Proceedings in Manufacturing Systems, Volume 7, Issue 2, 2012 ISSN 2067-9238

GAIT ANALYSIS IN CEREBRAL PALSY USING VICON SYSTEM

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Abstract: *Gait is a cyclical event, and Perry described it for the first time. The gait has two phases: stance* (*60%*) *and swing* (*40%*), *each divided, so stance phase includes pre swing, terminal stance, mid stance, loading response and initial contact, and swing phase includes terminal swing, mid swing and initial swing* (*Fig.* 1). *The stance phase allows body support while swing phase allows limb movement. During the researching we used Vicon system with MX Camera and MX Ultranet HD Cemra. The MX Ultranet HD provides the following functions in an MX system: supplies power, synchronization, and communications for up to* 10 *connected MX Cameras, supplies direct synchronization out* (*sync out*) *functionality for up to eight third-party Gigabit Ethernet cameras, and supplies power.*

Key words*: gait analysis, VICON, kinematics, cerebral palsy.*

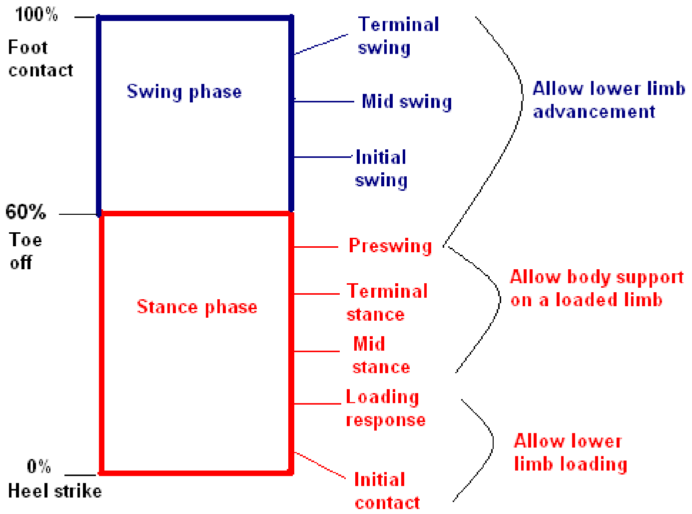

Fig. 1. Gait cycle phases.

1. INTRODUCTION

The system produced by Vicon is an optoelectronic system that uses, in this case, seven high speed cameras, a dedicated computer named Ultranet HD and the Nexus and Polygon software (Fig. 2). The cameras can record with a speed up to 2 KHz and have a 0.3 megapixels sensor. Usually the gait is recorded with a frequency of 50 Hz, but for these trials a frequency of 100 Hz had been used.

The system recognizes and reconstructs into a virtual space the passive markers put on specific anatomical

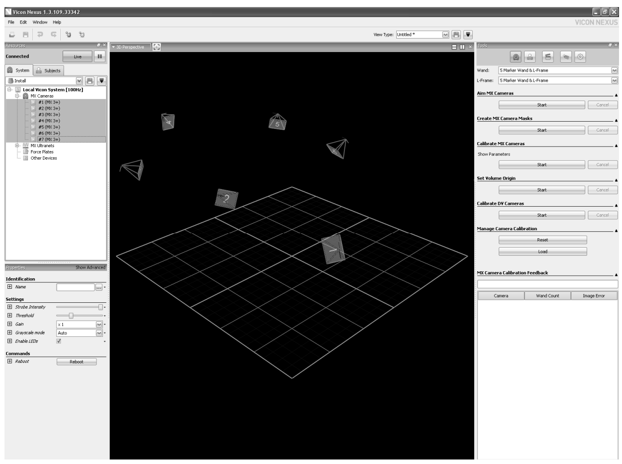

Fig. 2. Vicon Nexus interface.

