

Assessment technologies for the analysis of the efficacy of a Vestibular Neural Prosthesis

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Abstract

The development of systems of functional assessment following the implant of vestibular neural prosthesis is present: (1) a wearable sensor system for the recording of head kinematics; (2) a moving platform for the assessment of postural stability. The wearable system can be worn on the head and can be applied for the detection of rotational and linear accelerations. For this purpose, two methods are investigated. The first uses commercially available MEMS sensors, the second follows a biologically inspired approach to mimic the function of the natural vestibular system. Signals provided by the sensors are processed by a digital processor using a stimulus coding system including an extended Kalman filter (EKF). Outcomes of the EKF algorithm will be conditioned in order to control the stimulating unit leading the electrodes implanted in the vestibular system.

The moving platform can record information about the ground reaction forces produced during walking in different experimental conditions (different walking speeds, perturbation of locomotion in the antero-posterior and medio-lateral directions, etc.).

1 Introduction

The human vestibular system is located in the inner ear and consists of two components: the semicircular canal system for detection of rotational accelerations, and the otoliths for detection of linear accelerations [1].

The semicircular canals are filled with fluid (endolymph). Due to the mass inertia of this fluid, a flow is produced in the canals during rotational acceleration, causing pressure on the cupula and deflection of the kinocilia of the hair cells within it. These mechanical information are transduced into electrical signals and transmitted to the brain through the vestibulocochlear nerve (see Fig. 1 left). The mechanism in the otolithic organs (utricle and saccule) is similar and is based on the otoconia crystals resting on a viscous gel layer. As the crystals are heavier than the gel layer, they are displaced during linear acceleration, and thus deflect hair cells in the gel layer which again transduce the mechanical information into electrical signals (see Fig. 1 right).

A vestibular neural prosthesis aims at mimicking the function of the vestibular system by technical means, to treat patients suffering from loss of vestibular sensation. In order to verify whether the prosthetic implant significantly improve vestibular performance of impaired people, the recording of head movements can be used as a figure of merit. Another possibility is to develop a robotic platform able to isolate and quantify sensory and motor contributions to balance control and to assess the sensorimotor integration.

In fact, the measurement of postural sway in different experimental conditions is a widely adopted method to

deal analyze the integration of both visual, vestibular and somatosensory afference [2-4].

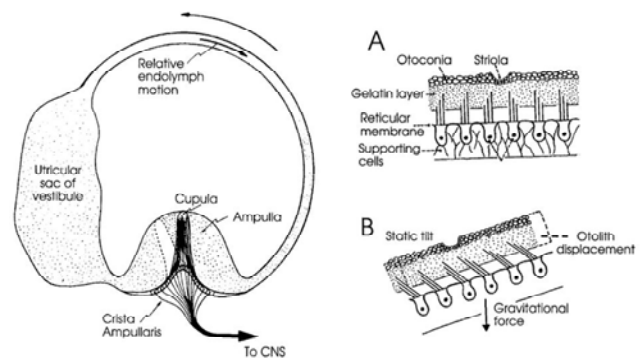


Fig. 1 Semicircular canal (left) and otolithic organ (right) of the vestibular system [1].

On the whole, by combining platform perturbations, with and without accordance with subject sway, permitting or depriving visual information and/or introducing movement of the visual enclosure, it is possible to study the influence of the labyrinth on the balance control through the vestibulospinal system in a quite isolated manner [5]. In particular, this approach has been widely adopted: to differentiate vestibular, visual, and somatosensory impairments to postural control; to differentiate peripheral sensory and central nervous system postural control abnormalities; to isolate sensory and motor components of postural instability associated with neurologic disorders; to document age-related changes in balance function and to

differentiate organic balance problems versus a physiological postural sway [6].

In this paper, some preliminary examples of possible novel approaches for the assessment of function in people with vestibular disorders are presented: (i) a wearable system for the assessment of head movements; (ii) a moving mechatronic platform to assess postural stability.

2 Wearable system for head movement assessment

An experimental setup was defined to test the performance of a commercial sensor (MTx, Xsens Technologies, Enschede, Netherlands) for the detection of kinematic information of the head. The MTx combines nine individual MEMS sensors to provide drift-free 3D orientation as well as kinematic data on 3D acceleration, 3D rate of turn (rate gyro ω) and 3D magnetometers. It provides Euler angles, kinematics and the orientation matrices as outputs. Experiments were done to test the performance of the MTx by means of a stereophotogrammetric system (VICON) as a “golden standard” reference system. In the experimental setup, the MTx was fixed to a bike helmet (see Fig. 3).



Fig. 3 Bike helmet with MTx unit and some VICON markers

Experiments with able-bodied subjects were carried out to create a database of human head movements (i.e. range of motions (RoM's), orientation, ...) during selected tasks. Particular attention was devoted to the possibility of highlighting abnormal patterns in subjects carrying a vestibular prosthesis. The experimental setup included “static” and “dynamic” tests. The first test aimed at the definition of RoM's while sitting subjects move only the head (e.g., flexion, extension, right and left rotations and lateral flexions). To evaluate the ability to carry out basic activities and especially the risk of falling, a Timed Up and Go test was used (see Fig. 4).

