INERTIAL SENSOR BASED IDENTIFICATION OF HUMAN MOVEMENTS

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Abstract: The scope of this paper is the presentation of experiments which involve measurements and identification of human movements by using the inertial sensors. We describe the purpose, design and obtained results of two experiments, as well as our future plans which include the exploration of the forces acting at spine segments by measurements with inertial sensors. The first experiment implemented the method for measuring the range of motion (RoM) of head in transverse plane (Kuzmanic, 2007). It was done in the Laboratory of Biomechanics and Automatic Control – LaBACS, University of Split. In the second experiment we analyzed the standing – up movement and we used the robot assistive device for the support of human while performing the standing – up task. Measurements for purposes of this experiment were done in the Laboratory of Biomedical Engineering and Robotics, University of Ljubljana. We have proposed the new method which uses the Extended Kalman filtering for combining the data acquired from inertial sensor measurements of standing – up movement with data from the dynamic human body model (Music, 2008). Our plans regarding the next experiment are focused on the identification of the spinal load during sitting and standing, by using the inertial sensors measurement system.

1 MEASUREMENT OF THE HEAD'S RANGE OF MOTION

The measurement of range of motion (RoM) and static posture of the head gives important physical parameters for clinical assessment and diagnosis related to cervical spine functions. In literature, this movement is referred as a cervical range of motion. The detection of an abnormal RoM or asymmetrical patterns is an essential for preventing cervical dysfunction (McAviney, 2005; Wu, 2007).

One of our aims was to investigate the feasibility of the use of inertial sensors in routine clinical assessments. Therefore, our goal was to design the system based on inertial sensors and to propose the method for measuring the range of motion (RoM) of head in transverse plane. The measurement was performed using single inertial measurement unit MTx XSens sensor (XSens Motion Technologies, Netherlands), Fig. 1. Specialized software for sensor data acquisition, with high visualization abilities has been developed in LaBACAS. MTx XSens sensor can provide useful, noninvasive measurement of head motion in three cardinal planes for the fast evaluation of disturbances related to head/neck problems and cervical dysfunctions. The advantage of the proposed method over standard methods is the ability to measure unilateral RoM of the head. This technique overcomes the limits of 'gold standard' measurement devices by estimating the neutral position, which is assumed to be a nontrivial problem in standard RoM measurement. In addition, a proposal for use of sensor for visual feedback RoM assessment is presented. LaBACS MTx Software was developed by in-house, to control the operation of the inertial measurement unit (IMU), acquire the data and display them in the real time. Program was developed under Microsoft Visual Studio 2005, using MFC (Microsoft Foundation Class). Fig. 2. shows a frame of running software. Measurement was done on 6 subjects without any known symptoms of

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cervical dysfunction. Five repetitions of movements were analyzed and averaged for each subject in order to eliminate the variability during movement recording. In accordance with standard, total RoM is calculated by subtraction of maximal and minimal angle, or by summation of left and right RoM, assuming that the neutral position angle is known. During the measurement neutral position is identified statistically, over time interval of five repetitions of cyclic RoM movement, Fig. 3 b).

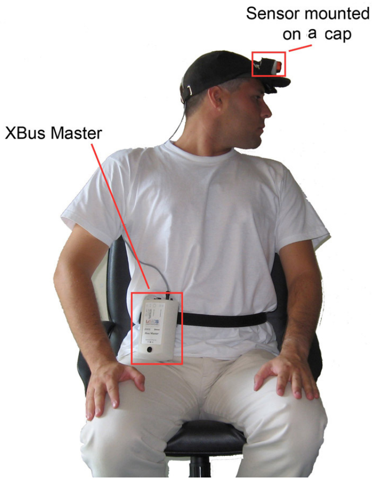


Figure 1: Measurement setup: Subject with sensor mounted on a cap.

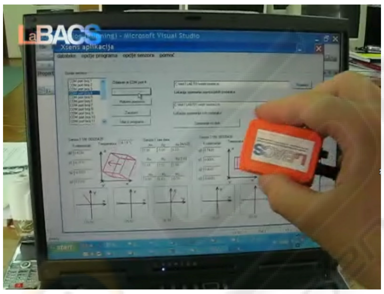


Figure 2: User interface of LaBACS MTx Software.