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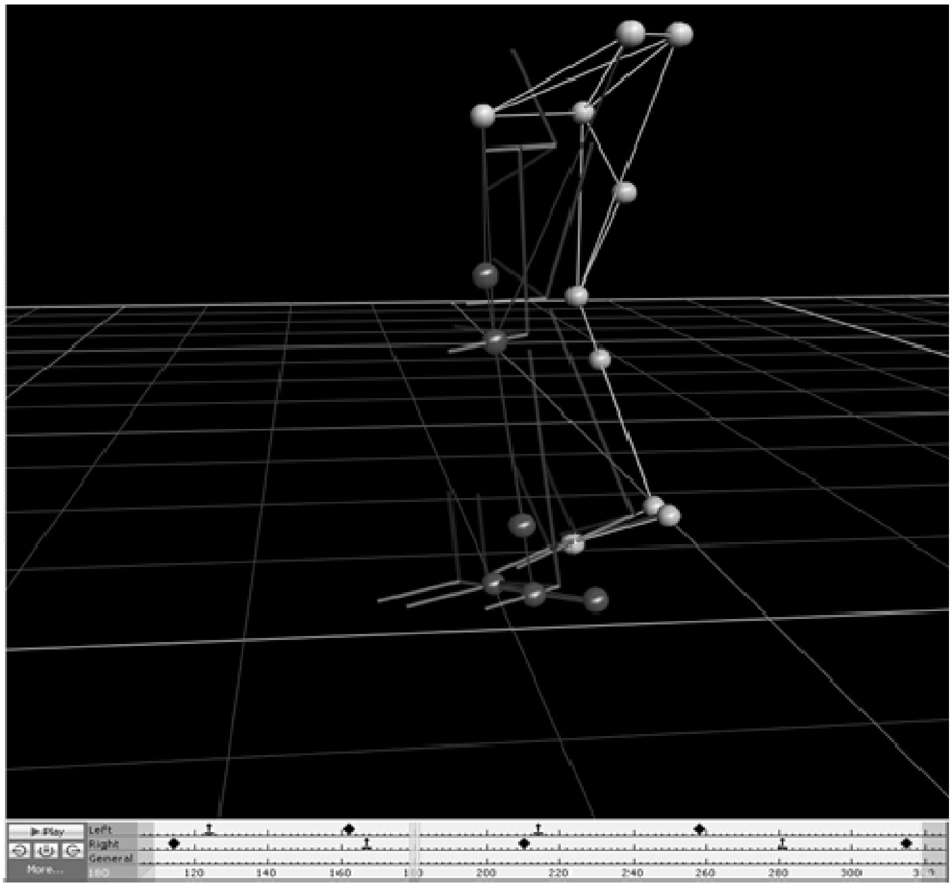

Fig. 3. Passive markers in virtual space.

references, the movement being reconstructed using these information. The user can have the reconstructed gait and other results as presented from this point forward.

Gait analysis has found many uses in the treatment of an individual with a neuromuscular disability, especially in cerebral palsy. Gait analysis can observe specific deviations of one patient, allowing us to be more accurate in motor diagnoses and treatment solutions. Because gait is a complex event we must use several methods to properly analyze it. Gait analysis has four directions: kinematics (represents body movements analysis without calculating the forces), kinetics (represents body moments and forces), energy consumption (measured by oximetry), neuromuscular activity (measured by EMG). We analyzed the gait using VICON system, providing us kinematic data. During kinematic evaluations, the motion of each joint is measured as the children walk, the children being measured and instrumented with retro reflective markers that are viewed by multiple video cameras. The markers define specific anatomic body points (Fig. 5), which the computer program uses to calculate joint motion (Fig. 3). Our purpose here is to discuss how these parameters are used in gait evaluation.

2. THE ANKLE

It is the most complex curve and can be divided in 4, as follows (Fig. 4):

- The first part takes place between initial contact of one and the other foot. The ankle is almost neutral when initial contact begins and is in plantar flexion until the entire foot is on the ground.

