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Identification of variation in mental strain of an agricultural tractor operator in the field during precise fertilizer spreading

***Abstract**. The article describes the possibilities of spatial identification of the level of brain activity of the operator of modern agricultural machinery, where control procedures have become largely automated. The operator operates a computerized interface to program the operation of the machine, whose geographical position within the field is monitored by GPS. Using the Muse 2 brain activity measuring armband, the operator's performance was monitored during the execution of control activities by assigning geographic coordinates and the machine's operating status to each event. This made it possible to identify places within the field where the operator's brain activity was high and places where attention levels were low. Linking the level of brain activity to the machine's operating data made it possible to generate maps of the spatial variation of the level of operator attention brain activity in relation to the aforementioned machine data.*

***Streszczenie.** W artykule opisano możliwości przestrzennej identyfikacji poziomu aktywności mózgu operatora nowoczesnych maszyn rolniczych, gdzie procedury sterowania w znacznym stopniu uległy zautomatyzowaniu. Operator obsługuje skomputeryzowany interfejs pozwalający programować pracę maszyny, której pozycja geograficzna w obrębie pola jest monitorowana systemem GPS. Posługując się opaską mierzącą aktywność mózgu Muse 2 monitorowano pracę operatora w czasie realizacji czynności sterowniczych przypisując każdemu zdarzeniu współrzędne geograficzne oraz stan pracy maszyny. Pozwoliło to zidentyfikować miejsca w obrębie pola, gdzie aktywności mózgu operatora był wysoki oraz miejsca, gdzie poziom koncentracji uwagi był niski. Powiązanie poziomu aktywności mózgu z danymi eksploatacyjnymi maszyny pozwoliło wygenerować mapy przestrzennego zróżnicowania poziomu aktywności mózgu uwagi operatora w relacji w/w danymi maszyny. (**Identyfikacja zróżnicowania obciążenia psychicznego operatora ciągnika rolniczego w przestrzeni pola podczas precyzyjnego rozsiewania nawozów**)*

Keywords: operator interface, operation, mental load, ergonomics
Słowa kluczowe: interfejs operatorski, eksploatacja, obciążenie umysłowe, ergonomia

Introduction

Modern ergonomic research to adapt technical systems to human psychophysical capabilities is most often focused around the operator interface (control panel). This is understandable and is due to the modern characteristics of human work, which is primarily limited to the management of machine state signals through the control panel. In agriculture, the use of information systems makes it possible not only to precisely guide the machine in real time, but also to spatially identify machine states that are markers of spatial variation in the field for subsequent passes and technological operations. Such identification makes it possible to conduct a treatment or vary its intensity only in a specific field space. This carries with it the need for the operator to be familiar with the operation of multiple computer systems, representing a clear mental burden. Juliszewski [1] examined a number of on-board computer interfaces of agricultural machines and tractors and procedures for running selected functions, often observing the lack of logical relationships between them in tractors and machines from different manufacturers. According to Zlowodzki [2], the information load is due not only to the amount of information, but also to the need to know many sequences and decode the information accordingly. In an ergonomic human-machine system, the carrier of this message is the signal of a device specially constructed for this purpose, the so-called signaling device. The purpose of its operation is to transmit information to the operator in a form that he understands. It is necessary in this case to use knowledge of human cognition (Cognitive Sciences), often called cognitive science or cognitive science. The research area of this field of science is the study of how the human senses, brain and mind work. The formulas for calculating the amount of information with equally likely, differently likely, mutually determined signals are described by the relationships:

H= $-\Sigma \mathrm{pi} \log_2 \mathrm{pi}$ (mutually undetermined signals)
H=$-\sum_{i=1}^{n} \mathrm{pi} \sum_{j=1}^{n} \mathrm{pji} \log_2 \mathrm{pji}$ (mutually determined signals)

where:
p_i – probability of the i-th signal (i=1,2,3….n),
p_{ji} - probability of the j-th signal (j=1,2,3....n) when preceded by the i-th signal

