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New Measurement Techniques for Gait Analysis: the Grail experience

L. Iuppariello[1], P. Bifulco[1] , M. Cesarelli[1], S. Esposito[2], M.Nespoli[2], L.Foggia[2] ,F.Clemente[3]

[1] Department of Electric Engineering and Information Technologies (DIETI), School of Engineering, University of Naples Federico II, Naples, Italy
[2]Department of Rehabiliation, AORN Santobono-Pausilipon, Naples, Italy.
[3]IBB, Italian National Research Council, Rome, Italy.

***Abstract* – Virtual Reality, otherwise referred to as VR, is a new approach in stroke rehabilitation that is gaining popularity. VR allows us to combine Virtual Reality and the latest in computer technology to assist patients in improving their motor functioning in ways that are not possible through physical therapy alone. These aspects are at the base of the GRAIL, the new solution for gait analysis and gait training. GRAIL uses an instrumented dual-belt treadmill, a motion-capture**
system and synchronized Virtual Reality (VR) environments next several video cameras and EMG, to analyse and improving gait abilities. The presence of these hardware devices and several software modules, need the high ability to manage the whole system. So, this work aims to accurately describe all the needed steps to accomplish a gait analysis measure

***Keywords* – Virtual Reality, Gait Analysis, Rehabilitation**

I. INTRODUCTION

During the last years, the use of Virtual Reality (VR) is increasing in Neurorehabilitation field and is currently part of advanced physical rehabilitation therapy [1-3], providing new interfaces where patients can interact within virtual worlds that simulates real world. VR simulates real-life activities and experiences, providing feedback that permit to evaluate the subject’s gait in an environment that more realistically mimics everyday life compared to a typical gait laboratory. To assure these characteristics, the applications of certain technologies make use of novel instrumented treadmills and several sensor types capable of generating scenarios which allow researchers to study and to precisely adapt the patient’s therapy. This results on several advantages of VR-based therapies over traditional rehabilitation programs. Among the new commercial platforms based on VR used to flank and support the traditional programs in clinical environments [4,5], the GRAIL (Gait Analysis Interactive Lab), produced by Motek Medical, represents the one which has shown encouraging prospects both as evaluative and rehabilitative system. GRAIL offers clinical gait analysis and gait training using the latest technologies solidly integrated in one functional system, providing the full functionality of a traditional gait lab and more. The GRAIL system permits to process all gait parameters in real-time, so they are directly available for gait training using immediate feedback. GRAIL can be used as a standard for a variety of patient groups like neurological, orthopaedic, muscular-skeletal complaints and elderly with increased risk of falling. The system complexity, due to the presence of hardware components of sophisticated level, requires competence and training requirements. So, this work aims to accurately describe the procedure needed to control the system and correctly achieve a gait analysis measure.

A. The Grail Architecture

GRAIL is a synchronized system that consists of self-paced instrumented dual-belt treadmill, an integrated motion-capture system and six video cameras.

The entire GRAIL setup can be split up in to three parts: i) the ‘System operating area; ii) the ‘Operator desk’; iii) the ‘Background processing’ (Figure 1). The “System operating area” includes all the hardware the subject has direct interaction with. Almost all components in this part are there to create the immersive experience for the subject. The “Operator desk” includes all the hardware the operator has direct interaction with. In particular, it includes two computers (D-Flow and MoCap) to manage the entire system. The D-Flow computer uses two dedicated monitors, one mouse and one keyboard. The operation of the D-Flow computer is like any other personal computer. The D-Flow software controls the whole system, overseeing the relationship between the subject, the scenario and the interactive feedbacks and stimulations [6].

Next to the D-Flow computer, the GRAIL includes multiple other computers. These computers are all connected to one monitor, mouse and keyboard. To control all computers with one set of monitors, mouse and keyboard a KVM switch is used (Figure 2). From here, the operator controls what happens in the 'System operating area'. Finally, the "Background processing" includes all the control hardware that is needed to control the system.

