A Fuzzy Qualitative Framework for Indoor Rowing Kinematics Analysis

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Abstract: - In this article an outline of a fuzzy qualitative framework for the indoor rowing kinematics analysis have been proposed. Main goal of introducing this fuzzy qualitative framework is to bridge the gap between high level of quantitative details obtained with various present – day sensory or video inputs and symbolic representation used by rowing experts. A Fuzzy qualification process of kinematic parameters is done on the basis of previously collected quantitative data and with possession of prior contextual knowledge for their qualification by rowing experts. Quantitative data acquisition is included indoor rowing kinematics recording by video motion tracking system. Generalizations of the proposed method on kinematics analysis of a common indoor human motion, problems of symbolic representation, as well as guidelines for method improvement are briefly discussed.

Key-Words: - fuzzy qualitative analysis, indoor rowing, quantitative analysis, fuzzification, human motion

1 Introduction

Nowdays, human motion analysis represents one of the most explored fields in science. There are numerous confirmations for this and we will mention only a few of them: sports (improving the performance and specific sport technique, strategy or tactics analysis in team sports, as well as prevention of the injury), man - machine interface, ergonomics of the working places, smart surveillance, virtual reality, intelligent medical robotics – precisely robotics in a broader sense, entertainment industry, etc. For this purpose numerous quantitative analysis methods of the human motion have been developed [1 - 5].

Generally, human motion can be divided into a body or body segements detection, tracking and activity understanding [6]. For this purpose 2D or 3D approaches have been used, i.e. the recording with one or more cameras. Models of the body or body segments are in range from various stick figures, over 2D - contours to the volumetrics representations. Parameters for kinematics analysis can be obtained by using active or passive markers, and by efficient markerless algorithms for human motion tracking which have been recently developed [7] or applying inertial sensors techniques [8]. All of these methods are characterized by relatively high degree of accuracy and precision, as well as reliability of the collected data. In all segments of analysis: human detection, tracking, and especially in behaviour understanding - which consists of action recognition and its description important role has a semantic description used in the interpretation. In other words - the quantitative parameters at the end should be appropriately interpreted by experts from the particular domain of motion study - such as coaches, doctors, physiologists, psychologists, etc. Increasing the precision of quantitative data necessarily leads to reducing of their importance for the end users, which is in accordance with the principle of incompatibility [9].

In order to be more useful for human experts, quantitative data obtained by advanced and reliable methods of the human motion analysis can be subjected to the process of qualification. This means that it is possible to switch to qualitative analysis of the human motion when the situation demands thus. This is particularly true for practical human motion analysis systems that require to be running in real time [10]. On this way these two methods become mutually complementary methods. In this sense it is important to find criteria for when to apply quantitative and when qualitative approach. Simplified, when we need a high degree of precision and details it will be more appropriate to use some of quantitative methods, and in all others cases diverse qualitative approaches. In what follows, we shall propose some basics aspects of fuzzy qualitative method for the indoor rowing kinematics analysis. Fuzzy qualitative methods proved to be a satisfactory reasonable approach to the study of kinematics of robots and human motion [10 – 12]. As a matter of fact, this paper is not presenting the full and final exposition of our approach and its applicability. Rather, it should be regarded as an rudimental outline of a method which has different approach in relation with the 'classical' quantitative methods. Theoretical foundation for fuzzy qualitative analysis nowadays is a well known and mathematically precisely defined, and it is represented with the Fuzzy set theory, Fuzzy logic, CW (Computing with Words) theory, Fuzzification, Fuzzy graphs, Fuzzy information granulation and General Theory of Uncertainty (GTU). Preliminary results of research showed a high degree of acceptance of the applied method by the rowing coaches.

The remainder of the paper is structured as follows. Section 2 derives the fundamentals for proposed fuzzy qualitative analysis, in particular how the data acquisition, quantisation and fuzzy qualitative kinematics framework are employed in the indoor rowing kinematics analysis. In Section 3 experimental procedure is described. Obtained results and discussion upon it presented in Section 4. Section 5 gives some concluding remarks on presented methodology.

2 Fundamentals of a fuzzy qualitative framework for indoor rowing kinematics analysis

The proposed fuzzy approach to qualitative analysis for indoor rowing kinematics is based upon acquisition of the kinematics parameters in sagittal plane by using a video motion tracking system. In this way, reliable quantitative data were obtained, which then can be subjected to fuzzy qualitative process modelling. In this section the theoretical basis of a fuzzy qualitative analysis in case of ergometer rowing (indoor rowing) are presented.

