Development of a Real-Time Assist System Increasing Walking Efficiency

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Abstract— **The aim of this study is to develop a gait assist system to lead users to energy-efficient walking. Energy consumption of walking is estimated by measuring both step length and stride frequency. Thus, in this paper, a test model to assist users based on measured step length and stride frequency in real-time is developed. Walking experiment is carried out and the validity of the proposed measurement method is confirmed.**

Keywords-energy comsumption; step length; acceleration sensor; gyroscope; potentiometer .

I. INTRODUCTION

Walking is the most important means of migration and is subjected to study from many different perspectives for years. In particular, a large number of articles on energy consumption of walking are published in the world, some of which are included in [1] to [3]. In addition, Farris et al. [4] and Kobetic et al. [5] explain that walking assist devices are being developed. Most of these devices are still in the research phase, but some of them are in practical use; for example [6] introduces "Walking Assist Device with Stride Management system", which is an assist device to reduce energy consumption. However, there still remains a difficult problem and that is the limitation on the gait of the user in calculating the step length only by hip joint angle.

In this paper, we present an assist system using an inertial sensor in order to develop an assist device that can be adapted to a wide range of the gaits.

In Sections 2 and 3, we explain the most appropriate relationship between step length and stride frequency, and present the method to measure them. After that, we present the test model that measures step length and stride frequency and could assist users in real-time in Section 4. Finally, in Section 5, we report the results of the verification of accuracy calculation method and measurement by test model.

II. ENERGY CONSUMPTION OF WALKING

Diedrich and Warren [1] and Molen et al. [2] show in Figure 1 that the energy consumption of walking is estimated by measuring step length and stride frequency. The most appropriate relationship between step length and stride frequency is computed from the following equation:

$$s = 0.0063n \quad (1)$$

where s (m) is step length and n (steps/min) is stride frequency.

Measurement tests were conducted using expiration gas analyser (PG-240) in order to determine the validity of the findings of [1] and [2]. Energy consumption of walking is measured changing stride frequency in different conditions: 1. The subject walks at 3.0 (km/h), 2. The subject walks at 6.0 (km/h). In addition, gait speed and stride frequency were determined by a treadmill and a metronome.

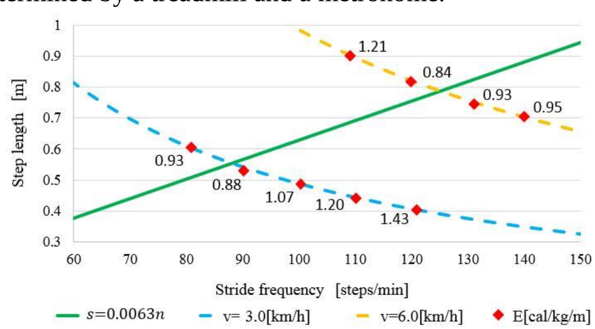

Figure 1. Verification of accuracy of the findings of [1] and [2]

In Figure 1, the green solid line indicates the most appropriate relationship between step length and stride frequency, and the red diamonds indicate energy consumption per unit distance (cal/kg/m). We can also see that the energy consumption of walking decrease when the relationship between step length and stride frequency is close to the green solid line.

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III. MEASUREMENT OF STEP LENGTH AND STRIDE FREQUENCY

In this study, step length and stride frequency are determined by joint angles while walking, and joint angles are measured by potentiometers and encoders (Figure 2). The model of lower limb and variables in calculation are shown in Figure 2.

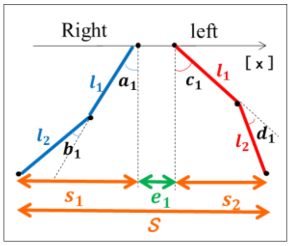

Figure 2. Variables in calculating step length

Walking cycle T(s) is easily determined because walking is a cyclic movement. Therefore, stride frequency is computed from the following equation:

$$f = 1/T \tag{2}$$

Right stride is computed from the following equation:

$$s_1 = l_1 \sin a_1 + l_2 \sin(a_1 + b_1) \tag{3}$$

where l_1 (m) is thigh length, l_2 (m) is lower length, a_1 (rad) is hip joint angle, and b_1 (rad) is knee joint angle. In addition, left stride is computed in a similar way. Then, an effect of twisting of the lower back is added. Finally, the step length is computed from the following equation:

$$S = s_1 + s_2 + e_1 \tag{4}$$

In addition, foot contact, which decides the timing of the calculation, stride frequency and an effect of twisting of the lower back can be determined by an inertial sensor on the lower back.

IV. MECHANISM OF TEST MODEL

Figure 3 is the test model that measures step length and stride frequency and could assist users in real-time.