This organisation permits for the calculation of all gait parameters in real-time (spatio-temporal parameters, kinematics, kinetics and muscle-activation). The self-paced mode permits the subject to walk at a self-selected speed, while the treadmill and the VR environment are perfectly synchronized. Accurate gait parameters are ensured due to a natural walking pattern, facilitated by an immersive VR environment projected on a 180° screen. This gives a subject the impression of walking in a natural with peripheral view. Accuracy of the data can be verified in real-time. An off-line analysis tool offers dedicated data analysis.

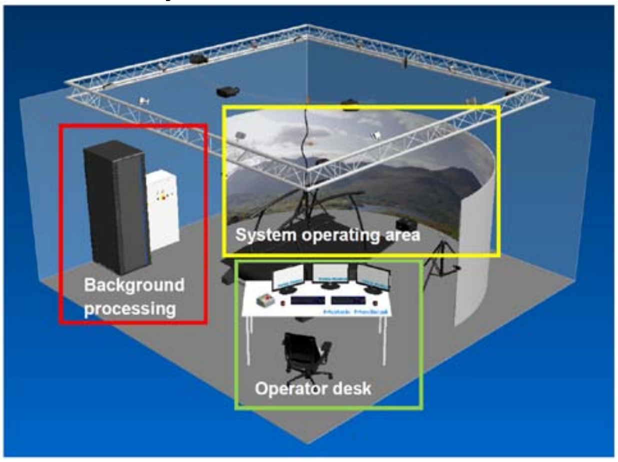

Fig. 1. The Grail system.

Fig. 1. The Operator desk.

B. The Grail calibration

This section gives a description of the daily operation for initializing the Grail system. At first, the system must be started by enabling the "treadmill control cabinet" (MIC). Then, D-Flow and MoCap computers, the motion capture system, the audio system and the monitors must be turned on. Before starting a gait analysis measure, the *motion capture system* and *the force plates* have to be calibrated. Two steps are commonly used for the motion capture systems calibration: the static calibration and the camera calibration. The static calibration is performed by using a wand embedded with five markers emitting red LED lights. This wand is accurately positioned on the origin (centre) of the treadmill (Figure 3).


Fig.3 The Wand used for the static calibration.

This step permit to set the camera position and the global origin of the acquisition volume where the subjects will be analysed.

The camera calibration consists in moving the wand (Figure 4) in the acquisition volume so that each camera collects the requested number of refinement frames in the acquisition volume. After calibrating the cameras, the average error of the position will be given with a Root Mean Square (RMS) value on the MoCap.

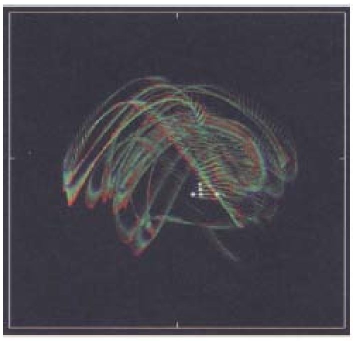
Fig. 4. The camera calibration obtained by moving the wand in the acquisition volume.

In order to get a good camera calibration, it is not only important to have a low RMS value but even more important is to have a homogeneous covered capture volume. This means that the whole capture volume must me covered well during wand waving. If this is not done very accurately, it will result in different RMS values for different parts of the capture volume. In general, the motion capture system should be calibrated before each first session of the day, to avoid unstable data due to cameras that are (possibly) moved.

Two force plates are integrated in the dual-belt treadmill and mounted on a two degrees of freedom motion frame. These plates are used to analyse the moving pattern of the point of application of the vertical component of resultant force during level walking (Figure 5). The calibration of the force plates with a specific module installed on the D-Flow computer, when no weight is exerted on them.

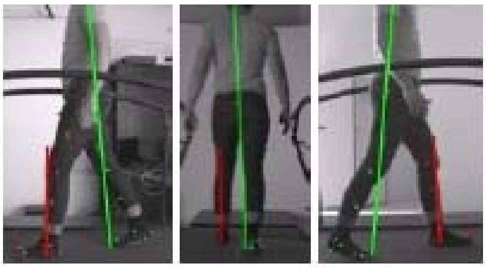

Fig. 5. Ground reaction forces during normal walking.

Once completed both the motion capture system and the force plates calibrations, the system is ready to collect a gait analysis session.