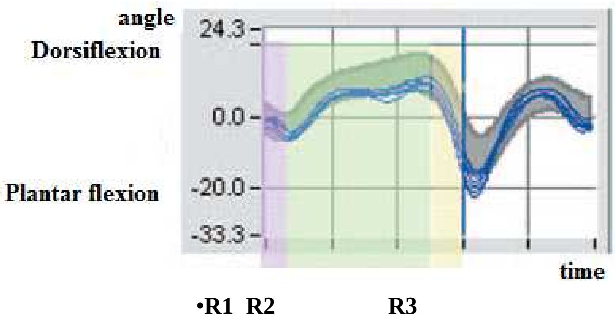

Fig. 4. Normal plantar flexion – ankle dorsiflexion slide using VICON [6].

- The second part takes place between contra lateral limb toe-off and heel strike. It is superiorly convex and reflects moving the body over the stationary foot. Arriving to the end of the unipodal stationary, the heel is lifting and dorsal flexors contracts concentrically.
- The third segment continues with initial contact of the other foot and ends with toe off, with a rapid plantar flexion.
- The forth segment is the rapid ankle dorsiflexion [1].

Also, the total movement amplitude is not big (between 20–40 degrees), it is essential to preserve it, for limb advancement and shock absorption in stance phase, and limb progression in swing phase. In stance phase, ankle movement was described in three steps, known as rockers. Rocker 1 (heel rocker) can be described like this: vusingv the heel as a fulcrum (rod motion axis), the

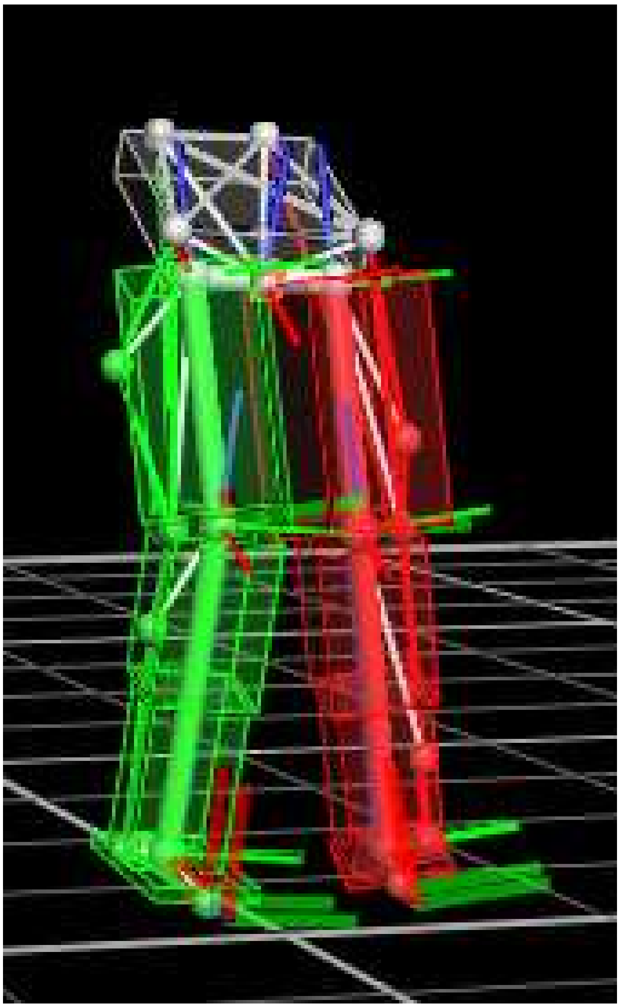

Fig. 5. Frame of the passive markers.

foot rolls into plantar flexion and tibialis anterior contracts eccentric. Rocker 2 (ankle rocker) – now the ankle is the fulcrum, as the forefoot strikes the floor; the foot is stationary and the tibia roles anteriorly by eccentric contraction of soleus and gastrocnemian muscles. Rocker 3 (forefoot rocker) provides the strongest propelling force during the gait cycle, and also serves as the base for limb advancement in pre swing; all is possible by concentric contraction of soleus and gastrocnemian muscles.

There are three foot articulations with biomechanical importance:

- Subtalar join – provides mobility in all three planes.
- Mediotalar joint – between talonavicular and calcaneocuboidian joints has a role in absorbing shock in forefoot contact.
- Metatarsophalangian joints –provides forefoot support and stability.