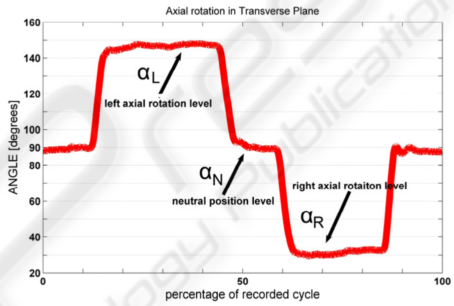
1.1 Results of the First Experiment

The results of the measurement on 6 asymptomatic subjects are given in Table 1. Resulting angles of each group are described in terms of mean RoM ± standard deviation [°], for the movement on the left (LRoM) and right side (RRoM). The results of the present study demonstrate similar ranges of motion as found in literature (Dvir, 2000), although the existing results are obtained with different instrumentation. Measurement of individual neutral position has a standard deviation ranging from minimally ±1.12° to maximally ±3.36°. These results imply that the subjects are able to return the head to a self-defined neutral position. Therefore, the measurement method of head motion based on inertial sensors is valid for current application of RoM in transverse plane and is suitable for measurement of head neutral position, as well.

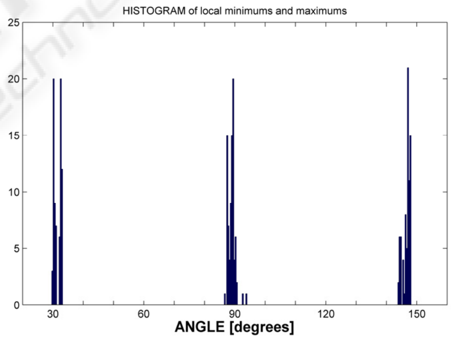
Table 1: RoM results for 6 asymptomatic subjects.

left side: LRoM	right side: RRoM	RoM (total) 1)	2)	LRoM/ RRoM
73.02° ± 7.61°	74.34° ± 9.44°	147.28° ± 15.51°	147.36° ± 15.54°	1.022° ± 0.096°

1) $\alpha_L - \alpha_R$ where α_L is maximal and α_R is minimal head angle; 2) LRoM + RRoM



a)



b)

Figure 3: a) Recorded angles of cyclic movement; b) Histogram computation of head neutral position and endpoint angles.

2 KINEMATIC MEASUREMENTS OF STANDING – UP MOTION

Number of aiding systems has been developed for the purpose of standing–up support. Recently, robot assistive devices have been introduced and their benefits demonstrated. In acquisition systems, the kinetic and kinematic parameters of the subject are required for operation of the robot control algorithm. Kinematic measurements are usually performed with optical motion analysis systems that are unsuitable for clinical applications. Therefore, introduction of miniature, low cost inertial sensors (accelerometers and gyroscopes) as a body mounted sensors, has shown to be promising.

We propose a new approach in which the Extended Kalman filtering (EKF) technique is used to fuse data acquired from inertial sensor measurements with data from the dynamic human body model (Music, 2008). In this way we believe that better kinematic measurements in ambulatory settings are possible. We named the approach Model Based Inertial Sensing - MoBIS.

The proposed human body model consists of shank, thigh and HAT (Head-Arms-Trunk) segments, Fig. 4.

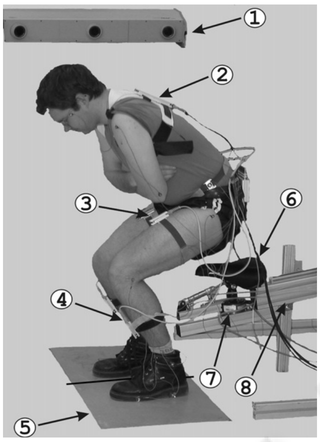


Figure 4: Measurement setup: (1) linear infrared cameras, (2) HAT inertial sensing unit, (3) thigh inertial sensing unit, (4) shank inertial sensing unit, (5) AMTI OR6-6-1 force plate, (6) seat, (7) JR3 40E15 force sensor, (8) standing-up robot assistive device.

