Feature Tracking using Particle Filter in Rope Skipping for Gross Motor Skill Development

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ABSTRACT
Learning a new skill for physical development can be a daunting task for many novice persons. To support such learners, an intelligent system is required to guide them in the learning process. In this paper, as first part of such a system, we propose a feature detection and tracking algorithm that can be used during rope skipping skill development using color processing and the particle filter. The data used is captured using a camera placed on the side of the learner. The learner wears markers on the head, hands and ankles; a marker is also attached on the rope to capture rope rotation. Initial point detection is achieved using HSV color space thresholding. The particle filter is then used to track these features especially because of misdetections due to noise and blurring due to rope speed. In this work, the rope skill attempted is the learning to do the "double under" jump. A "double under" jump is defined as completing two rope rotations per jump. Experimental results prove that this is an effective method for accurate feature detection and tracking.

General Terms
Pattern Recognition, Object tracking, Image processing, Gross Motor skills

Keywords
Motor skill, particle filter, learning support, Curve fitting

1. INTRODUCTION
Recently, the use of technology to support humans learn and develop motors skills has become paramount. The technology can be used to monitor and analyze the learner's process and offer advice as required to aid faster and easier acquisition of the skill. Moreover, learners can follow their progress using data from such systems including visual and audio information [1]. Motor skills can be acquired through specific training which means that it is not innate ability but potential change against specific conditions [2]. In this work, out target to develop a support system for rope skipping.

Rope skipping is a simple, fun and easy-to-learn activity that is great for fitness. All that is required is a rope and some little space to play. Rope skipping involves one or more participants who jump over a rope swung so that it passes under their feet and over their heads [3]. Rope skipping as a sport including definitions and howtos is explained in details in [7]. Three main variations exists, but in this work we are interested in the most basic one that involves a single participant rotating and jumping over the rope. Learning this kind of rope skipping is easy as it involves just one rope rotation per jump. In our work, we hope to design a support system for an advanced rope skipping variation referred to as "double under". Double under involves attaining two rope rotations per jump. This skill is on a different level to the single jump and is usually very difficult to master because of the rope speed variations, jumping height, rhythm and technique. We hope that our work will make it easy for learners to acquire this skill. As a first step, we will concentrate on feature detection from video to facilitate the development of the required support system.

In a related work, Yoshioka et. al. [3] used image processing to analyze a monitored video and give the appropriate feedback to the learners [4]. They use image processing technology on a desktop computer, which means that analysis can be performed using an efficient processor and the results to improve a player can be delivered in a relative larger display at asynchronous timing against the performance. However, the continuous detection and tracking of the markers was not accurate enough because of image capture conditions and occlusions.

Ideally, simple programing to capture a motor skill basic movements is possible if skill conditions and other environment conditions are known and fixed. This is referred to as a closed skill an example of which is rope skipping. We capture a video of a person performing rope skipping and use it to support the learning process. Rope skipping is a repetitive process, so as an initial we hope to accurately detect and track the heel, rope, hand and head positions using the particle filter. The use of the particle filter is necessary because simple detections using color information cannot be obtained steadily due to noise, capture position, rope speed, etc. The particle filter methodology is used to solve Hidden Markov Chain (HMM) and nonlinear filtering problems arising in signal processing and Bayesian statistical inference [5].

This work aims at accurately detecting the body parts heavily involved in the skill development including the hands, feet and head. The rope position will also be tracked at all times. Moreover, we will calculate the rope speed and positions during different parts of the jump. The motivation is based on the schema theory that states that as we learn a motor skill, we develop a rule that shows the relationship between movement outcomes and the intended goal, the conditions of the performance setting, and the details of the motor program created to control the movement [6]. Capturing the rope speed, angle, jump height, etc. can help as develop rules required for double under jump.

The rest of this paper is organized as follows. Section 2 discusses the marker detection from video using thresholds set in the HSI color space. Marker tracking using the particle filter is also discussed. Feature extraction is presented in section 3 with the experiments and results in section 4. Finally are the discussions and conclusion sections.