The functional role of the foot is shock absorption, loading stability and progression, as sequential tasks, from initial contact to foot support [2].

In this slide ("ankle dorsiplantar"), from a five years old child with cerebral palsy, we can see the modifications (Fig. 6):

- Delayed dorsiflexion in stance phase (rocker 2), lack of rocker 1 and rocker 3.
- Plantar flexion during the entire gait cycle;

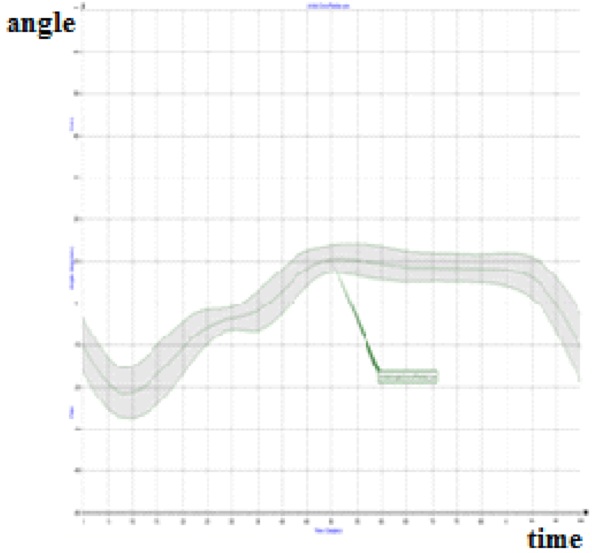

Fig. 6. Ankle plantar flexion-dorsiflexion slide in a 5 years child with CP, using VICON.

3. THE KNEE

The knee has two functions during gait (Fig. 7):

- Shock absorption as the limb is loaded.
- Lower limb length adjustment, allowing just a small vertical body weight vector modification (0.5 cm opposed to 9.5 cm); lowering the vertical oscillation also drops the energy cost by 50%.
- Stability after loading.
- Rapid flexion in swing phase required for limb advancement.

At initial contact, the knee is slightly flexed (5 degrees), allowing a better shock absorption. Quadriceps and hamstrings contract isometric, almost simultaneous, to stabilize the knee. In loading period, the knee flexes 10-15 degrees, allowing the body to advance. In mid stance phase, the knee begins to extend, to maintain the height; the movement is largely passive, controlled only by eccentric soles contraction and couple knee extension-ankle plantar flexion. This couple is very efficient when the knee is aligned with the ankle and it can generate a stable vector. If there is valgus foot deviation, then soleus is no longer so efficient in this biomechanical. In terminal stance, the knee begins to flect rapidly, as the ankle is in plantar flexion and the heel is lifted of the ground [3]. This flexion is passive, produced by forces generated at hip (flexion) and ankle (flexion), with no contraction in hamstrings. As the knee flexion continues,

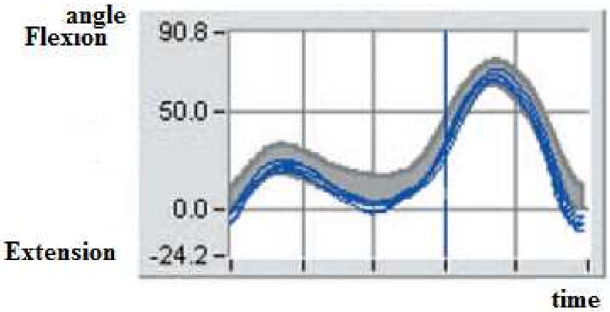

Fig. 7. Normal knee flexion-extension slide using VICON [6].

femoral rectus begins to contract eccentric, to lower the flexion speed. After it reaches maximum of knee flexion, rectus femoral stops to contract and the knee starts to extend passive. In terminal swing phase the extension starts to grow rapidly, counteracted by eccentric hamstrings contraction. This period is very important in controlling step length.