Despite the potentially vast capabilities of the human brain, the following limitation is relevant here [3]: the reduction in information flow is from 3,000,000 bits/sec. (flow through the nervous system) to 16 bits/sec. (information stream consciously perceived) and 0.7 bits/sec. (information stream permanently remembered). Tadeusiewicz [4] posits that the information capacity of the sensory channels can be estimated as: sight: 100 Mb/sec, touch 1Mb/sec, hearing 15 Kb/sec, smell 1 Kb/sec, taste 100 b/sec. Hagerer [5] film-recording the work field of a combine harvester operator, and then analyzing this image, calculated that the stream of information reaching the operator averages 1.3 bits/sec, with a maximum of 8.82 bits/sec. Kielbasa [6] observed that the driver's working time affects the relationship between energy expenditure determined by the number of heartbeats and energy expenditure determined by lung ventilation. The great diversity of agricultural tractor interfaces and the incompatibility of post-individual procedures for calling up set information, events and control sequences, makes it much more difficult - and sometimes impossible - for operators to work effectively [7]. Currently, for tractors and agricultural machinery, the current ISO 11783 standard specifies in the sixth part the general structure of the on-board computer interface. According to Juliszewski [8], the problem that is growing is the so-called compatibility of the human-machine system in terms of the flow of information from signaling devices to the operator and the performance of control actions (Figure 1). Kielbasa et al. [9] determined the interrelationship between the length and type of mental work activity and the degree of mental fatigue and heart rate reserve index. The study was carried out on a group of 25 people who were completing the various stages of the training process for operating modern agricultural tractors. Similar studies have been carried out in the case of the work of IT specialists configuring the rotation of employees within the activities performed on the basis of these studies [10].

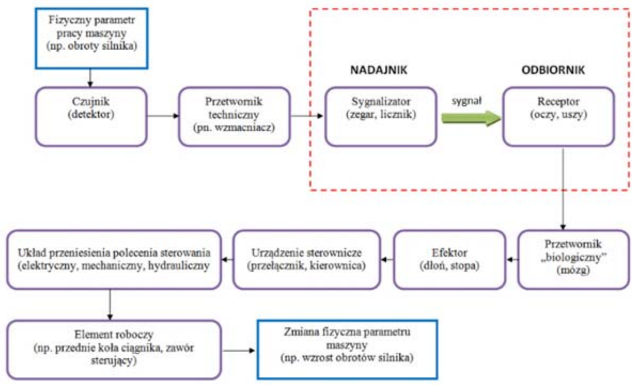

Fig. 1. The information chain and its relationship to the control process [8].

The situation of the operator of tractors and agricultural machinery is fundamentally different from that of operators of industrial equipment or communication workstations: this is because he works at different stations (sometimes during a single day), and some of the machines he operates for only a few dozen hours a year (e.g., a precision seeder or a sprayer). The algorithm of operating different machines, and therefore different signaling devices, for a relatively short period of time during the year is a specific characteristic of agricultural work [11]. In the case of a truck driver, the situation is different, as he spends about 2,500 hours in the car during the year. In contrast, the driver's working time can exceed 9 hours between rest periods. The rest period must be at least 11 hours, which can be taken in two parts: the first must be an uninterrupted minimum of 3 hours, and the second at least 9 hours. It is possible to extend the driving time to 10 hours if necessary, but this can take place no more than twice a week. Including daily rests, the driver's working time must not exceed 144 hours per week. The specific nature of the operator's work in agriculture also concerns the terrain and also the way the machine moves within the boundaries of the field being worked. The operator very often programs the track of the machine, which maintains it automatically. The operator's task in such a situation is to be able to program the systems and then observe them and intervene in abnormal situations. Observation of signaling devices and possible intervention by the operator generates an appropriate level of concentration of attention and adequate mental fatigue and a decrease in psychophysical abilities that can lead to mistakes. Identification of the concentration of attention related to the space of the area being processed gives the possibility of assessing the spatial gradation of the level of attention of the operator and thus information on the degree of complication of the control operation being implemented by the operator. Having such parameterized information makes it possible to identify the field in terms of the difficulty of operation and gives the possibility to identify places where an abnormal condition is likely to occur. This allows the operator to prepare for such an eventuality, or to automatically change the parameters of the machine operation at a given location to prevent the occurrence of an abnormal condition.

