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TEODOR WINKLER*

ANTHROPOTECHNICAL SYSTEMS IN THE MINING MACHINES DESIGNING PROCESSES

UKŁADY ANTROPOTECHNICZNE W BUDOWIE MASZYN GÓRNICZYCH

The present methods for designing of mining machines have a technocentric character and were focused mainly to obtain the possible best technical parameters in designed machines. The complicity of current roadway and longwall systems draw the attention to the meaning of human factor during their operation.

In the operational process between men and technical means *anthropotechnical systems* are created. In the anthropotechnical system between man and the technical mean two types of relationships are formed: *relationships of somatic type and relationships receptor type.* These relationships are assessed in the light of ergonomics and safety criteria. It was assumed that the state of anthropotechnical system, in which the relationships are assessed for the assumed system of criteria is called the *criterial state.* A model representing the real anthropotechnical system and containing all its features that are assessed in the light of detailed assumed criteria is called the *criterial model.*

Examples of anthropotechnical systems found in the mining machines were presented in the paper. Methods for machines and human silhouettes modelling using the CAD software were described.

Key words: anthropotechnical systems, designing, mining machines, computer aided designing (CAD), computer modelling and models, occupational safety, ergonomics

Dotychczasowe metody projektowania maszyn górniczych miały charakter „technocentryczny" i w głównej mierze były nakierowane na osiągnięcie jak najlepszych parametrów technicznych przez projektowane maszyny. Złożoność współczesnych systemów chodnikowych i ścianowych zwraca uwagę na znaczenie czynnika ludzkiego podczas ich eksploatacji.

W procesie eksploatacji pomiędzy środkami technicznymi a ludźmi tworzą się więzi, dzięki którym powstają *układy antropotechniczne* (Dietrych 1985). W układzie antropotechnicznym pomiędzy człowiekiem a środkiem technicznym zachodzą dwa typy relacji: *relacje typu somatycznego i relacje typu receptorowego* (rys. 1). Relacje te są oceniane w świetle kryteriów ergonomicznych i bezpieczeństwa. Przyjmuje się, że stan układu antropotechnicznego, w którym dla przyjętego układu kryteriów oceniane są relacje, nazywany jest *stanem kryterialnym.* Model reprezentujący rzeczywisty

* KATEDRA PODSTAW SYSTEMÓW TECHNICZNYCH, POLITECHNIKA ŚLĄSKA, 41-800 ZABRZE, UL. ROOSEVELTA 26, 28; CENTRUM MECHANIZACJI GÓRNICTWA KOMAG, 44-101 GLIWICE, UL. PSZCZYŃSKA 37

układ antropotechniczny i zawierający wszystkie te jego cechy, które są oceniane w świetle przyjętych kryteriów szczegółowych nazywany jest *modelem kryterialnym*.

W modelowaniu relacji somatycznych uwzględniana jest zmienność cech antropometrycznych. Czynniki wpływające na zmienność cech antropometrycznych pokazane zostały na rysunkach 2 i 3.

Relacje somatyczne posiadają swoją strukturę, do której należą: sposób połączenia elementów układu antropotechnicznego ze sobą oraz kolejność łączenia elementów. Obraz struktury relacji dla operatora kombajnu chodnikowego podczas urabiania przodka w strefie spągu zarejestrowany został na rysunku 4a. Zapis tej relacji w formie grafu umieszczono na rysunku 4b. Propozycję zmodyfikowanej konstrukcji układu sterującego wraz z odpowiadającą mu strukturą relacji przedstawiają rysunki 5a i 5b.

Na potrzeby modelowania receptorów przyjmuje się *uogólnione cechy receptorów*: lokalizacja w przestrzeni, cechy antropometryczne związane z rozmieszczeniem receptorów na powierzchni ciała, cechy biofizyczne, cechy biochemiczne. Na rysunku 6 pokazano rozmieszczenie receptorów na powierzchni ciała, a w tablicy 1 umieszczona jest przykładowa lista uogólnionych cech dla receptorów słuchu. Na rysunkach 7a, 7b i 7c przedstawiono reprezentacje graficzne modeli receptorów. Na rysunku 8 widoczne są pośrednie położenia modelu sylwetki operatora podczas obsługi maszyny oraz chwilowe położenia modeli receptorów (rys. 9). Przykładowe wartości uogólnionych cech receptorów słuchu pokazane zostało na rysunku 10. W tablicy 2 przedstawiony został fragment przykładowego pliku z danymi wejściowymi do programu RAYNOISE służącego do modelowania pól akustycznych (RAYNOISE 1995).

