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CONTROLLED BREAKING SCHEME FOR A WHEELED WALKING AID

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Abstract: A wheeled walking aid with an embedded controlled braking system is described. The frame of the prototype is based on combining features of standard available wheeled walking aids. A braking scheme has been designed using hydraulic disc brakes to facilitate accurate and sensitive controlled stopping of the walker by the user, and if called upon, by automatic action. Braking force is modulated via a linear actuating stepping motor. A microcontroller is used for control of both stepper movement and for supervisory control. An encoder is used to supervise walker movement in terms of time, distance and speed. Copyright © 2005 IFAC

Keywords: Walking Aid, Adaptive Control Braking, Rollator.

1. INTRODUCTION

The primary motivation behind this research was to consider mobility aids available on the market and to improve their performance and usefulness, with a focus on stability, ease of control and safety. In particular, the intention was to enhance the prospects of people with conditions such as muscular dystrophy, by providing them with the mobility necessary to maintain a reasonably independent lifestyle. The inspiration was that of a colleague, who in spite of developing such a condition has maintained his position in the workforce and who continues to commute on a daily basis into the city of Dublin. Whilst both electric and manual wheelchairs serve a useful purpose, the ability of the user with disability to walk with assistance over short distances, is highly desirable if possible, and helps to boost individual morale and assists in maintaining muscle tone.

1.1 Commercially Available Walking Aids

Walking (Zimmer) frames are lightweight units, which come in a range of styles. They can be fixed height or adjustable, with a fixed or folding frame. Two-wheeled walkers are similar in design to Zimmer frames, with two wheels positioned to the front of the frame. Both walking frames and two-wheeled walkers are “pick-up” walkers, i.e. they must be picked up and moved to a new location to take a step. They have advantages in that they are both stable in design and cheap to purchase. They also have the disadvantage that the user has to stand unaided upon lifting the frame, and their use can encourage an unnatural gait.

Another category of wheeled walker is that of the three-wheeled walker, designed with two fixed rear wheels and a swivel front wheel. Advantageous features of these units include foldable design and a selection of handles and/or arm-troughs to suit user preference. They may be fitted with either spring-loaded or loop brakes. A major disadvantage is that they are inherently unstable.

Four-wheeled walking frames are also available, designed with two front swivel wheels and two rear fixed wheels. These units are foldable and have a basket, which may also be used as a resting seat when stationary. Again, they may be fitted with either spring-loaded or loop brakes.

2. BODY KINEMATICS

Adrezin et al. (1992) instrumented a standard walker, and measured axial forces and anterior-posterior and medial-lateral bending loads at each of its four legs. It was found that the wide range of user disabilities led to differing walker usage patterns. Hence, it was
concluded that a need exists for future research leading to better understanding of walkers and new walker designs, which will address the varying needs of users.

Power assisted walkers have been designed to support people with weak lower limbs. The use of walkers is difficult for hemiplegic users, as the illness weakens one side of the body, making it difficult to control the direction of the walker. Egawa et al. (1999) have developed a power-assisted walking support system to compensate for this difficulty. The power-assisted walker allows hemiplegics better control of their walk by compensating for force input bias caused by imbalanced gait.

2.1 User Requirements

Development of the system in the current research has mainly focused on the physical requirements of, and the knowledge imparted by, a colleague for whom this prototype has been developed. His condition is such that he cannot stand independently and must be supported at all times. At present, crutches are the only viable option available suitable to his requirements. The walking approach is to place one crutch forward and then swing the opposite foot forward. When stable, he then switches over and moves the alternate crutch forward and then the other leg. At all times his centre of gravity is maintained to the front of his feet position; this locks his ankles and knees and enables his legs to bear weight. This is a very physically demanding process, is wearing on shoulders, elbows and wrists, and is becoming increasingly difficult with the progression of time.

As our user’s centre of gravity is to the front of his feet, there is always a forward force on any walking aid he uses. This forward force increases the requirements of the walker in the areas of safety and braking (see Figure 1).

Standard walking frames or two-wheeled walkers are not a suitable option, as both of these require the user to stand unaided and to lift the unit forward before taking a step. This has led to the option of developing an alternative wheeled-walker, which would overcome the difficulties associated with existing available models.

2.2 Walker Feature Design

A design decision was made to utilise the base of a commercially available four-wheeled rollator, “Voyager” by Worldwide Mobility, for stability. This base has two swivel wheels positioned at the front and two fixed wheels at the rear. The swivel wheels facilitate manoeuvrability while the fixed wheels encourage the unit to move in a straight line. The combination of two fixed wheels and two swivel wheels, and a large footprint, gives the unit both controllability and stability, making for a good general-purpose walker.