2.1 Indor rowing modelling

For the purpose of the rowing stroke kinematics analysis simplified 2D link segment model has been given as it is shown on the Fig.1. Eight markers (M1 - M8) are attached on crucial body points and from their coordinates ((xi, yi), i = 1, 2, 3, …, 8) major parameters for rowing kinematics analysis were calculated according equations (1 - 5). Thereby, relative coordinate systems have been used at kinematics parameters definition. All wanted angles (φ_1, φ_2, …, φ_5) were calculated using the following equations:

$$\varphi_1 = arctg\frac{y_7 - y_6}{x_6 - x_7} \quad (1)$$

$$\varphi_2 = arctg\frac{y_6 - y_5}{x_5 - x_6} \quad (2)$$

$$\varphi_3 = arctg\frac{y_2 - y_1}{x_2 - x_1} \quad (3)$$

$$\varphi_4 = \pi - arctg\frac{y_3 - y_4}{x_4 - x_3} \quad (4)$$

$$\varphi_5 = \pi - arctg\frac{y_5 - y_4}{x_4 - x_5} \quad (5)$$

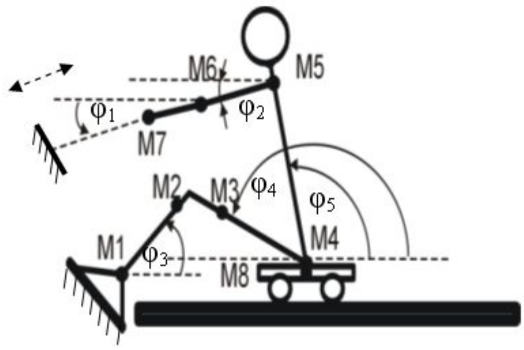


Fig.1 Simplified 2D link segment model together with the wanted angels and the marker positions pointed out

Position of markers M1, M2, M3 and M4 was selected in order to eliminate the problem of occlusion.

2.2 Data acquisition and processing

Recording of the stroke kinematics in sagittal plane by using marker method [13] is performed by a camcorder SONY DCR – TRV12E (in general any digital camcorder can be used). For the kinematics data acquisition PC with AMD ATHLON 750MHz processor and an external TV card with a video input is used (also recorded video data can be transferred in PC trough USB port if used camcorder has a such possibility and appropriate acquisition software) [14].

Marker tracking was done by program written in C++ which elaborated recorded video and produced a Matlab compatible file (matrix) containing coordinates of each marker recording throughout the time. This program is able to use different types of correlation or Walsh transform to follow selected markers on sequence of frames. It also relies on simple prediction of next position of marker [15]. The markers were placed on each rower, from whose coordinates; the figures necessary for the kinematics analysis of the stroke were obtained (Fig.2).

Numerical differentiation and noise removal with discrete Fourier transformation was done in Matlab in order to obtain smoothed linear and angular velocities and accelerations according to presented 2D indoor rowing model of link segment body. Markers positions on body were obtained from anthropometrical tables [1] accordingly rowers high, weight, age and gender. These points were on ankle, lower leg, thigh, hip, shoulder, arm, wrist and one on ergometer seat.

Fig. 2 Rower with markers positions pointed out

The more detailed view of data processing can be found in [16]. The quantitative kinematics data obtained on described manner represents the basis for implementation of a fuzzy qualitative kinematics analysis in case of indoor rowing.

2.3 Conceptual framework for fuzzy qualitative analysis of the indoor rowing kinematics

Usually at motion analysis, observed movement is divided into several phases. Depending on the complexity of the movement any or some phases can be additionaly divided into sub phases. Each phase or sub phase is described by the experts. Number of phases varies even for the description of the same movement. Generally, there is no consensus among experts nor scientists which division to accept. The main reason for that is in the approximative equal number of given pros and cons arguments for those that dominate in the literature. Thus, in rowing, there are divisions on 3, 5 and 7 phases. We accepted 5 phases division of the rowing stroke, respected recommendations of an rowing coaches with whom we were cooperated. According to the that division rowing stroke is divided into the following phases:

1) catch
2) drive
3) finish
4) release
5) recovery

First three phases represent the active part of the stroke, while the last two are passive part. Let's look at how one of the experts[17] described finish:

> „At the finish the legs and back finish together. The legs lock to stabilize the end of the stroke. With the hips locked and back braced, the arms can pull strongly....“

Or part of description for recovery phase [18]:

> „...The aim should be to extend the arms until they are straight, to pivot from hips until the body is in the correct position for the catch, and only then to start breaking the knees to slide forwards.“

Similar descriptions can be found for human gait or another movement. It is obvious that the experts are using qualitative descriptions and that was main reason why we have decided for qualitative approach of human movement analysis in this particular case of indoor rowing. Because of its high level of symbolic representation we decided for fuzzy qualitative representation.

