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OPEN SOURCE INFORMATION TECHNOLOGIES APPROACH FOR MODDELING OF ANKLE-FOOT ORTHOSIS

Slavyana Milusheva, Stefan Karastanev, Yuli Toshev

Abstract: Computer modeling is a perspective method for optimal design of prosthesis and orthoses. The study is oriented to develop modular ankle foot orthosis (MAFO) to assist the very frequently observed gait abnormalities relating the human ankle-foot complex using CAD modeling. The main goal is to assist the ankle-foot flexors and extensors during the gait cycle (stance and swing) using torsion spring.

Utilizing 3D modeling and animating open source software (Blender 3D), it is possible to generate artificially different kind of normal and abnormal gaits and investigate and adjust the assistive modular spring driven ankle foot orthosis.

Keywords: biomechanics; 3D computer modeling, ankle-foot orthosis

ACM Classification Keywords: I.3.7 Three-Dimensional Graphics and Realism, I.6.5 Model Development

Introduction

Open source software refers to computer software available with its source code and under an open source license. Such a license permits anyone to study, change, and improve the software, and to distribute the unmodified or modified software. It is the most prominent example of open source development. This software gives an outstanding flexibility in terms of extensibility and modularity.

The study is based of 3D modeling technology provided by one of the most advanced open source software – **Blender.** Blender is a free 3D modeler program. It is used for modeling and rendering three-dimensional graphics and animations. Blender is available for several operating systems, including FreeBSD, IRIX, GNU/Linux, Microsoft Windows, Mac OS X, Solaris, SkyOS, and MorphOS. In addition, Blender's recent burst of new features in the last few versions has actually brought it close in feature set comparison to high-end 3D software such as 3D Studio Max and Maya. Among these features and user interface ideas are, for example, complex fluid and cloth effects, a comprehensive and well-thought out hotkey program, which rivals that of most higher end applications, and a wide range of easily accessible and creatable extensions using Python scripting. Regardless of lack of natively implemented CAD functionality there are a lot of possibilities for development of Python based helper scripts for precise engineer modeling.

Ankle-foot orthosis (AFO) is commonly used to help subjects with weakness of ankle dorsiflexor muscles due to peripheral or central nervous system disorders. Both these disorders are due to the weakness of the tibialis anterior muscle which results in lack of dorsiflexion assist moment. The deformity and muscle weakness of one joint in the lower extremity influences the stability of the adjacent joints, thereby requiring compensatory adaptation.

During level plane ambulation the ankle should be close to a neutral position (right angle) each time the foot strikes the floor. Insufficient dorsiflexion may be the result of hyperactive plantarflexors that produce very high plantarflexion moment at the ankle, or weakness of the dorsiflexion muscles. This affects the ability of the ankle to dorsiflex. As result the patient make a forefoot contact instead of normal “heel-strike”. If there is a weak push-off, the stride length reduces, and the gait velocity decreases. Similarly, during the gait swing phase, the ankle is dorsiflexed to allow the foot to clear the ground while the extremity is advanced. Hyperactive or weak dorsiflexors may result in insufficient dorsiflexion, which must be compensated by alterations in the gait patterns so that the toes do not drag. This insufficient dorsiflexion during the gait swing phase is termed as “foot-drop”. In addition to the toes dragging, the foot may become abnormally supinated, which may result in an ankle sprain or fracture, when the weight is applied to the limb. Foot-drop is commonly observed in subjects after a stroke or personal nerve injury.

There are several possible treatments for foot-drop - medicinal, orthotic, or surgical. It is to note that the most common is the orthotic treatment. Orthotic devices are intended to support the ankle, to correct deformities, and to prevent further occurrences. A key goal of orthotic treatment is to assist the patient achieving normal gait patterns.

Different orthoses are used to enhance the ankle-foot position and mobility. The most common types are hingeless and hinge orthoses. Using springs, the hinge orthoses could assist ankle flexion/extension during gait, i.e. they are pseudo-active orthotic devices. The standard ankle foot orthoses (AFO) is a rigid polypropylene structure which prevents any ankle motion.

