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Improvement of a multi-stage model for the modeling of a functionalized nursing bed as support for the sensor-assisted functionalization of furniture in the hospital and care sector

Abstract: Development of preparation-free functionalized furniture based patient monitoring systems for use in the area of home- or stationary- care is often empirically driven. In particular, functionalization of furniture by means of different sensors is strongly affected by this development methodology. As a result, the systems are often not extensive-ly extendable or cannot be optimized because basic mechanisms are not comprehensible. In order to support development or optimization, a modelling approach is often useful. Thus, using a more comprehensive approach the required sensitivity of the sensors as well as their position in the system can be derived from a simulation model. In order to solve this problem, a multi-stage model was introduced at the BMT conference in 2014 by the authors, which allows the designer to model the entire system. The model has been extended and improved in the meantime and the achieved progress is presented in this work. The presented modelling approach can be divided into three main components. These are the person under supervision, the furniture (in our case a nursing bed) and the sensors (force measuring cells) which are modelled separately. In this work the main focus will be on improving the modelling of the human movement process and its implementation. Furthermore, the modelling of the sensor behavior in the nursing bed is described in detail with regard to their oscillation behavior and the influence on the model.

Keywords: Biosignal processing, model driven development, biomechanical modelling, motion pattern database, modelling

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1 Introduction

The 13th coordinated population pre-calculation of the Federal Statistical Office of the Federal Republic of Germany [1] has determined for the year 2060 that the share of the under 20-year-olds will fall to 16% and the proportion of the 20- to 65-year-olds to 51-52%. Every third citizen (32 to 33%) is at least 65 years of age and there will be almost twice as many 70-year-old seniors as children are born. In addition to the aging society, critical and chronic diseases are also a problem, which increased rapidly in recent years. This development results in new requirements for the hospital and care. On the one hand, the declining number of nurses must be handled, and on the other hand the increasing number of patients must be taken into account. For this reason the incipient problem must be addressed from two sides. One of the tasks is the mandatory support of the nursing staff. In addition, diseases of patients should be detected at an early stage by means of long-term monitoring in order to provide suitable treatment facilities at this early stage to improve the healing ability and treatment. A forward-looking approach to

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assist people in need of care and to carry out long-term monitoring is the support using functionalized furniture. For this, the technological basis is the preparation-free derivation of patient parameters using sensors integrated into domestic or clinical furniture. An appropriate platform for the functionalization of furniture and to perform a preparation-free long-term monitoring is, for example, the (nursing) bed. The advantage of this "sensor platform" is the universal applicability and the relatively long duration of patients' stay from about six to eight hours a day in comparison to other approaches. Furthermore, disturbances of the signal by talking, eating, additional movements, etc. can almost be excluded. The research focus on functionalized beds has been steadily expanded in recent years. Approaches with different sensor systems [2, 3] and different purposes [4, 5, and 6] have been developed. Such systems can be used without the patient's preparation and provides the possibility of acquiring a large amount of data, e.g. during sleep. Most of these approaches work quite well, but a strong empirical development is usually pursued. This is due to the fact that usually not enough test persons from the target group are available or other restrictions make an independent evaluation of the system more difficult or even impossible. Further challenges are time and personnel consuming acquisition of the data as well as the fact that it is ethically and morally unacceptable to generate test data for the systems from old and frail people.

In order to compensate for many of these disadvantages, the authors propose a model-driven development. For this purpose, the preparation-free measuring system can be modelled and, depending on the extent of the model, many points can be tested and verified at an early stage of development. Within the scope of this paper, current supplements and extensions of the already existing multi-stage model are presented. The focus of this work is on the modelling of human movements using movement data of a markerless body-motion tracking system as well as on the modelling of the used force-measuring cells.

The paper is structured as follows. First, the overall system of the functionalized nursing bed and the associated multi-stage model are presented. Subsequently, the expansions in the area of the human model and the modelling of the sensors are discussed. An assessment of the expansion and an outlook are concluded.

2 Model driven development

Our research focuses on a model-based development of a functionalized nursing bed. The laboratory prototype device used as development platform consists of a commercially available nursing bed that has been functionalized with two industrial force measuring systems. The sensor setup is shown in Figure 1.

