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PREDICTION FUNCTIONAL INDEPENDENCE MEASURE IN HIP FRACTURE PATIENTS

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I. INTRODUCTION

Hip fractures are most frequent cause of hospitalization after the fall in geriatric population [1] worldwide and consequently have been subject of great research interest in both medicine and biomedical engineering due to the incident frequency, corresponding mortality as well as treatment expenses. It has been reported that the incidence of hip fractures is rising at the approximate rate of 1-3% per year, with subsequent mortality rates at approximately 33% in first year after the fracture [2], [3]. Consequently because of the increasingly large number of elderly patients with these fractures significant advances have been made with respect to surgical procedures, post-surgical rehabilitation procedures as well as social support services. It is often emphasized that management and allocation of resources is of utmost importance in patient care. In practical situations the amount of resources is limited and thus proper assignment of priorities may play crucial role in recovery. As an example certain patients experiencing hip fracture may show significant progress if surgeries and rehabilitation programs are allocated in timely manner thus leading to more efficient health care.

To this purpose there are different rehabilitation protocols that are used for the treatment of these patients as well as variety of efforts to identify parameters that could serve as useful predictors of the treatment outcome. One of the commonly used parameters which is used for this evaluation is functional independence measure (FIM) which evaluates patients' ability to perform particular tasks. There is still a lack of consensus among physicians regarding the factors that are of greatest significance for the recovery [4]-[5].

In our previous work we proposed a clustering algorithm for selecting patients with largest recovery capacity with respect to Berg Balance Scale (BBS) [6]. In this paper we propose linear and nonlinear prediction algorithms of the FIM using multivariate regression with respect to age, comorbidity and type of treatment (we consider two different control groups: with and without hydrotherapy). It is often argued that proper administration of intrahospital as well as post-recovery procedures can significantly improve the recovery of patients. To this purpose it would be extremely beneficial to properly triage (cluster) patients at the admission stage in order to ensure optimal distribution of resources. We then evaluate the proposed prediction algorithms on a data sample consisting of 203 patients that have been admitted to the Institute for Rehabilitation, Belgrade, Serbia.

The paper is organized as follows. In Section II we describe the data set and the proposed estimation algorithms. In Section III we evaluate the applicability of the proposed algorithm using a real data set. Finally, in Section IV we discuss the results and future work.

II. SIGNAL PROCESSING MODELS

A. Data Set

We have evaluated 203 eligible participants that were referred to the rehabilitation facility after hip fracture for inclusion into rehabilitation program and follow-up. To assess eligibility for the inclusion in the study the patients were evaluated by board certified physiatrist and specialist of internal medicine. Prior to the inclusion, all the participants were informed about the study protocol and informed consent was obtained. The study was approved by the Institutional Review Board and was carried out according to the principles of good clinical practice. The eventual onset of early complications was indication for the termination of the rehabilitation program for defined period of time. The exclusion criteria for the study were recurrent hip fractures and inability to completely finish the rehabilitation program or follow-up that was defined by the study. Therefore, the initial group on admission consisted of 237 patients, where 11 (4.6%) did not complete rehabilitation program due to the worsening of health condition and thus transferred to specialized referring hospitals, while 23 (9.8%) subjects dropped out from discharge period to the planned follow-up after 3 months post-discharge.

Beside Board certified Physiatrist, rehabilitation team consisted of: licensed physical therapists, licensed occupational therapists and nurses. Once a week, above mentioned rehabilitation team gathered on meeting to evaluate patients improvement and further implementation of rehabilitation program.

Prescription of rehabilitation program was individually addressed with particular attention to the patients functional status. Patients were included twice a day for the duration of two hours (60/60 minutes) into physical therapy. First part of physical therapy was composed of different exercises including those for strength and balance improvement,

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conditioning and coordination improvement. These exercises aimed to improve walking and mobility. The second part of the program was conducted by occupational therapist and consisted of improving activities of daily living. The maintenance of proper hygiene during the rehabilitation program was conducted by experienced nurses.

Functional Independence Measure (FIM) was used to evaluate patients functional status on 3 occasions: at admission (Admission), on discharge from the rehabilitation facility (Discharge) and 3 months after discharge (Follow-up). After discharge, patients were not included into any kind of rehabilitation program and were referred to home of residence. FIM presents valid and reliable test in the estimation of aggregated changes in functional status that appears in the defined period of the study evaluation [7]-[8]. It is composed of 18 categories that are scaled from 1-7 each [7] For the estimation of comorbidity of participants we used Cumulative Illness rating Scale for Geriatrics (CIRSG), and findings were presented as severity index (SI), where SI was calculated as total CIRS-G score divided by the number of endorsed categories [9].

