Eye tracking data cleansing for dialogue agent

Czyszczenie danych okulograficznych dla agenta dialogowego

Karolina Gabor-Siatkowska[1], Izabela Stefaniak[2], Artur Janicki[3]

Abstract: Eye trackers are commonly used in many research fields, e.g., education, marketing, psychology, medicine, and human-computer interface. Although eye tracker companies provide software with built-in preprocessing algorithms for handling undesired data issues, e.g. blinks, in eye tracking data, the gathered data often has to be additionally processed to become useful for further analyses. In this article, we present an algorithm for eye-tracking data preprocessing, especially when talking about cleansing pupil diameter data. Due to the insufficient detection algorithm provided by the eye-tracking software, our algorithm considers the maximum velocity of human pupil contraction. Our experiments have been conducted on a Gazepoint GP3 device with a sampling frequency of 60 Hz, which is widely used in various research fields. This proposed approach enables researchers to better preprocess their collected pupil data, referring to the behaviour of the human pupil diameter. It makes pupil data preprocessing quick and applicable for any further analyses in various research fields.

Streszczenie: Urządzenia śledzące ruch gałek ocznych (tzw. okulografy) są powszechnie stosowane w wielu dziedzinach, np. w medycynie, edukacji, marketingu, psychologii oraz w interfejsach człowiek–komputer. Producenci okulografów proponują nie tylko sprzęt, ale również odpowiednie oprogramowanie, które umożliwia wstępną analizę takich parametrów jak punkty fiksacji wzroku czy wielkość średnicy źrenicy użytkownika. Oprogramowania te zazwyczaj posiadają już wbudowany algorytm do wstępnego oznaczenia niepożądanych danych (np. mrugnięć). Mrugnięcia te zazwyczaj nie są pożądanym zjawiskiem i muszą być dodatkowo przetworzone na wczesnym etapie przed przystąpieniem do dalszych analiz. Niestety nie zawsze wbudowany algorytm detekcji mrugnięć jest wystarczający na potrzeby badań. Niniejszy artykuł opisuje algorytm wstępnego przetwarzania danych okulograficznych, a konkretnie danych źrenicznych; uwzględnia on maksymalną prędkość skurczu ludzkich źrenic. Nasze eksperymenty zostały przeprowadzone na urządzeniu Gazepoint GP3 o częstotliwości próbkowania 60 Hz, które jest powszechnie dostępne. Zaproponowane przez

[1] Warsaw University of Technology, Faculty of Electronics and Information Technology, e-mail karolina.gabor-siatkowska.dokt@pw.edu.pl, ORCID 0000-0001-7458-5003.
[2] Lazarski University, Faculty of Medicine, e-mail istefaniak.terapia@gmail.com, ORCID 0000-0001-7332-6157.
[3] Warsaw University of Technology, Faculty of Electronics and Information Technology, e-mail artur.janicki@pw.edu.pl, ORCID 0000-0002-9937-4402.

nas rozwiązanie umożliwia szybsze i dokładniejsze przetwarzanie tych danych, uwzględniając przy tym własności ludzkiej źrenicy, i może być szeroko wykorzystywane przy eksperymentach w różnych badaniach okulograficznych.

Keywords: data cleansing, eye tracking, pupillometric data, human-computer interaction, dialogue agent, psychiatry

Słowa kluczowe: czyszczenie danych, okulografia, dane źreniczne, interakcja człowiek–komputer, agent dialogowy, psychiatria

1. Introduction

Eye trackers allow eye movement tracking using the near-infrared light spectrum. The tracking of eye movements and the pupil is used in many fields, such as education, marketing, psychology, and medicine. The most important parameters obtained during an eye tracking session include pupil diameter and eye movement parameters, among many others (e.g. number of blinks, blink duration, time to first fixation, etc.). The choice of a particular parameter for analysis always depends on the purpose of the test performed. For example, the output data can serve as input to algorithms supporting early medical diagnosis or as part of the human-computer interface (HCI).

Today, pupil size is a measure that has become of interest to a broader public, e.g., in psychology, education, marketing, and medicine[4]. For the past dozen years, eye trackers have also been used to study human-computer interaction. An example in this area is Embodied Conversational Agents (ECAs), which have received much attention recently. These works use non-verbal behaviour to establish contact with a human user[5]. For such dialogue to become more reliable, these agents should be equipped with communicative and expressive abilities similar to those we know from human-to-human interaction (speech, gestures, facial expressions, gaze, etc.)[6]. Thanks to eye tracking studies, it is possible to obtain several