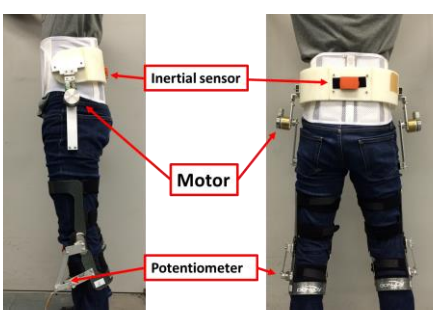

Figure 3. Test model

Motors with encoders were positioned on the axis of the hip joints for the purpose of measuring hip joint angles. Two potentiometers were positioned on the axis of the ankle joints for the purpose of measuring hip joint angles. An inertial sensor that has an acceleration sensor and a gyro sensor were positioned on lower back for purpose of measuring a longitudinal-direction acceleration value and an effect of twisting of the lower back.

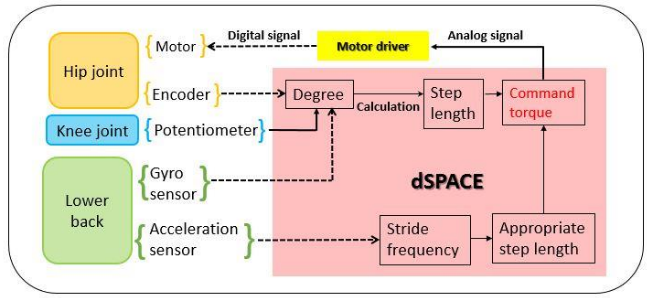

Figure 4. Real-time control system using dSPACE

Figure 4 shows the real-time control system. A PC is loaded with MATLAB/Simulink, a dSPACE data acquisition and real-time control system. The controller is designed in MATLAB/Simulink. Command torque is given to motor driver as analog signal. This system could measure step length and stride frequency and assist users in real-time.

V. VERIFICATION OF ACCURACY OF CALCULATION METHOD AND MEASUREMENT BY TEST MODEL

In order to confirm the validity of the proposed method in section 3, the accuracy of measurement was verified by using 3D motion analysis (Hawk Digital Real-Time System: Motion analysis). The results of the calculations and 3D motion analysis are compared.

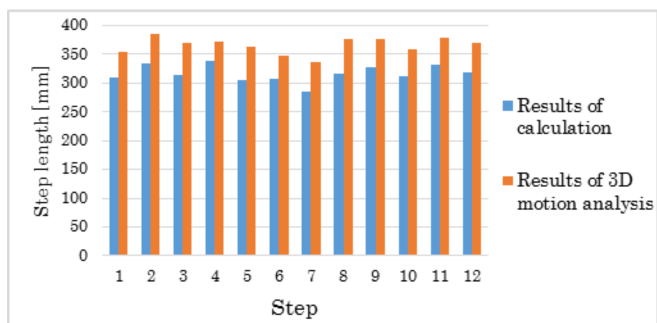

Figure 5. Step length

Figure 5 shows that the measurement error is 2.57(%) and standard deviation is 1.54(mm). The method that proposed had limitation of measurement accuracy. However, the results of calculation could be corrected by using the decided correction coefficient because standard deviation is very small.

Measurement tests were conducted using the test model. First, the floor was marked at 1 meter intervals. Second, the subject walked using regular steps using the markers as a guide. The subject was asked to walk 5 meters in 5 steps. Third, the result of calculation was compared to the actual walking distance.

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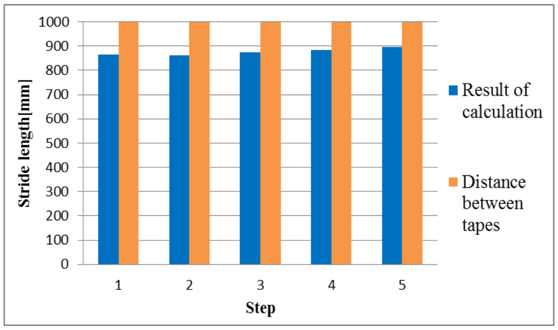

Figure 6. Step length measurements by test model and tape pith

Figure 6 shows that the measurement error is 12.4(%) and standard deviation is 12.6(mm). A main error source may be the walking movement misalignment between the potentiometers and legs. However, this result is positive because improvement of accuracy is expected by multiplying calculation result by calibration coefficient.

VI. CONCLUSION

In conclusion, a method for measuring step length and stride frequency was proposed and the test model that could measure step length and stride frequency, and assist users in real-time was developed. In addition, verification of measurement accuracy was conducted using the test model. The results show that the proposed method to determine walking efficiency was reasonable. In order to find out the optimal assist timing and the size of motors torque of this assist method, future experiments with the test model need to be conducted.

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