Application of inertial sensors for motion analysis

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***Abstract*—this paper presents our results on the application of various inertial sensors for motion analysis. After the introduction of different sensor types (accelerometer, gyroscope, magnetic field sensor), we discuss the possible data collection and transfer techniques using embedded signal processing and wireless data communication methods [1,2]. Special consideration is given to the interpretation of accelerometer readings, which contains both the static and dynamic components, and is affected by the orientation and rotation of the sensor. We will demonstrate the possibility to decompose these components for quasiperiodic motions. Finally we will demonstrate the application of commercially available devices (Wii sensor, Kinect sensor, mobile phone) for motion analysis applications.**

I. INTRODUCTION

Motion analysis can be used in rehabilitation and motion therapy for several purposes. One possibility is to provide objective parameters for the qualification of the improvements induced by the therapy. Another area of application is to provide direct feedback during the therapy session about the proper performance and accuracy of the movement. One can also use motion analysis for diagnostic purposes.

Traditionally, these measurements require expensive equipment and specialized laboratory conditions, which fact inhibited their wide spread application. With the development of cheap sensors and embedded data collection techniques, this situation is changing. One can develop application specific systems or one can utilize ready-made sensor systems for the specific application.

There are two categories of sensors, which can be applied for motion sensing. The inertial sensor like the accelerometer, gyroscope, or magnetometer does not require any external reference system. Another possibility is to use optical- or infra cameras which detect the motion of object or special marker point. An external reference frame is also needed when ultrasonic or electromagnetic wave propagation time measurements are used to determine the position of the points of interest like for example in a GPS system.

Some sensors are also affected by the presence of external static fields like the accelerometer and the magnetic sensor. These static fields can be used to determine the orientation of the sensor, but can also interfere with the determination of the dynamic accelerations.

The raw sensor data must be filtered and then stored locally or transferred wirelessly to an external data processing system. In case of diagnostic or motion analysis application, the data processing step can be performed off-line. When feedback is required the data processing must be performed real time during the measurement.

I. ACCELEROMETRY WITH SEVERAL SENSORS

We have developed a data collection system with three accelerometer sensors for the purpose of motion analysis during horse riding and gait analysis. The data logger is based on an Atmel ATMEGA-128 microcontroller which stores the data to an MMC card. The card can be put on a PC for processing. The data logger has a one button interface, which can be used to start and stop the measurement. Acoustic feedback is provided by a buzzer to the user about the normal operation or internal error (like a missing MMC card). Two LEDs shows the state of operation (powered on, standby, measuring). The sensor units are connected trough USB type connectors with a non standard data line wiring. These connectors provide good contact, but can easily be disjoined, which is important for safety and convenience reasons.

Figure 1. MMA7260QT 3-axis accelerometer sensor AT MEGA 128 microcontroller USB commectors MMC card for data storage

We have chosen the MMA 7620Q accelerometer sensors (Freescale Inc., USA, Austin). The acceleration sensitivity can be set to four different levels by jumpers. Two ranges are applicable for small accelerations up to 1.5 g and 2 g and two ranges are applicable for higher accelerations up to 4 g and 6 g limits. The accelerometer data presents the dynamic accelerations and to the static acceleration of the Earth's gravity together. The static acceleration was used for the calibration of the sensors. The calibration can be easily performed before the actual measurement, by placing the rectangular sensor box on its six sides onto a horizontal surface. In this way systematic errors related to the drift of sensitivity and zero point with temperature can be eliminated.

A separate video camera recorded the motion for documentation and analysis. The subject of the measurement can receive various instructions or the performed motion can change for other reasons. These events are recorded on the video, and can be used later to segment the acceleration measurement into different parts.

II. MOTION ANALYSIS APPLICATIONS

The above described system was used for gait analysis and for hyppotherapy measurements. The aim of the study was to compare the acceleration patterns of the horse's back to the accelerations of persons during normal gait, and to study the acceleration patterns of normal and disabled horse rides. The aim of the hyppotherapy is to improve the motion coordination and muscular development of children with mental disorders.

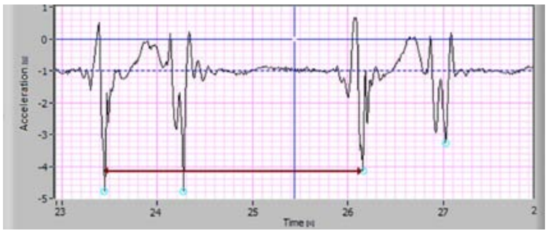

Figure 2. Gait cycle identification

The data analysis starts with the gait cycle identification. This is achieved based on the heel strike signals, which provides high acceleration peaks in the measurement.

In order to compare the phases of the motion for the different subjects, the gait cycles are averaged and scaled in the time axis to the same length.

We could scale the acceleration patterns in this way for people with different size and walking speed. We have found a good matching of the acceleration signal for the horse back with the motion of the subjects back. Results of these studies were published elsewhere [1,2]

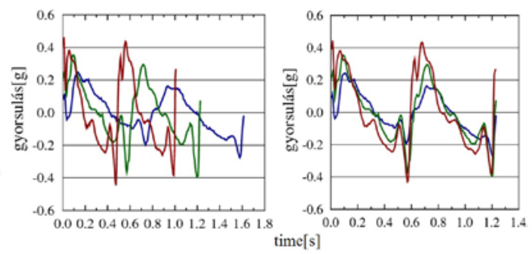

Figure 3. Averaging single data sets | Scaling different data sets

III. APPLICATION OF COMMERCIALLY AVAILABLE DEVICES

There are several sensor devices, which were developed for gaming interfaces, which are applicable for motion sensing applications. In the following sections, we are providing application examples for three cases.

