

HYBRID ORTHOSIS WITH CONTROLLABLE HIP AND KNEE JOINTS AND MULTICHANNEL FES FOR WALKING IN PARAPLEGIA

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Abstract

A hybrid system including trunk-hip-knee-ankle-foot (THKAFO) orthosis and multi-channel functional electrical stimulation with implanted electrodes has been designed for walking in paraplegia. The THKAFO has been instrumented with commercially available spring wrap clutches at the hips and knees. Clutches provide free movement in extension and allow flexion only when they are disengaged by solenoids. Microprocessor controlled stimulator provides activation signals for solenoids, in addition, to multi-channel muscle stimulation. This system provides free motion of the hips and knees during swing phase of gait and selectively locks the hips and knees during stance to prevent collapse. The initial use of this hybrid system has shown the importance of close coupling of THKAFO and the body. This hybrid system has a potential to provide gait powered by muscle stimulation without the usual restrictions in joint motion imposed by the bracing but with stability normally seen only with bracing. Further advantages include reduction in required stimulation during standing and support phases of gait.

Introduction/Background

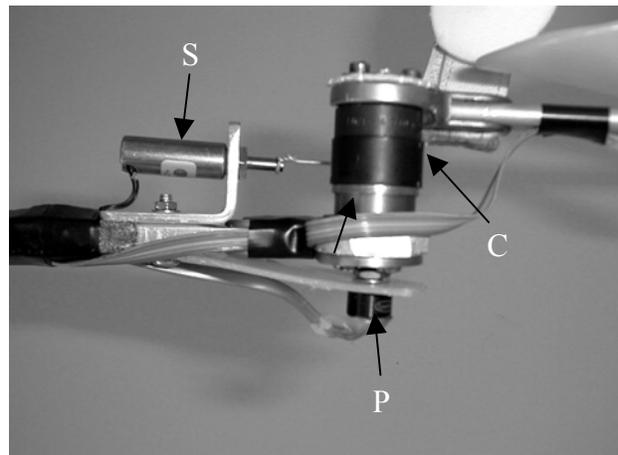
Standing and short distance walking and stair climbing with multi-channel functional electrical stimulation (FES) in paraplegia has been shown feasible. The FES walking, however, has been limited to short distance due to instability requiring considerable effort of the user, resulting in high metabolic energy consumption. An approach to improve stability during walking has been the use of hybrid orthosis – a combination of FES and extensive bracing. Others have used reciprocating gait orthosis (RGO) combined with FES where the knee and ankle joints were locked and the hips were controlled with a reciprocating mechanism [1]. In other attempts, the knee and hip joints were controlled electromechanically with surface FES assisting the movement [2]. The purpose of this project is to implement a hybrid system combining at least 16 channels of implanted FES to provide power to stand up and to move the body forward during walking together with an electronic THKAFO for stability.

Methods

Our prototype THKAFO consists of a trunk corset with a strap at the chest level. Legs are braced with a

molded ankle foot orthosis (AFO) extending to just below the knee having a sliding lock joint at the ankle. A lateral upright connects the trunk corset with the AFO. A strap just below the knee keeps the brace coupled to the body. Abduction joint with sliding lock at the hip allows donning and doffing of the brace in the wheelchair. The THKAFO has been instrumented with a commercially available mechanically actuated wrap spring clutches (Warner Electric, Pitman NJ) at the hips (PSI-5) and knees (PSI-2). Mounting of the clutch at the eccentric knee joint is shown in Figure 1.

Figure 1. Instrumented knee joint (S-solenoid, P-



potentiometer, C-clutch)

A 48-channel microprocessor controlled stimulator provides electrical stimulation through percutaneous intramuscular electrodes implanted in hip flexors and extensors, knee flexors and extensors and ankle plantar and dorsiflexors. The stimulator controller samples eight channels of analog sensor data. The sensors include foot pressure sensing resistors placed on the insoles and potentiometers at the joints (see Fig 1). The combination of sensor thresholds can be used to provide solenoid actuation signals for selective disengagement of clutches for flexion at the hip and knee.

Evaluation of this hybrid prototype system is underway using Vicon (Vicon Motion Systems, Tustin CA) gait analysis system. Data analysis includes evaluation of: kinematic and kinetic data, upper body support (measured with instrumented walker or crutches), sensor data for step initiation and solenoid control, and strain analysis of the brace upright measured with strain gauges.

Results

This prototype hybrid system has been tried on an individual with complete spinal cord injury at T-7 level. Standing up and sitting down was easy with all clutches in unlocked position. Once he achieved standing, the solenoids would engage the clutches preventing collapse of the hips and knees and providing stable erect standing with less than 8 percent of body weight taken up by the arms (Figure 2).



Figure 2. Subject standing with hybrid system.

A control algorithm was developed that synchronizes patterned FES, which provides power for movement during standing up and walking with selective disengagement of clutches at the hips and knees during swing and to provide stability by locking the joints during stance. The brace did not impede the motion of the joint provided by FES. While the brace was able to maintain the subject in erect posture during standing, there was a separation of the lower portion of the trunk corset from the body during walking. This resulted in posterior displacement of the brace hip joint and subject was unable to maintain erect posture during walking as shown in Figure 3.

Discussion/Conclusions

The initial experience and preliminary data with the hybrid system using instrumented THKAFO and at least 16-channels of implanted stimulation has shown that progression in gait can be achieved by FES and stability provided by the brace. The coupling of the brace and body is critical for achieving erect posture and thus reducing the amount of weight carried on the arms. Further analysis will provide the bases for the control algorithm modifications, design of carbon fiber orthosis, and redesign of brace joint controller based on a mechanism combining coaster brake and wrap spring clutch designs.



Figure 3. Motion Analysis of walking with hybrid system.

References

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