A Kinematic Study of the Sway of Upper Limb through Normal Gait and Drop Foot

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Abstract

Drop foot happens because the muscle groups are too weak to contract. Throughout analyzing the kinematic parameters on three anatomical planes with two walking speeds, this paper aims at exploring the relationship between the upper limb and the lower limb in terms of displacement, velocity, acceleration, angle, angular velocity, and angular acceleration. The turning points chosen from the above mentioned kinematic parameters could be used as inputs and outputs which are assessed in different stages of one gait cycle. The result can be used for future FES feedback control by receiving signals from the upper limb and stimulating the drop foot.

The Kinematic parameters are collected by Visualeyez™ System during one gait cycle and each cycle is divided into nine stages. Kinematic parameters of the upper limb are used as inputs, and the angular variation in the ankles of the normal and the paraplegic is regarded as the output. Five normal subjects and three paraplegics move with comfortable-walking and the fastest-walking speeds. The results show that turning points appear regularly and shift about 7% for different subjects.

1 Introduction

FES is to activate the paralyzed muscles and to regulate the artificial movements. According to the control strategies, there are three methods to govern FES signals: open-loop control, closed-loop control, and adaptive control. For an open-loop system, the subject gives commands to generate the muscle activation patterns. For example, Keith et al. proposed an open-loop FES system for restoring functions [1, 2]. This system is controlled by a single-graded command thus stimulates muscles. Another method is the closed-loop system which employs feedback to controllers and modifies the activation patterns. For instance, Vodovnik and his co-workers established the closed-loop controller applied to the one-degree-of freedom joint [3]. The third method is the adaptive control which has the feasibility to modify FES system according to the changes of inputs or disturbances. Applications have been built under this controller with different strategies, such as the development of controlling the knee joint of paraplegics [6] and the neuro-control system for the knee joint position [7].

Recent work on rehabilitation of drop foot focused on the kinetics and kinematics of lower extremity. It is often used signals from lower extremity to control functional electrical stimulation. However, those signals from lower extremity could have the problems of instability. The aim of this paper is to investigate the relationships between upper limbs and lower limbs and compare the normal gait with the abnormal gait. The results might contribute to future FES control strategy.

2 Methods

Table 1 lists all kinematic parameters defined by the axis-direction.

Table 1 List of kinematic parameters

	Unit	Axis-direction	Detection-motion
Hip	Angle(°)	Axis of femur	Extension and Flexion
Knee	Angle (°)	Axis of tibia	
Ankle	Angle (°)	Axis of foot	Dorsiflexion and Plantarflexion
Shoulder	Displacement, velocity, Acceleration, Angle, angular velocity, angular acceleration (cm, cm/s,	Posterior aspect of trunk	Shrug movement
Elbow		Longitude axis of humerus	Internal rotation and abduction of arm
Wrist		Longitude axis of forearm	Supination and pronation
Hand		Lateral axis of hand	Extension and flexion of wrist

	cm/s^2, °, °/s, °/s^2)		
Gait speed	m/s	Walking direction	10m distance

Fig. 1 shows the motion of upper and lower limbs on three anatomical planes. Circles represent shoulder, elbow, and wrist joints; the pentagon stands for the palm. The positive signs are to move outward, front, and upward. Linear kinematic parameters including displacement, velocity, and acceleration are defined by the normal line of three anatomical planes. Angular parameters are defined by three anatomical planes.

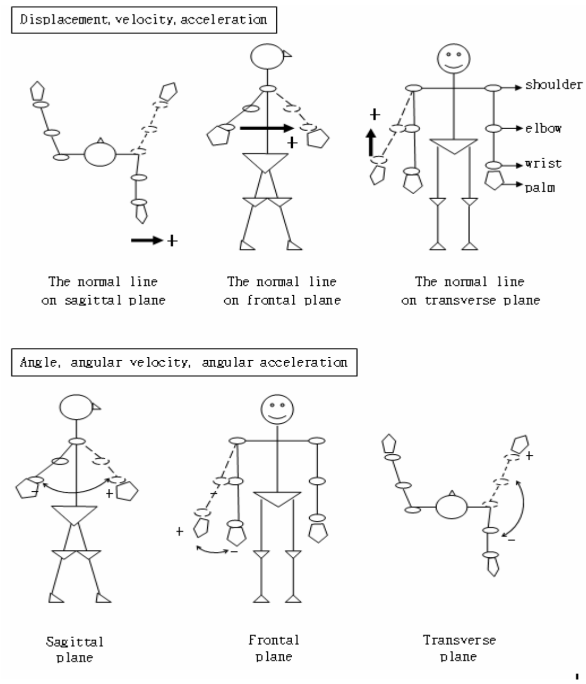

Fig. 1 Definitions of motion and signs on three anatomical planes

3 Results

Fig. 2 shows the kinematic parameters in terms of the inputs and output. The principle of choosing the inputs and output is in accordance with the turning points and zero-value points which control the on and off of FES. For convenience, input parameters such as wrist velocity on the transverse plane, elbow angle on the frontal plane, elbow angle on the sagittal plane and palm velocity on the transverse plane, are chosen to discuss. Output is the variation of the angle of the ankle between the normal and paraplegics.

If the turning point of the input could correspond with the zero-value point of the output in Fig. 2, a dashed line would link with two parameters. Throughout the dash lines, the relevant inputs, output, and the timing of stimulation could be found.