Sposób modelowania relacji wzrokowej został przedstawiony dla operatora ładowarki podczas wyrównywania spągu w przodku chodnikowym. Na rysunku 11a pokazany jest model kryterialny ładowarki i cech antropometrycznych operatora. Widok osprzętu od strony siedzącego operatora umieszczono na rysunku 11b. Z rysunku wynika, że potencjalne punkty kolizji nie są widziane przez operatora. Na rysunkach 12a i 12b pokazano tę sama sytuację, z tym że operator stoi z przodu ładowarki, obok osprzętu. W tym położeniu operator widzi punkty kolizji.

Stosowanie modeli komputerowych pozwala na ocenę warunków eksploatacji maszyn górniczych już we wczesnych fazach ich projektowania.

Słowa kluczowe: układ antropotechniczny, projektowanie, maszyny górnicze, wspomaganie komputerowe projektowania (CAD), modelowanie komputerowe, bezpieczeństwo pracy, ergonomia

1. Introduction

During the exploitation process links are created between men and technical means and thus we obtain the *anthropotechnical systems* (Dietrych 1985).

The anthropotechnical system is described in a set of features C_{antrop} that is a sum of elementary sets *of the anthropomorphic part*[1] of the system c_a^{elem} and technical means together with the surroundings, which elements will be further named as the technical part of the system c_k^{elem}.

The anthropomorphic part can be described by the following elementary features:

- anthropometric features describing the external body structure,
- anatomic features of the skeletal system,
- features of the receptor system.

[1] People (or a single man) operating a technical mean (technical means) make *the anthropomorphic part*. This is a "vivacity" part of the anthropotechnical system.

The technical part is described by designing features (geometric and material) of the elements, assemblies and entire technical means.

Set of anthropotechnical system's feature can be given as:

$$C_{\text{antrop}} = \{c_a^{\text{elem}} \vee c_k^{\text{elem}}\} \tag{1}$$

Between man and a technical mean, two types of relationships can occur in the anthropotechnical system:

- relationships of somatic type,
- relationships of receptor type.

Relationships of somatic type describe spatial relationships between artificial real objects and a human body. They result directly from a man "corporeality" and are expressed by:

- limitations put on a space occupied by a man,
- assuming a posture,
- range of limbs,
- exerting the force,
- transferring of the external loads by musculoskeletal system.

Somatic relationships are realized by a human locomotive system. Due to the receptor relationships a man can respond to exogenous stimuli.

The concept of *the state* found in the machine diagnostics (Cholewa-Kaźmierczak 1995) can be used to describe relationships in the anthropotechnical system, by the way, as the anthropotechnical system we can assume the selected, momentary image of features that describes technical means and human organism.

In such a concept, the somatic relationships are relationships between states of a technical mean and states of the locomotive system, Fig. 1. While the states of technical means and receptors are linked by the receptor relationships.

From the conditions of the man psychophysical unity it results that there is a relation that conditions a harmony between the states of locomotive system and receptors. Disturbances of the harmony cause that one of the relationships or at the same time two

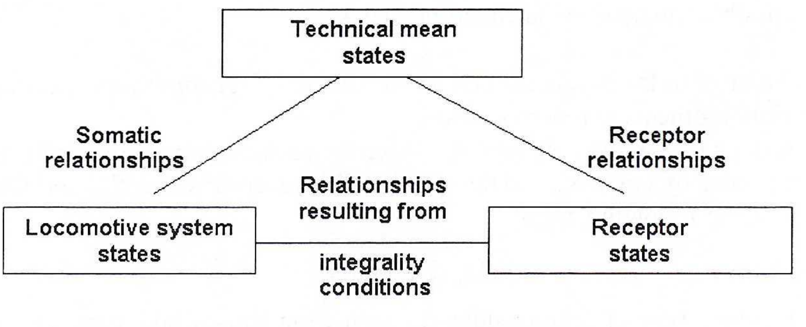

Fig. 1. Relationships network in the anthropotechnical system

Rys. 1. Sieć relacji w układzie antropotechnicznym of them can be formed not properly. Thus the necessity of common examination both somatic and receptor relationships results. The states of the technical mean acting both on a human body and on its receptors were marked in the figure by the joint block, however the character of both actions is different. In the case of the somatic relationship those states of a technical mean that have a straight connection with a body posture will be examined. These are e.g. momentary position of movable devices, levers, assemblies etc.