Material and methods

The purpose of the study was to spatially identify the degree of brain activity of an agricultural tractor operator within the experimental field during fertilizer spreading. The scope of the study also included determining the relationship between working conditions within the field space and the degree of operator brain activity. The research was carried out on a John Deere 6210R tractor aggregated with a Rauch fertilizer spreader The operator operated the tractor's on-board computer, the seeder's control computer and the Trimble CFX-750 satellite navigation system and performed all the control activities necessary for the correct execution of the technological operation. It should be noted that the guidance and maintenance of the vehicle in the regime of technological paths implemented by means of the EZ-Pilot electric steering wheel. The tractor operator's mental load was monitored using a Muse 2 wristband (Fig.2).
In the future it is worth to use the wearable solutions to monitor the physical factors [12,13].

Fig. 2. Measurement apparatus used in the experiment

The armband allows monitoring brainwave activity, position and acceleration of the operator's head movements, as well as heart rate. A simplified version of the meter was a necessity due to the specific nature of the operator's work and the long time it takes to take measurements, as well as the method of archiving measurement data (Fig.3).

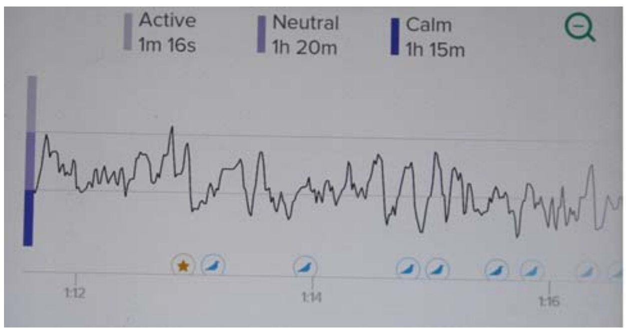

Fig. 3. Cell phone application interface, where measurement data was recorded

The measurement was carried out over the entire work cycle, i.e. from the start of the sowing operation to its completion. Signals for engine operating parameters, driving speed and specific fuel consumption were also assigned in geographic coordinates. The measurement systems used were then integrated as a function of the frequency of recording the measured quantities, which allowed specific geographic coordinates to be assigned attributes that were the results of the measurements of the systems used. The Inverse Distance Weighted (IDW) method was used to interpolate the measured quantities treated as deterministic variables, and the generation of vector and raster maps, the execution of the relevant map operations in the form of logical queries and the resulting spatial selection of data, as well as the overlaying of the interdependent data of individual maps were realized using

ERSI ArcView GIS 3.3 software. The traffic track, as in the case of the first run, was plotted on the orthophoto layer to facilitate interpretation (Fig. 4).

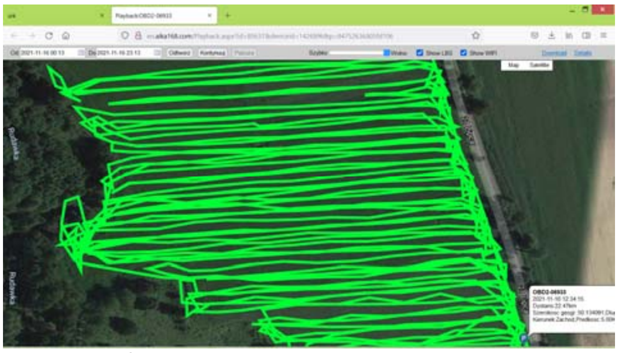
Fig. 4. Track of the aggregate during sowing

Results

Figure 5 shows the statistical characteristics of the operator's brain activity considering the speed of the aggregate. It was found that the lowest brain activity was observed at zero speed, the highest at 11 km/h. It should be noted that as the speed increased, an increase in brain activity was observed except for the highest driving speed of 12 km/h.