First knee flexion, in stance phase, is important because is shock absorbing, lowering the limb length and preventing excessive vertical body vector translation. This can be done by eccentric contraction of quadriceps, active until ground reaction force reaches anteriorly to the knee, generating an extension force and bringing the knee back in extension until mid-stance; also, this passive extension cannot take place without powerful eccentric contraction of plantar flexors. The second knee flexion is necessary foot clearance at pre swing. It begins at the end of unilateral stance phase, while the heel begins to lift from the floor, and precedes the beginning of hip flexion at contra lateral heel strike. This flexion shortens the length of the limb, allowing foot clearance. Then the knee is extended and it reaches maximum prior to heel strike [6].

In this slide ("knee flexion/extension") of a 5 years old child with CP, we can see the modifications (Fig. 8):

- The second flexion is missing because of numerous factors: lack of force for forward movement (no rockers so no force for soleus and gastrocnemius muscles), lack of normal contraction for hamstrings and hip flexors, rectus femoral spasticity.
- Limited knee mobility, with flexum, in stance phase, because of hamstring spasticity.

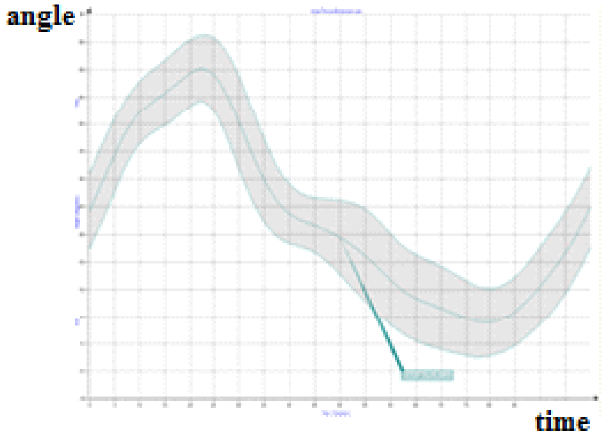

Fig. 8. Knee flexion-extension slide in a 5 years old child with CP, using VICON.

4. THE HIP

The hip moves in all three directions:

- Hip flexion/extension

Mmaximum flexion takes place at terminal swing, and maximum extension at contra lateral heel strike.

- Hip abduction/adduction

The peak of adduction is at toe off and contralateral initial contact, and the peak of abduction is at toe off.

- Hip rotation.

It is the difference between pelvis rotation and femoral rotation. It begins in mid swing and ends at contra lateral initial contact (Fig. 9).

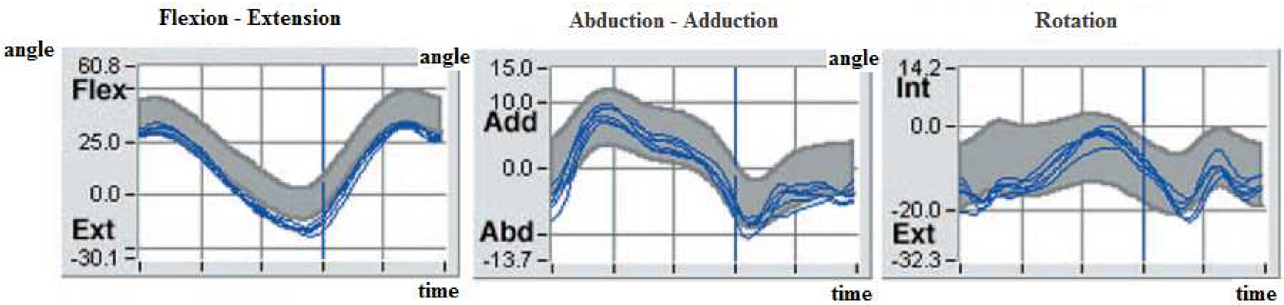

Fig. 9. Normal hip flexion/extension, abduction/adduction and rotation slides using VICON [6].