Taking into account the character of interactions in the somatic relation R_{som}, we can assume that this relation connects together two sets: set of geometrical elements (el_{geom}) belonging to the technical mean (*ST*) and set of segments (seg_{som}) belonging to a human body (*SOM*). Points, surfaces, parts and devices belonging to the technical mean and described by its geometric design features are the examples of elements from the first set. Fingers, hands, feet or limbs features are the examples of elements from the second set. The somatic relationship can be written using the set theory (Kuratowski 1977) as the set of ordered pairs of elements $<el_{geom}, seg_{som}>$ from both sets:

$$R_{som} = \{(el_{geom}, seg_{som}) : el_{geom} \in ST, seg_{som} \in SOM\} \tag{2}$$

This relationship can also be written as the subset in the Cartesian product:

$$R_{som} \subset ST \times SOM \tag{3}$$

Phenomena (physical, chemical, biological, atmospheric etc.), when each of them can be expressed by a certain set of features having momentary values, can act on the human receptors. Features belonging to the human surroundings in the period of time t make the momentary state of surroundings $s_{ot,t}$, and for the fixed period of time: s_{ot}.

Streams of stimuli coming from the surrounding of man cause excitations of the receptors. Stream of stimuli is changeable in time, thus momentary states of receptors excitation $s_{rec,t}$ can also be examined. The state of receptor excitation is called *the state of receptor* s_{rec}.

Ordered pairs $< s_{ot}, s_{rec}>$ can be identified for each of these receptors, such that:

- s_{ot} belongs to the S_{ot} set, described as *the sphere of surrounding states*, containing all possible momentary surrounding states,

and:

- s_{rec} belongs to the S_{rec} described as *the sphere of receptor states*, containing all possible momentary receptor states.

Relationships of the receptor type R_{rec} describe relationships between the sphere of surrounding states of a man S_{ot} and the sphere of his receptor states S_{rec} and finally they are written in the following form:

$$R_{rec} \subset S_{ot} \times S_{rec} \tag{4}$$

In the receptor type of relationships the following senses take part: vision, touch, hearing, smell and taste.

2. Criterial states and criterial models of anthropotechnical states

An idea of the anthropotechnical system includes within its range two parts of technosphere: its vivacity and non-vivacity part. Designing, in a technical meaning, concerns artificial forms — artifacts (Dietrych 1985). That what does not exist is designed and during designing process characteristics and features of the technical means are identified. Man as the user of technical means is the shaped psychosomatic creature that does not submit itself to the rules of technical designing. Thus interrelations man — technical mean can be the subject of a designing process. These relationships are assessed in the light of safety and ergonomics criteria.

The state of the anthropotechnical system where the relationships are assessed for the assumed criterial system is called *the criterial state*. It was assumed that when the anthropotechnical system is in a criterial state then the technical mean, man anthropometric features and his sensors are also in the criterial state.

Detailed criterial systems *Ukr* that are used to assess the anthropotechnical systems are created from the limited numbers of elementary criteria kr^{elem}, what we can write in a following way:

$$Ukr = \{\, kr^{\mathrm{elem}} : kryt(kr^{\mathrm{elem}})\} \tag{5}$$

Where $kryt\,(kr^{\mathrm{elem}})$ is a record of so-called *prepositional formula* (Kuratowski 1977). This formula says that to the Ukr set belong not only those elementary criteria kr^{elem}, that have *kryt* features responding to the formulated system of criteria *Ukr*.

The features should be of such character that will allow the system of criteria for e.g.:

- assessment of load of the musculo-skeletal system in awkward postures caused by the insufficient field of vision,
- assessment of limbs range e.g. during reaching dangerous zones in emergency situations,
- assessment of the minimal size of passages, pass in awkward postures,
- assessment of the receptor relationships in relation to the hearing organs, when crossing the acoustic field in different body positions,
- assessment of limbs range and field of vision in awkward postures,
- assessment of loosing feet adhesion on an uneven ground,
- testing the possibility of exerting forces in awkward postures,
- prediction of locomotive system injuries caused by the work.

A model representing real anthropotechnical system including all its features that are assessed in the light of assumed detailed criteria is called *the criterial model.*

In creation of criterial models we knowingly use some images of real objects or their states that during modelling enable to limit the number of included features. So-called *images of features* are created as the result of such imaging (Cholewa-Kaźmierczak 1995).

In this place we recall to the graphical interpretation of conception of image for imaging the features of technical and anthropomorphic part of the anthropomorphic system using graphic elements. Thus we have the following imaging:

- for the image of design features Ic_k im (c_k)
- for the image of features of the anthropomorphic part Ic_a im (c_a)

where Ic_k means the image of design features, c_k technical part, and Ic_a means the image of anthropometric features, c_a anthropomorphic part.

