Mouse Tracking Algorithm Based on the Multiple Model Kalman Filter: Design and Implementation of Ophthalmological Corrector

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***Abstract*—The article deals with a software implementation of the ophthalmologic corrector. The corrector is perceived as a medical device for a correction of the amblyopia. During the exercise, children are requested to draw a template, which is placed on a metal board. This therapeutic procedure has been used in clinical practice for many years. There is a big disadvantage of using the mentioned device. There is no any manageable way for storing and archiving patient's data. Furthermore, exercise must be performed on the clinical workplace. Due to these facts, we are interested in software design and implement the ophthalmologic corrector. The proposed corrector is based on a mouse-tracking algorithm, which is able to perform the tracking of the mouse movement in the form of continuous line. Formed line overlaps the selected template. This procedure allows the identification of the real time accuracy and distance of the generated line from a given template. Furthermore, the algorithm allows for storing the achieved results for further data processing. It is a required tool for assessment and plan of therapeutic treatment in the field of ophthalmology.**

***Index Terms*— Amblyopia; Mouse Tracking; Ophthalmologic Corrector; Pleoptic Exercise.**

I. INTRODUCTION

Refractive disorders represent the most frequent cause that leads to a significant visual impairment among children in the Czech Republic. The impairments, in particular the unrecognizable and untreated refractive disorders as well as their consequences may lead to the development of amblyopia and strabismus [1, 2, 3, 4].

Refraction disorder is an eye infliction that goes to the wrong fragility of the sun beams that drop to the human's eyes. These beams are not displayed on the retina as desired, resulting in a blurred vision. The common refraction disorders are called myopia, hyperopia and astigmatism.

Amblyopia is the inability of brain to recognize an image sensation that comes from the retina. The main causes of amblyopia are, such as strabismus, astigmatism or any other higher refractive errors. During amblyopia, the image from inflictive eye senses a blurry. Children who have this problem tend to cover the better vision eye and tilt their head; hence, they are not able to orient in space [5, 6, 7, 8].

It is essential to treat this problem early for a successful treatment. In the case of amblyopia, a vision function, which is not trained until six years would be permanently lost. Amblyopia is primarily treated by glasses and occlusion, which is applied by occluder on the better sighted eye [9, 10].

Figure 1: The child with total occlusion

II. PLEOPTIC EXERCISES

The essential part of the treatment process of amblyopia is called pleoptic exercises. A set of designed procedures under the supervision of medical staff is performed during these exercises. These exercises lead to a progressive training (recovering) of visual acuity on an impaired eye. Ophthalmologic corrector is a device where children draw a black template placed on the metal board using a metal pencil. In the case of a missing template, the patient will be pointed out by an acoustic signalization [11, 12].

Figure 2: Ophthalmologic locator (corrector)

III. PROPOSED ALGORITHM FOR OPHTHALMOLOGIC CORRECTOR

The whole implementation of a corrector is composed of three essential parts, which is the generating of vector images (templates), discrete detection of template and smooth drawing of template using mouse tracking algorithm. First of all, the templates in the vector format were generated. A corrector is especially intended for young children; therefore, children-friendly templates should be designed. According to the therapeutic procedures, templates were produced based on three alternatives, which differs according to line thickness. We particularly used three different thickness: 1, 2 and 3mm. Examples of the proposed templates are shown in Figure 3.

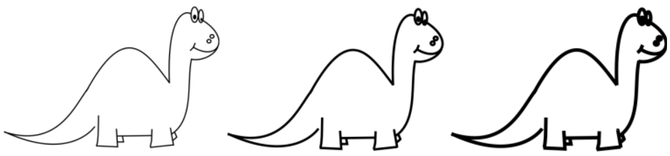

Figure 3: Template with thickness 1mm (left), template with thickness 2mm (middle) and template with thickness 3mm (right)