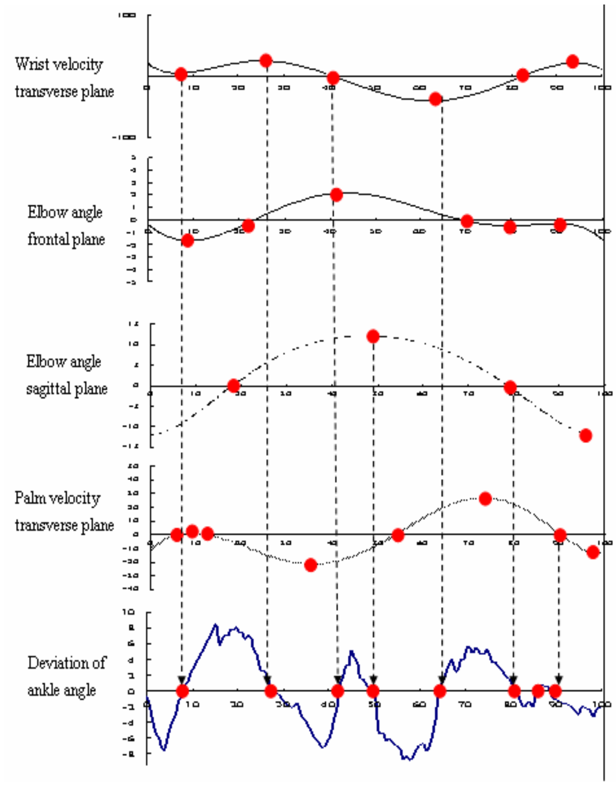

Fig. 2 Relationships between turning points of inputs and output

4 Discussion and Conclusions

4.1 Two walking speeds

Fig. 3 shows two walking speeds. The solid line represents the comfortable-walking speed (0.86 sec/step), and the dashed line shows the fastest-walking speed (1.13 sec/step). It is to discuss that two walking speeds differ 24%, yet their maximum data differ about 41%. Their turning points appear on 19%, 50%, 72%, and 92% of the gait cycle in term of comfortable-walking speed, and on 21%, 50%, 71%, and 90% in term of fastest-walking speed. Two walking speeds affect the gait cycle of turning points 2% at most. As for the zero-value points, two walking speeds differ 4% at most.

The conclusions of this work are as follow. Faster walking speed would affect the maximum value of the elbow velocity on the transverse plane. When subject walk faster, the amplitude increases, yet the gait cycle of turning points and zero-value points appear merely 4% biased.

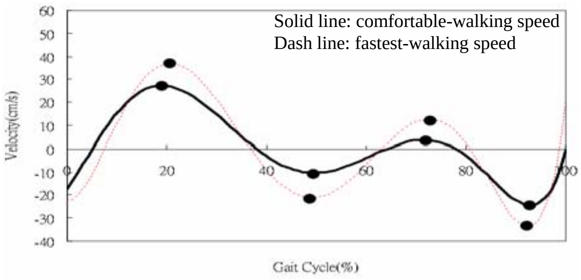

Fig. 3 The comparison of elbow velocity on the transverse plane in two walking speeds

4.2 Parametric variations of Different Subjects

Fig. 4 shows wrist velocity of all normal subjects on frontal plane. The first turning points of the five normal subjects appear on 22%, 24%, 26%, 27%, and 34% of the gait cycle. There is 12% variation between the earliest and the latest one, and 12% of one gait cycle is equal to 0.126 sec. The second turning points appear on 70%, 72%, 77%, 78%, and 80% of the gait cycle. There is 10% variation which is equal to 0.105 sec.

To conclude from above, the turning points has the maximum deviation of 0.126 sec. The difference between each subject might be relevant to the fitness, walking habit, and the walking speed. Once the turning points of kinematic parameters are used on FES control strategy, the time deviation should be considered.

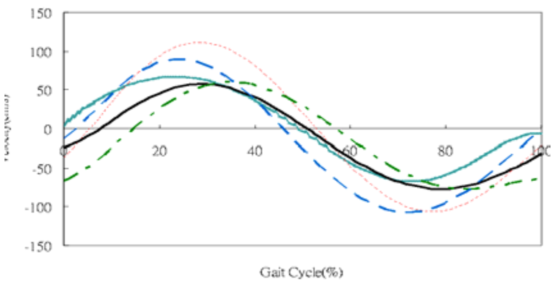

Fig. 4 Wrist velocity of five normal subjects on frontal plane

4.3 The reappearance of kinematic parameters

Fig. 5 shows the normal wrist velocity on transverse plane. The solid line represents the comfortable-walking speed, and the dashed line shows the fastest-walking speed. On 0% of gait cycle, the parametric value of comfortable-walking speed is -17cm/s. Perfect periodicity means the parametric value still remain -17cm/s on 100% of gait cycle. However, the parametric value reaches -17cm/s on 94% of the gait cycle. For fastest walking speed, the parametric value is -22cm/s and reaches the same value on 96% of the gait cycle.

To conclude from above, although waveform would reappear at next gait cycle, not all of them have good periodicity. There are about 4~6% deviation.

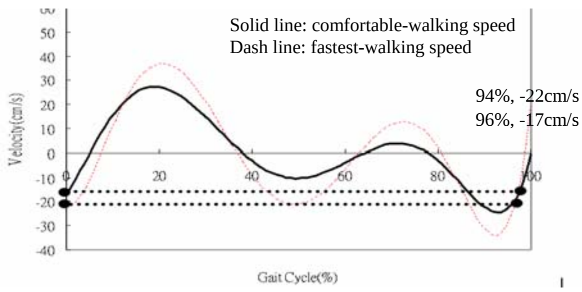

Fig. 5 The periodic discussion of normal wrist velocity on transverse plane

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