On the ground of computer modelling images become the geometric models presented by the methods of visualization.

Identity of the image and model we can write respectively:

$$Ic_k \equiv m_k \tag{6}$$

$$Ic_a \equiv m_a \tag{7}$$

where m means the model of a technical part (m_k) or anthropomorphic part (m_a).

For each j-th detailed system of criteria, pair of criterial models $m_k^{\text{kryt},j}$ and $m_a^{\text{kryt},j}$ is created.

Criterial models of the anthropotechnical system, as the set of pairs of criterial models of technical and anthropomorphic part, can be written in the following form:

$$M_{\text{antrop}}^{\text{kryt}} = \left\{ (m_k^{\text{kryt}}, m_a^{\text{kryt}}) : m_k^{\text{kryt}} \subset M_k^{\text{kryt}},\ m_a^{\text{kryt}} \subset M_a^{\text{kryt}} \right\} \tag{8}$$

where:

$$M_k^{\text{kryt}} = \{m_k^{\text{kryt}}\} \tag{9}$$

$$M_a^{\text{kryt}} = \{m_a^{\text{kryt}}\} \tag{10}$$

3. Computer models of anthropotechnical systems in mining machines

3.1. Criterial models of anthropometric features

Changeability of anthropometric features are included in the modelling of somatic relationships. Factors that influence the changeability of anthropometric features are:

- proportion in body constitution,
- somatic type,
- body weight distribution.

In anthropometry the proportions in body constitution are determined by relationships between trunk length and arms length. In columns of table in Fig. 2a the following pictograms are placed:

- trunk of normal length (A),
- long trunk (B),
- short trunk (C).

And meaning of pictograms in lines is as follows:

- arms of normal length (*a*),
- long arms (*b*),
- short arms (*c*).

Field with sign "*x*" means that a combination of different factors is possible.

In columns of table in Fig. 2b there are pictograms that describe the following somatic type:

- normal body constitution (*D*),
- thin (*E*),
- thick (*F*).

Lines in the table contain pictograms that express the following body weight distributions:

- weight distributed evenly (*d*),
- weight cumulated at chest (*e*),
- weight cumulated at abdomen (*f*).

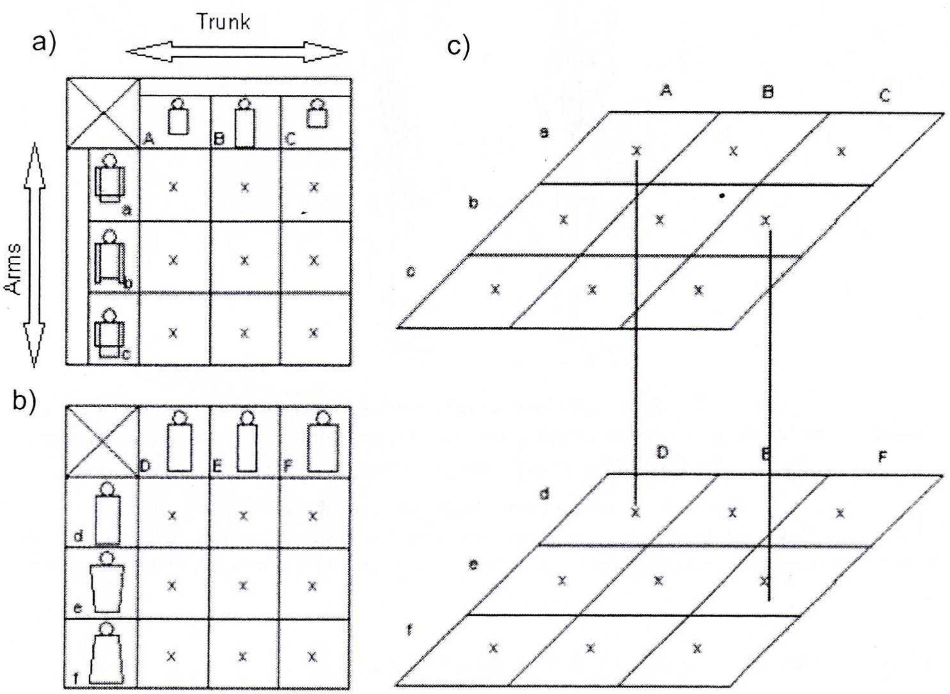

Fig. 2. Changeability of the anthropometric features
a — relationship between the trunk length and arms length; b — somatic types

Rys. 2. Zmienność cech antropometrycznych
a — związek jaki zachodzi pomiędzy długością tułowia a długością ramion; b — typy somatyczne

Both tables, given in form of planes, determine a sphere of anthropometric features Fig. 2c. Vectors that connect points from the plane of proportion of body constitution with points laying on the plane where there is a somatic type of specified body weight distribution, determine the type of anthropometric features changeabiltiy.