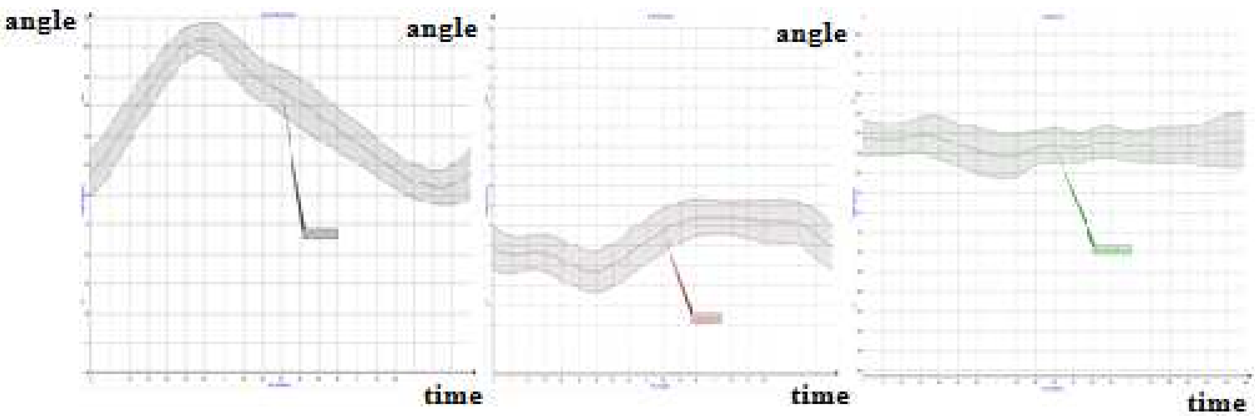

Fig. 10. Hip flexion/extension, abduction/adduction and rotation slides in a five years old child with CP using VICON.

On these slides (Fig. 10), form a five years old child with cerebral palsy, we can observe the modifications:

- Lowering hip extension because of psoas spasticity.
- Posterior pelvic tilt because o psoas spasticity.
- Excessive hip adduction and lowering hip abduction, for entire gait cycle, because hip adductor spasticity (it can be observed on slide "Hip adduction").
- Excessive internal rotation with greater femoral anteversion (it can be observed on slides "Hip rotation").

Hip musculature control is important in two ways: in stance phase stabilizes the trunk and then, initiate limb advancement. Hip extensors decelerate lower limb at terminal swing, preparing it for stance phase, controls pelvis and trunk advancement as the limb is loaded. Hip abductors balances pelvis drop, and in swing phase hip flexors helps limb advancement. At initial contact, the hip begins to extend, by strong glutens contraction; also, hamstrings, abductors and adductors stay active almost all stance phase. In mid and terminal stance the only muscle constant active is tensor fascia lata.

In terminal stance hip flexion is produced by psoas and gastrosoleus muscle. In pre swing and swing phases, adductors became active as flexor and hip adductor. At the beginning of swing phase, glutens maximus contracts strongly, generating an important moment in body propolsion, second after gastrosoleus [4].

5. THE PELVIS

Pelvis has three important movements recorded by VICON systems (Fig. 11):

- Pelvic anterior tilt – is controlled by gravity, inertia, action of hip flexors and extensors. Pelvis has maximum of horizontality at the end of double support
- Pelvic obliquity – normally, contra lateral pelvis drops at the beginning of stance phase, working as a shock absorbent and adjusting limb length.
- Pelvic rotation – it is a single sinusoid curve, just like hip flexion/extension. Internal rotation is maximal at initial contact and external rotation is maximal at contra lateral initial contact.
- During gait cycle, at pelvic level, muscles have two functions: shock absorption and trunk stability [5].

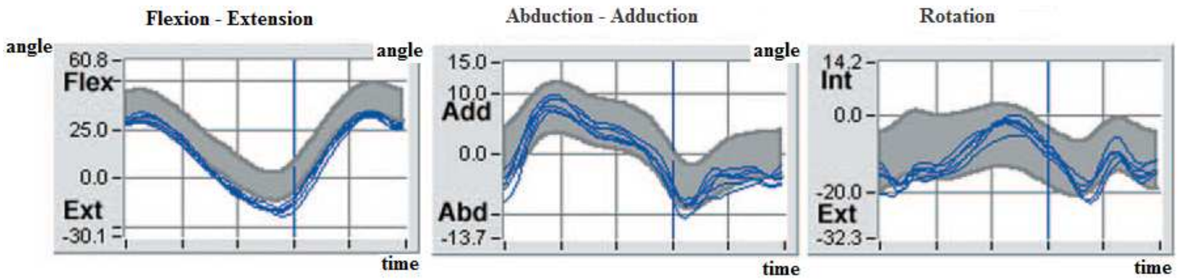

Fig. 11. Normal pelvic flexion/extension, abduction/adduction and rotation slides using VICON.

