Optimal Treatment Selection for Hip Fracture Patients using a Hybrid Decision Making System

Aleksandar Jeremic[1], Natasa Radosavljevic[2], Dejan Nikolic[3] and Milica Lazovic[4]

[1]*Department of Electrical and Computer Engineering McMaster University, Hamilton, ON, Canada*

[2]*Institute for Rehabilitation Belgrade, Belgrade, Serbia*

[3]*Physical Medicine and Rehabilitation, University Childrens Hospital, Belgrade, Serbia*

[4]*Faculty of Medicine, University of Belgrade, Belgrade, Serbia*

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Abstract: Hip fractures are most frequent cause of hospitalization after the fall in older population and consequently have been subject of great interest in medicine and biomedical engineering. It has been observed 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. Although in some cases the hydrotherapy may be improve recovery of patients it may not be easily accessible due to limited resources. To this purpose we propose a hybrid decision making system consisting of computer-aided decision combined with an expert opinion. We then evaluate and compare the performance of the proposed algorithms using a data sample consisting of 413 patients that have been admitted to the Institute for Rehabilitation, Belgrade, Serbia.

1 INTRODUCTION

Hip fractures are most frequent cause of hospitalization after the fall in geriatric population (Roudsari et al., 2005) 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 (Johnell and Kanis, 2004; Roche et al., 2005). 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. Two of the commonly used parameters, often correlated, which are used for this evaluation is functional independence measure (FIM) which evaluates patients' ability to perform particular tasks and Berg Balance Scale (BBS) which evaluates patients ability to maintain the balance. There is still a lack of consensus among physicians regarding the factors that are of greatest significance for the recovery (of the long-term disability associated with hip fractures., 2011)-(Adunsky et al., 2012).

In our previous work we proposed a clustering algorithm for selecting patients with largest recovery capacity with respect to Berg Balance Scale (BBS) (Jeremic et al., 2012) as well as 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) (Jeremic et al., 2013). It is often argued that in order to perform proper clinical care and management the patients should be triaged upon admission according to their ability for recovery and/or predicted efficiency of the treatment using hydrotherapy. To this purpose in this paper we propose multichannel fusion algo-

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rithm for decision making in which the two decisions are modelled as uncorrelated binary decisions. At the present time there is no consensus whether or not these are correlated decisions so in order to obtain preliminary results we propose to model them as uncorrelated decisions. We then evaluate the proposed prediction algorithms on a data sample consisting of 413 patients that have been admitted to the Institute for Rehabilitation, Belgrade, Serbia. For comparison purposes we compare the performance of our computer based system with expert opinion of the physiatrist performing patient evaluation.

The paper is organized as follows. In Section II we describe the data set and the proposed decision making/binary hypothesis decision 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.

2 SIGNAL PROCESSING MODELS

2.1 Data Set

We have evaluated 413 eligible participants that were referred to the rehabilitation facility from January 2011 until April 2013 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 467 patients, where 24 did not complete rehabilitation program due to the worsening of health condition and thus transferred to specialized referring hospitals, while 30 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, the aforementioned 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, 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) and Berg Balance Scale were 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. Both of these measures presents valid and reliable test in the estimation of aggregated changes in functional status that appears in the defined period of the study evaluation (Young et al., 2009)-(Dodds et al., 1993). It is composed of 18 categories that are scaled from 1-7 each (Young et al., 2009) 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 (Firat et al., 2002).

We organize the data set in a database consisting of 413 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.) In our previous work we analyzed 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.

2.2 Parameter Estimation and Decision Making

We first partition patients into two groups, those that participated in hydrotherapy and those who did not. Then, let y_i denote our measurement vector consisting of the FIM and BBS values 6 months after the discharge from the rehabilitation program for the ith patient. The corresponding MANOVA model for the first group of patients can be written as

$$y_i = Xa_i + e$$

where X is the matrix of unknown parameters and a_i is the "source" vector for the I-th patient consisting of

$$a_{i,i} = \left\{ \begin{array}{cc} 1 & j=1 \\ \text{age of the i}-\text{th patient} & j=2 \\ \text{comorbidity of the i}-\text{th patient} & j=3 \\ \text{BBSatadmission} & j=4 \\ \text{FIMatadmission} & j=5 \end{array} \right\}$$

The unknown matrix X can then be estimated using a technique similar to one proposed in (Jeremic et al., 2013). Similarly we formulate equivalent model for patients that were not subject to hydrotherapy and denote corresponding MANOVA coefficients as Y.