In Fig. 3a we can see a record of anthropometric features for the individual of normal trunk length, normal arms length, normal body structure (somatic type) of even distribution of body weight. This refers to the vector of coordinates (*Aa*, *Dd*). And in Fig. 3b we can see a record of anthropometric features for the individual of short trunk, long arms, thick, what refers to the vector of coordinates (*Cb*, *Fe*).

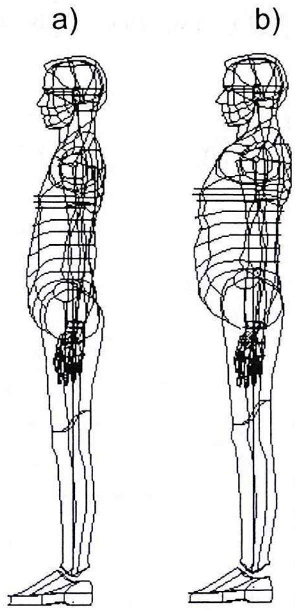

Fig. 3. Record of anthropometric features of individuals of:
a — normal trunk length, normal arms length, normal body constitution; b — short trunk, long arms, corpulent body, weight cumulated in the chest area

Rys. 3. Zapis cech antropometrycznych osobników o:
a — normalnej długości tułowia, normalnej długości ramion, normalnej budowy ciała; b — krótkim tułowiu, długich ramionach, tęgiej budowy ciała, masie skupionej w okolicach klatki piersiowej

3.2. Modelling of somatic relationships

Somatic relationships have their own structure that consists of:

- a method of connecting together the elements of the anthropotechnical system,
- sequence of elements connection.

An image of some existing structure of relationship was recorded in Fig. 4a. It shows a roadheader operator during face cutting in the area of floor. The operator observes

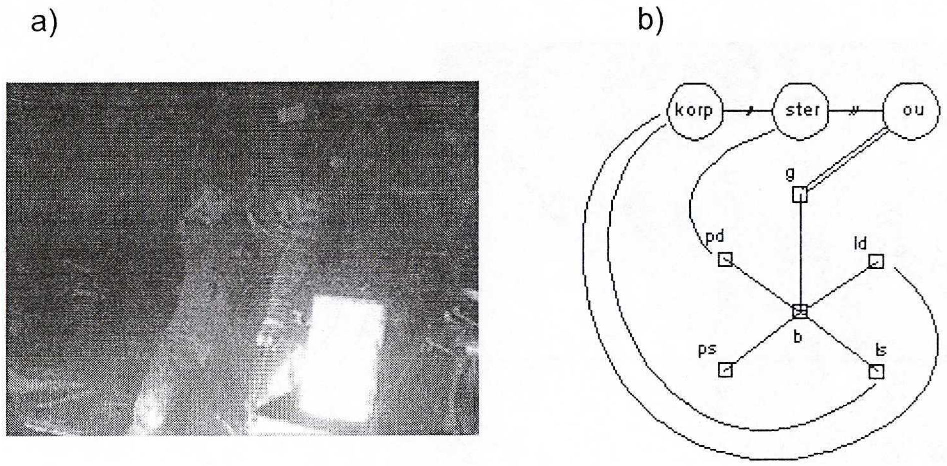

Fig. 4. Relationships structure in the anthropotechnical system
a — image of a structure; b — record in a form of graph

Rys. 4. Struktura relacji w układzie antropotechnicznym
a — obraz struktury; b — zapis w formie grafu

cutting drum operation (receptor relationship) and at the same time operates the controlling lever (somatic relationship). Such a structure of relationship causes an awkward posture, and in consequence it leads to the chronic injuries to the locomotive system (KOMAG Centre 2001). This structure is presented in Fig. 4b in a form of graph. Anthropomorphic elements (body segments) are the knots of graph, for which the following letter symbols have been assumed:

- *g* for a head,
- *b* for a basic point,
- *ld* for a left hand,
- *pd* for a right hand,
- *ls* for a left foot,
- *ps* for a right foot.