[4] M. Wedel, *Attention Research in Marketing: A Review of Eye Tracking Studies*, "SSRN" 2013, pp. 1–28. S. Białowąs, A. Szyszka, *Eye-Tracking in Marketing Research* [in:] *Managing Economic Innovations – Methods and Instruments*, R. Robert (ed.), Poznań 2019, pp. 91–104.
[5] O. Bartošová, C. Bonnet, O. Ulmanová, M. Šíma, F. Perlík, E. Růžička, O. Slanař, *Pupillometry as an Indicator of L-DOPA Dosages in Parkinson's Disease Patient*s, "Journal of Neural Transmission" 2017 (4), pp. 699–703.
[6] N. Bee, E. André, S. Tober, *Breaking the Ice in Human-Agent Communication: Eye-Gaze Based Initiation of Contact with an Embodied Conversational Agent* [in:] *Intelligent Virtual Agents*, Z. Ruttkay, M. Kipp, A. Nijholt, H. Vilhjálmsson (eds.), Berlin–Heidelberg 2009, pp. 229–242.

parameters that characterise, for example, a person's emotional state[7] or concentration[8]. Increasingly, eye trackers are used as an additional source of information during user conversations with a dialogue agent[9]. Thus, the data obtained are used to support or control conversational agents. The human-computer dialogue that is carried out is thus more natural, and as a result, dialogue agents can interact more realistically with people.

It is essential to mention that regardless of the field and application, eye-tracking data, especially when considering pupil diameter, must be appropriately preprocessed to ensure further analysis. Unlike in EEG, there is no official pre-processing path for handling pupil diameter data[10]. These data always depend on the physiological aspects of the participants involved in the study. Due to the variety, many researchers try to find common problems and establish propositions and guidelines, which can be found in the literature[11]. When analysing pupil diameter data, researchers must consider a physiological aspect: eye blinking. For some disciplines, it has even been a research topic, e.g., considering blinking as a measure of fatigue[12]. However, there must be interest or need for the analysis of blinking data; otherwise, it plays a minor role when the research topic is not connected to or associated with blinks. When analysing complex experiments dependent on the focus, the blinks of participants are treated as undesired or missing data. In these situations, there is no information on the actual size of the pupil, which can often be a problem for further data analysis. Eye tracker companies generally provide some labelling of the blink data in the exported dataset within their eye tracking software (e.g., Gazepoint, Pupil). But, very often, their approach may not be sufficient. When the research areas are not connected to the blink duration or blink number, the blinks do not contribute any informative value to the obtained pupil diameter values (obtained during the individual experiments). There are some ways to deal with the problem of missing/erroneous data from various fields. An example was presented in the article by where different

[7] M. M. Bradley, L. Miccoli, M. A. Escrig, P. J. Lang, *The Pupil as a Measure of Emotional Arousal and Autonomic Activation*, "Psychophysiology" 2008 (4), pp. 602–607.
[8] K.–M. Chang, M.–T. W. Chueh, *Using Eye Tracking to Assess Gaze Concentration in Meditation*, "Sensors" 2019 (7), pp. 1–14.
[9] N. Bee, E. André, S. Tober, *op. cit.* G. Bailly, F. Elisei, S. Raidt, A. Casari, A. Picot, *op. cit.*
[10] S. Mathôt, J. Fabius, E. Van Heusden, S. Van der Stigchel, *Safe and Sensible Preprocessing and Baseline Correction of Pupil-Size*, "Behavior Research Methods" 2018 (1), pp. 94–106.
[11] S. Mathôt, J. Fabius, E. Van Heusden, S. Van der Stigchel, *op. cit*. M. E. Kret, E. E. Sjak–Shie, *Preprocessing Pupil Size Data: Guidelines and Code*, "Behavior Research Methods" 2018 (3), pp. 1336–1342. S. Mathôt, A. Vilotijević, *Methods in Cognitive Pupillometry: Design, Preprocessing, and Statistical Analysis*, "Behavior Research Methods" 2023 (6), pp. 3055–3077.
[12] J. A. Stern, D. Boyer, D. Schroeder, *Blink Rate: A Possible Measure of Fatigue*, "Human Factors: The Journal of the Human Factors and Ergonomics Society" (2), pp. 285–297.

perspectives and approaches to handling missing data are described[13]. The idea is that incomplete data may be grouped into imputation procedures and procedures based on models. In imputation procedures, the aim is to complete the missing data, whereas in the second approach, probability models are suggested (e.g., Bayesian inference models). In practice, there are various ways to deal with such cases, which include the following:

- Inserting extrapolated pupil diameter values from the last few moments before the blink into those time moments where a blink occurred:
- Replacement of all those data points that have been affected, with data from before the disturbance (here: blink);
- An average calculated using several data points before the disturbance is used and inserted in place of the erroneous data;
- A data forecast used in place of the disturbance (e.g. linear interpolation), from the last point before the disturbance to the first point correct after the disturbance,
- Removal of data containing information on the blink itself from the entire experiment,
- Inserting the mean/median of the entire data set in place of the data during the blink.

