] P. Jonas, J. Mitani, T. Igarashi, “Interactive climbing route design using a simulated virtual climber” SIGGRAPH Asia 2011 Sketches, pp. 1-2, December 2011.

[7] N. Kourosh, J. Takatalo, P. Hämäläinen, “Towards Computer-Aided Imagery in Sport and Exercise” Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play, pp. 479-485, October 2017.

[8] C. Navarro, “Improvements in Generative Adversarial Networks with hard constraints” Web link: https://cmougan.github.io/files/TFM.pdf

[9] F. Fuss, Y. Weizman, G. Niegl, A. Tan, “Climbers' Perception of Hold Surface Properties: Roughness Versus Slip Resistance” Front. Psychol., March 2020.

[10] F. Fuss, G. Niegl, “Instrumented climbing holds and performance analysis in sport climbing” Sports Technology 1.6, pp. 301-313, March 2009.