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# Ellipse Feature Detection in Rope Skipping for Gross Motor Skill Development

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***Abstract*— To support novice learners to acquire a new skill, it is important to understand the underlying principles of the skill. This means that the support system must analyze the skill and develop methods therein to offer credible support to enable efficient learning. This work employs the data from 8 skilled rope skipping subjects to analyze the rope skipping task to find features that can be used for support. The processes involved include finding the best rope and hand trajectory fitting using ellipses. This will enable better speed variation detection and timing that can be used to support new learners. In this work, the rope skill attempted is 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.**

***Index Terms*—Motor Skills, Curve Fitting, Action Timing Detection.**

## I. INTRODUCTION

As opposed to traditional gross skill learning methods that depended on effort, trial and error, etc., owing to technological advancements, better and easier methods are appearing to more effectively and efficiently support new learners. As already stated in our earlier works, Karungaru et. al. [1], 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 [2]. Motor skills can be acquired through specific training, which means that it is not an innate ability but potential change against specific conditions [3].

In this work, our target is 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 [4]. Rope skipping as a sport including definitions and how-to is explained in details in [5]. Three main variations exist, 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 will extract better features using ellipse shape fitting to support 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. To acquire rhythm necessary to succeed in the double unders jump, rope rotation timing is vital. To enable rope timing, understanding rope trajectory and location are necessary. We therefore hope that understanding the mechanics of rope rotation trajectory will assist this goal.

The rest of this paper is organized as follows. Section 2 discusses the results of our earlier work on marker detection from video using thresholds set in the HSI color space, marker tracking using the particle filter. Section 3 outlines the gross motor skill processes sec. 4 the ellipse fitting process with the experiments and results in section 5. Finally are the discussions and conclusion sections.

## II. MARKER DETECTION AND TRACKING

In our earlier works, we already showed how the markers on the subjects head, hand, shoes and the rope can be successfully detected and tracked [1]. In summary, the markers are initially detected using color thresholds in HSI color space thresholds and later tracked using the particle filter. In the work, we also attempted to detect the speed and starting points of the rope. However, due to individuality of the subjects, stable determinations could not be achieved.

### *A. Gross Motor Skill*

Motor skills learning is complex and depends on an individual. However, the learning process that individuals go through is similar. Fitts & Posner [6] has proposed three stages of learning: the cognitive, associative, and autonomous stages. The cognitive stage is characterized by the learner's trying to figure out what exactly needs to be done. During this phase, learners often experiment with different strategies to find out which ones work or don't work in bringing them closer to the movement goal.

Also, learners tend to pay attention to the step-by-step execution of the skill, which requires considerable attentional capacity. In the second stage, learners organize more effective movement pattern because they obtain embodiment to some extent in motor stage. Until the last stage at which they can acquire unconscious movements, they need to pay attention to learning the movement way. In particular, in motor stage, learners monitor feedback in order to improve their own performance gradually.

### *B. Fitting an Ellipse*

Curve fitting is the process of constructing a curve, or mathematical function that has the best fit to a series of data points, possibly subject to constraints. Curve fitting can involve either interpolation, where an exact fit to the data is required, or smoothing, in which a "smooth" function is constructed that approximately fits the data, [7].

Curve fitting can be extended to fit circles or ellipses. Suppose that the data points $\{(x_i, y_i)\}$ lie near a circle/ellipse of unknown center and radius. If the center is known, the process is simple. However, if the center is unknown, one could assume it to be near the center of gravity of the given points for evenly distributed points. Otherwise, a function that measures the error between an arbitrary circle and data points is necessary. A circle centered at $(a, b)$ with a radius of $r$ can be represented as following general equation

$$(x - a)^2 + (y - b)^2 = r^2 \quad (1)$$

One reasonable measure of the distance between the points and a circle is the "area difference", that is,

$$\mathrm{E}(\mathrm{a,b,r}) = \sum_i ((x_i - a)^2 + (y_i - b)^2 - r^2)^2 \quad (2)$$

Solving this equation, will fit the circle. However, fitting an ellipse could be more challenging. The problem boils down to the fact that the task of ellipse fitting falls into the category of errors-in-variables regression and is inherently non-linear. According to Zygmunt [8], there are two possible ways of fitting an ellipse to data. The first is called orthogonal distance regression, where one minimizes a geometrically meaningful error: the orthogonal distance between data points and the ellipse. This is the cost function that arises naturally when one assumes independent Gaussian noise in the data points and applies the principle of maximum likelihood estimation.

However, the implementation of this method is quite involved. In its classic formulation it requires, for each iteration, computing the roots of a quartic polynomial as an intermediate step. This step can pose many numerical problems. An alternative approach is to minimize an algebraic cost function. Here one does not minimize a geometrically meaningful cost function. Instead, the cost function is based on how much a data point fails to satisfy an ellipse equation, [8]. For simplicity, this work employs the latter method.

