**Introduction**

The exoskeleton robot is a mechanical structure that is worn on the lower limbs of a human body and incorporates robot technology such as sensing, control, information coupling, and mobile computers. It integrates support, protection and movement. By controlling and driving external mechanical mechanisms, it can face complex external environment and extreme working conditions with greater adaptability. It coordinated with the human body to complete the corresponding actions, which extends the scope of people's movement.

Walking up and down the stairs is a common human behavior in our daily life. With the continuous development of social modernization, tall buildings have risen. Whether it is high-end residential personal home furnishings, various types of residential areas or in public facilities such as shopping malls, hotels, office buildings, and stairs are closely related to our lives, at the same time, the height of the stairs and the width of the stairs in different occasions are often not the same. Up and down the stairs become behavior actions that often need to be completed in people's daily lives. In order to satisfy the exoskeleton wearers who can exercise on different occasions, it is important to study the gait planning up and down the stairs. Compared with normal gait research, there are relatively few researches on the up and down stairs of the exoskeleton robot. The main reasons are: 1. The purpose of research on the up and down stairs is mainly the exploration of pathological causes, evaluation of treatment effects and external factors affecting the walking gait of stairs. 2. There is little research on skating up and down stairs for exoskeleton robots in China, and the results of foreign studies cannot represent the sports characteristics of the Chinese population.

In this article we first introduce a wearable lower limb exoskeleton（WLEXO） robot that can help paraplegic patients perform daily activities such as standing/sitting, walking, and going up and down the stairs. In order to ensure the comfort between the exoskeleton and the wearer, a novel configuration of the exoskeleton robot combining active and passive joints, self-adaptive structure size, and high compatibility with human physiological parameters/motor functions was proposed. Secondly, the two different movement modes of upstairs and downstairs are analyzed according to the actual situation. Different motion modes have different motion characteristics. Different motion modes have different motion characteristics. Therefore, we will plan different constraint conditions for different phase moments of each motion pattern and decompose the gait planning problems of the up and down stairs into hip motion position planning and ankle motion position planning. According to the leg length constraint and kinematic principle, the knee position of the knee joint is obtained and the motion angle of each joint is solved according to inverse kinematics. The planning result of each movement mode is represented by joint angle estimation. A combination of different phases can obtain a complete cycle of dynamic gait planning algorithm.

**Problem definition**

The purpose of this paper is to provide a gait planning algorithm adapted to different stairs according to different body parameters and different stair heights and widths. The stair gait and the stairway down stair gait are planned in real time according to the different stair heights and different stairway widths detected by the depth camera installed on the exoskeleton robot. According to different stair heights and different stairway widths detected by the depth camera installed on the exoskeleton robot, the stair gait and downstairs gait are planned in real time and applied to the exoskeleton robot of the lower extremities. Due to the characteristics of gaits up and down the stairs and the requirements of practical applications. We make the following assumptions:

1. The algorithm is based on the kinematic characteristics of different motion patterns, regardless of the dynamics.
2. The wearer and WLEXO robot maintain body balance through upper limbs and two crutches that do not affect gait.
3. Considering that gait is a cyclical process, the goal of this study is a gait cycle.
4. Considering that the safety of wearing exoskeletons up and down the stairs, the gait of the plan is a two-step ladder.

**Mechanical design of Exo**

The role of the exoskeleton's mechanical structure is to support the wearer's body shape and to wear comfortable. Therefore, its design takes into account ergonomics and human biomechanics, so that the wearer and the exoskeleton have minimal discomfort in wearing comfortably.

**Overall mechanical structure**

The lower limbs of a person have seven degrees of freedom on each leg, of which there are three at the hip, one at the knee, and three at the knee. In general, human gait and other daily movements are three-dimensional and can be described in the three main planes of the human body [10, 11], including the frontal, transversal, and sagittal planes. The frontal plane divides the body into anterior and posterior parts, and the lower limbs of the human body in this plane are responsible for balancing the weight. The transversal plane divides the body into upper and lower parts. The movement in this plane is to ensure that the body moves in a straight line. The sagittal plane divides the body into two parts. The movement in this plane is mainly responsible for moving the body forward. In these planes, the sagittal plane that describes the person moving forward and backward is the most important one. This is because in most of our sports, the largest torque and forces of the lower limb joints occur in this plane [11,12].