We organize the data set in a database consisting of 203 rows corresponding to the patients and 40 columns of different features (age, height, weight, respiratory conditions, heart conditions, FIM at the admission, FIM at the discharge, BBS three months after discharge, etc.) Then we analyze cross-correlation between all the features and extract statistically significant ones using Pearson coefficient. In order to study dynamics of rehabilitation we use log-values of BBS score ratios. The rationale behind this approach is that we expect exponential change in balance improvement and thus log (semi-log) models may represent better fit.

B. Parameter Estimation and Model Fitting

We propose to determine the significant parameters using Spearman correlation coefficient which is commonly used technique in cases/models where nonlinearity is expected. After preliminary analysis we determined that the two most significant factors are age and comorbidity. Then, let y_i denote the FIM value 6 months after the discharge from the rehabilitation program for the ith patient and let $y = [y_1, \dots y_n]$ where n is the number of patients. In the first scenario we propose to model the FIM value as a linear combination of the physiological parameters: age and comorbidity using different models for patients with and without hydrotherapy i.e.

$$\begin{aligned} y_{\text{noht}} &= A_{\text{noht}} x_{\text{noht}} + e \\ y_{\text{ht}} &= A_{\text{ht}} x_{\text{ht}} + e \end{aligned} \quad (1)$$

where A_{noht} and A_{ht} represent transfer matrices for patients without and with hydrotherapy respectively. The structure of transfer matrix is as follows

$$a_{ij} = \left\{ \begin{array}{cc} 1 & j=1 \\ \text{age of the i}-\text{th patient} & j=2 \\ \text{comorbidity of the i}-\text{th patient} & j=3 \end{array} \right\} \quad (2)$$

	Age	Severity Index
Total N=203	77 ± 6.11	1.74 ± 0.49
Female N=149	78.28 ± 5.86	1.74 ± 0.43
Male N =54	76.19 ± 6.56	1.76 ± 0.64

TABLE I: General characteristics of patient population with respect to the age and severity index of fracture

	Age	Com.	Wait time	FIM - adm.	FIM - 6mo.
Age	1.00	0.37	-0.15	-0.29	-0.57
Com.	0.37	1.00	0.20	0.48	-0.52
Wait time	-0.15	0.20	1.00	0.71	0.24
FIM - adm.	- 0.29	0.48	0.71	1.00	0.51
FIM - 6mo.	-0.57	-0.52	0.24	0.51	1.00

Similarly x_{noht} and x_{ht} represent vectors of intercept and regression parameters for patients without and with hydrotherapy.

In the second scenario we propose the nonlinear models in which the 6-months FIM for the i-th patient is modelled as a polynomial function of age and comorbidity i.e.

$$y_i = \sum_{k,l=-p}^{p} x_{k,l} * \theta_i^k \psi_i^l \quad (3)$$

where p is the order of the approximation (i.e. the number of significant parameters), θ_i and ψ_i are age and comorbidity of the i-th patient, and $x_{l,l}$ are unknown regression coefficient. To model the nonlinear dependence we propose a hierarchical polynomial with respect to two parameters. This is a commonly used approach for modelling patient-to-patient dependency when no other information is available a priori.

Similarly to the first scenario we split the data into two separate models with the respect to whether or not hydrotherapy was used. We obtain the parameters using iteratively reweighed least-squares estimator in which the weights are proportional to the covariance estimates [10]. To evaluate the applicability of the proposed algorithms we find the normalized mean-square error and likelihood ratio test. Note that the above models can be easily extended to include larger number of parameters and this will be discussed further in Section 3.

III. Results

The total number of patients admitted was 203 (160 with hydrotherapy and 43without hydrotherapy) with general characteristics being described in Table 1.

Additionally in Table 2 we show the correlation coefficient of the 6-month FIM with respect to the model parameters. Based on these results we select age and comorbidity as two most significant parameters in the remainder of the paper.