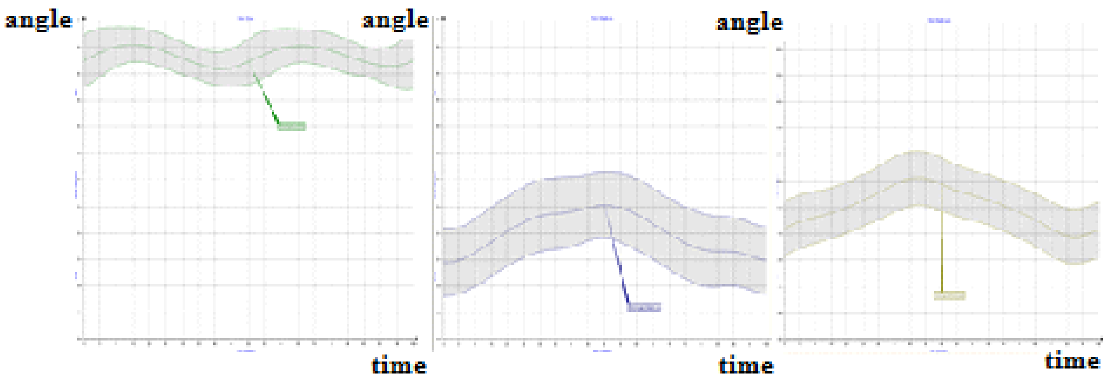

Fig. 12. Pelvic flexion/extension, abduction/adduction and rotation slides in a 5 years old child with CP using VICON.

Fig. 13. Hardware structure.

On these slides (Fig. 12), from a five years old child with cerebral palsy, we can see the modifications:

- Lowering pelvic extension secondary to psoas spasticity (it can be observed on slide "Pelvic tilt").
- Modifying pelvic obliquity.

Vicon is a motion capture platform designed expressly for Life Sciences applications (Fig. 13). Clinical and research laboratories, sports performance centers, universities and other institutions can take advantage of the user-friendly interface to track and measure motion in real time. Optical, digital, and analog capture are all contained in a single, easy-to-use platform that will give Life Sciences professionals an advantage in their applications for gait analysis and rehabilitation; biomechanical research; posture, balance and motor control.

The ranges of Vicon motion capture cameras for Vicon MX feature multiple high-speed processors that perform real-time proprietary image processing.

MX Cameras are fitted with commercially available CMOS sensors. Vicon Motion Systems subjects all of its cameras to stringent checks for linearity, sensitivity, and absence of jitter. All MX Cameras provide high-speed and low-latency motion capture. You can combine the different types of MX Camera within a single Vicon MX system to meet your application requirements for resolution and/or coverage.

MX Cameras evaluate an entire image in grayscale, rather than applying a black and white threshold. This provides more information and increases motion measurement accuracy over an equivalent resolution black and white camera. The MX Cameras perform the majority of data processing. They generate grayscale blobs for reflections from objects in the capture volume and then use centroid-fitting algorithms to determine which of these objects are likely to be markers. MX Camera data is sent to Vicon application software for viewing and further processing.

6. CONCLUSIONS

Simply observing the gait and noting abnormalities is of little value by itself. Visual gait analysis is entirely subjective and the quality of the analysis depends on the skill of the person performing it. The use of kinematic systems (like VICON), or, better kinematic/kinetic systems combined with EMG, has led to more accurate identification of gait problems, and in children with cerebral palsy in distinguishing between the primary problem and secondary adaptation. All these information are analyzed by the physician, in order to develop a proper treatment management: surgery intervention, botulinum toxin injection, use of ortosis, physical kinetic therapy, oral medications, and implanted baclofen pump.

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