We then proceed to define a computer based decision for therapy selection in the following way. According to expert input the hydrotherapy is considered sufficiently efficient if the average sum of FIM and BBS after dismissal from the program is more than 25% larger compared to the value that would be achieved without therapy. Therefore we formulate following decision problem

$$H_1 = \left\{ \text{choosehydrotherapy} \quad \frac{\hat{X}a}{\hat{Y}a} \geq 1.25 \right.$$

In our previous work (Jeremic et al., 2013) we also derived the nonlinear estimator for predicting values of BBS and FIM. Similarly to the above approach we estimate the corresponding coefficients X_n and Y_n where we use subscript n to denote that the coefficients are estimated using a nonlinear model in which the predicted value is modelled as a polynomial function of age, weight and BBS and FIM admittance values. Similarly the second local detector is formulated as

$$H_2 = \left\{ \text{choosehydrotherapy} \quad \frac{\hat{X}_n a}{\hat{Y}_n a} \geq 1.25 \right.$$

We then propose to fuse the above two decisions using blind adaptive algorithm proposed in our previous work (Mirjalily et al., 2003). The authors demonstrated that by formulating empirical probabilities of decisions one can solve in a closed form for prior probabilities as well as probabilities of false alarm and miss under the assumption that the performance of local detectors does not vary significantly. We apply the following approach using similar technique we demonstrated in (Li and Jeremic, 2011) to fuse the above decisions of linear and non-linear predictor. We recall it here for the case of $N = 3$.

$$\begin{aligned} u_0 &= \begin{cases} 1, & \text{if } w_0 + \sum_{n=1}^{2} w_n > 0 \\ 0, & \text{otherwise} \end{cases} \\ \text{where,} \quad w_0 &= \log\left(\frac{P_1}{P_0}\right) \qquad (1) \\ \text{and} \quad w_n &= \begin{cases} \log((1-P_n^m)/P_n^f), & \text{if} \quad u_n = 1 \\ \log(P_n^m/(1-P_n^f)), & \text{if} \quad u_n = 0 \end{cases} \end{aligned}$$

The probabilities of false alarm and missed detection of the nth local detector are denoted as P_n^f and P_n^m, respectively. The optimal fusion rule tells us that the global decision u_0 is determined by the a priori probability and the detector performances, i.e., P_1, P_n^f and P_n^m which can be solved for by solving algebraic set of equations as demonstrated in (Mirjalily et al., 2003)

3 RESULTS

The total number of patients admitted was 413 (260 with hydrotherapy and 153 without hydrotherapy) with general characteristics being described in Table 1.

Table 1: General characteristics of patient population with respect to the age and severity index of fracture

	Age	Severity Index
Total N=413	77.63 ± 6.21	1.84 ± 0.59
Female N=271	78.28 ± 5.86	1.74 ± 0.43
Male N =142	76.39 ± 6.56	1.79 ± 0.62

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.

Table 2 .