To illustrate the statistical properties of the data sample we present two scatter plots. In Figure 1 we illustrate two-dimensional scatter plots of age and comorbidity (as a preliminary approach we arbitrarily selected the two parameters with largest coefficients) using therapy indicator as grouping parameter. In Figure 2 we present a similar three-dimensional scatter plot with 6-months FIM as an indicator. Obviously the decision whether or not the therapy should be used was not randomized in this study and hence we expect to have

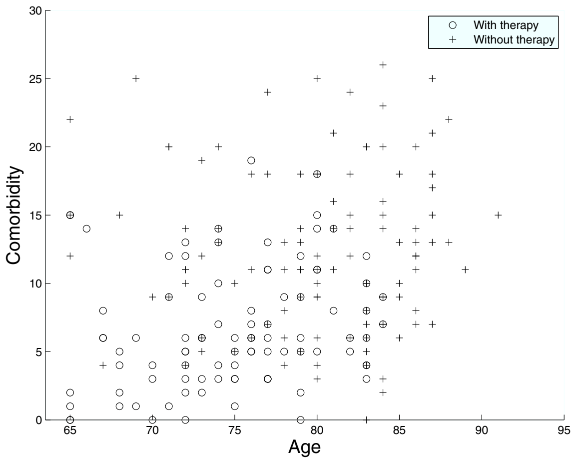

Fig. 1: Two-dimensional scatter of age and comorbidity

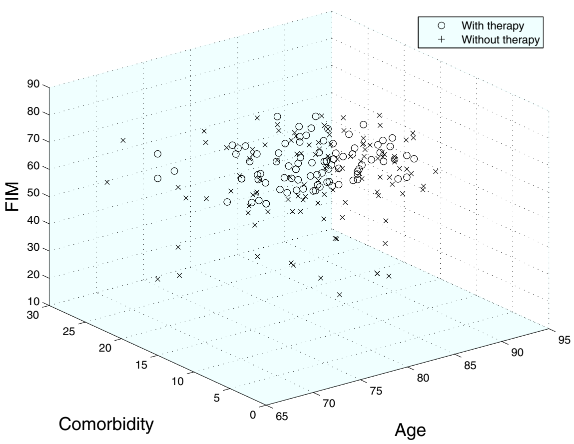

Fig. 2: Three-dimensional scatter of age, comorbidity and FIM

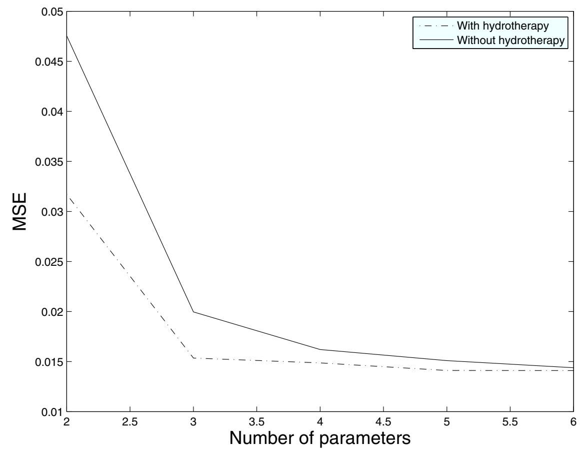

Fig. 3: MSE of nonlinear model

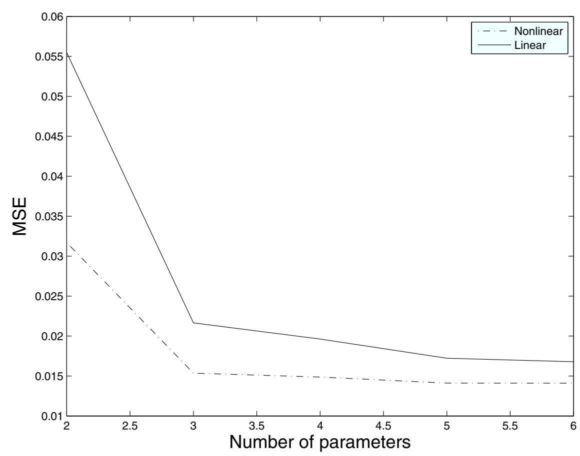

Fig. 4: MSE comparison nonlinear vs. linear model for patients with hydrotherapy

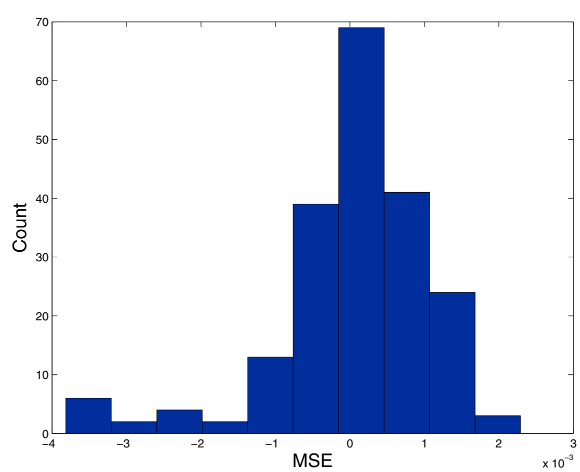

Fig. 5: Two parameters linear estimation

different performance. Obviously in making clinical decision not all the decisions can be randomized as it may contradict clinical protocols.