Figure 1B shows the overall mechanical structure of the exoskeleton. It is mainly made of aluminum alloy (7075) for light weight and high rigidity. In addition, other materials are used, such as steel for transmission shafts. The mechanical structure of the exoskeleton is designed to be adjustable and can accommodate wearers in the range of 1.55-1.90 meters. The brackets and belts are designed for the exoskeleton and transfer the assisting force/torque of the exoskeleton to the wearer. In order to make the wearer feel comfortable, an integrated pad is placed around the bracket. According to the range of motion of human joints, the range of motion of exoskeletons is shown in the table. In this study, the sign of the joint angle is defined as follows: When the WlEXO is in the upright position, the bending direction of each joint angle is positive and each joint angle is zero. As can be seen from Table 1, the range of motion of the exoskeleton is designed to be smaller than the range of motion of humans in order to protect the wearer. These range of movements are sufficient to allow the paralyzed patients to perform basic daily activities with the help of exoskeletons, including walking, sitting, standing up, going up the stairs, and going downstairs. To ensure safety, a mechanical stop is designed at the very end of the allowable range of motion for each degree of freedom.

**Waist Structure**

The mechanical structure of the waist section of the exoskeleton should have high stiffness and strength because it needs to withstand the weight of the HES swing leg to resist leg sagging during the swing phase of the gait cycle [7, 12]. As shown in FIG. 1C , the waist of the exoskeleton mainly consists of a backpack, a waist belt, a lumbar support, and a waist-to-hip joint. The motor driver, embedded controller and exoskeleton power are placed in the backpack. The waist connection can accommodate different wearers of different waist widths.

**Leg structure**

Figures 1D and 1E respectively show the EXO's thigh and lower leg structures. The hip has a flexion/extension degree of freedom. EXO's thigh and lower legs are designed with leg length adjustment mechanisms to accommodate different wearers. The knee has a flexion/extension degree of freedom. In order to prevent the worn knee from bending in a standing position, a baffle was designed in the middle of the lower leg. When the wearer pulls the anti-buckling bar outward when standing up, the wearer can press the anti-buckling bar inward to achieve self-locking to better suit different wearers.

**Foot structure**

The EXO foot structure is shown in Figure 1F. The ankle has one degree of freedom (plantar flexion/dorsal flexion). The foot consists of a foot pedal and non-slip rubber. The foot pedal is rigidly attached to the ankle joint and anti-slip rubber is placed on the sole to increase the friction between the foot and the ground.

Up and down stairs gait generation algorithm

This paper proposes a dynamic gait generation algorithm for UP and DOWN stairs, which aims to provide different individuals with gait patterns for different situations. The algorithm uses the inertial measurement unit IMU module located on the back to identify the wearer's movement intention and generates a dynamic gait according to the depth camera which detects different stair heights and stairway depths as well as different sizes of the wearer's lower extremities. The algorithm includes single-leg support mode, swing mode, and two-leg upright mode. When the two legs support phase in each gait cycle, it is judged whether to re-plan a new gait mode according to the depth camera detection value, and it is possible to flexibly switch the step length and step height of the up and down stairs to meet the wearer's response to the complex sports environment demand.

Gait phase division

In order to satisfy the generation of dynamic gait patterns during walk, the phases in the gait cycle should be clearly defined. These phases can be reliably detected by the angle sensors of the gait. Considering these conditions, we divide the gait cycle of the ascending and descending stairs into two large phases of the supporting phase and the swing phase based on the contact conditions of the foot and the ground, and subdivide into four phases at the same time. On the gait phase of the stairs: double-leg support -> left foot off the ground (swing phase) -> left foot touch 1st step (swing phase) -> right foot off the ground (single leg support phase) -> The right foot touches the 1st step (single leg support phase) -> double-leg upright support..