They are connected with technical elements by the receptor and somatic relationships: by a trunk (*korp*), by a cutting drum (*ou*) and by roadheader control system (*ster*).

Fig. 5a presents a suggestion of the modified design of control system. The lever of control system is installed on the control desk as a joystick. The control desk has itself a possibility of adjusting the height of its position so it can be operated in a sitting or standing position. Operator observes the cutting drum operational movements. Thus a partition of vision receptor relationship between modified control system (*ster'*) and a cutting drum (*ou*) occurred, so the somatic relationships have been improved. Now the operator is standing on two legs in a straighten position (Fig. 5b).

This case of changing the structure of relationships draws an attention to the mutual conditions between somatic and receptor relationships.

a) b)

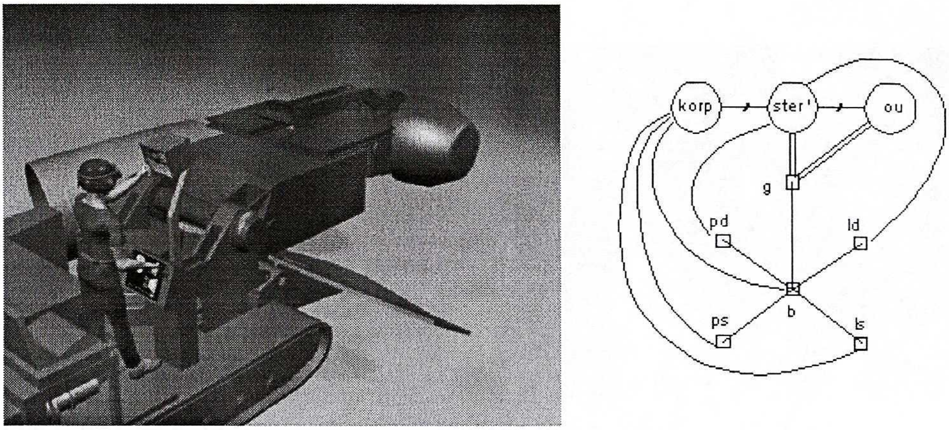

Fig. 5. Change of the relationships structure in the anthropotechnical system
a — relationships image for the modified design of the control system; b — record in a form of graph

Rys. 5. Zmiana struktury relacji w układzie antropotechnicznym
a — obraz relacji dla zmodyfikowanej konstrukcji układu sterującego; b — zapis w formie grafu

3.3. Modelling the receptor relationships

From the sphere of states describing all phenomena that surrounds a man, some elemental states having a character of stimuli that produce adequate state of receptors are selected. These basic states (stimuli) have their own features:

- localization in a work sphere,
- physical features,
- chemical features,
- biological features.

Receptors are the first, the most external part of human sense organs. These are the special sensory cells or bare endings of afferent nerve fibers that can receive stimuli. These stimuli are then transformed into bioelectric impulses conveyed to the executive organs, where they release reflex reactions (Miętkowski 1984). Properties connected with receiving stimuli are the subject of modelling.

For the requirements of receptors modelling we assume *generalized features of receptors:*

- localization in the work area,
- anthropometric features connected with displacement of receptors on the body surface,
- biophysical features,
- biochemical features.

A displacement of receptors on the body surface is shown in Fig. 6, and in Table 1 an exemplary list of generalized receptor features is given.

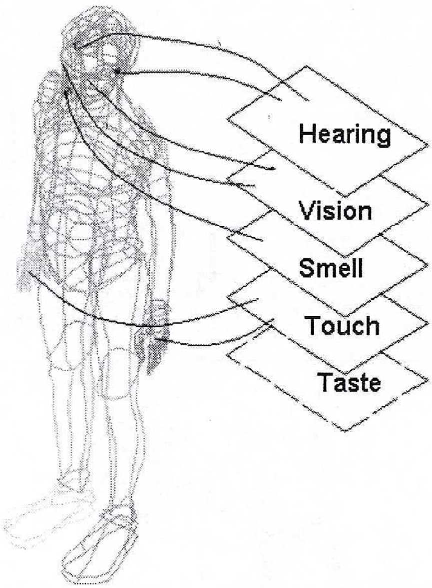

Fig. 6. Displacement of the receptors on the body surface

Rys. 6. Rozmieszczenie receptorów na powierzchni ciała

TABLE I

Generalized features of hearing receptor

TABLICA I

Uogólnione cechy receptorów słuchu

Anthropometric features	<ear> <left> <ear> <right>
Localization of receptors in space	<position of left ear> <*x,y,z*> < position of right ear > <*x,y,z*>
Physical features	<level of acoustic pressure for the left ear> <*dBA*> < level of acoustic pressure for the right ear > <*dBA*> <exposure time> <time unit>

The spatial geometric objects associated with non-geometric attributes that are stored in the graphic data base of the CAD system, where both models of technical means and human body are created, are used for modelling the generalized receptor features, Fig. 7a.