Approach 1) does not force a reduction in the number of data because it assumes a "swap" of data during blink. This might be beneficial in some cases from the point of view of further data processing. However, this approach has the disadvantage that the resulting prediction may be wrong for the total data. In practice, linear/non-linear prediction is a good data-handling method for similar issues. Processing data using approach 2) may not be applicable when considering particular conditions of some experiments. Approach 3) is unsuitable for the blink problem presented because the mean/median of the data of the entire experiment, depending on the stimuli type, may not add any informative value to the pupil's behaviour at specific moments in time. This approach could significantly negatively affect the result of further analysis. There might also be other possibilities listed here, but since it is not the main agenda of the paper, only the most common ones were mentioned. However, treating blinks as missing data is one of many problems researchers may have when considering eye tracking experiments.

[13] L. O. Silva, L. E. Zárate, *A Brief Review of the Main Approaches for Treatment of Missing Data*, "Intelligent Data Analysis" 2014 (6), pp. 1177–1198.

Sometimes, even correct blink detection is not provided, so the mentioned "blinks as missing data" handling propositions may also not be sufficient.

2. Automatic blink recognition provided by software

After exporting data from a performed study, the initial step is to look at the raw data. When dealing with the Gazepoint GP3 eye tracker, the exported data contains the following types of data gathered during the experiments (regarding the behaviour of pupils):

- pupil size [pixel];
- pupil size [mm];
- a valid flag: if pupil diameter data has been recorded (0: no, 1: yes);
- blink id;
- blink duration [ms].

Depending on which mode was activated during an experiment (monocular or binocular), these types are recorded separately for one or both eyes. Fig. 1 shows an example of raw data of recorded pupil size of one eye when a participant looked at a colorfoul picture (static stimuli) for 10s.

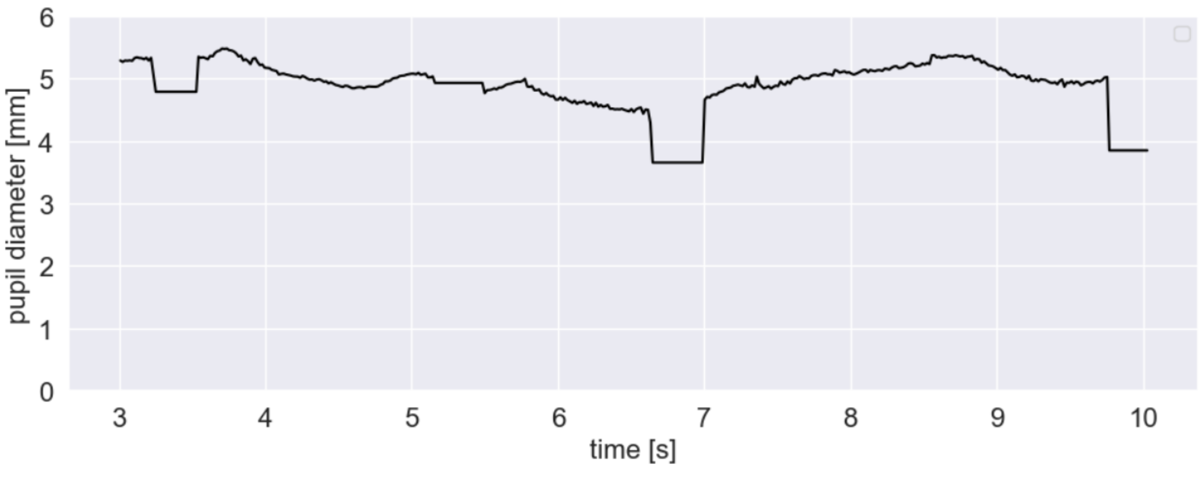

Fig. 1. Example graph of pupil diameter from an experiment with a participant and static stimuli

When looking deeper into the data, one can recognise that there is a built-in blink detection algorithm for pupil size data, which consists of the following steps:

- Check if there are every three consecutive pupil data records whose difference in pupil size is equal to 0 [mm];

- If so, then label the next (so forth) record of pupil size as a "blink" – increase the 'blink id' column';
- Continue labelling the consecutive pupil data records as "blink" as long as the difference between each two new records remains 0;
- If there is any difference > 0 mm in the upcoming pupil data record, stop labelling this record as "blink".

Require: t_i - timestamp in $i - th$ time;
d_{t_i} - measured pupil diameter [mm] in timestamp t_i
bk_{t_i} - column with labels (0 - no blink, 1 - blink) in timestamp t_i
if $d_{t_{i+3}} - d_{t_{i+2}} = 0$ and $d_{t_{i+2}} - d_{t_{i+1}} = 0$ and $d_{t_{i+1}} - d_{t_i} = 0$ **then**
  record $d_{t_{i+4}}$ label with $bk_{t_{i+4}} = 1$
else
  record $d_{t_{i+4}}$ label with $bk_{t_{i+4}} = 0$
end if

Alg. 1. Provided built-in blink detection algorithm

As shown in Fig. 1, even with regard to such a short experiment, this blink labelling is insufficient. Horizontal lines can be observed because the participant closed the eye (blinked). In the exported data, there are additional columns, e.g., the blink ID, which may indicate in which timestamps blinks occurred. When we leave out that data (with a marked blink ID out of the graph or just filling it with *NaN*-values, the graph will look like shown in Fig. 2.