C. The gait analysis session with the Grail system

A GRAIL normal walking session needs a proper preparation with additional steps in the motion capture software and D-Flow. At first, it needs the subject's preparation. In particular, the gait analysis session needs to capture the three-dimensional movement of specialized reflective markers, which reflect light from the strobe back into the camera. To enable motion capture, the operator attaches these markers to the subject (Figure 6). These are used by the D-Flow software to define the biomechanical skeleton. Accurate placement of these markers is essential for accurate kinematic and kinetic results.

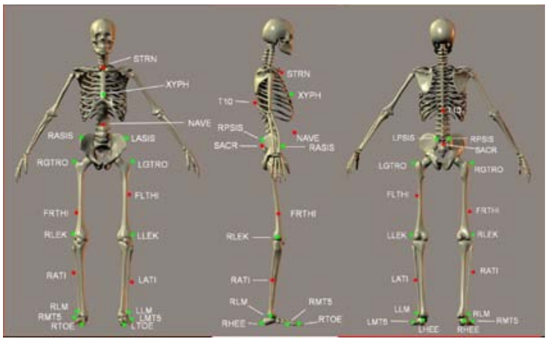

Fig. 6. The position of the markers on the body subject.

After positioning the markers, the operator helps the subject while stepping on the treadmill. Here, he supports the subject with putting on a safety harness (Figure 7), adjusting and securing it.

Fig. 7. The safety harness used to prevent the subject from falling off the treadmill.

The gait analysis session also requires Range Of Motion trial (ROM). In this step, the subject performs a Range Of Motion trial on the treadmill in the middle of the capture volume. This ROM is recorded and processed in MoCap software in order to minimize the real time labelling errors and to create the virtual skeleton (Figure 8) or full human body model (HBM) that can produce a real-time analysis of 3D kinematics, kinetics, and muscle function.

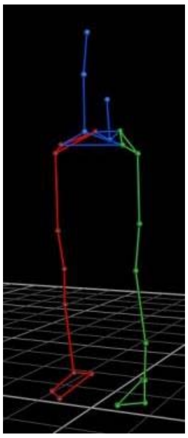

Fig. 8. The full Human Body Model.

In this step, the subject start from standing in a T-pose for few seconds, then he walks for a few seconds at his comfortable walking speed. Then, the ROM trial is processed calibrating the subject's bone lengths, joint locations and marker locations using the whole trial, in order to obtain the HBM for that walking session. Once the MoCap module, Treadmill module are set up properly and the HBM is ready, gait data can be recorded by using the D-Flow software. At this point, the operator runs or a normal walking session or the Standard Applications Suite (Figure 9) which contains a set of four Serious games for Rehabilitation, aimed at training balance control and dual tasking for patients facing problems in the area of coordination, posture, gait, balance and/or stability.

Fig. 9. Standard Application Suite.

The gait session produces can be processed with the Gait

Off-line Analysis Tool (GOAT) which checks spatio-temporal, kinematic and kinetic parameters in combination with the corresponding video, also producing a gait report of the session can be exported to PDF.

II. CONCLUSIONS

Recently, with the expansion of medical-related technology, a new type of physical therapy has arisen. For the first time ever, virtual reality is playing a role in the execution of physical therapy. The use of virtual reality in physical therapy has yielded studies with some very encouraging results, demonstrating a clear link between the effectiveness that the duo might be able to provide. For patients recovering from strokes, surgeries, or injuries [7-8], virtual reality-augmented rehabilitation has shown hope for recovery [9]. Recently, virtual reality environments have been integrated with motion platforms, instrumented treadmills, motion-capture systems, in the GRAIL, which represents a total solution package, for both gait analysis and gait re-training. Synchronized VR environments, projected on a semi-cylindrical screen, immerse the patient in virtual worlds and natural walking environments. The self-paced mode of the treadmill allows the patient to initiate gait and walk at a self-selected speed, while the treadmill and the VR environment run in perfect synchronization, providing a 'functional gait analysis'. Walking on the treadmill permits long-term gait analysis and rehabilitation sessions, especially useful in cardiovascular pathologies [10] or obesity [11]

This work aimed to describe the steps which are involved in performing this functional gait analysis, by managing all the sophisticated hardware devices and software modules of the GRAIL.

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