The segments are assumed to be rigid bodies with their masses contained at center of mass (CoM). Segment masses, lengths, moments of inertia and CoM positions are defined using anthropometric data. Three joints (ankle, knee and hip) are assumed to be ideal pin joints with no added friction during rotation. The model is in contact with its environment only by the distal end of the shank segment i.e. by subject's feet. The assumption of symmetry of sit-to-stand motion in respect to sagittal plane was adopted in modeling phase. This assumption enables the measurements to be carried out only on one side of the body and results projected on the other side. The symmetry assumption does introduce certain error.

2.1 Results of the Second Experiment

The method is validated on both simulated and measured data. The presented results (Figures 5, 6 and Table 2) show that Model Based Inertial Sensing (MoBIS) in robot assisted standing-up is a reliable alternative to optical measurements systems for motion kinematics assessment. To improve method performance in terms of accuracy and reliability, further development (e.g. extensive testing on a group of healthy and impaired subjects, introduction of adaptive EKF) is suggested (Music, 2008).

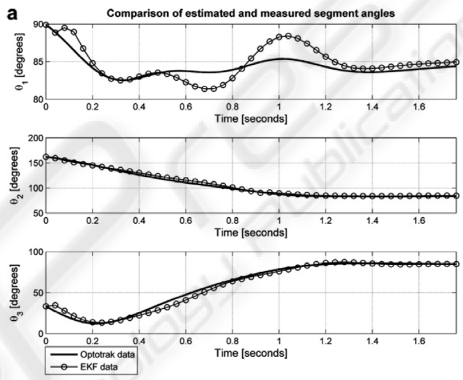


Figure 5: Comparison of actual and measured angles.

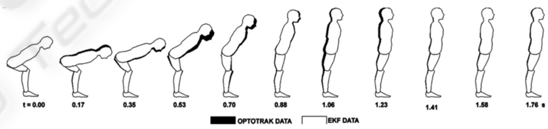


Figure 6: Comparison of Optotrak and EKF data.

Table 2: Measurement error.

	Shank RMSE [deg]	Thigh RMSE [deg]	HAT RMSE [deg]
Normal/self-selected standing up speed			
Meas. *01*	6.1	4.1	3.8
Meas. *02*	2.1	7.8	6.8
Meas. *03*	2.4	5.2	6.8
Meas. *04*	3.7	3.5	5.9
Average *1*	3.6	5.2	5.8
Fast standing up			
Meas. *05*	1.4	2.5	3.2
Meas. *06*	4.8	2.6	4.7
Meas. *07*	4.9	2.4	5
Meas. *08*	3.9	2.1	5
Average *2*	3.8	2.4	4.5

3 DISCUSSION AND CONCLUSIONS

Results obtained in described experiments show that inertial sensors can be implemented into different measurement systems and bio – devices as reliable and yet inexpensive tool for identification of versatile human movements. Our future work regarding the implementation of inertial sensors includes the identification of the spinal load during sitting and standing.

3.1 Segmental Spine Load: Model and Force Analysis

The main idea is to explore forces acting at single spine segments. All the measurement procedures, used in the research, will be noninvasive. The identification of the single spine segment coordinates will be done using the inertial sensors. The later stages will also include the analysis and calculations of corresponding forces, and therefore, to that end, ground reaction forces will be measured (Supuk, 2002). Research will be performed in static and dynamic conditions, on sitting and standing subject, Figures 7 and 8. Partial differential equations will provide mathematical support during the modeling process, keeping in mind that we are dealing with compartmental system. Configuration of the spine, that will be identified based on the results of measurements obtained by five different sensor outputs, along with the seat reaction forces will serve as input parameters for the calculations of forces acting at the diverse points of the spine (33 vertebrae including the five that are fused to form the *sacrum* (the others being separated by intervertebral discs) and the four bones which form the *tailbone*.).

Figure 7: Standing subject spine model.

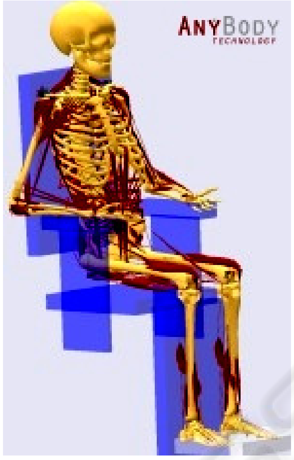


Figure 8: Musculoskeletal model used to identify spine configuration of the subject in the seated position.

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