To give our user upper body support and to allow for loss of power, the handles have been changed to arm rests. The arm rests are height and position adjustable for maximum comfort.

Fig. 1. Walking profile with forward inclination

The brakes have been changed to hydraulic disk brakes. Brake disks have been attached to both the rear wheels with their callipers attached to the frame. Disk brakes, as they are not in contact with the ground, have a high accuracy and repeatability. The brakes use a closed hydraulic system, which is very responsive. Hydraulic disk brakes have been specifically chosen to give a controlled stop and for ease of activating two disk brakes at the same time. An area of concern is that due to the slow speed of a walker, the brakes will be “grabby” and will stop the walker instantly once the calliper comes in contact with the disk surface. To overcome this potential problem, the brake pressure can be modulated to give gradual application.

The brakes were connected to the outside of the wheels to maximise the walking space for user feet between the rear wheels. Wheel shafts were modified and replaced by extended rotating shafts. A wheel hub was constructed of 50 mm diameter acetal copolymer material. The new wheel hub was machined from a 50 mm diameter rod. At one side the shaft was machined to 30 mm with an inner cut cylinder to fit over the existing plastic wheel shaft (Figure 2). The middle section of the hub is 50 mm in diameter. The other side of the rod has been turned down to the inside diameter of the brake disc, thereby enabling the brake disc to be screwed to the machined surface. The assembled disc brake is shown in Figure 3.
Initially for testing purposes, the brakes were activated by a lever. Upon obtaining and quantifying the fundamental braking information, the brakes were adapted to automatic controlled operation. The brakes will have an emergency / parking brake switch and an activate brake option in normal walking mode. The supervisory controller will determine brake application and will not require user intervention. Activation of the brakes is via a stepping motor controlled by an on-board electronic drive. The stepping motor is a linear actuator and is a high speed, high torque unit (to facilitate modulation). The motor is attached to the brake cable and will activate a hydraulic brake piston, as required.

A pressure transmitter in the hydraulic line gives feedback of the pressure being applied to the brake and the work done.

Information on distance, speed and acceleration are measured by using a differential encoder attached to the rear wheel of the walker. The two pulse trains from the encoder are fed into the microcontroller, which calculates the magnitude variation of walker movement.

The microcontroller facilitates both the automatic controller and the supervisory controller working in parallel with the user. The automatic controller controls brake position to a selected control strategy. As the supervisory controller, the microcontroller uses historical data as well as current data to determine whether, and to what degree, the brake should be applied. Decisions are based on stored profiles and stored maximum values and the purpose is to ensure user comfort and safety.

3. WALKING AID DYNAMIC STEP PROFILE

The ambulation of an intended user of the proposed walker, using crutches as a walking aid, was studied. It was observed that the cycle of movement contained three phases; the walker is first pushed forward, the user moves one foot forward, pauses and then moves the second foot forward. To determine the maximum force required to activate the brake, an estimate will be required of maximum velocity and braking deceleration.

A test was set up whereby the walking aid was pushed in a straight line emulating the step pattern of the intended user. The time taken and distance travelled for six sets of five walking cycles using the walking aid were recorded, as shown in Table 1.

<table>
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<tr>
<th>Time (s)</th>
<th>Distance (m)</th>
<th>Cycles/minute</th>
<th>Distance/cycle</th>
<th>Distance/minute</th>
</tr>
</thead>
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</tr>
</tbody>
</table>

Based on the results recorded, an average ‘walking aid moves per minute’ of 14.66 was recorded. A figure of 15 was therefore selected. The average ‘walking aid distance’ travelled is 0.33 m per move, with a distance travelled per minute of 5.0 m and an average speed of 0.08 m/s (0.3 km/hr).

The encoder on the walker wheel measures distance travelled and the microcontroller calculates speed and acceleration. This data is the basis for profiles of the walker movement, measured and recorded over a number of steps for different users. A correlation between profiles for steps for one user, and for different users, has also been made.

A velocity step profile from experimental test results is displayed in Figure 4. The profile consists of an acceleration phase and a deceleration phase. It was used to determine component size when building the walker.
The walker prototype has been used to develop step profiles. These were analysed and broken into a defined number of stages depending on their natural profiles. The natural profile comprises an acceleration phase, a constant speed phase and finally a deceleration phase, as shown in Figure 5. The movement of the walker has therefore been reduced to three stages. This step profile becomes the controller setpoint. At each stage, maximum distance, speed and acceleration for the safety of the user will be recorded from experimentation.