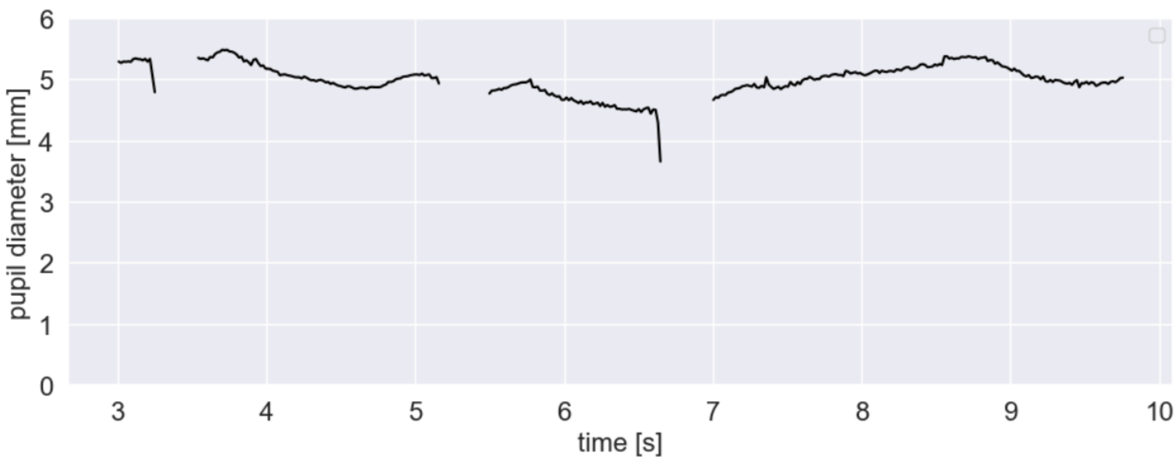

Fig. 2. Example graph of pupil diameter with particular "blink data" left out

The valid-flag column is another column which may also be considered necessary when analysing blinks. When we try to visualise the data regarding this parameter additionally (we visualise only that data, which has a valid-flag marked as valid, so “1 == yes”), the result is the same as presented before, no differences occurred. What is undesirable are the vertical lines, which are associated with the beginning/ending of the blink, that is, when the participant was rapidly closing/opening the eye. Even if the labelled blink data records and valid-flag are considered, this idea of the suggested preprocessing path by the software remains inefficient. It will generate ongoing problems with pupil data analyses. The reason for these problematic data is the first three data records, which are precisely the same size (see step 1 in the blink detection algorithm provided by the GP company). First, after recognising these three, the software recognises only the fourth record as the beginning of a blink. When researchers or data analysts handle blinks in pupil data, only using these software-provided indications, these three records remain falsely classified as real pupil diameter (as it is not recognised as a blink yet) and may lead to undesired problems in further analyses.

The number of such inconvenient vertical lines (as the rest of blinks) in pupillometric data depends mainly on two main parameters: of the blinking rate of the individual (taking part in the experiment) and on the duration of each eye tracking session itself. There are also other circumstances, which can have an impact on the blinks, e.g. the participant’s concentration state of the experiment or the involvement of drugs. Regardless of the number of blinks in the data, this is a major issue that will definitely occur and therefore should be handled whenever dealing with eye tracking data.

3. Proposed algorithm

As a result of this problem, we present a novel filtering method for pupil diameter data, which considers the velocity of human pupil constriction. This data preprocessing idea makes it highly applicable to various research fields. Fig. 3 shows our suggested pre-processing steps for the pupil data. First, we propose an extended blink detection (in the first two steps marked in yellow rectangles). The last but one block shows that data filtering should be done with a threshold, whose calculations we report below.

We wondered if there is a maximum value that the human pupil can reach in every timestamp. We investigated some facts about the nature of the human eye. Because the main task of the pupil is to protect the inner eye from too much light coming in, the pupil constriction velocity is always greater than the pupil dilation velocity. In healthy people, this constriction velocity was reported to be in the range of 3.83–9.27mm/s (in subjects aged 20 to 75 years old)[14]. Because, unfortunately, there is no value of pupil constriction velocity calculated on a much larger population, we decided to set the maximum possible velocity for healthy humans hypothetically at 11mm/s. Our idea of pupil diameter data preprocessing is that the pupil diameter will never naturally achieve greater values than calculated for a timestamp considering the pupil constriction velocity. Then, using an eye tracker with a measuring frequency of 60 Hz, we calculated the maximum constriction of a pupil in one timestamp. When taking into account not only the reported 9.27mm/s but actually a higher value like 11mm/s, the maximal pupil constriction, which can occur in 0.016667s (for 60 Hz), is calculated to be 0.18337mm for pupil diameter. This is the threshold that we used in our approach.