2. MARKER DETECTION

2.1 Set up

The data used in this work is captured outdoors. The background is a solid wall of uniform color and patterns for easy and fast background extraction. The camera is placed about 3 meters on the side of the rope skipping subject. The subject wears the following color markers, fig. 1. These markers are necessary to track rope and body parts movement during the exercise.

- Rope: Red
- Feet: Green
- Hands: Yellow
- Head: Blue

Fig 1: Marker positions

2.2 Marker Detection

After video capture the first process applied is background subtraction to extract the person location. The clips are captured on a relatively simple background to make this process simple.

Each marker is then detected using the HSI color space by assigning the appropriate thresholds based on the sample colors extracted from the captured images. The thresholds assigned are as follows, (minimum and maximum).

- Rope: Red (130,80,90) ~ (50,150,250)
- Feet: Green (60,80,90) ~ (80,200,200)
- Hands: Yellow (20,50,150) ~ (50,150,250)
- Head: Blue (100,170,100) ~ (180,250,250)

These thresholds were determined using experimentation. A more intuitive method for marker detection is planned for in the future.

These simple threshold can detect the marker positions fast and at fairly good accuracies (85%). However, not all markers can be detected in all frames because of image noise and occlusion. Figure 2 shows the spikes (black oval regions) created on the jump curve due to the mis-detections for the rope. The ground position is at 100 on the Y-axis.

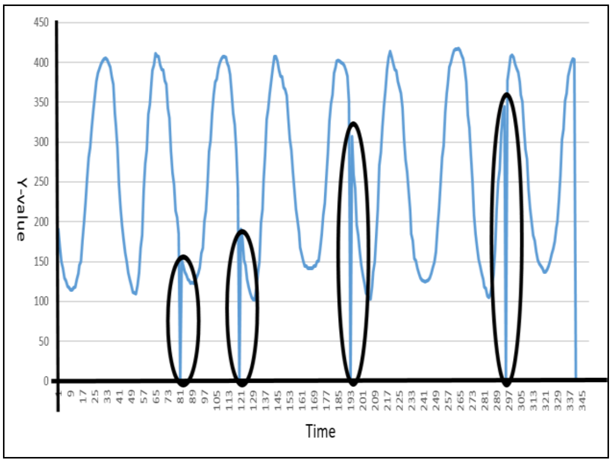


Fig 2: Marker positions

To solve these problems we introduce the particle filter to estimate the position of the markers at all times and conditions. The positions of the markers are captured in every frame of the video. This data is used to extract the required features.

2.3 Marker Tracking: Particle Filter

The filtering problem consists of estimating the internal states in dynamical systems when partial observations are made, and random perturbations are present in the sensors as well as in the dynamical system. The objective is to compute the conditional probability (posterior distributions) of the states of some Markov process, given some noisy and partial observations [3]. In Markov models, given the current state, the past and future states are conditionally independent. Therefore, only the current state is required.

In non-linear and non-gaussian problems the particle filter cam be applied. That is based on a hypothesis, it can approximates the posterior distribution by a group of weighted particles. Weights are assigned to the particles based on a likelihood score and re-sampled according to a given model.

In this work we must track multiple feature points including the head, hand, feet and rope. The images are first processed using the HSI color space to extract the locations of the objects to be tracked. Every object is tracked individually. The number of particles per object is set to 50 based on experiments. Each particle will represent a state the object may be in at a given time. Different colors are used to differentiate between the markers being tracked, fig 3.

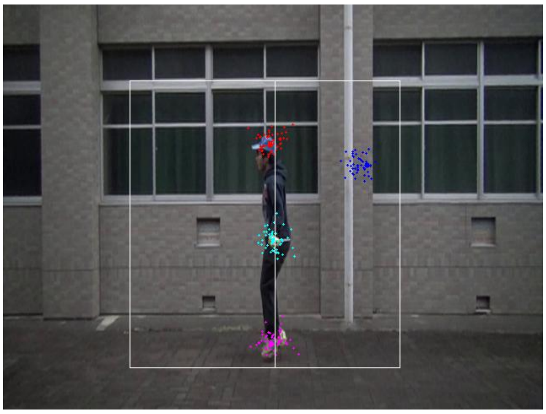


Fig 3: Particle Filter initial locations

3. FEATURE EXTRACTION

To support learners in rope jumping, several features that can be used to define the process that are necessary. These include:

- Rope rotation speed
- Jump height
- Head and feet positions
- Hand movements
- Body form during jump
- Rhythm

3.1.1 Process Start point

The feature capture starting position of this experiment is when the rope is just above the head. At this position, the head and feet are approximately on a straight vertical line running from the head to the feet. The hands are in slightly bent position in front of other points (A bit forward). Moreover, all the markers (except the rope which is at its maximum point) are at their lowest point, Fig 4, 5.