A. Nintendo Wii sensor

The Nintendo wii sensor contains an Ir camera 1024x768 100Hz which is capable of providing the coordinates of four IR LED light sources. In this way the spatial orientation of the sensor can be determined relative to the fixed markers. The sensor contains an accelerometer (ADXL330) and can be extended with a gyroscope module. The wii sensor can be connected to the PC using the Bluetooth radio. There is a software development kit and a LabVIEW modul available .

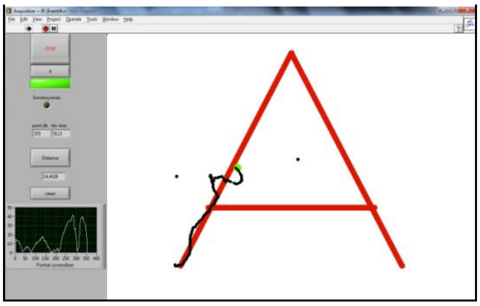
Figure 4. Coordination testing

We have used the Wii sensor for a motion coordination testing application. The users have to move wii to follow the lines of a character on the screen. The precision of the motion is evaluated by the software, and can be used to measure the progress of some muscle degradation related diseases.

B. Microsoft Kinect

The Microsoft kinect sensor is a motion sensing input device, which was developed by Microsoft for the Xbox 360 console. The goal was to enable the user to communicate with the consol without touch or any hand held control device. The main advantage of the Kinect sensor for motion analysis is that it can provide markerless position information. The system became open for external developers in jun. 2011, when Microsoft released an SDK (Software Development Kit) for the Windows 7 operating system.

The Kinect sensor has two cameras and an infrared light source, which projects a textured light on the nearby objects. The RGB camera has 1280x1200 pixel resolution while the infrared camera, which provides the depth information, has 640x480 resolution and 30 frames/sec sampling rate.

We have applied the Kinect sensor for motion analysis. The data of the Kinect sensor was processed with LabVIEW program utilizing the SDK. The image processing was performed with the IMAQ package.

In order to simplify the object identification, the motion of a white box was followed. The program automatically identifies the box, and calculates its position based on the depth image. The actual orientation of the box could also be calculated from the image and 3D data. In this way, both spatial position and orientation of the moving object could be determined.

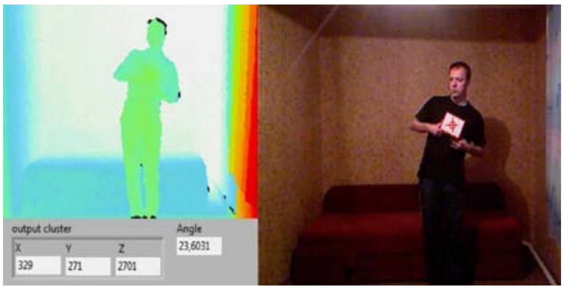

Figure 5. RGB and depth image of the Kinect sensor, and the measured position and orientation of the box

We have used the kinect system in combination with a force plate for the study of human balance [3]. Balancing motion during quite standing can be described as a pendulum motion.

The force plate can determine the center of pressure (COP) of the object on the balance. The force plate has three legs, each is supported by a force sensor. The COP is calculated as the point, where the angular momentum of the three forces is zero.

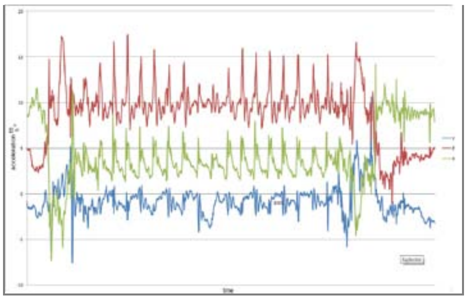

Figure 5. Acceleration of a gait logged on an android phone

We have placed a simple pendulum on the force plate and determined the COP motion and also applied the kinect sensor to determine the actual coordinates of the pendulum. We have found that the COP coordinate varies in sync with the coordinates of the pendulum, but the amplitude of the COP is larger, than the amplitude of the pendulum mass motion. The difference between the two amplitudes can be accounted for by the dynamics of the motion. For static configurations, the COP coordinate is the vertical projection of the center of mass of the object.

C. Android mobile phone

Beside the devices mentioned before, one can also consider a mobile phone for motion sensing applications, A typical Android phone contains the following sensors:

Accelerometer (BMA150), Magnetic field sensor (AK8973), Gyroscope (certain models only L3G4200)

Cameras. There is a built in wireless connectivity (Wifi,3G, Bluetooth), and high signal processing power, in a compact form. There are free development tools and and a large developer and customer base.

CONCLUSIONS

We have provided several examples for the application of cost effective sensors for inertial motion sensing applications. We have shown, that after the appropriate data processing steps, one can capture the main characteristics of motion phases, which can be used for biomedical studies and therapy.

One can conclude that the smart phones can be easily utilized for motion sensing applications due to the high number of sensors, extended hardware integration, and easily available software tools.

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