## III. EXPERIMENTS AND RESULTS

To prove the effectiveness of the proposed method, experiments were conducted. Detection of the rope, head, hands and feet markers using color information and particle filter was tackled in Karungaru et. al. [1]. We fit the rope trajectory and extract features in this work.

### *A. 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

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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.

### *B. Results*

In the evaluation, we went out to fit the ellipses on the rope rotations. The idea is to investigate the shape and other factors during the jumping. The process is as follows,

- Extract the first jump, fit the ellipse and calculate the rope speed and the ellipse angles.
- Extract the second jump, fit the ellipse and calculate the rope speed and the ellipse angles.
- Repeat the process for all the 8 subjects.

Some of the results are shown in the figure 1 below. As can be observed, the second jump is tilted towards the back at an angle of about 12 degrees. Table 1 on shows the results for all other subjects.

**Table 1: Results**

| | First Jump Speed | First Jump Angle | Second Jump Speed | Second Jump Angle |
|---|---|---|---|---|
| Subject 1 | 1.35 | 2.1 | 1.22 | 10.3 |
| Subject 2 | 1.45 | 3.0 | 1.06 | 9.4 |
| Subject 3 | 2.15 | 2.5 | 1.98 | 11.5 |
| Subject 4 | 1.49 | 1.5 | 1.02 | 12.9 |
| Subject 5 | 1.38 | 1.8 | 1.06 | 10.3 |
| Subject 6 | 1.32 | 3.2 | 1.25 | 9.3 |
| Subject 7 | 1.12 | 1.8 | 1.09 | 11.1 |
| Subject 8 | 1.12 | 2.3 | 1.12 | 13.2 |

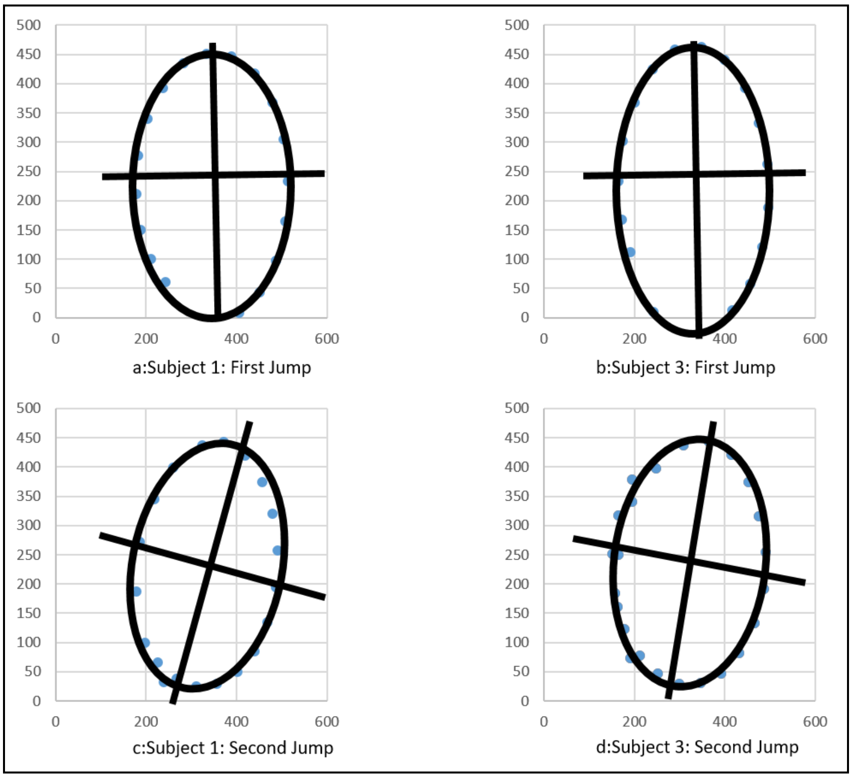


**Fig 1. Results showing the ellipse fit for the first and second jump for selected 2 subjects. Observe the obvious tilt in the second jump.**

## IV. CONCLUSION

In this work, we set out to extract features in double unders rope jumping that could be used to enhance and improve the level of support that can be offered to novice learners. In particular, we investigated the speed and shaped of the rope trajectory. Our method employed ellipse fitting method. Our results show that,

- The rope speed is higher during the second jump
- The ellipse of the first jump is a fairly regular and upright
- The ellipse of the second jump tilts backwards on average about 12 degrees.

In future, we hope to include these finding in the support system for runners in the positioning of their hands and also the first cognitive stage that helps the learners understand the motor skill.

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