For the purpose of a fuzzy qualitative analysis acquisition of data and its computer processing is needed. In accordance with that 2D model and procedures described in sections 2.1 and 2.2 are used respectively. Since this is the observation of motion in a closed area, where the background conditions can be quite controlled, it is not necessary to carry out the step of the human body detection. In support of this is going the application of markers tracking method. We can freely say that classical quantitative methods are the base for the proposed qualitative analysis. After that first phase it is necessary to make transformation of the selected variables in the qualitative domain. In this step we use knowledge of the experts to determine the limits within which the linguistic variables are defined and associated hedges. In fact, on this manner we have made fuzzification of the input acquisition parameters. It is important to develop a unified semantic approach that best describes the observed motion. Finally, still remains to determine the memebership function that best fit a given case. Triangular, Gaussian and sigmoidal membership functions can be applied. Usually, common procedure understands implementation of all three mentioned functions and after that of choosing the one that gives the best results - it is therefore the iterative process of finding a satisfactory solution. On figure below (Fig.3) a conceptual representation of the qualitative analysis is shown:

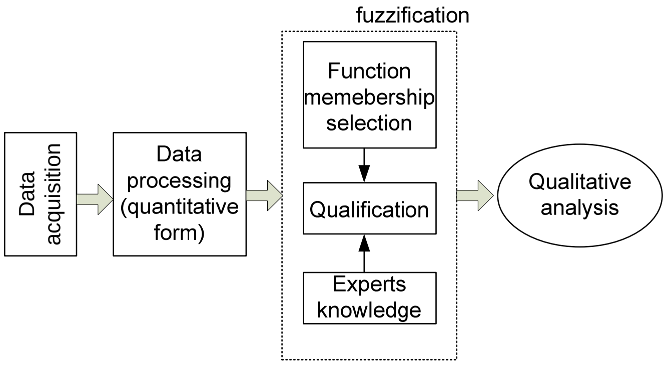


Fig.3 Conceptual framework for qualitative analysis of the human movememt

If the body is viewed as a system of linked segments [19], [20] then, for any segment BS (body segment) following parameters can be defined:

BS_n → lp_n; lv_n; la_n | n = 1,2,3, … (6)

And / Or

BS_n → anp_n; anv_n; ana_n | n = 1,2,3,… (7)

Where is:

lp_n.........................linear position of the nth body segment

lv_n ....velocity of the nth body segment

la_n ....acceleration of the nth body segment

anp_n ....angular position of the nth bodysegment

anv_n ....angular velocity of thr nth body segment

ana_n ....angular acceleration of the nth body segment

As we can see the linear and / or angular variables of each segment might be defined. Also some other variables, such as position of the one segment with respect to another (relative position), could be defined if needed. Linguistics variables [21, 22], which are used for description of motion, are defined by taking into account the upper division on the linear /angular and relative variables, so we have:

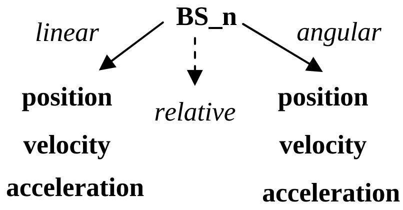


Fig.4 Lingvistic variables of the particular body segment

If for an example, the trunk is observed BS_n then one of the relevant linguistic variables is angular position, which can take values extremely sloped, very sloped, moderate sloped, gently sloped, upright, etc. Introduces direction in analysis we will have forward and backward. Fuzzification takes place based on the knowledge of experts (desirable not only one), so that the area of a set of crisp values is transformed into fuzzy set. The whole process can be summarized in the following steps:

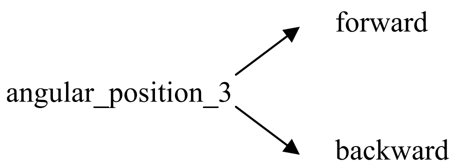
1) Pick up segment – e.g. BS_3 ≡ trunk

2) Membership function selection

3) Determining the lingvistic variable – for example:

   anp_3 → angular_position_3

4) Defining of the primary terms for the lingvistic variable:



5) Determining the lingvistic variable values together with experts:

   forward = {value_1, value_2, value_3, ..., value_n}

   backward = {val_1, val_2, val_3, ... , val_m}

   $n,m \in \mathbf{N}^+$

6) If necessary specify the **negation** and connectivenes **and** and **or**

7) Repeat the whole procedure for different memebership function selection

This procedure should be repeated for all parameters of interest in the analysis of an observed movements.

3 Experimental procedure

The proposed method is based on fuzzification of the collected and processed variables of observed movement on rowing ergometer. Experiment was done on sample of 20 rowers and it is included indoor rowing kinematics recording and data acquisition by using the video motion tracking system. Video camera – PC system records positions of markers attached on eight crucial points (Fig. 2), in sagittal plane (Section 2.2). With a human body link segment model, the associated lines and the angular parameters of particular segments were calculated from the markers positions (Section 2.1). All 20 rowers were rowed a 6 minutes session, divided into three same parts as it can be seen from the following Table 1.

Table 1 rowing time sections

2min tmp 22/min	2min tmp 28/min	2min tmp 34/min
+10 sec than the 6000m test	the same average as on the 6000m test	-5 sec than the 6000m test

Rowers were divided into 4 categories accordingly to the rowers' skills and the years of active training. On this way we have obtained curves of essential parameters for rowing kinematics analysis in sagittal plane – exactly qualitative values necessary for the process of fuzzification.

Afterwards the rowing experts are consulted (in our case, two coaches in the lower categories and coach in junior team of the Croatian rowing team), and rowing stroke phase exposition, as well as available rowing technique descriptions available in the literature [17, 18, 23] in order to fuzzification of the obtained data could be conducted through the steps 1) - 7) (described in Section 2.3. of this work). Fuzzification and accompanying data processing was performed using the Matlab Fuzzy Logic Toolbox and Simulink [24 – 27].

4 Results and discussion

Analysis and descriptions of the quantitative data that can be transformed into a form suitable for fuzzy qualitative analysis by the process of fuzzification might be found in papers [16] and [28]. Figures 5, 6, 7 and 8 are typical examples of the quantitative analysis data depiction. Figures on which two curves of observed kinematical parameters are depicted have shown results of comparison with selected representative sample (an elite rower).