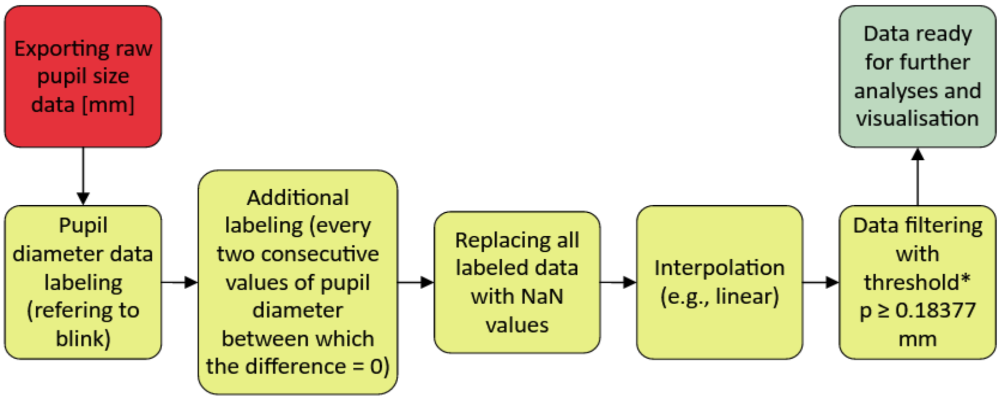

Fig. 3. Block diagram of the proposed steps for pupil data filtration, with the indicated threshold (*).

4. Experiments and results

4.1. Application example 1: healthy participants

First, we tested our algorithm when dealing with the real-life application of our eye tracker. It accompanies the Terabot dialogue system during conversations in Polish language[15]. Firstly,

[14] F. D. Bremner, 2012. *Pupillometric Evaluation of the Dynamics of the Pupillary Response to a Brief Light Stimulus in Healthy* Subjects, "Investigative Ophthalmology and Visual Science" 2012 (11), pp. 7343–7347.
[15] M. Kozłowski, K. Gabor-Siatkowska, I. Stefaniak, M. Sowański, A. Janicki, *Enhanced Emotion and Sentiment Recognition for Empathetic Dialogue System Using Big Data and Deep Learning Methods* [in:] *Computational Science – ICCS 2023. 23rd International Conference, Proceedings, Part I, Lecture Notes In Computer Science*, J. Mikyška, C. de Mulatier, M. Paszyński, V. Krzhizhanovskaya, J. Dongarra, P. M. A. Sloot (eds.), Berlin 2023, pp. 465–480. K. Gabor-Siatkowska, M. Sowański, R. Rzatkiewicz, I. Stefaniak, M. Kozłowski, A. Janicki, *AI to Train AI: Using ChatGPT to Improve the Accuracy of a Therapeutic Dialogue System*, "Electronics" (22), pp. 1–14.

while using this speech-to-speech system, we acquired pupil diameter data when the testers talked with this system. Here, we used the Gazepoint GP3 eye tracker with a measuring frequency of 60 Hz. This eye tracker is widely used in research in different areas[16, 17, 18], and its sampling frequency was sufficient for our purposes. We did not want to use any mobile eye trackers (with cables), because of the patient's comfort, as this would disturb relaxation exercises.

We present visualisations of a participant's pupil raw data (see upper graph in Fig. 4). As can be observed, there are some unrealistic amounts of reported pupil size presented in this gathered data (e.g., about timestamps 100, 310, etc.). We observed the reported blink column and also the valid-flag provided by the software. Unfortunately, this approach did not make any difference to that data. With the application of our algorithm, such problematic data can be easily handled (see lower graph in Fig. 4).