As mentioned above, the proposed algorithm offers two therapeutic procedures. A discrete way is especially intended for those patients who do not have a completely damaged vision. This procedure is more demanding and requires more attention. At the beginning of the algorithm, the number of attempts is set. After running the procedure, the patient is trying to hit the selected template in consecutive steps. After taking the procedure, it is necessary to evaluate the distance between the patient's hit and defined the point on the template. The distance is calculated based on Euclidean equation, as given by the following formulation:

$$d(p,q) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2} \quad (1)$$

where p denotes reference points placed on template and q denotes points given by the user. On the base of this measurement, we can store the patient's data, and perform consequent analysis. Furthermore, the algorithm is equipped by acoustic signalization. In the case when the template is not hit, the generated sound points out the negative event. The events of the individual sound are stored as well. Example of the therapeutic procedure based on its discrete way is shown in Figure 4.

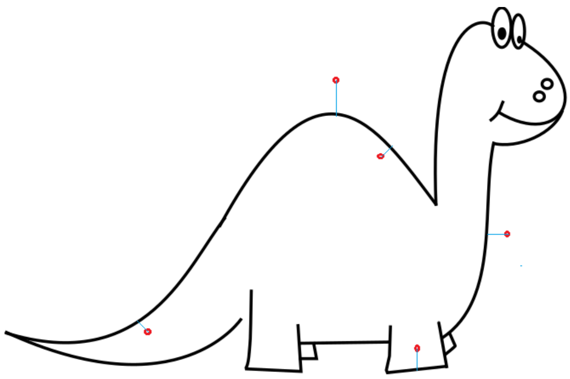

Figure 4: The example of discrete alternative of corrector. User's hits are indicated by red circles

Finally, the minimum distance between the set points and edge points is calculated. The points given by user are marked by red color. For these points, a minimum distance to the edge of the template is calculated. Based on this procedure, we are able to estimate a level of the vision infliction. The implementation of the whole corrector can be summarized into the following block diagram as shown in Figure 5 [1, 2, 3, 9, 10].

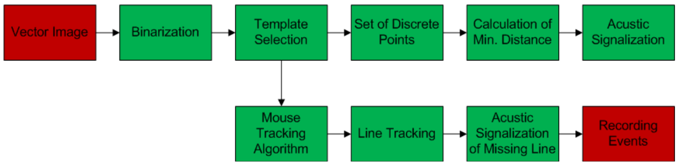

Figure 5: Block scheme of software corrector

IV. Proposed Mouse Tracking Algorithm

A used mouse-tracking algorithm is based on a multiple model Kalman filter (MMKF). The method uses N multiple sub-Kalman filters in a parallel scheme. This approach uses configuration of different coordinate system for a different model. All filters are updated during the measurement simultaneously. The resulting prediction of the movement is given by a weighted sum of individual predictions from all the Kalman filter modules. The overall structure of the multiple model Kalman filter is shown on Figure 6.

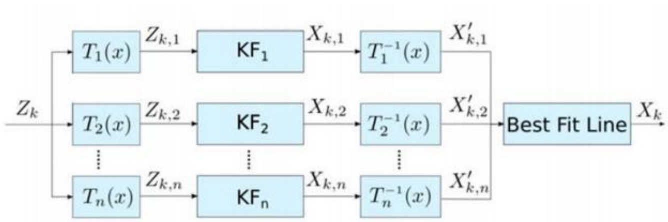

Figure 6: The overall scheme of multiple Kalman filter

Parameter Z_k represents the measurement process at time k. Consequently, it is transformed to coordinate the system of the i-th Kalman filter, called as KFi by transformation T_i into $Z_{k,I}$. Parameter $X_{k,I}$ corresponds with the prediction of the state closets point in the next frame by i-th Kalman filter. The prediction results are reversely transformed into one common coordinate system. This task is performed by corresponding to the inverse transformation $(Ti)^{-1}$. At the end, a line-fitting function is applied to find the resulting prediction of the line.