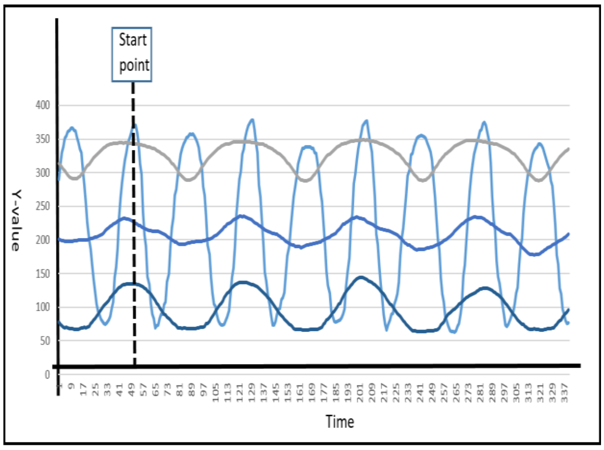


Fig 4: Starting Point: The curves from top shows the head, hand, feet and rope positions.

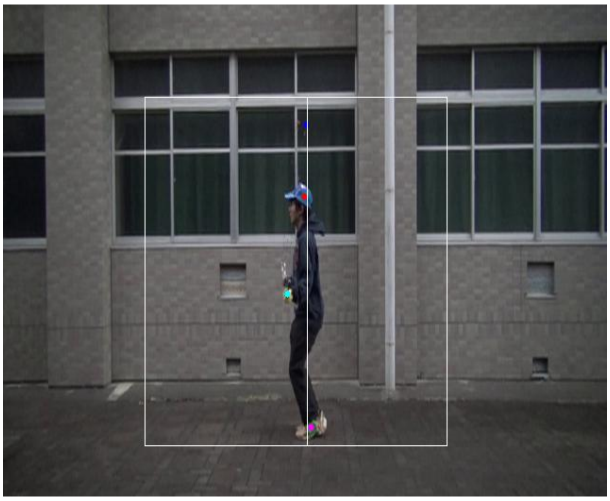


Fig 5: Starting Point

3.1.2 Double under

A successful double under jump will be defined as the rope passing the starting point twice before the feet again touches the floor, Fig 6.

In most cases (people), the rope, head and to some extent, the feet positions can be well represented using only the vertical positions of the markers.

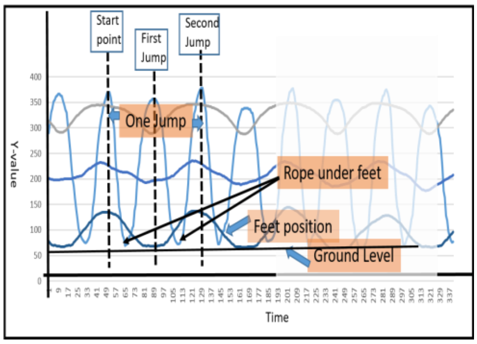


Fig 6: Successful "double under"

However, during "double under", the horizontal movement of the hands is vital. The hands move in a stretched "8" movement for some subjects as shown in fig. 7, 8 (a). However, for some subjects the hand movements are as shown in fig. 8(b).