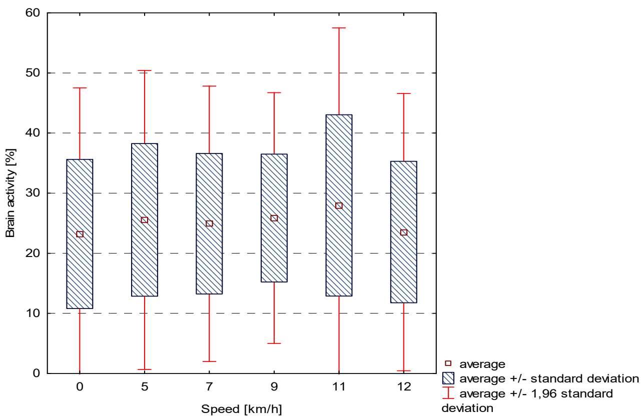

Fig. 5. Degree of operator attention in relation to aggregate driving speed

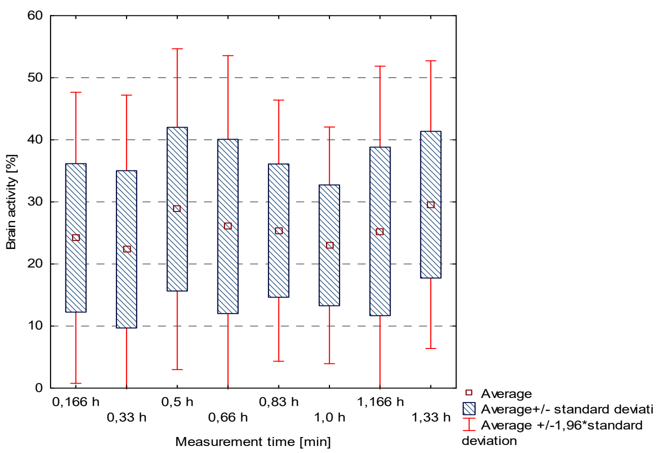

Fig. 6. The degree of operator attention in relation to the length of working time

Low stability of the operator's brain activity was noted for each driving speed, suggesting that abnormal states occurred in each of the analyzed cases. Analyzing the time of measurement, it was noted that the selected interval did not significantly affect the obtained test results. However, it should be noted that the highest values of the operator's brain activity were recorded during the last measurement interval (Figure 6). This is likely due to the synergistic effect of operator fatigue and the abnormal states of the machine that occurred, which forced the need to increase brain activity. Extremely important information from the point of view of automation of technological processes and prediction of abnormal states of the machine generated by variation of the working environment is the spatial identification of the aforementioned elements.

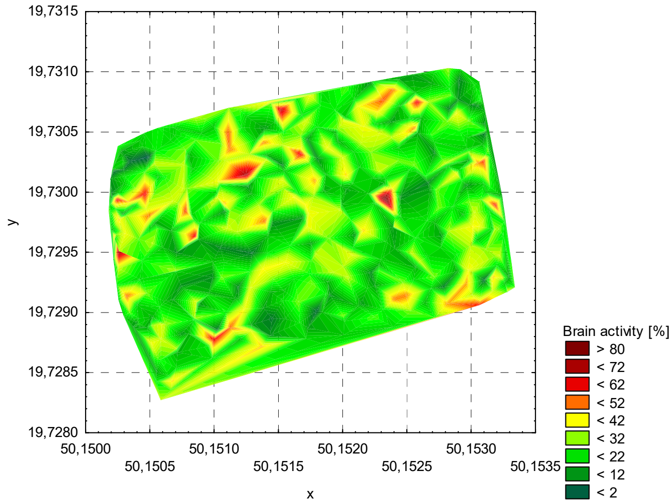

Fig. 7. Spatial distribution of the tractor operator's degree of attention within the treated acreage

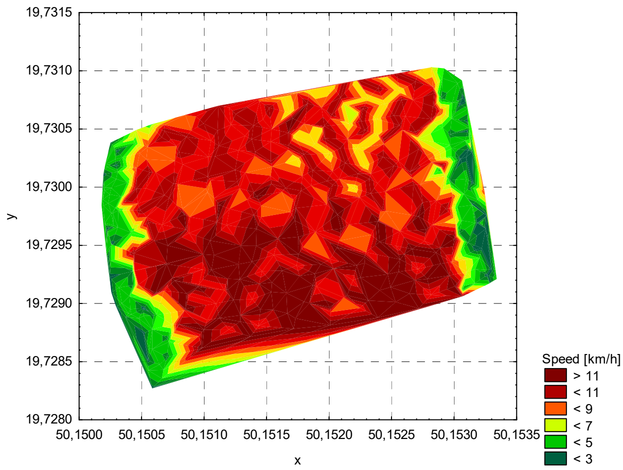

Fig. 8. Spatial distribution of driving speed of the aggregate within the treated acreage

