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The Gait Orthosis. A Robotic System for Functional Compensation and Biomechanical Evaluation

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I. INTRODUCTION

Knee ankle foot orthoses are prescribed to provide stability and maintain lower limb joints at their functional position. Current devices provide stability by locking joints permanently during the unsafe phase of a pathological gait (the stance phase). Though stability is obtained with such orthoses, gait patterns are unnatural and non-cosmetic. Other systems adapt more dynamically during gait, applying different strategies to recover or improve mobility. A classification can be made, regarding the type of control actions on the joints, segments or muscles: locking/releasing, braking, damping or powering. In the first group, systems like the UTX Swing Orthosis [1] control the knee joint during the swing phase triggering a mechanism based on ankle range of motion. In the second category, engineering attempts on adaptation of brakes [2] and clutches [3] to knee braces have been reported. Finally, there are systems which can control joint movements, passively, modulating the impedance of the joint [4], [5], or actively, using active actuators (pneumatic, electric, etc.), [6], [7], [8]. Problems present in these systems are: unnatural gait patterns, energy consumption, and the necessity of an external power source. Hybrid systems, combining functional electrical stimulation with orthoses to provide ambulation to paraplegic patients, have been explored widely [9]. Discomfort related to stimulation is the major problem of this technique and results are not evidence of a good control of body motion neither energy expenditure reduction. In the field of clinic evaluation, the gait monitoring systems give clinicians useful information to calibrate and optimize rehabilitation equipment. This tools can also help therapists in training patients in the use of new orthotic devices. Commonly, calibration of KAFOs is a trial and error procedure based on clinician experience. Electronics for orthotic devices has been developed [10], [5], [11] but mainly oriented to control. There also exist gait monitoring devices, e.g. step counters. The purpose of this type of device is to help measure physical activity under unconstrained conditions. There are no systems that measure gait biomechanical parameters under normal life so far. Moreover, there is a lack of information about patients performance with orthotic devices, specially during activities of daily living. The GAIT project (EU contract IST-2001-37751) aims to provide an integrated approach to active functional compensation and biomechanical evaluation of lower limb joints disorders by means of robotic exoskeletons. To achieve this goal, the project developed an active KAFO provided with a measurement system (sensors and ambulatory electronic unit), actuators and an intelligent a control system to regulate joint functions during walking and other common daily activities. The system is also conceived as a biomechanical evaluation tool, for both laboratory and daily use, capable of storing data and communicating wirelessly with a software platform for medical analysis.

II. DESCRIPTION OF THE SYSTEM

The system presented consist in a wearable set of sensors, actuators at knee and ankle joints, and a control and monitoring ambulatory unit, all integrated in a custom designed knee-ankle-foot robotic exoskeleton. A base unit allows wireless communication of the ambulatory unit, trough a Bluetooth link, with a PC software platform conceived for on-line and off-line data evaluation. Sensors adapted to the mechanical frame of the orthosis collect kinematics, such as angles at knee and ankle joints, and angular positions and accelerations at lower limb segments; kinetics, such as forces at the orthosis rods and fixation parts, and also foot contact information. The set of sensors used consists of an angular position sensor at the knee, a gyroscope attached to the thigh, a gyroscope/accelerometer combo at the foot, and pressure sensors at the orthosis rods and at the insole. Regarding biomechanical compensation, a biomimetic actuator system, consisting in two actuators based on springs, applies compensation strategies to both joints during walking. These actuators are designed according to their linear elastic behaviour, and functional compensation is applied with timing information of gait events as control input. During the stance phase the system aims to maintain the stability and avoid risk of falling, and during the swing phase, to allow knee flexion, avoid foot drag, and help final extension of the leg. In the all-electronic version of the system, the ambulatory unit performs the necessary control actions on the knee actuator during continuous gait, based on signals from the sensor set. In the case of the mechanically-driven version, this action on the knee actuator is controlled by the ankle angle. Control strategies are also applied to allow smooth and safe operation with automatic detection of transitions between activities (stable standing-sitting-negotiating stairs-negotiating slopes) looking forward to minimize patient intervention.

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