CALCULATION OF HUMAN STEP LENGTH BY USING THE GOLDEN SECTION SEARCH ALGORITHM

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Abstract

The aim of present study is to find theoretically the human step length using with The Golden Section Search Algorithm and to compare it with experimental measurement result. First, the step length function of an adult participant that is known leg lengths was found by using The Law of Cosines, and then the step length was calculated according to The Golden Section Search Algorithm. Additionally, a participant was normally walked and experimentally found his step length. It was compared with the theoretical result. As a result, it was determined that the theoretical and experimental value found was almost the same.

Keywords: Golden section search, step length, Matlab, Tracker.

INTRODUCTION

Researchers and engineers have been inspired by nature while developing mechanical systems and architectural structures since antiquity, because there is an incredible harmony, which is an engineering wonder, in nature and in the universe.

This harmony is expressed mathematically as the golden ratio. That is, if a system has a golden ratio, it is considered to work visually and physically in harmony. The golden ratio corresponds practically to the number of $\Phi = 1.6182$ [1].

In this study, to find the mathematical result of the harmonic effect of the walking step size value of the person, it was proposed that the step length of a person's normal gait might be calculated with The Golden Section Search Algorithm and the Matlab software.

2.MATERIALS AND METHODS

That study consist of The Law of Cosines, The Golden Section Search Algorithm, Matlab and Tracker software, to find the human step length.

2.1. The Law of Cosines

When a human walking on the sagittal plane is observed, it can be seen that it formed a triangle with two legs and the ground.

The base edge of this triangle is the step length therewithal. The step length formula can be found in The Law of Cosines.

Therefore, The Law of Cosines is "the square of a side of a plane triangle is equal to the sum of the squares of the other two sides minus twice the product of the other sides multiplied by the Cosine of the angle between them", as shown in Figure 1.

The Law of Cosines (also called the Cosine Rule) says:

$$c^2 = a^2 + b^2 - 2ab\cos C \qquad (1)$$

For any triangle: a, b and c are sides. C is the angle opposite side c [2].

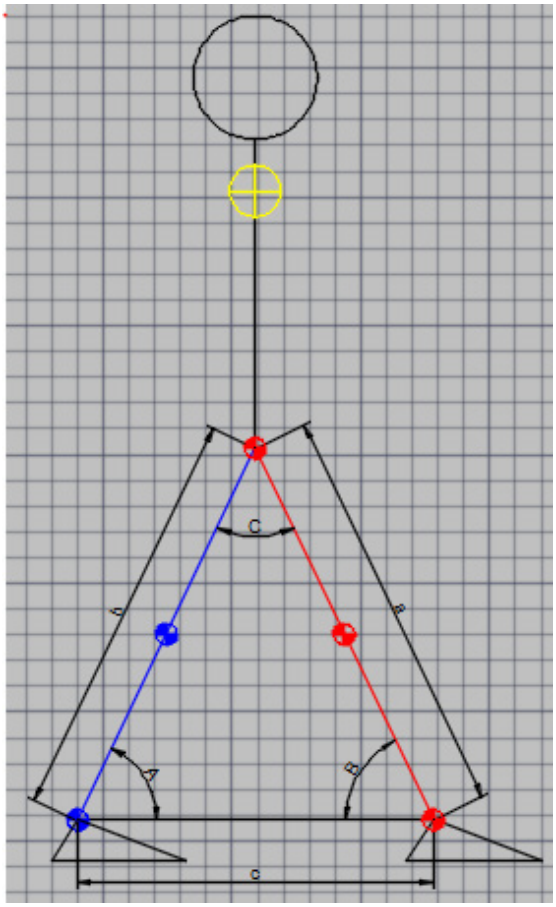

Fig. 1. *Triangle representation created from two legs and the ground*

2.2. The Golden Section Search Algorithm

The Golden Section Search is a simple, general purpose and univariate method. This algorithm is preferred by the engineers in the optimization of the systems. When solving the roots of a nonlinear equation, the goal is to find the value of the variable x which makes the function $f(x)$ zero. However, the goal of optimizing a univariate function is to find the value x which makes the function maximum or minimum or gives the extremum point.