Point P1 is a conventional point of the receptor localization. Together with points P2 and P3, they determine a plane, which spatial orientation is determined by the vector

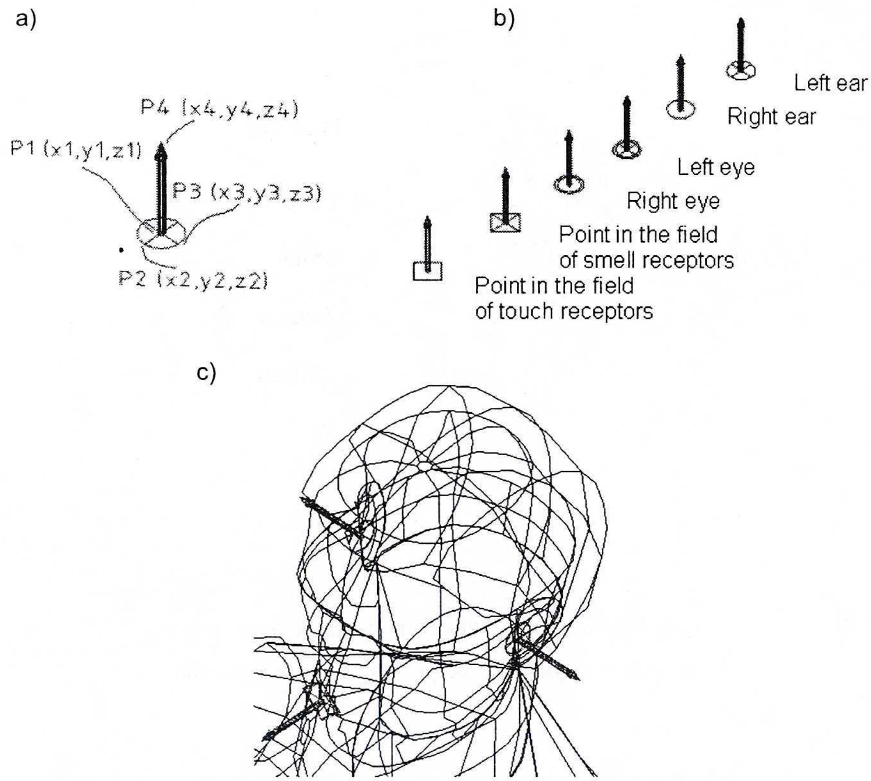

Fig. 7. Graphic models of receptors
a — spherical geometric objects associated with non-geometric attributes; b — graphic representations of the receptor models; c — anthropometric model of a head together with objects representing hearing and smell receptors

Rys. 7. Modele graficzne receptorów
a — przestrzenne obiekty geometryczne stowarzyszone z atrybutami niegeometrycznymi; b — reprezentacje graficzne modeli receptorów; c — model antropometryczny głowy wraz z obiektami reprezentującymi receptory słuchu i węchu

P3P4. It points the direction to the outside of human body. Graphic representation of the receptor models is presented in Fig. 7b. Anthropotechnical model of a head together with the objects representing hearing and smell receptors is shown in Fig. 7c.

Models of human silhouettes are relocated in the work area and are brought to the postures that can be assumed during an operation of real technical means. During the changes in position of human silhouettes, the models of receptors together with their attributes are moved as well. The operational cycle of bolting and drilling machine that operates in the roadway face is shown in Fig. 8. During a time of approaching the bolting place, an operator controls the machine from his stand in a sitting posture. After placing the accessories in a proper position and drilling a hole the operator takes bolts from the store box (path 1). Then he translocates to the accessories (path 2), where he puts the bolt