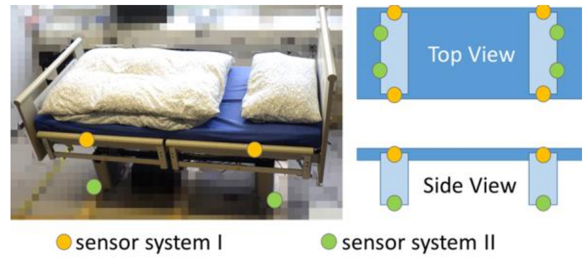

Figure 1: Laboratory prototype "functionalized nursing bed"

The setup is divided into two independent parallel force sensor systems I (Bosch) and II (Zemic) to detect the load weight and temporal mass changes within the bed. The prototype is presented in detail in [7], so no further details are presented here.

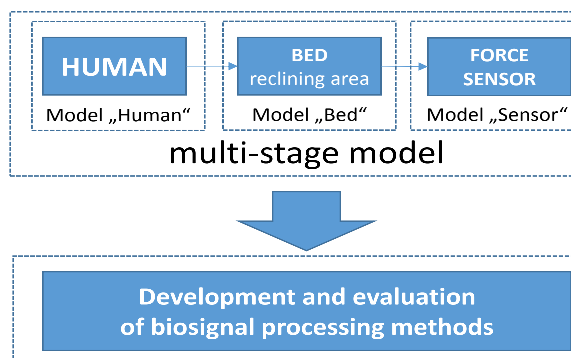

Figure 2: Schematic of the multi-stage model

Based on the measurement setup it is possible to derive the persons' centre of mass, the weight of the person in bed, the bed occupancy, an indicator of unrest and the current respiratory rate [8] as patient parameters. In addition, different body postures and actions of a human being in the nursing bed [9] can be derived by a Hidden Markov Model (HMM) based recognition system.

During the development of different methods and algorithms, it quickly became clear that additional references to evaluate the particular developed algorithm were missing.

For this reason, a multi-stage biomechanical model was developed. The basic principle of the model [7] is shown in Figure 2. The human being, the furniture and the sensors are modelled separately in three stages in order to be able to obtain a reference setup as precise as possible in appropriate models. Every part of the model can be modified and adapted independently, which is an advantage of this method. All simulation steps are carried out and calculated using Mathworks Matlab and Simulink.

3 Improvements of the model

The major drawback in modelling is that there is a compromise between realistic representation and the required effort regarding the number of measurements or test data. Based on partly very theoretical assumptions from the related literature, it turned out that the modelling approach has to be supported by real data in order to be able to use the system in a meaningful manner. The details of the improvements are described below.

3.1 Improvement model part "human"

The first stage of the model, the human itself, considers different body parameters (body dimensions {height and width}, weight, cardiovascular and respiratory elements {heart rate, breathing rate and the caused mass shift}), movement and body position (initial and after the movement). The body dimensions are modelled with regard to anatomical models [8, 9] and are represented into a so-called stickman model in which the body dimensions were taken into account. Initially, a linear movement of limbs and torso was assumed. But compared to real body postures and actions, the modelled movements seem to be very "robotic". This is also evident in the direct comparison of the electrical signal sequences of the four sensors of each sensor system and the simulated signal profiles of the model. To solve this issue, the body posture and body motion database "MoveHN" was created in order to investigate the movement patterns of real people and later to use them in own developments. The XSens MVN Awinda System was used for this purpose. This system consists of 17 cordless trackers attached to straps to derive the motion of the person who is wearing the measuring setup. Further details on the XSens system are not presented here, but can be found in [10]. The focus of our dataset is on movement sequences and body positions of people in nursing beds. To use the data later e.g. for modelling, corresponding movement sequences were defined. A total of 680 files, which cover about 400 minutes of motion data were recorded. These were divided into data from five male and five female test persons, each with two recording sessions on two different days. The age of the test persons is in a range of 23 to 30 years, the weight is in a range of 67 kg to 114.1 kg and the body size is in a range of 156 cm to 184 cm. 20 different actions and nine different body positions were taken into account. Individual records can be loaded and used directly in the model after conversion. However, the use of a "standard" movement sequence, which is averaged from the movement sequences

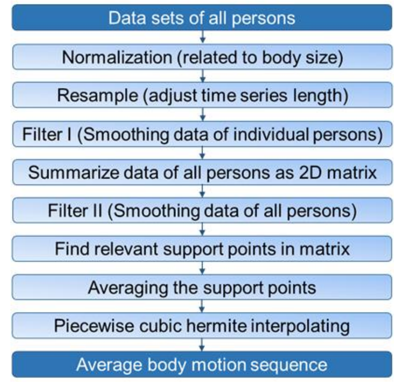

Figure 3: Block diagram "Averaging the motion sequences"

of different test persons, is of great interest. This allows the model to be used universally, but is based on real human movements instead of assumed "robot"-like motion. We propose the scheme shown in Figure 3 to average the motion sequences.