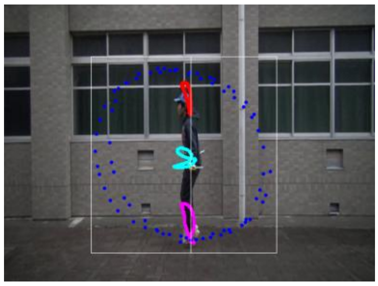
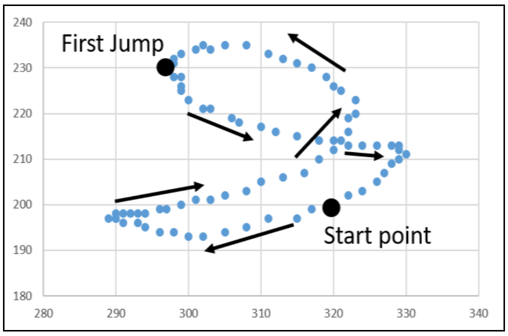
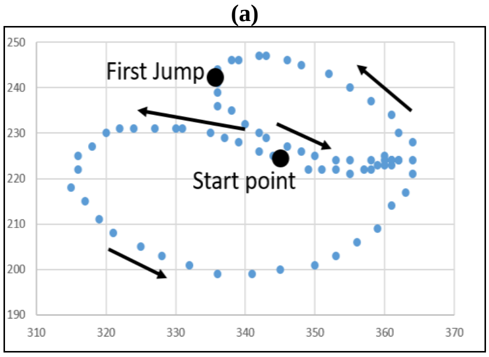


Fig 7: Successful "double under": marker movements



(a)



(b)

Fig 8: Hand movements during a Successful "double under" for 2 subjects

3.1.3 Rope Speed

To successfully complete double under, the rope speed varies widely during the two full rotations. Generally, the speed is slowest above the head and under the feet on every rotation. The speed increases when the rope is behind the subject and maximizes when the rope is just in front of the subject during the start of the second rotation.

4. EXPERIMENTS AND RESULTS

To prove the effectiveness of the proposed method, experiments were conducted. The main aim of the experiments is to accurately detect the rope, head, hands and feet markers using color information and particle filter, and extract features that can be used to create a support system for double under learners. All the volunteer subjects in the work can execute the double under jump.

4.1 Experimental data

The data used in this experiment was captured outdoors next to a building. The capture background is relatively uniform and easy to extract.

There are eight subjects and a total of 10 video clips each about 11 seconds long (About 380 frames at 30fps). All the subjects can perform the double under jump and are asked to do it a minimum of 3 times per session. Some of the clips have low contrast making it harder to detect the markers accurately.

This work was carried out using a computer with an Intel Core(TM) i7-4790 4GHz CPU.

4.2 Results

The particle filter performed as expected by tracking the marker position especially when the color information failed to extract it position. In this work, 50 particles per marker were sufficient because the initial marker positions could be estimated fairly well.

Different colored marker we used to simultaneously track all the markers. Figure 9 shows the plot of the rope height and time taken to complete the jump for all the subjects. The green line shows the slowest and the orange one the fastest subject.

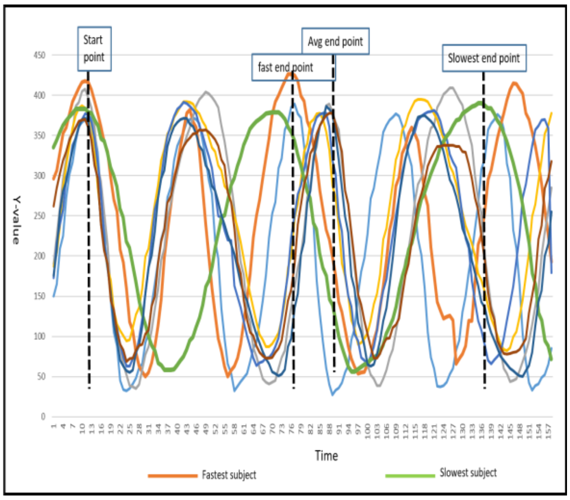


Fig 9: Rope height during the double under jump

Table 1 below shows the results of the rope features extracted by our proposed method. The features include the average time taken for first and second jump and the max rope speed for each subject. The calculations are based on a frame rate of 30.

The head, hand and feet vertical movement is consistent covering the period required to complete two rope rotations regardless of the rope speed. Some variations were observed in horizontal hand movements which depend on the rope rotating style of the subject.

