Design and implementation of a wearable exoskeleton system for lower limbs

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Abstract. Exoskeleton is a kind of wearable mechanical device. It combines the intelligence of human beings with the “physical strength” of robots, and the robots is controlled by human intelligence in this device, then some assignments that could not be accomplished by human alone are achieved by the robots. The lower limbs walking exoskeleton, a human-machine integrated device falls in between the human and the biped robots, could help people walk around. Because decisions could made by people in this device, the gait planning and gait balance during walking become more simple compared with the bipedal walking robots, the structure design is more convenient, and at the same time, the walking ability of the human body can be greatly enhanced, and the range of activities could be enlarged. In this project, a new type of wearable lower limb walking exoskeleton mechanism was designed by using electric system based on the in-depth study of the movement mechanism of human lower limbs musculoskeletal groups. Moreover, a prototype test system for the lower limbs walking exoskeleton was developed on the basis of theoretical research, including the processing and assembly of the mechanical structure, and the concrete realization of the software controlled framework. This prototype test system could serve as the experimental platform for further studied in the future. The ultimate goal of this project is to achieve a walking exoskeleton that has comfortable wearing and stable walking, reduce the energy consumption during walking, reduce the feeling of fatigue, and improve the speed of body weight-bearing exercise. This robot will greatly reduce the load that the heavy object brings to the muscles, and the servo motor will bear the main weight. This can greatly reduce the physical exhaustion of occupational groups mentioned as above and increase the duration of work, so as to bring qualitative changes in work efficiency and effectiveness.

1. Research background and significance
Exoskeleton is a wearable human-machine integrated mechanical device. This device combines the intelligence of human beings with the “physical strength” of robots, and the robots is controlled by human intelligence in this device, then some assignments that could not be accomplished by human alone are achieved by the robots.

The lower limbs walking exoskeleton is a human-machine system that can help people walk. It combines human and bipedal walking robots, and uses human intelligence to control the robots’ walking,
which simplify the most common problems of gait planning and gait stability in the autonomous walking biped robots, meanwhile enhance people’s ability and speed of walking via providing power to assist people walking. Moreover, this device could ease the feeling of fatigue that can easily occur when a person is carrying a heavy load and is walking for a long time, greatly expand the scope of people's movement, so this device could be widely used for military, scientific research, tourism, transportation and other aspects with broad application prospects.

2. Theoretical research

![Figure 1. Schematic diagram of unilateral machinery.](image1)

The limit of this device is all the weight supported by one foot while walking, and the knee is bent at an angle with 172 degrees (will be involved in the gait analysis later). In this case, the two steering engines on one side are at maximum load, so I will use the appropriate steering gear by calculating its limit torque load. When the body is supported on one leg at an angle with 172 degrees, with CAD equal scale drawing calculation, we can see that the crossing angle of the bracing to the waist is about 70 degrees, and the crossing angle of the heel to the bracing is about 25 degrees, the diagonal support slider and the diagonal braces are approximated at a 13-degree angle. Substituting all required data into the above equations and using the matrix method via MATLAB concluded that the larger steering gear requires approximately at least 216.5 kg/cm and the smaller steering gear requires approximately at least 9.76 kg/cm of torque.

3. Hardware design

As a load-bearing exoskeleton robot, the primary goal of this design should be to minimize the load on the person and transfer as much load as possible to the robot under the same load. Since the diagonal bracing adopts the motor-assisted motion, the length of the diagonal bracing in the above state is obtained by measurement and evaluation of the solid works.

![Figure 2. Calculation schematic diagram of motor rotation angle.](image2)
Through theoretical calculation and design, the overall structure after construction is shown in figure 3 below.

**Figure 3.** Overall structure.

4. **Software design**

4.1. **Gait analysis**

The recorded walking video was processed by TensorFlow, the picture of the leg is collected in units of 30 milliseconds, the edge pixels of the leg in the time frame image are analyzed, and the edge pixel points are contracted toward the inner central axis to obtain the joint skeleton, and then the linear regression of the thigh and calf skeleton pixels was performed using the machine learning gradient descent method, and the angle between the thigh skeleton and the calf skeleton straight line is obtained. After many measurements, the knee bending angle test chart is shown in Figure 4 below.

**Figure 4.** Statistical diagram of knee bending angle.

4.2. **Program design**

The program design of this exoskeleton robot is shown in the block diagram of the following figure. The Bresenham algorithm is used to realize the linkage operation of the large and small steering gears, and the check and stop procedure is added after each step of the motor action, which greatly increases the controllability of the robot and achieve the effects of moving and stopping at any time. It avoids the situation that accidents in actual use caused by failure to stop the machine timely.
5. Test and result analysis of this system

In the actual carrying test, I placed objects with different weights in the load box to test the walking condition of the machine under each kind of counterweight. The test results are shown in the following table:

| Tests | Weights | Results                          |
|-------|---------|----------------------------------|
| 1     | 5kg     | normal walking, users feel relaxed |
| 2     | 10kg    | normal walking, users feel relaxed  |
| 3     | 15kg    | normal walking, users feel relaxed     |
| 4     | 20kg    | normal walking, users feel relaxed     |
| 5     | 25kg    | normal walking, users feel relaxed     |
| 6     | 30kg    | normal walking, users feel relaxed     |
| 7     | 35kg    | normal walking, users feel relaxed     |
| 8     | 40kg    | normal walking, users feel relaxed     |
| 9     | 45kg    | difficult walking, users feel relaxed  |
6. Conclusion and expectation
The completed product of this exoskeleton machine generally meet the design requirements, and have significant effects in saving manpower and improving efficiency. They can effectively increase the load and could be widely used in the work. The project is summarized as follows after the load test:
1. The exoskeleton robot can effectively carry weight and improve the user's feeling of carrying weight and save physical energy.
2. The walking speed of the exoskeleton robot meets the requirements and has practical use value.
3. The structure of the exoskeleton robot is stable, highly reliable, easy to be maintained, and easy for the users to use.
4. The wearable experience of the exoskeleton robot meets the design requirements. A sponge pad is added to the part where the aluminum profile is in contact with the body, which further enhances the usage experience, and improve the safety and reduce the probability to hurt others via adding a sponge pad at the corner of this device.

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