The tracking method uses different coordination system for each filter. The prediction of each sub-Kalman filter is the position and velocity of the closest point. Least square fitting method is used for finding the best fitting line. This approach minimizes the sum of square errors between the line and the closest points.

A. The Design of Kalman filter

Kalman filter is used for tracking procedure x,y coordinates of the closest point C of the line L. At the beginning of procedure, we assume that the closest point is moving with a stable acceleration. The motion in both axes is independent and linear. The motion of the x-axis describes the motion of point C:

$$x_t = x_{t-1} + \dot{x}_{t-1}\Delta t + \frac{1}{2}\ddot{x}_{t-1}(\Delta t)^2 \quad (2)$$

$$\dot{x}_t = \dot{x}_{t-1} + \ddot{x}_{t-1}\Delta t \quad (3)$$

$$y_t = y_{t-1} + \dot{y}_{t-1}\Delta t + \frac{1}{2}\ddot{y}_{t-1}(\Delta t)^2 \quad (4)$$

$$\dot{y}_t = \dot{y}_{t-1} + \ddot{y}_{t-1}\Delta t \quad (5)$$

where, x_t, $\dot{x}_t$ and $\ddot{x}_t$ represent displacement, velocity and acceleration of the point C in i frame of horizontal direction.

Parameters y_t, $\dot{y}_t$ and $\ddot{y}_t$ denote to the displacement of velocity and acceleration of the point *C* in the vertical axes. Kalman filter is defined by the state matrix X_t and the measurement matrix Z_t at time *t*:

$$X_t = [x_t \; \dot{x}_t \; y_t \; \dot{y}_t]^T \tag{6}$$

$$Z_t = [x_t \; y_t]^T \tag{7}$$

By derivation of the motion equations, we obtain the transition model *A*, and the observation model *H*:

$$A = \begin{bmatrix} 1 & \Delta t & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \Delta t \end{bmatrix} \tag{8}$$

$$H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{9}$$

B. Implementation of Tracking Algorithm

Initialization of each sub-Kalman filter is performed with the closest point, which belongs to the line in the first frame. Posterior error covariance matrices are set to zero. There is a requirement on the number of sub-Kalman filters. We should use at least four sub-Kalman filters.

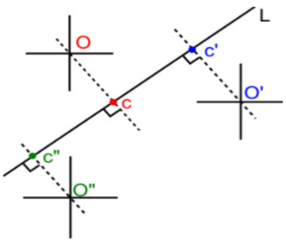

Figure 7: Representation of line by different coordination systems

Figure 7 shows the example of representation of different coordination systems with origins *O*, *O'*, *O''*. The coordinate origin can be placed arbitrarily inside the image. It is needed to define vector *r*. Let us consider a coordinate system centered at *O*, the vector from *C* to *O* is denoted as *r*. The angle between the horizontal axes and the vector *r* is denoted as ϕ. Similar expressions are used for other coordinated systems [13, 14].

V. Data Analysis of Corrector Implementation

The main intention of our work is developing software for ophthalmologic corrector as a therapeutic procedure for the amblyopia suppression. There are two main procedures, namely the discrete and the continuous plan. The discrete plan is more demanding when used for examining a person because it requires a close attention. Contrarily, the continuous procedure requires less attention and it is more effective in terms of therapeutic effect. The most important part of data analysis is the evaluation of the achieved results. It is important to highlight the events when patient misses the line. For the purposes mentioned, acoustic signalization has been used to highlight the recorded events. Another significant benefit is the possibility of saving and storing all the events.