Table 1: Rope Feature Results

	Average Rope Rotation (sec)			Rope Speed
	First jump	Second jump	Double under	Max
Subject1	1.35	1.22	2.57	56
Subject2	1.45	1.06	2.51	55
Subject3	2.15	1.98	4.13	44
Subject4	1.49	1.02	2.51	58
Subject5	1.38	1.06	2.44	60
Subject6	1.32	1.25	2.57	59
Subject7	1.12	1.09	2.21	63
Subject8	1.12	1.12	2.24	64

Another observation was in the rope position when maximum or above average speed was observed. In all cases, the maximum speed was attained during the second rotation, with the rope position directly above the subject as shown in fig. 10. At this point, the feet position are is also at the highest point. The rope passes just under the feet to complete the second jump and therefore the double under.

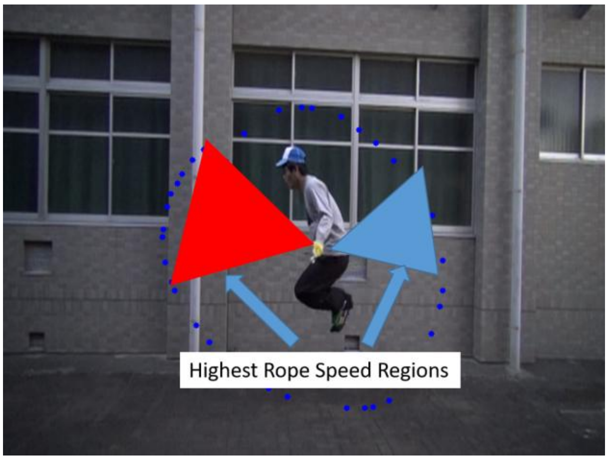


Fig 10: Highest rope speed regions: In general the speed is higher in front of the subject (red triangle)

4.3 Discussions

From the data and results, we can conclude that the double under jump can be accomplished by combination of high rope speed and medium jump or medium rope speed and high jumps. Jumping height and rope rotation speed also seem to depend on learner. Therefore, because of the this individuality, either each learner might require a more specialized support system or the system should be modelled to account for these differences.

The average double under jump takes about 2.5 seconds for most subjects. However, subject 3 still accomplished the double under jump in spite of lower than maximum rope speed of 44 (above 50 for other subjects) and a duration of about 1.5 second slower. Subjects 7 and 8 achieved faster times than all other subjects.

5. CONCUSION AND FUTURE WORKS

In this work, as a first step in the creation of an intelligent rope skipping support system, we proposed a feature detection and tracking algorithm using particle filter that can accurately extract the markers required by the system. Initial point detection is achieved using HSV color space thresholding.

The particle filter is then used to track these features especially because of misdetections due to noise and blurring due to rope speed. In this work, the rope skill attempted is the learning to do the "double under". Experimental results prove that this is an effective method for accurate feature detection and tracking.

Consistent results were observed in all subjects. The average jump duration was about 2.6 seconds. The fastest was 2.21 seconds and the slowest at 4.13 seconds. However, the jumping rhythm (features timings) was similar for all the subjects.

In future the features detected and tracked in this work will be incorporated in the support system to learn rules required to effectively aid rope skipping learners. Moreover, to improve the system the individuality of each learner needs to be established for easier support.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Clark J.M. and Paivio A. Dual coding theory and education. *Educational Psychology Review*, 3(3):149-210, 1991

[2] Richard A. Schmidt. *Motor Learning & Performance: From Principles to practice*. Human Kinetics Books, 1991.

[3] Yoshioka S. Yamada K. and Matsuura K. Supporting system for the form improvement on rope skipping skill by image processing. In *2014 IIAI International Conference on Advanced Applied Informatics*, pp.328-331, 2014.

[4] Yoshioka S. Matsuura K. and Gotoda N. Hand-motion analysis for development of double-unders skill. In *9th International Conference in Knowledge Based and Intelligent Information and Engineering Systems*, pages 775-783, 2015.

[5] Particle_filter, https://en.wikipedia.org/wiki/Particle_filter (last modified on 21 October 2016)

[6] Schmidt, R. A. A schema theory of discrete motor skill learning. *Psychological Review, 82*, 225–260, 1975.

[7] Carolyn Barker and Kym Warner: Australian Rope Skipping Association: Level 1 Coaching Manual, http://www.sports-media.be/links/Coaching-Manual-Rope-Skipping.pdf.