Methods

The study is oriented to develop modular ankle foot orthosis (MAFO) with two units (shank brace and foot brace) connected with lateral and medial adjustable hinged joints.

Gait analysis

Gait analysis is useful in objective documentation of walking ability as well as identifying the underlying causes for walking abnormalities in patients with cerebral palsy, stroke, head injury and other neuromuscular problems. The results of gait analysis are useful in determining the best course of treatment in these patients.

Normal gait

The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limb's next initial contact. Stance phase accounts for approximately 60 percent, and swing phase for approximately 40 percent, of a single gait cycle.

Each gait cycle includes two periods when both feet are on the ground. The first period of double limb support begins at initial contact, and lasts for the first 10 to 12 percent of the cycle. The second period of double limb support occurs in the final 10 to 12 percent of stance phase. As the stance limb prepares to leave the ground, the opposite limb contacts the ground and accepts the body's weight. The two periods of double limb support account for 20 to 24 percent of the gait cycle's total duration.

Stance phase of gait is divided into four periods: loading response, midstance, terminal stance, and preswing. Swing phase is divided into three periods: initial swing, midswing, and terminal swing. The beginning and and ending of each period are defined by specific events.

Each subphase is accompanied by a change in position, ground reaction force, and/or internal muscular forces. Gait cycle analysis in this sense is essentially a sagittal plane function.

The ankle is plantarflexed 10 degrees at heelstrike, with further plantorflexion dampened by the ankle dorsiflexors, aiding with shock absorption. At midstance, ground reaction tends to dorsiflex the ankle which is held rigid by the plantarflexors, controlling forward thrust of the tibia. Ground reaction continues to push the ankle toward dorsiflexion in terminal stance, resisted by the plantarflexors. The ankle passively dorsiflexes as it is unloaded in preswing.

Ankle joint motion (sagittal plane):

- between initial heel contact and foot flat ankle undergoes ~3-4° plantar flexion (first 6% of stride);
- after foot flat ankle dorsiflexes until a little beyond 40% of stride (as hip moves over ankle), reaching maximum of 8-10°;
- ankle plantar flexes for remainder of stance phase until after push-off (reaches maximum plantar flexion of 16-19° just after toe-off);
- after push-off ankle rapidly dorsiflexes during early swing for toe clearance;
- ankle dorsiflexion slows or stops during mid-swing but may continue to dorsiflex slightly in late swing until just prior to heel contact when plantarflexion begins.

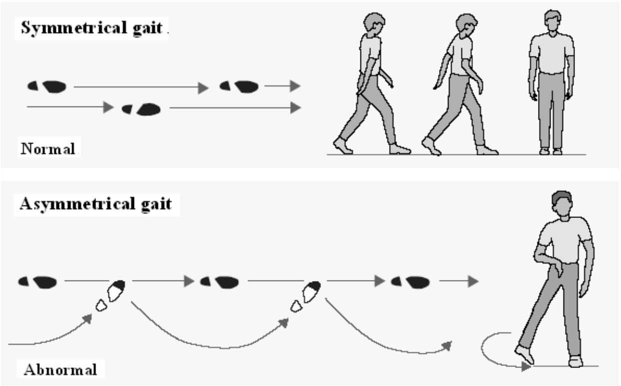

Fig.1.Gait analysis

Abnormal gait

Pathological gait describes altered gait patterns that have been affected by deformity (usually in the form of contractures), muscle weakness, impaired motor control. Any alteration affecting one or more motion or timing pattern can create a pathological gait pattern.

Deviations to normal gait patterns can be observed during both swing and stance phases and requires systematic evaluation for assessment of functional compensations and/or neuromuscular-skeletal factors. Functional compensations are voluntary posturings that attempt to substitute for specific motor weaknesses and joint instabilities. It is important to identify functional compensations from imposed mechanisms for appropriate orthotic design and therapeutic considerations.

Gait analysis can be used to evaluate more objectively the dynamic basis for an observed gait deviation in the patient requiring a lower limb orthosis. It also can be a valuable tool in objectively assessing the impact of different orthotic interventions.