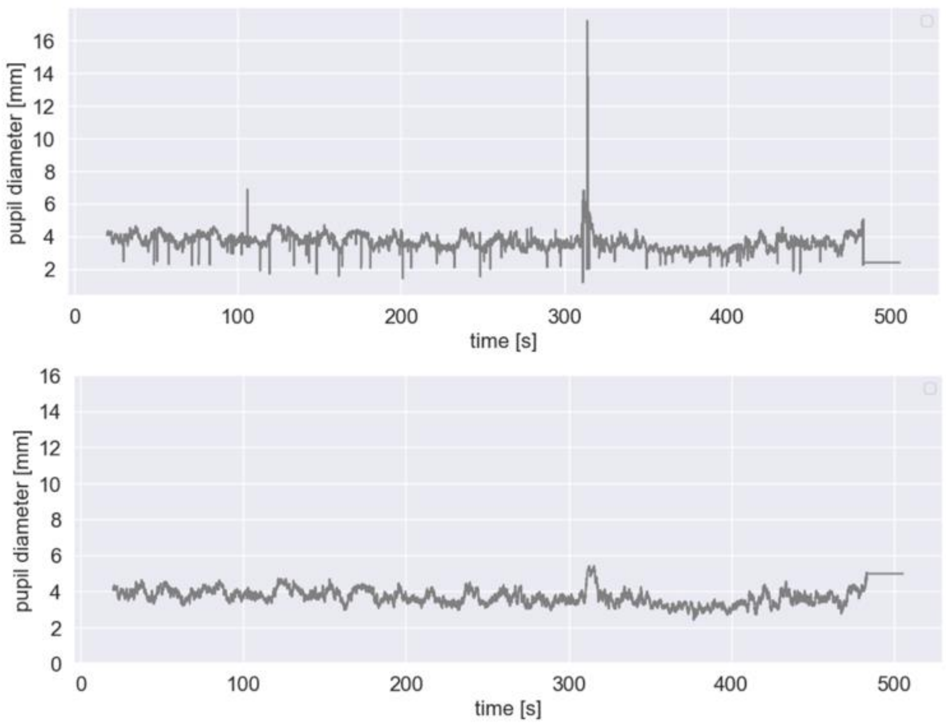

Fig. 4. Pupil diameter data from an experiment with a healthy participant before (upper graph) and after (lower graph) application of our filtering method

[16] P. Sulikowski, T. Zdziebko, *Deep learning-enhanced framework for performance evaluation of a recommending interface with varied recommendation position and intensity based on eye-tracking equipment data processing*, „Electronics" 2020 (9), pp. 1–15.
[17] J. Xu, K. Guo, P. Z. H. Sun, *Driving Performance Under Violations of Traffic Rules: Novice vs. Experienced Driver*s, "IEEE Transactions on Intelligent Vehicles" 2022 (7), pp. 908–917.
[18] J. Xu *et al.*, *Left Gaze Bias Between LHT and RHT: A Recommendation Strategy to Mitigate Human Errors in Left- and Right-Hand Driving*, "IEEE Transactions on Intelligent Vehicles" 2023 (8), pp. 4406–4417.

4.2. Application example 2: psychiatric patients

Nowadays, dialogue systems are increasingly used to improve existing therapies and provide additional help to patients in different areas, e.g. psychiatry. An example is hallucination therapy for psychiatric patients[19]. Our dialogue system has been used at the Institute of Psychiatry and Neurology in Warsaw, Poland. Due to the diagnoses of the patients, they take neuroleptics (antipsychotics) and a combination of drugs from different groups, including antidepressants and mood stabilisers. We used the proposed algorithm to data gained during conversations of our dialogue system with psychiatric patients (more specified information is provided, e.g., in our publication[20]. Again, we used the measuring frequency of the eye tracker of 60 Hz. The upper graph in Figure 5 shows the raw output pupil data of a patient during a dialogue with our dialogue system. Analogously, when considering only the blink data labelled by the software, also regarding the valid-flag labelling, these steps are insufficient. When our algorithm is applied to these data, the output values look much better and are, therefore, ready for further analysing steps (Fig. 5).

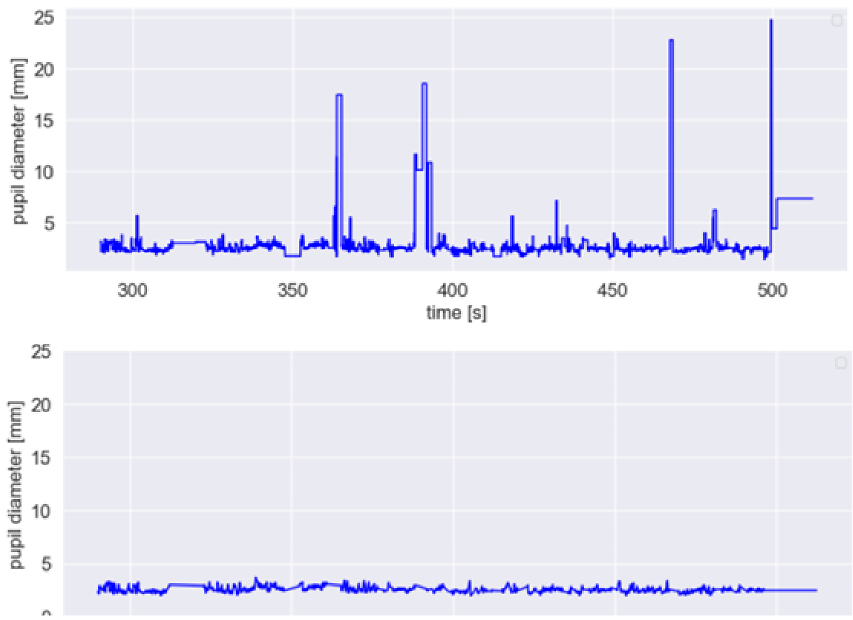

Fig. 5. Pupil size data from a psychiatric patient before (upper graph) and after (lower graph) applying our algorithm