The results of measured stepped averaged movements for ten cycles of walking aid ambulation are shown in Figure 6, with overlaid movements shown in Figure 7. From these tests, it was noted that the distance travelled per stepped movement ranged from 0.31 m to 0.38 m. Initial tests and results showed that walker movements were consistent. The next requirement was to develop a profile of an expected walker movement, which could be used to determine set points for the control of the walker.

When a user takes a step, should the parameters be outside the maximum values, the walker brakes will automatically come into action. The normal force required to stop the walking aid at maximum acceleration was estimated by calculation at 83 N. An EADmotors DuraPlus two-phase bipolar stepping motor/linear actuator was chosen as the brake drive motor, powered by a Yuasa valve regulated lead acid battery. The system is controlled by a 68HC11 microcontroller.

### 4. CONTROL STRATEGY

A supervisory control system, that can be activated manually by the user or activated automatically, has been implemented. For the automatic system, three types of walker movement are taken into account. The first type is a short slow movement to enable the user manoeuvre in an enclosed area. The second type is stepped walker movement in one direction, and the third type is an ‘unchecked’ movement which might precipitate a fall by the user.

The automatic control supervisory system determines the user intent by examining data from the encoder and comparing it with stored profiles in memory. On determining user intent, the controller then decides which of the following three control strategies to implement:

- If the supervisory system determines that the user intent is a short slow movement, the control output to the brake is put to zero. Likewise, if the controller determines that the user is taking stepped movements but is travelling slower than the stored profile, the control output to the brake is put to zero. Thus, the brake will not be activated.

- If the supervisory system determines that the user is taking a stepped movement and is travelling faster than the stored profile, the controller is implemented as a gain term. Thus, the brake output increases as the error between the profile and the actual speed increases.

- If the supervisory system determines that the speed of the walker is above an acceptable maximum, then the controller output is such that the brake is fully activated.

If the user tires, walking aid movement length and speed will reduce. Likewise, if a taller or stronger person uses the walker, walking aid movement length and speed may increase. To account for such scenarios, an optional “dead-band” feature may be incorporated into the walker. Over a period of typically 10 steps, the parameters of each step are measured; the average values then become “normal” step. Around this normal step, dead-bands of distance, speed and acceleration are defined. This information is incorporated into the walker controller. Therefore, if the user is taking a normal step and the walker is following the accepted norm, the brakes will not operate. However, if the walker is
not following the norm the brakes will come into action, initially ‘gentling’, but as the difference increases, engaging with more effect. There is a dead-band around the norm where no intervention will take place.

4.1 Brake Tests

A 0 to 4 bar pressure transmitter was connected into the brake hydraulic pressure line to monitor brake application. Tests showed that pressure in excess of 2.75 bar will hold the wheel ‘braked’ regardless of driving force applied by the user. A pressure of less than 1.25 bar will result in free rotation of the wheel. The initial pressure can be set at the closed system master cylinder. The brake was set to be off at 1.25 bar and fully on at 3 bar. The stroke of the linear actuator was set accordingly; this involves 600 stepping motor steps in two-phase on activation, resulting in a linear actuator movement of 4.7 mm. Brake activation and deactivation is shown in Figure 8.

Fig. 8. Application of Brake after Stepped Movement

During normal stepped movement, the user moves the walking aid a distance and then moves first one leg and then the second leg. This process is then repeated. When the walking aid speed stays below the speed parameters set to activate the brake, there will be no brake action until the control system recognises that the walker has stopped. Once stopped the brake will activate and apply fully. This is seen in Figure 8.

5. DISCUSSION

A major area of concern with mobility aids is the number of rejections by clients of the chosen aid. The core problem, which leads to rejection, is that of the unit not meeting the user requirements. A recommendation from studies in this area is increased individualisation of walking aids to meet user needs (Brandt et al., 2003).

Extensive tests have been carried out to compare design parameters to recorded values and to ensure correct operation of the prototype walker design. To address “grabbing” in the system, a pulse width modulation design has also been investigated to improve the braking characteristic. As there are a number of step types made when using a walker, the supervisory controller will determine which step type is currently being taken. The step types include: full walking speed step forward, small step forward, small step backward, and turning movement. Each of these movements will have a separate profile, to which the walker will automatically switch. In future work, additional tests and design modifications will be made in order to authenticate and validate the unit from a safety perspective. The viability and efficacy of the design has been demonstrated and it has been shown that the system is a viable option for people requiring a safe walking support mechanism.

REFERENCES