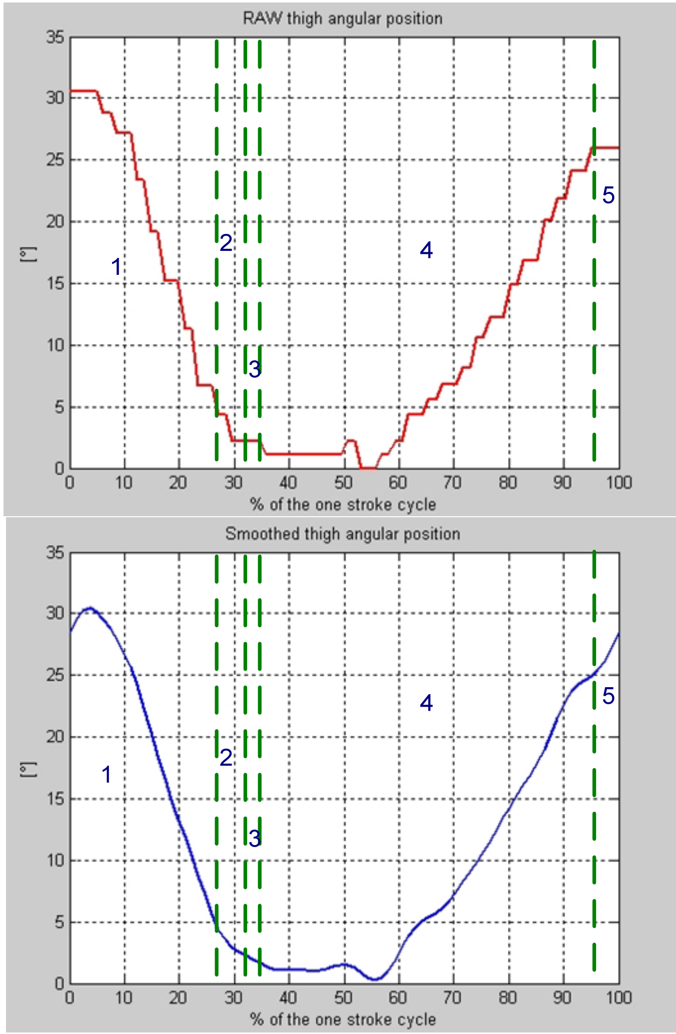


Fig.5 RAW and Smoothed thigh angular position during one stroke (tmp 22/min)

Labels 1 – 5 attached on figure above (Fig.5) represents rowing stroke phases: drive, finish, release, recovery and catch, respectively. As can be seen, the converted coordinates from recorded file contains noise signal from many sources - mostly VF signals (environment electronics and recorded equipment influence), and NF noise signals (small marker displacement). Those signals are called RAW data. For the purpose of removing noise from RAW signals discrete Fourier transformation were performed in Matlab program package. First eight harmonics have been used for signal reconstruction. Number of harmonics was determined by the method of attempts and faults. Smoothing procedure is especially important for getting the corresponding segments velocities and acceleration, since this parameters are obtained in process of a numerical differentiation.

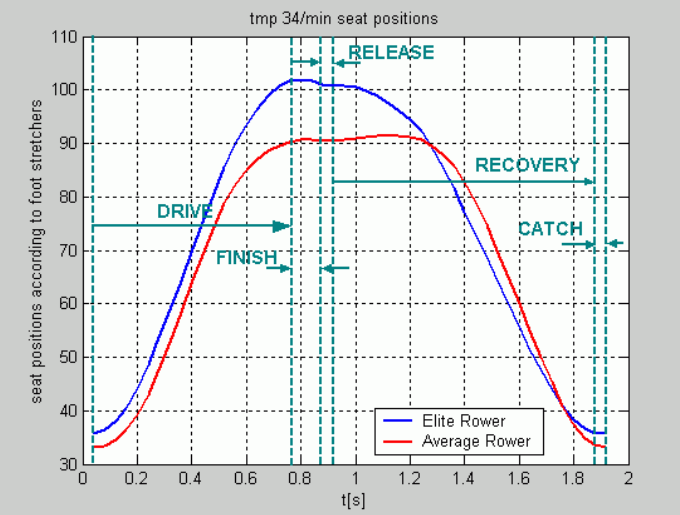


Fig.6 The seat position according to foot stretchers of average rower and elite rower (tmp 34/min)

The stroke phases have been marked on each curve so that it could be possible to establish in which moment a single parameter of the rowing stroke differs significantly from the representative sample. This kind of presentation enables a simple comparison of all observing kinematics parameters for two or more rowers. Representative sample is the rower with numerous World and Olympic medals, which in the opinion of most rowing experts has satisfactory pattern of motion.

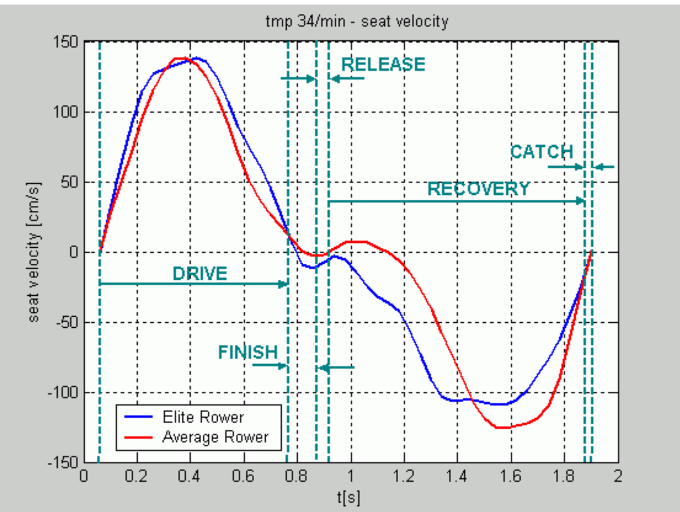


Fig.7 The seat velocity of average rower and elite rower (tmp 34/min)

Phases of stroke were defined manually from the captured videos and in that proceeding rowing coaches were participated.