[19] I. Stefaniak, K. Sorokosz, A. Janicki, J. Wciórka, *Therapy Based on Avatar-Therapist Synergy for Patients with Chronic Auditory Hallucinations: A Pilot Study*, "Schizophrenia Research" 2019, pp. A1–A3.
[20] Gabor-Siatkowska, *op. cit.*

Analysing the eye tracking data of one week, four patients had dialogues with Terabot every day, with the time of one dialogue about 7–15min (depending on the progress of the conversation with the patient). It is assumed that in healthy people there are about 15–20 blinks during one minute (each of them lasts about 0.3s), so it can be said that the average number of blinks during such a dialog is about 150–200 (for healthy people). In a group of one-week patients, about 150–360 blinks/patient/dialog were registered during our research, but there were also cases of patients with 84 blinks or 423 or 490 blinks during a dialog. It is important to remember that the number of blinks can vary from person to person, and factors such as fatigue, concentration, or the presence of eye diseases or medication can have a significant impact on it. As it turned out, with such a total number of blinks during about a 10-minute dialog, the algorithm we proposed proved to be very useful.

5. Discussion and further work

As the graphs present, our proposed method has great value in pupil diameter data preprocessing regardless of the state of health of the participants. It reduces undesired noise in the data, and it gives certainty that any data out of range of pupil size will be considered as not realistic and can, therefore, be appropriately processed. Although we are aware that certain medications used in psychiatry may influence pupils' behaviour in psychiatric patients[21], we opted that it could also be helpful in this particular case. In our opinion, there is a lack of any recommended preprocessing path for pupil diameter data from psychiatric patients, although many pupillometric studies are made in general. As a result, our algorithm gives engineers and researchers from many areas the possibility of fast and accurate preprocessing of their pupil diameter data. We have already used the proposed algorithm to focus on areas related to eye movements during specific intervals in the dialogue with our conversational agent. We are specifically interested in the relaxation exercises and want to find out if the patients' pupil's behaviour can give us information about the quality of their relaxation state. We also see that further work on our algorithm, e.g., adjusting this algorithm with particular criteria only for psychiatric patients with specified conditions, e.g., anxiety disorders.

[21] O. Bartošová,, C. Bonnet, O. Ulmanová, M. Šíma, F. Perlík, E. Růžička, O. Slanař, *op. cit.* K. N. Thakkar, J. W. Brascamp, L. Ghermezi, K. Fifer, Je. D. Schall, S. Park, *Reduced Pupil Dilation during Action Preparation in Schizophrenia*, "International Journal of Psychophysiology" 2018 (128), pp. 111–118.

6. Acknowledgements

The study was approved on 27 April 2022 by the Institute of Psychology and Neurology Ethics Committee in Warsaw, Poland; resolution No. IV/2022.

This research was funded partially by the Center for Priority Research Area Artificial Intelligence and Robotics of the Warsaw University of Technology within the Excellence Initiative: Research University (IDUB) program.

Bibliography

1. Bailly G., Elisei F., Raidt S., Casari A., Picot A., *Embodied Conversational Agents: Computing and Rendering Realistic Gaze Patterns* [in:] *Advances in Multimedia Information Processing – PCM 2006*, Y. Zhuang, S. Yang, Y. Rui, Q. He (eds.), Berlin–Heidelberg 2006, pp. 9–18.
2. Bartošová O., Bonnet C., Ulmanová O., Šíma M., Perlík F., Růžička E., O. Slanař, *Pupillometry as an Indicator of L-DOPA Dosages in Parkinson's Disease Patients*, "Journal of Neural Transmission" 2017 (4), pp. 699–703.
3. Bee N., André E., Tober S., *Breaking the Ice in Human-Agent Communication: Eye-Gaze Based Initiation of Contact with an Embodied Conversational Agent* [in:] *Intelligent Virtual Agents*, Z. Ruttkay, M. Kipp, A. Nijholt, H. Vilhjálmsson (eds.), Berlin–Heidelberg 2009, pp. 229–242.
4. Białowąs S., Szyszka A., *Eye-Tracking in Marketing Research* [in:] *Managing Economic Innovations – Methods and Instruments*, R. Robert (ed.), Poznań 2019, pp. 91–104.
5. Bradley M. M., Miccoli L., Escrig M. A., Lang P. J., *The Pupil as a Measure of Emotional Arousal and Autonomic Activation*, "Psychophysiology" 2008 (4), pp. 602–607.
6. Bremner F. D., *Pupillometric Evaluation of the Dynamics of the Pupillary Response to a Brief Light Stimulus in Healthy* Subjects, "Investigative Ophthalmology and Visual Science" 2012 (11), pp. 7343–7347.
7. Chang K.–M., Chueh M.–T. W., *Using Eye Tracking to Assess Gaze Concentration in Meditation*, "Sensors" 2019 (7), pp. 1–14.