Currently, the expansion of the "human model" is still in the development phase. It can, however, be shown that this approach makes it possible to create average motion sequences from the XSens data and to use them in the model stage. In a next step, the expansion is tested with respect to the overall model. The presented database "MoveHN" is available for download, corresponding information are given at the end of the paper.

3.2 Improvement "model sensor"

Another point, which has been extended in the presented model, is the description of the sensors. In this work, we focus on sensor system 1 shown in Figure 1 for modeling. System 2 serves as a reference. The basic sensor model is realized with the data from the sensor datasheet. The used force measuring sensor [11] has a linear characteristic as described in formula (1). The applied force F_{LPx} is converted to a proportional voltage value $V_{out}(F_{LPx})$.

$$V_{out}(F_{LPx}) = (s \cdot F_{LPx} + V_{out,0}) \cdot \frac{V_{DD}}{5.0V} \quad (1)$$
$$-850N \leq F_{LPx} \leq 850N$$
$$Saturation\colon |F_{LPx}| > 850N$$
$$V_{out,0} = 2.5V,\ s = 2.5\frac{mV}{N},\ V_{DD} = 5.0V$$

The sensor noise can be modelled as additive Gaussian distributed noise. However, another additional effect must be considered: If the sensor is loaded or unloaded, an additional transient response occurs, the so-called "ringing" [12]. This effect is neglected in the datasheets, but must, according to the authors, be considered in the model. In order to observe the ringing effects, the measurement set-up was loaded and unloaded at predefined points (head left and right, centre, foot left and right) with fixed weights (15 and 30 kg). The analysis of the resulting signals shows that the effect can be described as an exponential decaying sinusoidal oscillation. For the description in the model, we propose the relation in formula 2 (with $b > a > 1$, $A_0 = 1.45$, $f_0 = 8.25$ Hz).

$$osz(n) = A_0 \cdot \exp\left(\frac{-n}{\tau}\right) \cdot \begin{bmatrix} sin\left(2\pi n \frac{f_0}{f_a}\right) + \cdots \\ 0.3 sin\left(2\pi n \frac{a f_0}{f_a}\right) - \cdots \\ 0.1 sin\left(2\pi n \frac{b f_0}{f_a}\right) + \cdots \end{bmatrix} \quad (2)$$

The average decay time τ is assumed to be about 1.5 to 2.5 s in our tests and experiments. The real and simulated datasets are shown in Figure 4.

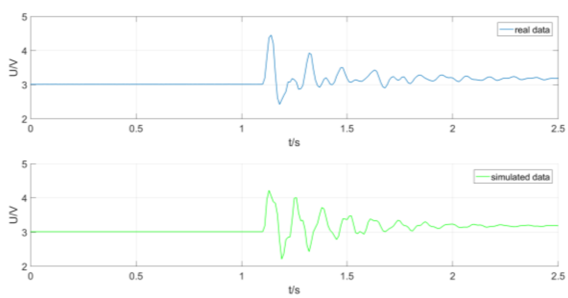

Figure 4: Real and simulated sensor “ringing” (test weight 30kg, loaded at the centre of the reclining area)

Figure 4 shows that the transient behaviour of the sensors can be described by formula 2. However, it is to be noted that a complete match is not achieved and that this is not desirable in the development because a general model is to be created. Furthermore, in addition to the sensor, effects from portions of the bed construction are also present in the real signal. In a further step it is necessary to test how the expansion in the overall model behaves and to separate the system parts sensor and bed frame.

4 Conclusion and outlook

This paper presents the extension of an existing multi-stage model to support the functionalization of furniture in the care and hospital environment. The "human" sub model was supplemented by a more realistic movement process. The used motion data was obtained using an XSens MoCap system and then averaged using an own method. Furthermore, the sub model "sensor" was supplemented by the description of transient and deceleration processes. Both approaches have so far only been tested separately. To prove the correct function of the selected procedures in the overall model, the overall model and the data resulting from the simulation must be compared with real data in a next stage.

5 Download

The entire MoveHN database is subject to the Creative Commons (CC-BY-NC-SA) and is available for download at http://ami.kr.hs-niederrhein.de/moveHN.

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