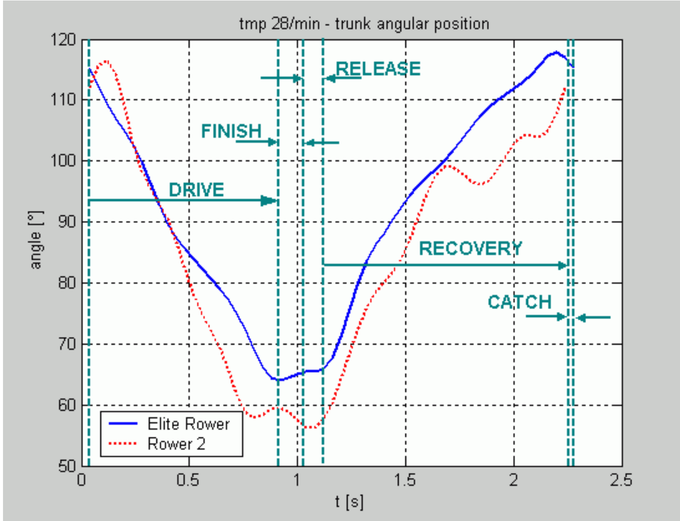


Fig.8 Trunk angular position of one rower from the test group and an elite rower

As the measure of kinematics data deviation in all comaprisons relative error has been calculated. Obtained results of comparison were checked between the kinematical parameters of two elite rowers. Thus the basis assumptions of comparing rowing motion patterns were checked. Examples of these errors are depicted on figures 10 and 11. This way of data depiction were presented to the rowing experts trough the previously published papers [16, 28], and was rated by them as an unacceptable in the training process practice. In addition to the reasons mentioned in section 2.3 this was one of the major reasons for moving to the fuzzy qualitative approach. A typical example of the fuzzy qualitative data depiction is shown on figures 12 and 13. In the performed analysis each segment has been observed separately and for the initial consideration trapezoidal membership functions was taken. On the basis of the collected data experts have defined the linguistic variables and their associated values.