	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

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

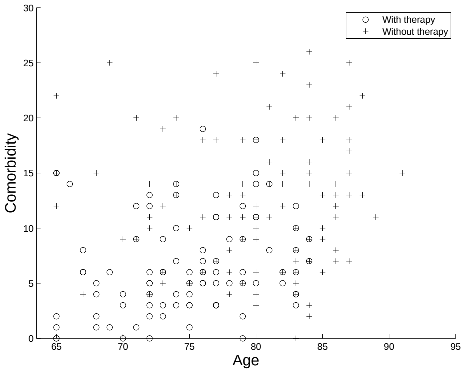

Figure 1: Two-dimensional scatter of age and comorbidity

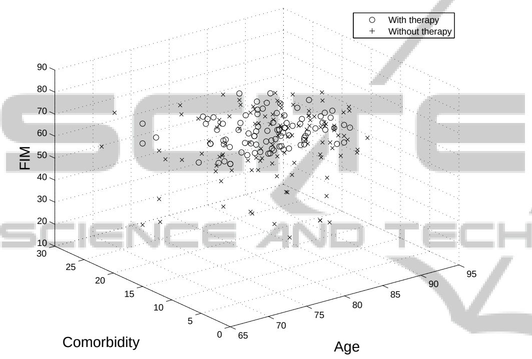

Figure 2: Three-dimensional scatter of age, comorbidity and FIM.

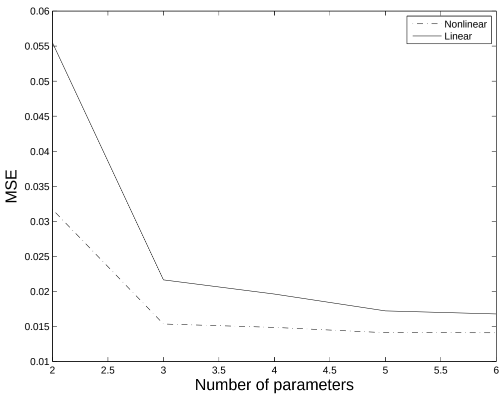

Figure 3: MSE comparison nonlinear vs. linear model for patients with hydrotherapy.

was not randomized in this study and hence we expect to have different performance. Obviously in making clinical decision not all the decisions can be randomized as it may contradict clinical protocols.

In order to evaluate the performance of the proposed hybrid system we run the fusion center consisting of three local detectors: linear detector, nonlinear detector and human expert system. As expected the overall probability of error decreases with the increase in the number of the patients. It demonstrates

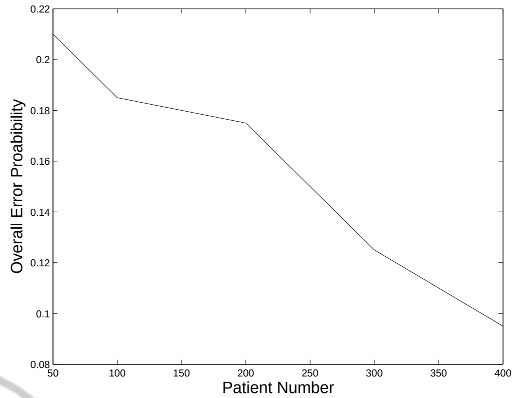

Figure 4: Overall Probability of Error for Hybrid System.

Table 3: General characteristics of patient population with respect to the age and severity index of fracture.

	Linear	Nonlinear	Expert
False Positives	12%	10%	11%
False Negatives	10%	9%	8%

significant dip after number of patients reaches 300 which is consistent with our findings in (Liu et al., 2011) where we developed optimal M-ary distributed detection system.

In Table 3 we list the estimated performance measures of our local detectors. Note that by false positives we determine selection of hydrotherapy when it is not expected to provide significant advantage. As expected the human system outperforms the computer-aided systems except with the case of false positives when compared to the non-linear system. Note that the results in Table 3 are overall results and it may be potentially useful to decompose these error with respect to patients' age and gender which may affect human decision making.

4 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 (Sipila et al., 2011). 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 determine whether or not hydrotherapy is required. This question may be of significant resources in scenarios in which the number of geriatric physiatrists as well as access to resources and/or their cost may be a limiting factor. Furthermore we proposed a framework that can potentially be useful for evaluating performance of fellows and/or residents and assist them in their training and educations as well as professional development as it can point to potential mistakes. This could be further used in order to evaluate the cause of such mistakes and potential was to remedy them.

As a preliminary approach we proposed computer-aided decision making using linear and nonlinear models in which 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 and BBS 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. 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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