Ankle-foot orthosis

A standard polypropylene AFO is a rigid polypropylene structure which prevents any ankle motion.

Different orthoses are used to enhance the ankle-foot position and mobility. The most common types are hingeless and hinge orthoses. Using springs, the hinge orthoses could assist ankle flexion/extension during gait, i.e. they are pseudo-active orthotic devices.

Which are to assist the quite popular gait abnormalities inherent to a spring-controlled human ankle-foot complex.

Previous studies have shown the DACS (dorsiflexion assist controlled by spring) AFO to have the following desirable characteristics: 1) the magnitude of the dorsiflexion assist moment and the initial ankle angle of the AFO can be changed easily, and 2) no plantarflexion assist moment is generated.

Torsion springs

Torsion springs (Fig.2) can store and release angular energy or statically hold a mechanism in place by deflecting the legs about the body centerline axis. They offer resistance to twist or rotationally applied force.

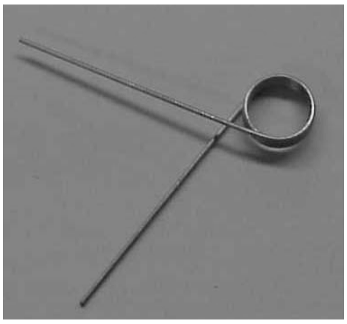

Fig.2. Torsion springs

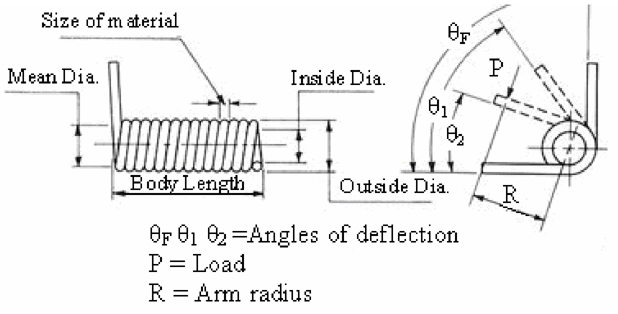

Fig. 3.Linear characteristic of the spring

Figure 3. shows the linear characteristic of the torsion spring

$M_{spring} = -k$ linear spring

where M_{spring} is the spring torque, k is the spring constant and is the angular displacement from its rest angle

Dynamic equilibrium at joints

For normal leg, the dynamic equilibrium at each joint can be expressed as:

$M_i = M_g + M_s + M_d + M_a$

where M_i, M_g, M_s, M_d and M_a represent the torque due to moment of inertia of the rotating segment, gravity, joint stiffness, joint viscosity and muscle activation respectively. As there will be no muscle activity during the period considered, M_a becomes zero.

Results

Using the advanced open source 3D modeler (Blender3D) with outstanding user script capabilities (by Python script language extensions), different 3D computer solid models of MAFO were developed (Fig.4, Fig.5, Fig.6 and Fig.7).

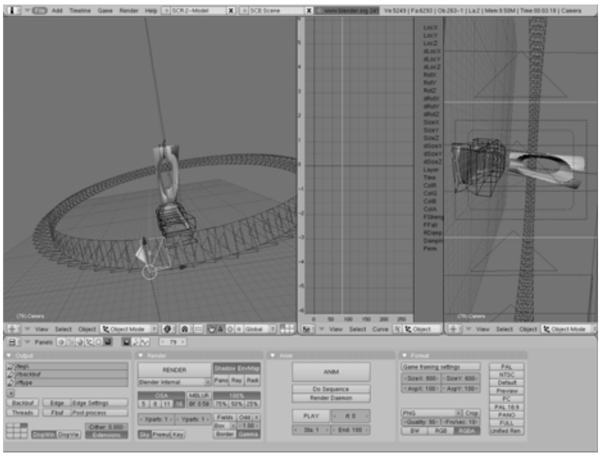

Fig.4. Dump screen of Blender3D during modeling process

Fig.5. 3D computer solid model of MAFO normal state

Fig.6. 3D computer solid model of MAFO in state of tension includes two parts: lower part (foot) and upper part (calf) with two torsion spring (lateral and medial).