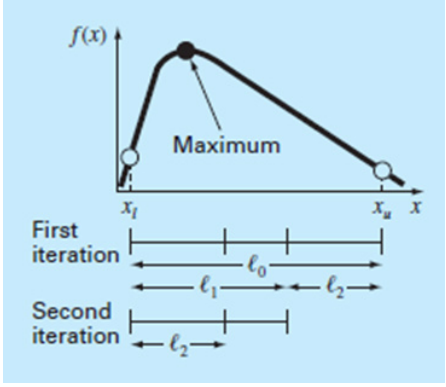

Fig. 2. *The Golden Section Search Algorithm [3]*

When a $f\ (x)$ function that is defined in the closed interval $[a, b]$ takes a minimum or maximum value of $f(x)$ in this range, approximate value is $r\ =\ 0,618$ which is the positive root of the

$$r^2\ +\ r\ -\ 1\ =\ 0 \qquad (2)$$

equation. This value is the golden ratio. In each iteration, new point pairs are found by reducing the length of the interval at a constant rate. If this process is continued until the interval is smaller than a certain number $\ell\ >\ 0$, the desired solution is reached [3].

2.3. The Matlab

In this study, The Matlab software have been used to calculate the participant's step length using The Golden Section Search Algorithm. The function that operates on Matlab program was developed by Aamir Alaud Din (2013). Thus, the function, start and end points must be entered into the Matlab software to calculate optimization [4].

The MATLAB code is here [4].

```
% Program : goldensection.m
function optimal =
goldensection(f,a,b,uncertain)


rho = (3 - sqrt(5))/2;

if (nargin < 3)
    error('Too few input arguments for golden
section search');
    optimal = 'Golden section search requires
at least three inputs';
    return;

elseif (nargin == 3)
    if (a == b)
        error('same values of a and b do not
make an interval');
        optimal = 'No interval given for
optimization'
        return;
    end
    n = log(0.001/(b - a))/log(1 - rho);
    n = ceil(n);
    fprintf('Iteration\t    a    \t\t    b
\t\t   f(a)    \t\t   f(b)\n');

fprintf('=========\t=========\t\t=========\t\t=
=========\t\t==========\n');
    for ii = 1:n
        a1 = a + rho * (b - a);
        b1 = a + (1 - rho) * (b - a);
        fprintf('%4d', ii);
        fprintf('%21.4f', a1);
        fprintf('%16.4f', b1);
        fprintf('%17.4f', f(a1));
        fprintf('%16.4f', f(b1));
        fprintf('\n');
        if (f(a1) < f(b1))
            b = b1;
```

```
        else
            a = a1;
        end
    end
    optimal = min(a,b);

elseif (nargin == 4)
    if (a == b)
        error('same values of a and b do not
make an interval');
        optimal = 'No interval given for
optimization'
        return;
    end
    n = log(uncertain/(b - a))/log(1 - rho);
    n = ceil(n);
    fprintf('Iteration\t    a    \t\t    b
\t\t   f(a)   \t\t   f(b)\n');

fprintf('=========\t=========\t\t=========\t\t=
=========\t\t=========\n');
    for ii = 1:n
        a1 = a + rho * (b - a);
        b1 = a + (1 - rho) * (b - a);
        fprintf('%4d', ii);
        fprintf('%21.4f', a1);
        fprintf('%16.4f', b1);
        fprintf('%17.4f', f(a1));
        fprintf('%16.4f', f(b1));
        fprintf('\n');
        if (f(a1) < f(b1))
            b = b1;
        else
            a = a1;
        end
    end
    optimal = min(a,b);

elseif (nargin > 4)
    error('Too many input arguments for golden
section search');
    optimal = 'Golden section search can''t
procees with too many inputs';
    return;

end
```

2.4. Motion analysis software program

In this study, the Tracker software, which processes a video image, was used to measure the participant's step length. This software is a user friendly and freely available [5].

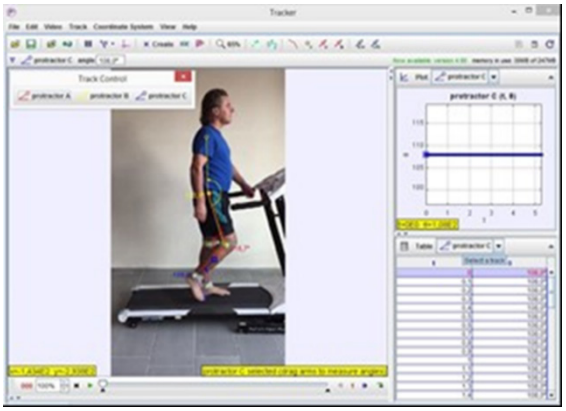

Fig. 3. *Tracker software*

3.Experiments and results

3.1. Theoretical measurement of gait step length of participant

The participant in this study has a height of 170 cm and a leg length of 80 cm. It is assumed that when the participant opens own two legs, participant's legs angles will have 0 to 180 degrees. Therefore, to calculate using The Golden Section Search Algorithm, the function of the step length according to The Law of Cosines is taken as

$$f\,(x)\;=\;\sqrt{\left(12800*(1-\cos x)\right)} \qquad (3)$$

and the first angle value 0 and final angle value 180 degrees. Then, functions and start and final angle values are entered into the function in the Matlab software, as shown in Figure 4.