Figure 7 shows a map of the spatial variation of operator brain activity within the treated field. Spatial analysis of the degree of the operator's attention concentration showed that the highest values exceeding 80% of the operator's capabilities occurred in several places in the field (red) and a small incidental character. The identified locations will be subject to detailed analysis, with the aim of eliminating abnormal states in subsequent technological operations. It should be noted that in most areas where the technological process was implemented, the required operator brain activity did not exceed 30%. Such a low value of brain activity is the result of the operator support systems used and the possibility of automatic driving. Noteworthy is the lack of increased operator brain activity on headlands, which traditionally required special attention due to their specifics. Nowadays, the implementation of headlands can be performed fully automatically, which relieves the operator from a number of steering operations.

When analyzing the degree of the operator's brain activity within the space of the treated field, attention should be paid to the spatial distribution of speed (Figure 8).

It was found that only in the case of headlands the driving speed decreased noticeably, while with minor exceptions in the field space it was between 10 km/h and 11 km/h. This was understandable because the operator was using the automatic driving mode, the speed of which is enforced by the technological procedure being carried out.

Figure 9 shows the relationship between the driving speed of the aggregate and the measurement time and activity level of the operator's brain.

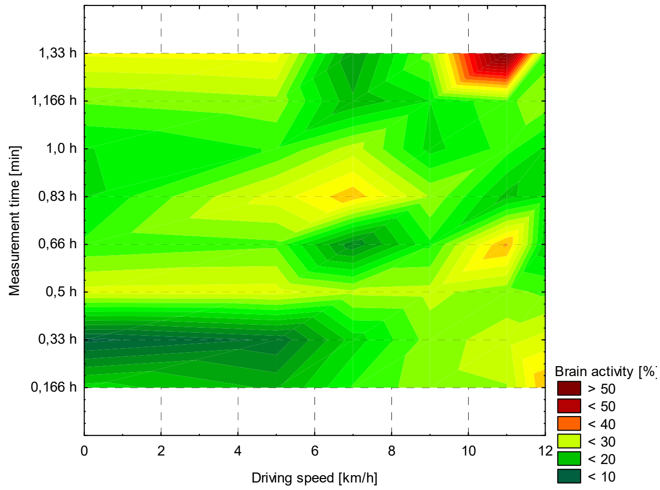

Fig. 9. Spatial distribution of the speed of the aggregate within the treated area

Only one area with high operator brain activity was identified, the value of which exceeded 50% of its potential capacity. It should be noted that this was the result of the overlap of two factors, i.e., the speed of the aggregate and the time at which the measurement was made. The measurement time of 1.33 hours was carried out after 10 pm and was the last hour of the operator's work on that day. The study also analyzed the concentration level of the operator in relation to the direction in which the aggregate was driven in the field. The highest values of the operator's brain activity were recorded when driving in the northeast direction and the lowest in the west direction.

Conclusion

It was found that the degree of brain activity of the tractor operator during the technological activity of spreading fertilizer averaged 26% of its capacity. There was a slight variation in the level of brain activity within the studied field, identifying several places where brain activity exceeded 80%. The research methodology used made it possible to generate spatial maps of the operator's brain activity level and thus locate the value of mental involvement in a specific area of the field. Based on the maps of spatial variation of the level of attention involvement by the operator, it is possible to generate information on which parts of the field on the farm will require special attention. A qualitative relationship between the spatial variation of the operator's level of mental fatigue and the spatial distribution of tractor speed was noted. An interesting observation is the absence of increased brain activity of the operator on the headland, which traditionally required special attention due to its specificity. The developed research methodology allows to locate the level of mental fatigue in a specific place of the field giving the possibility to generate ergonomically innovative solutions.

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