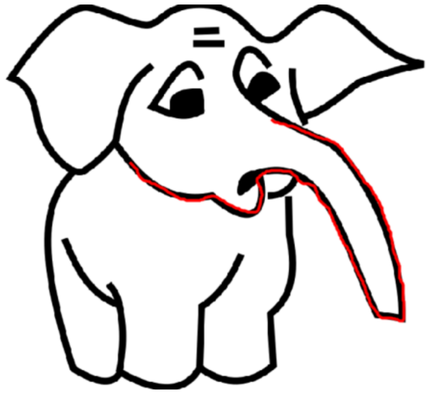

Figure 8: Output of corrector with line tracking

Figure 8 shows the output of line tracking algorithm for ophthalmologic corrector. The templates used are represented by a black line and white background. It is advantageous that we work with binary image, which contains two values: 0 and 1. Tracking algorithm is set at an initial spot and line development is controlled by the patient's hand. In the case that patient is moving on the template's line, no acoustic signalization is performed. If the user's line is deflected, acoustic signalization will be recorded, and events will be detected in the template image as well. This situation is illustrated in Figure 9. Furthermore, the peaks of deflective line are detected. It is an effective feedback for physicians as an assessment of effectiveness of the treatment.

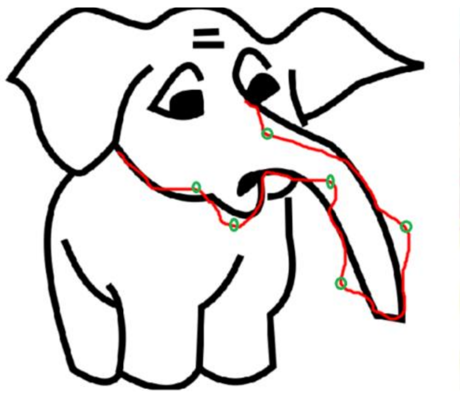

Figure 9: Line tracking algorithm with detection of deflections

The proposed methodology for ophthalmologic corrector has been implemented into a clinical software, and currently it is tested in the University hospital in Ostrava. From the clinical point of view, patient' attention is less demanding in the continuous line tracking; hence, this alternative has great potential to be commonly used in the clinical practice. On the other hand, the discrete plan is more suitable for patients having better vision. An important functionality is the data storing. This procedure allows a comparison of the individual exercises to be made over time and a setting of a clinical prediction of the vision progression. Table 1 summarizes the testing of the continuous alternative on 10 persons suffering from vision impairment. In this testing, a template with line thickness of 4 mm has been used.

In this procedure, only attempts indicating the missing of black line are counted (number of miss). Errors are partially influenced by the shaking hand and incorrect line tracing.

Table 1
Continuous procedure testing

Patients with vision impairment		
Birth day	Gender	Number of Miss
2004	Male	10
2003	Female	1
2006	Female	4
2006	Male	1
1990	Male	3
1998	Male	1
1993	Male	1
2008	Male	9
1996	Female	4
1991	Female	1

VI. CONCLUSION

There are more therapeutic techniques for the treatment of amblyopia in the clinical practice. Although ophthalmologic methods are effective and able to achieve their purposes, they are usually very obsolete. The major problem is the inability of storing data and performing data analysis. The main intention of the proposed paper is to design a suitable methodology for software implementation of ophthalmologic corrector, called the locator. This device consists a mechanical machine. A patient who holds the metal pen and makes a drawing during a certain period of time produce a drawn template. Each patient's deflection is recorded via acoustic signalization. After this therapeutic procedure, we do not have any feedback of the procedure process. The designed method allows two therapeutic procedures, so-called discrete and continuous approach. The discrete approach is intended for advanced patients because it is more demanding and requires more attention. Patient defines a set of initial points on the template, in which each of them is recorded. If the point misses the template, acoustic signalization will be run. Data for the procedure are stored for the later data pre-processing. The main procedure introduces continuous line drawing, which is based on the line-tracking algorithm. A patient is trying to draw a line, which reflects the shape of the selected template. Acoustic signalization is made when each template is missing. There are three alternatives for overcoming the difficulties according to the selected line width. The patient starts with a template of the widest line and in the consecutive procedures they advance to the thinner lines. The patient's records are stored and there is a possibility to evaluate the number of missed attempts and make comparison among the individual therapeutic procedures.