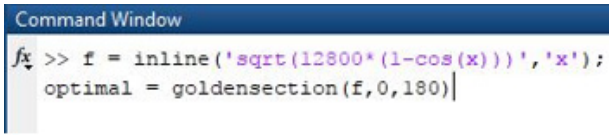

Fig. 4. *Entering step function to Matlab*

As a result, the optimum step length is calculated as 69,1147 cm with the Matlab software and The Golden Section Search Algorithm, as shown in Figure 5.

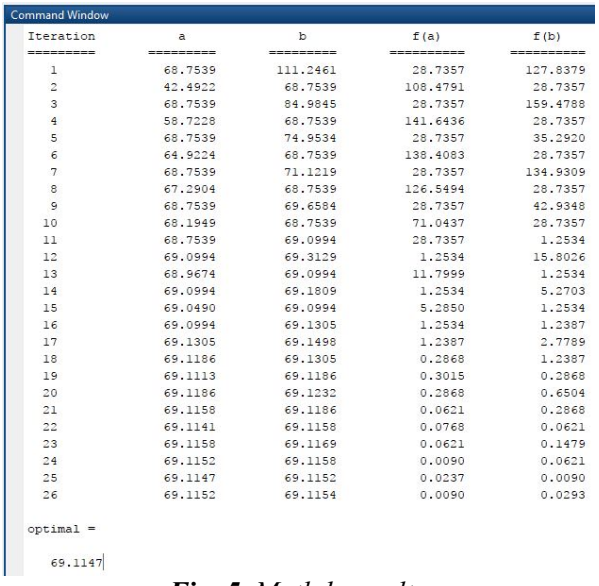

Fig. 5. *Matlab results*

3.2. Experimental measurement of gait step length of participant

The participant in the study has been walked at 1.36 m / s or about 5 km / h [6]. This walking speed value is the average speed for a normal healthy person. After the participant's walking images were recorded at 60 fps, The step length was measured in the Tracker program. As shown to figure, the value of the participant's between ankle and the knee has been assigned a value of 40 cm. Firstly, the gait footage loaded on the Tracker program was calibrated to the leg length of the participant. And then, The participant's gait step length was measured on the Tracker program. Eventually, The participant's gait step length has been found to be 69,12 cm, as shown in Figure 6.

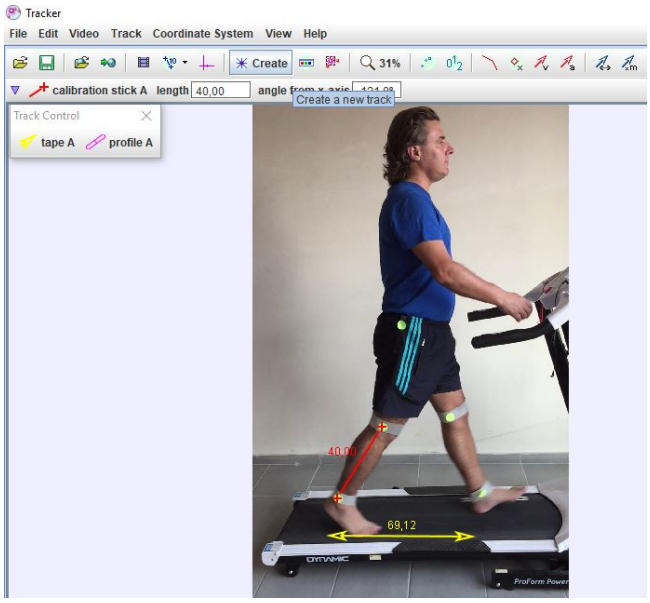

Fig. 6. *Determination of a participant step length with Tracker program*

4.Discussion

When we have compared experimental and theoretical results, we have found that both values are nearly equal. These values are theoretical value = 69,1147 cm and experimental value = 69,12 cm. In addition, step length was found 69,5 cm in a study by Jacquelin Perry [6,7]. Consequently, it was found that our study experimentally supported to calculation of human step length using The Gold Section Search Algorithm.

CONCLUSION

In the present study, we introduced The Golden Section Search Algorithm that is inspired by nature to calculate human gait step length. Theoretically and experimentally of the results of present study showed that The Golden Section Search Algorithm was successfully used to calculate the human gait step length in the sagittal plane of a person. Additionally, our studies can be beneficial for the science of gait. Therefore, we suggest that in future studies, The Golden Section Search Algorithm should be used to calculate other motions of the human.

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