Fig.7. 3D model of the human ankle-foot segment with a model of orthoses.

The main idea was to design two personalized AFO parts - lower (foot) and upper (calf), using 3D human model (artificially generated by specialized Blender3d script).

On the base of the obtained 3D surfaces two personalized AFO parts were designed and different variants of elastic elements (torsion spring) connecting the two parts of the orthosis.

A modular ankle-foot orthosis (MAFO) with one degree-of-freedom (dorsiflexion-plantarflexion motion) has been developed. The flexion/extension is controlled by springs. Dorsiflexion correction is achieved via the compression force of springs within the assistive device.

The big advantage of the 3D model is the possibility for further dynamics and kinematics development in field of more precise simulation of the real orthosis behavior. This could be achieved by combination of build-in physics engine of Blender3D, which covers both rigid and soft body simulation and user developed scripts.

Discussion

The magnitude of the MAFO dorsiflexion assist moment and the initial ankle angle can be modified by variation of the spring parameters (spring constant, spring rest angle). Regardless the simplicity of MAFO, the results in improvement of plantarflexion during swing phase are similar to the results obtain using commercial AFOs. The proposed modular ankle-foot orthosis is currently under additional mechanical durability tests. Continuous plantarflexion was applied to MAFO to check the durability of each part. At present, more than two million repetitions of plantar flexion have been applied and no serious problems have arisen. The results of the durability test will be use to improve the design of MAFO. Our MAFO can be used by the patients daily, and is also useful for gait training, since various characteristics can be easily modified. Moderately large dorsiflexion assist moment and small dorsiflexion initial ankle angle facilitates the increase of knee extension muscle forces, thus preventing forward foot slap during the initial stance phase.

References

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APPLICATION OF THE ARTIFICIAL INTELLIGENCE ALGORITHMS FOR SYSTEM ANALYSIS OF MULTI DIMENSION PHYSIOLOGICAL DATA FOR DEVELOPING POLYPARAMETRIC INFORMATION SYSTEM OF PUBLIC HEALTH DIAGNOSTICS

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Abstract: The polyparametric intelligence information system for diagnostics human functional state in medicine and public health is developed. The essence of the system consists in polyparametric describing of human functional state with the unified set of physiological parameters and using the polyparametric cognitive model developed as the tool for a system analysis of multitude data and diagnostics of a human functional state. The model is developed on the basis of general principles geometry and symmetry by algorithms of artificial intelligence systems. The architecture of the system is represented. The model allows analyzing traditional signs - absolute values of electrophysiological parameters and new signs generated by the model – relationships of ones. The classification of physiological multidimensional data is made with a transformer of the model. The results are presented to a physician in a form of visual graph – a pattern individual functional state. This graph allows performing clinical syndrome analysis. A level of human functional state is defined in the case of the developed standard ("ideal") functional state. The complete formalization of results makes it possible to accumulate physiological data and to analyze them by mathematics methods.

ACM Classification Keywords: J.3 Life and Medical Sciences: Health. Medical information systems. I.3.5 Computational Geometry and Object Modeling. I.5.1 Models Geometric.

Introduction

One of problems of the contemporary preventive medicine is the development of an informational system of health diagnostics, which could enable to conduct a system analysis of multitude data, while could be comparable with existing clinical functional diagnostics and corresponding to the modern requirements to medical information systems [Hummel et al. 2000]. The experience obtained by us through the use of the visualized patterns and graphic modeling of functional states of an organism under activity of physiological substances [Dmitrieva et al. 1982] created the basis for development of the polyparametric method for evaluation of a human functional state in terms of the pattern recognition theory [Dmitrieva et al. 1989]. Patient data are presented in graphical formats as visual patterns, which permit to interpret these data in clinical-physiological terms. According to the recommendations of the Word Health Organization we have conducted the comparative research of a health state of students by polyparametric and clinical physiological methods [Dmitrieva, Glazachev, 2000]. These results demonstrated advantages and disadvantages of polyparametric method and lead us to development of new model on the basis of an artificial intelligence algorithms to improve one [Pospelov,1992; Zenkin, 1991].