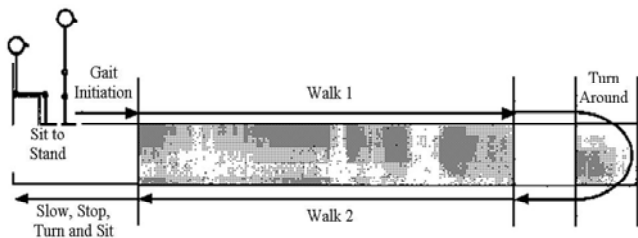


Fig. 4 Timed Up and Go test

An extended Kalman filter (see Fig. 5) was used to improve the accuracy of orientation estimates. The EKF incorporates an in-line calibration procedure for modelling time-varying biases which may affect sensors like accelerometers and magnetometers, and a mechanism for adapting their measurement noise covariance matrix in the presence of motion and magnetic disturbances

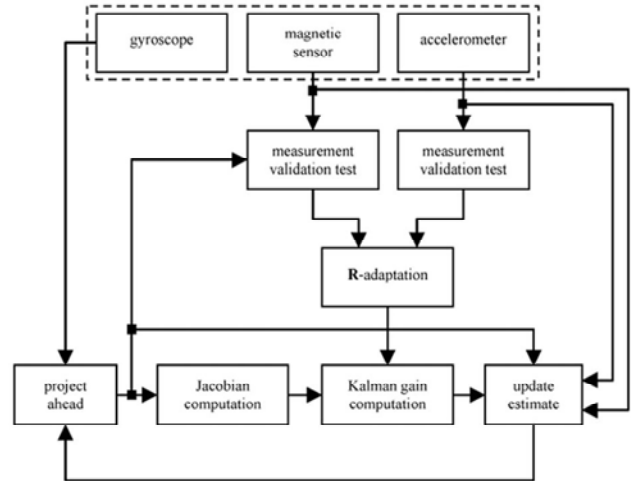


Fig. 5 Extended Kalman filter (EKF)

The orientation and angular trajectories obtained by the native Xsens algorithms were compared with those obtained using the EKF. An example of the comparison between the orientation (roll, pitch, and yaw (RPY) angles) obtained using the native algorithms provided by Xsens and EKF is shown in Fig. 6. In terms of root mean square errors, MTx estimates of head orientation in terms of RPY angles were very close to the stereophotogrammetric system estimates.

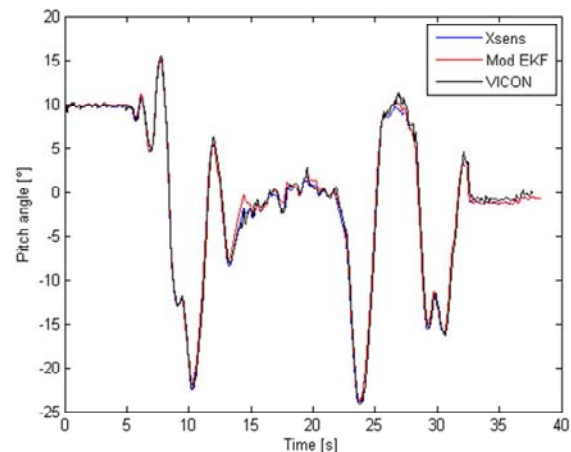


Fig. 6 RPY angles measured by MTx (Xsens, blue), using a modified EKF (Mod EKF, red), and a stereophotogrammetric system (VICON, black) for an exemplary head movement

3 Moving platform for vestibular assessment

The platform is mainly made by two treadmills, each acted by an electrical motor (Figure 7). Each treadmill is provided with an aluminum plane for supporting tester during the motor tasks. Furthermore treadmills are designed to be translated in the media lateral direction (300 mm of lateral translation). In order to obtain the required displacement, each treadmill is placed on two cylindrical rails passing laterally through the two treadmills. The treadmills are moved laterally through two racks each with its driving pinion. The belt slides on the walking plane generating on the tester a lateral perturbation on the foot/feet. The platform is provided with a structure where the tester, wearing a harness, is attached by means of a damper-cable-snap-hook system to avoid hits on the treadmill surface.

Next step will be to provide the platform with a suitable screen to combine mechanical and visual perturbations.

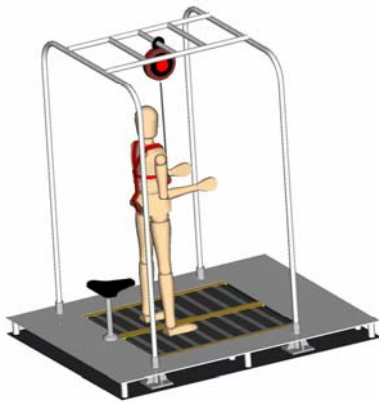


Fig. 7 Concept of the platform for vestibular assessment.

4 Discussion and conclusions

Extensive experiments with Xsens as well as tests of the algorithms developed for the estimation of orientation and angular trajectories will be carried out. A novel algorithm combining inertial and visual information will be also developed. The investigation on the bio-inspired solution will also be pursued to define a possible preliminary concept together with a novel MEMS-based system.

In order to characterise the response of the artificial inertial sensors, some kinematic data from monkeys after vestibular ablation will be used. The Xsens will be fixed over a DC motor that will be controlled using the recorded angular velocities of the monkeys. Moreover, experiments for the alignment of the inertial units will be done using bi-axial gyroscopes and bite-bars.

At the same time, the moving platform will be developed and integrated together with systems with immersive reality to play with the visuo-vestibular integration of the subjects.

5 Acknowledgment

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6 References

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