To evaluate the performance of the proposed algorithms we split both group of patients into half and use different groups for regression coefficient estimation and calculation of MSE. In Figure 3 we present the prediction result in terms of MSE for nonlinear model as a function of number of parameters. Using the Spearman rank correlation coefficient we evaluated the most significant parameters with respect to FIM value 6 months after discharge: therapy indicator, age, comorbidity, FIM at the admission, FIM at discharge, and waiting time (time until the rehabilitation program begins). As expected after initial decay the MSE slope decreases significantly which means that the benefits of introducing additional parameters should be examined in more details as they may lead to increase in the computational complexity as well as Cramer-Rao bound. In Figure 4 we show the comparison between nonlinear and linear models for two parameters for the patients with hydrotherapy treatment. In order to illustrate the validity of implicit Gaussian assumption in Figures 5 and 6 we present histogram of the residual vector for nonlinear and linear estimation using two parameters.

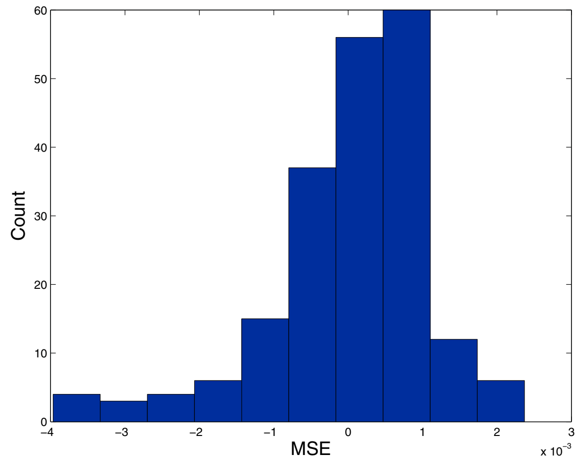

Fig. 6: Two parameters nonlinear estimation

	Likelihood-ratio nonlinear vs. linear
With hydrotherapy	0.15
Without hydrotherapy	0.74

TABLE II: Likelihood-ratio

The likelihood ratio for two parameters models is given in Table 2. From the results it seems that the nonlinear model provides better fit in terms of the likelihood function for the patients without hydrotherapy. When the hydrotherapy is used the results indicate that the linear model may provide better fitting. However it should be noted that the sample size for the patients without hydrotherapy is smaller which may affect the results. In addition the presence of hydrotherapy may create nonlinear dependence which may not be capture well by polynomial fitting proposed in this paper.

IV. CONCLUSIONS

The importance of early inclusion in rehabilitation program and exercise of older people after the hip fracture could be explained by the fact that physical activity influences the muscle strength, balance and eventually degree of hip pain [11]. Such determinants are very important particularly for individuals quality of life and could prevent further risks of comorbidities and falls later in life. It has been often hypothesized that the success of recovery is extremely dependent on the timeliness and adequacy of the treatment. While it is desirable to provide the best possible care as soon as possible the actual limitations that may exist in health-care systems due to a limited number of medical staff as well as limited capacity in rehabilitation programs may create need for appropriate planning and/or scheduling.

To this purpose in this paper we proposed an algorithm which can potentially be used to predict the functional recovery which is one of the most important factors that indicate ability for self-functioning of the patients and return to daily activities. As a preliminary approach we proposed and compared two parameters linear and nonlinear models using mean square error and likelihood-ratio. The parameters were chosen based on the correlation coefficient. An effort should be made to compare the performance of these models to non-parametric, multilevel histograms in which FIM can be modelled using the joint probability density function and consequently determining a histogram based maximum likelihood estimate. In addition the residual vector may not be Gaussian distributed especially in which case an effort should be made to investigate different estimation techniques that may be more suitable for non-Gaussian models.

Finally, a clinical study with a larger number of patients and different waiting times should be performed in order to evaluate the correlation between waiting time (time from operation to admission to rehabilitation program). In this particular data set, due the similarity between waiting times, this parameter was not a significant factor in predicting FIM six months after discharge. However that may not be the case if the waiting times are larger than certain threshold value which should be investigated in future work.

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