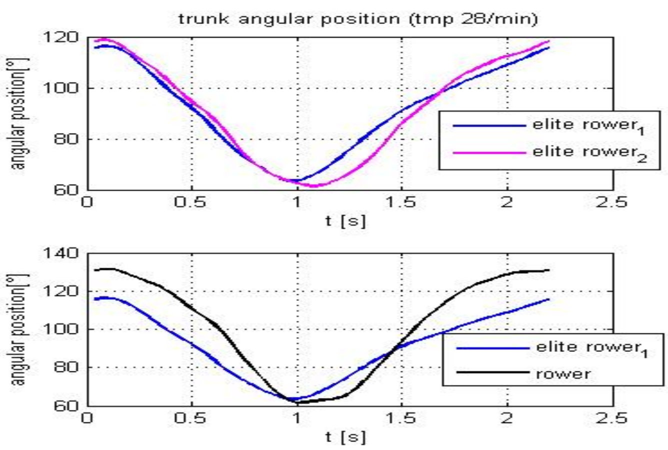


Fig. 9 Angular trunk position

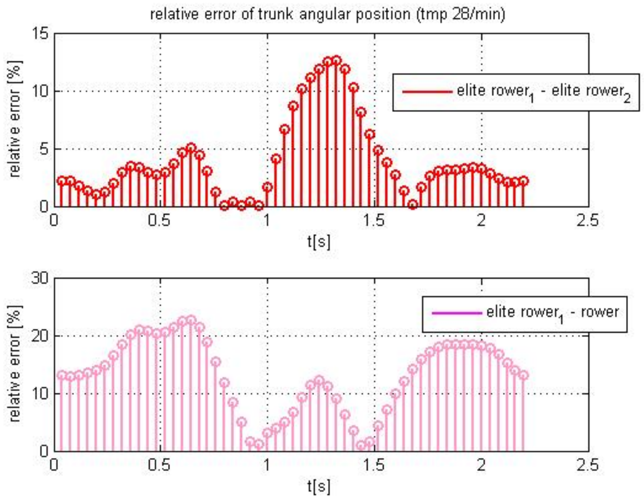


Fig. 10 Presentation of relative errors associated to the angular trunk position

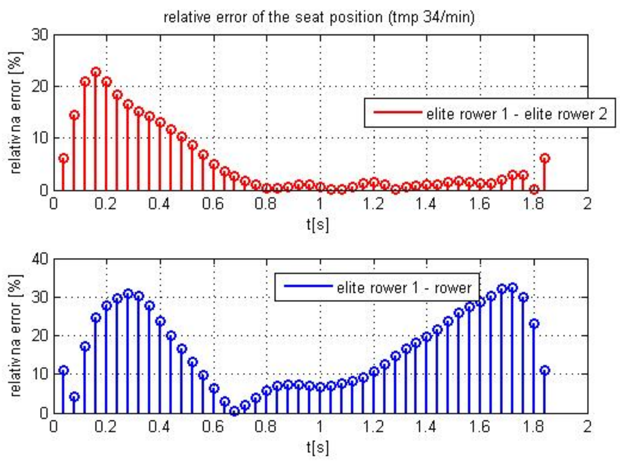


Fig.11 Relative errors of the seat positions (tmp 34 / min)

These results are compared with descriptions of the rowing stroke in an available literature, and according with that a less additional corrections of certain values was done. For example, the lingvistic variable angular_position is defined for trunk. Primary terms forward and backward, which refered to the trunk slope during rowing stroke in relation to the chosen referential coordinate system, were elected. Values of the linguistic variables (hedges) are {very sloped, moderately sloped, gently sloped, upright). Defined values are different for every selected primary term. Fuzzification result of the trunk angular position for randomly chosen rower from the test group and an elite rower is shown on figure below. These results corresponds to the quantitative data depicted on figure 8, while results from figure 13 coresponds to the quantitative data shown on figure 7.

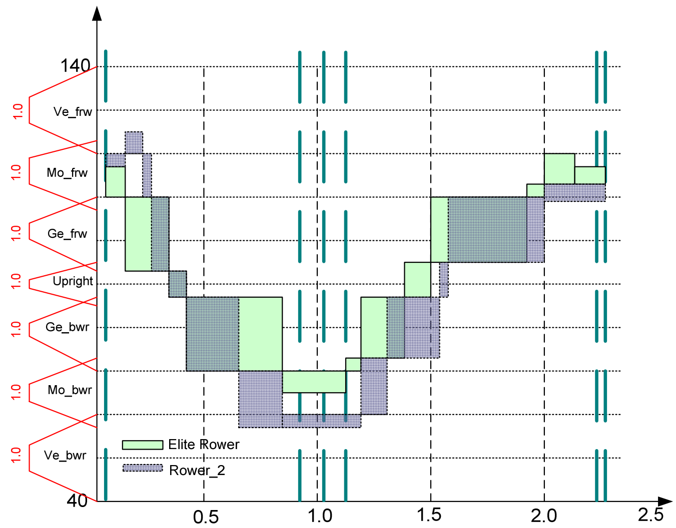


Fig.12 Results of fuzzification for trunk angular position – an elite rower and randomly choosen rower (tmp 34/min)

Obtained results for randomly chosen rower indicates a partially incorrect body position in the initial phase of the drive, completely unacceptable backward slope of the body in the second part of this phase and throughout the whole finish and release phases of the stroke. In recovery phase of the rowing stroke trunk was too much in the open position for that phase. This results in improper catch tilt of the body - generally a rowing experts this case call an unprepared catch position.
In the case of seat, lingvistic variable seat_velocity were defined. Primary terms forward and backward which herein defines rowing ergometer seat velocity direction during the stroke according to the referential coordinate system. Precisely, forward indicates direction from foot stretchers, and backward toward them. Slow, fast, moderately fast and idle are selected values for seat_velocity hedges.

Hedges for seat_velocity → {slow, fast, moderate fast, idle}

Large number of hedges can give better resolutions, but computational demands then increases rapidly. Described procedure can be applied to all segments and its associated kinematics parameters. It is important to emphasize the necessity of carrying out the recording in three stated rowing rates (22, 28 and 34 strokes per minute), so as to gain an insight into the manner of transferring the "stroke smoothness" at a bigger number of strokes. This is rather important since a large number of rowers have a relatively good rowing technique at a lower number of strokes, which they easily lose at a larger rate (regatta rate) [29].