8. *Eye-Tracking Technology Applications in Educational Research*. *Eye-Tracking Technology Applications in Educational Research*, C. Was, F. Sansosti, B. Morris (eds.), Hershey 2017.
9. Gabor-Siatkowska K., Sowański M., Rzatkiewicz R., Stefaniak I., Kozłowski M., Janicki A., *AI to Train AI: Using ChatGPT to Improve the Accuracy of a Therapeutic Dialogue System*, “Electronics” (22), pp. 1–14.
10. Hershaw J. N., Ettenhofer M. L., *Insights into Cognitive Pupillometry: Evaluation of the Utility of Pupillary Metrics for Assessing Cognitive Load in Normative and Clinical Samples*, “International Journal of Psychophysiology” 2018 (134), pp. 62–78.
11. Kozłowski M., Gabor-Siatkowska K., Stefaniak I., Sowański M., Janicki A., *Enhanced Emotion and Sentiment Recognition for Empathetic Dialogue System Using Big Data and Deep Learning Methods* [in:] *Computational Science – ICCS 2023. 23rd International Conference, Proceedings, Part I, Lecture Notes In Computer Science*, J. Mikyška, C. de Mulatier, M. Paszyński, V. Krzhizhanovskaya, J. Dongarra, P. M. A. Sloot (eds.), Berlin 2023, pp. 465–480.
12. Krejtz K., Duchowski A. T., Niedzielska A., Biele C., Krejtz I., *Eye Tracking Cognitive Load Using Pupil Diameter and Microsaccades with Fixed Gaze*, “PLOS ONE” 2018 (9), pp. 1–23.
13. Kret M. E., Sjak–Shie E. E., *Preprocessing Pupil Size Data: Guidelines and Code*, “Behavior Research Methods” 2018 (3), pp. 1336–1342.
14. Mathôt S., Fabius J., Heusden van E., Stigchel van der S., *Safe and Sensible Preprocessing and Baseline Correction of Pupil-Size*, “Behavior Research Methods” 2018 (1), pp. 94–106.
15. Mathôt S., Vilotijević A., *Methods in Cognitive Pupillometry: Design, Preprocessing, and Statistical Analysis*, “Behavior Research Methods” 2023 (6), pp. 3055–3077.
16. Pfleging B., Fekety D. K., Schmidt A., Kun A. L., *A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions* [in:] *Conference on Human Factors in Computing Systems – Proceedings (CHI’ 16)*, J. Kaye, A. Druin (eds.), New York 2016, pp. 5776–5788.
17. Silva L. O., Zárate L. E., *A Brief Review of the Main Approaches for Treatment of Missing Data*, “Intelligent Data Analysis” 2014 (6), pp. 1177–1198.
18. Stefaniak I., Sorokosz K., Janicki A., Wciórka J., *Therapy Based on Avatar-Therapist Synergy for Patients with Chronic Auditory Hallucinations: A Pilot Study*, “Schizophrenia Research” 2019, pp. A1–A3.

19. Stern J. A., Boyer D., Schroeder D., *Blink Rate: A Possible Measure of Fatigue*, "Human Factors: The Journal of the Human Factors and Ergonomics Society" (2), pp. 285–297.
20. Sulikowski P., T. Zdziebko, *Deep learning-enhanced framework for performance evaluation of a recommending interface with varied recommendation position and intensity based on eye-tracking equipment data processing*, „Electronics" 2020 (9), pp. 1–15.
21. Thakkar K. N., Brascamp J. W., Ghermezi L., Fifer K., Schall J. D., Park S., *Reduced Pupil Dilation During Action Preparation in Schizophrenia*, "International Journal of Psychophysiology" 2018 (128), pp. 111–118.
22. Xu J. *et al.*, *Left Gaze Bias Between LHT and RHT: A Recommendation Strategy to Mitigate Human Errors in Left- and Right-Hand Driving*, "IEEE Transactions on Intelligent Vehicles" 2023 (8), pp. 4406–4417.
23. Xu J., Guo K., Sun P. Z. H., *Driving Performance Under Violations of Traffic Rules: Novice vs. Experienced Driver*s, "IEEE Transactions on Intelligent Vehicles" 2022 (7), pp. 908–917.
24. Wedel W., *Attention Research in Marketing: A Review of Eye Tracking Studies*, "SSRN" 2013, pp. 1–28.