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REFERENCES

[1] Z. Zhang , Visual panel: Virtual mouse keyboard and 3d controller with an ordinary piece of paper. (2001) *Proceedings of the Workshop on Perceptive User Interfaces.ACM* Press, 2001, pp.1-8.

[2] H.K. Fung, K.H.Wong, A Robust Line Tracking Method Based on a Multiple Model Kalman Filter Model for Mobile Projector Systems (2013), *Procedia Technology, 4th International Conference on Electrical Engineering and Informatics (ICEEI)*, pp. 996-1002

[3] K. Tang, M. Wu. and X. Hu, Multiple model Kalman filtering for mems-imu/gps integrated navigation (2007) In Industrial Electronics and Applications, *ICIEA 2nd IEEE Conference*, pp. 2062-2066.

[4] M. Isard and A. Blake, Condensation: conditional density propagation for visual tracking (1998) *International Journal of Computer Vision 29(1)*, Kluwer Academic Publishers, pp. 5-28.

[5] S. Mills, T. Pridmore and M. Hills, Tracking in a Hough Space with the Extended Kalman Filter (2003) In *proceedings of the British Machine Vision Conference BMVC*, September 2003, pp. 173-182.

[6] J. Kubicek, M. Penhaker, I. Bryjova and M. Kodaj, Articular cartilage defect detection based on image segmentation with colour mapping (2014) *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 8733, pp. 214-222.

[7] J. Kubicek, M. Penhaker, Fuzzy algorithm for segmentation of images in extraction of objects from MRI (2014), Proceedings of the 2014 *International Conference on Advances in Computing, Communications and Informatics, ICACCI 2014*, art. no. 6968264, pp. 1422-1427.

[8] J. Kubicek, M. Penhaker, K. Pavelova, A. Selamat, J. Majernik and R. Hudak, Segmentation of MRI Data to Extract The Blood Vessels Based on Fuzzy Thresholding (2015) In *7th Asian Conference on Inteligent Information and Database Systems ACIIDS*. 23th - 25th March, 2015 Bali, Indonesia

[9] D. Angmo, B. Nayak, and V. Gupta, Post-strabismus surgery aqueous misdirection syndrome (2015) BMJ Case Reports, Retinoblastoma: diagnosis and management- the UK perspective (2015) *Annals of the Rheumatic Diseases*.

[10] J. Kubicek, M. Penhaker, Fuzzy Algorithm for Segmentation of Images in Extraction of Objects from MRI, 2014 *International Conference on Advances in Computing, Communications and Informatics (Icacci)*, pp. 1422-1427, 2014.

[11] Z. Rezaei, A. Selamat, M. S. M. Rahim, and M. R. A. Kadir, Image Segmentation of Coronary Artery Plaque Using Intuitionistic Fuzzy C-Means Algorithm, *Proceedings of International Conference on Artificial Life and Robotics (Icarob 2014)*, pp. 26-31, 2014.

[12] L. Sulik, O. Krejcar, A. Selamat, R. Mashinchi, and K. Kuca, Determining of Blood Artefacts in Endoscopic Images Using a Software Analysis, in *Computational Collective Intelligence*. vol. 9330, M. Nunez, N. T. Nguyen, D. Camacho, and B. Trawinski, Eds., ed, 2015, pp. 388-397.

[13] J. Blahuta, T. Soukup, and P. Cermak, How to Detect and Analyze Atherosclerotic Plaques in B-MODE Ultrasound Images: A Pilot Study of Reproducibility of Computer Analysis, in Artificial Intelligence: *Methodology, Systems, and Applications, Aimsa 2016*. vol. 9883, C. Dichev and G. Agre, Eds., ed, 2016, pp. 360-363.

[14] J. Blahuta, T. Soukup, M. Jelinkova, P. Bartova, P. Cermak, R. Herzig, et al., A new program for highly reproducible automatic evaluation of the substantia nigra from transcranial sonographic images, *Biomedical Papers-Olomouc*, vol. 158, pp. 621-627, 2014