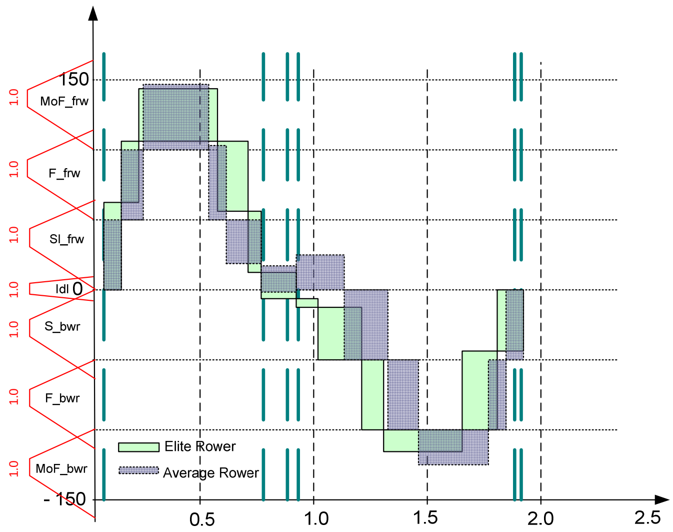


Fig.13 Results of fuzzification for seat_velocity – an elite rower and average rower (tmp 34/min)

From graphical depiction it is visible that most part of the drive phase an elite rower keeps the fast or moderate fast velocity, while an average rower in final part of the drive starts to get slow seat pace. An average rower has been obtained as the average value of the kinematics data information from the test group with 20 rowers (mean value of the all matrix data). During the finish and release phase of the stroke seat of the average and elite rower is almost idle. In the first part of recovery phase the seat of the average rower is moving slowly but in wrong direction. This is very useful information for coaches wich indicates that rower did not extended legs fully in previous drive phase and it is not so obvious in quantitative data representation. After that, a large part of the recovery phase the athlete is moving slowly, and in the middle and last part of the this stage he held fast or moderately fast motion. Such velocity pattern in the recovery phase is the main cause for significant slowing of a rowing boat. The velocity patterns of the elite rower in this phase do not show any particular negative trend that will be cause for significantly slowing down of a rowing boat.

Thus obtained preliminary results are evaluated positively by the rowing experts who consider it very useful for a qulitative rowing stroke analysis. According to the experts advices applied method can be used for selection of the best possible crew.

5 Concluding remarks

Method presented in this article can be considered as an introductory outline of a fuzzy qualitative framevork for the movement analysis in case of ergometer rowing. Taking into accout a good aspects of fuzzy qualitative reasoning, wich means a high level of symbolic representation, this kind of analysis could provide a tool for practical evaluation of the rowing technique quality in each phase of the stroke. All good benefits of fuzzy reasoning have attracted much attention and exploration from industry and research's communities in the past four decades [30]. Main goal of introducing this fuzzy qualitative framework is to bridge the gap between high level of quantitative details obtained with various present – day sensory or video inputs and symbolic representation used by rowing experts. The lack of a symbolic representation is in a high degree of ambiguity which applied symbols or groups of symbols may have. Hence, the bases for any symbolic system usage in real motion description are the development and adoption of a unified and practical semantic system, which is not an easy task.

In cases where human motion can be studied in controlled indoor conditions by using the human body system of linked segments, it is possible to apply steps 1 to 7 of the proposed method (Section 2.3). Therefore, if it is also possible to well define kinematics parameters of interest mathematically and to acquire knowledge of experts from the domain of the observed motion this method could be generalized almost in all cases where human motion have been studied in indoor environments. However, further researching need to be done in regard to this.

Consulted coaches have suggested the application of quantitative methods in all cases when it is necessary to get more detailed insights into the kinematics parameters which is especially referred in training process of elite rowers and crews - in this way, these two methods become mutually complementary.

For all concluding remarks mentioned up to now, it is necessary to have appropriate educated staff that would be the bridges between different types of experts which are participate in the analysis of human movement [31]. Prerequisites for application of the IF - THEN rules for the rowing movement performance rating as a whole, and not only through particular segments have been created. The second application of the IF - THEN rules can be particularly suitable for kinesiologists and sports physicians in the process of prevention of athletes injuries.

Also, possibility for automatic rowing stroke phases detection are opened. Improvements of the method in the first place are possible by chosing different memebership functions and by more detailed analysis through the application of the Computing with Words theory and the General Theory of Uncertainty. So, our future work is focused on the development of a fully automated monitoring system by using the markerless method, as well as intelligent system for description of kinematics in case of the indoor rowing applying methods of machine learning and to built the public fuzzy database of indoor rowing kinematics [32 – 34]

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