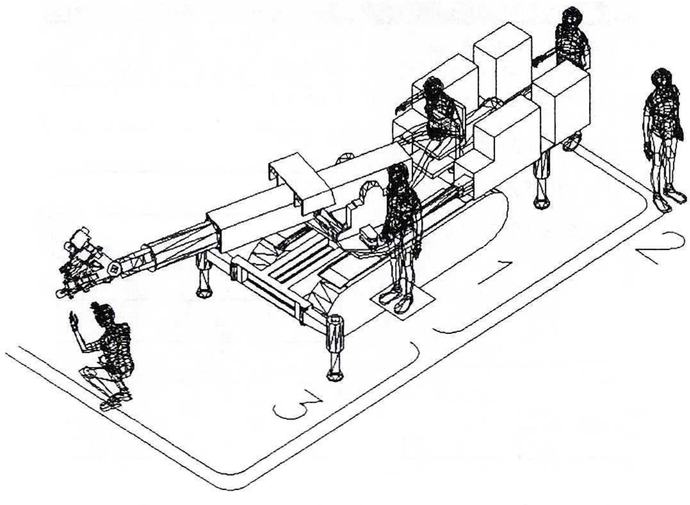

Fig. 8. Imaging of the operation of bolting and drilling machine

Rys. 8. Odwzorowanie cyklu obsługi maszyny wiercąco-kotwiącej

into a hole, then he passes to the platform (path 3), from which he controls the bolting process. Some intermediate positions of the operator's silhouette, that are related to the positions of receptors, is shown in Fig. 9.

Some exemplary values of generalized features of hearing receptors were given in Fig. 10. We can see values of coordinates for the right ear taken from the drawing database. In the areas of exposure time, time of staying in the certain place is recorded. In such a way the geometrical space model is created, where not activated receptors are placed. They are exposed to noise and dust. Noise is generated by a drive system of the machine as well as by drills that additionally emit the dust. These phenomena are modelled in the separate software that was not a subject of the work. Models of stimuli

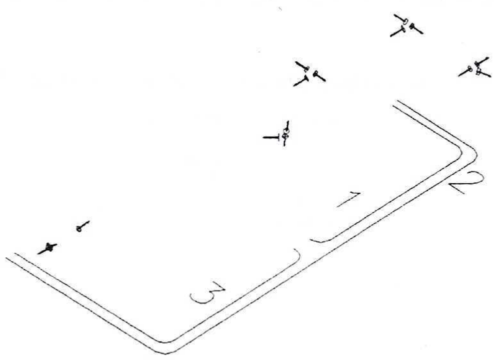

Fig. 9. Momentary positions of the receptor models

Rys. 9. Chwilowe położenia modeli receptorów ssories and the surrounding that consists of arch support, conveyor and air and water hoses. The criterial state of the machine at the initial stage of the run of mine coal unloading at the moment of approaching to the conveyor is analyzed. For that state the potential points of collision of the accessories with the surrounding are identified (KOMAG Centre 1995). Criterial model of loader and a model of anthropomorphic features of operator are given in Fig. 11a. The view of accessories from the side of sitting operator is shown in Fig. 11b. From the figure it results that the collision points are not visible by the operator. The same situation but with the operator standing in front of the loader, aside to the accessories is given in Fig. 12a. The view of field of vision of the operator standing by the loader is given in Fig. 12a. In that position the operator can see the points of collision. Thus approaching the dangerous zones the control of machine operational movements should be carried out remotely, from behind the operator's work stand.

4. Conclusions

Current methods of designing the mining machines have had a "technocentric" character and they were focused on achieving the best technical parameters. Complexity of the state-of-the-art longwall and roadway systems draws an attention to the human factor during their exploitation. In most cases these systems are assembled underground and only there possible, not properly formed, relationships man-machine can be identified. Computer model of machines and men allows for identification of somatic and receptor relationships that can occur in early stages of the designing process of both mining machines and mining developments even before the real machine systems are created.

Currently the main part of designing processes of mining machines and mining development is computer aided using the CAD software. The presented method of modelling the anthropotechnical system in the mining industry is placed in an environment of these systems. Thus it is possible to create computer models in all stages of designing process and their analysis in the light of ergonomics and safety criteria.

REFERENCES

Cholewa W., Kaźmierczak J., 1995. Data processing and reasoning in technical diagnostic. WNT, Warszawa.

CMG KOMAG, 2001. Praca E/BD-8241/OR1: Identyfikacja powiązań pomiędzy schorzeniami narządu ruchu a czynnościami roboczymi występującymi na górniczych stanowiskach pracy. Gliwice.

Dietrych J., 1985. System i konstrukcja. WNT, Warszawa.

Miętkowski E., 1984. Zarys fizjologii lekarskiej. Państwowy Zakład Wydawnictw Lekarskich, Warszawa.

Kuratowski K., 1977. Wstęp do teorii mnogości. Wyd. 7, PWN, Warszawa.

RAYNOISE Rev.2.1., 1995. Users manual. Numerical Integration Technologies N.V. Leuven, Belgium.

REVIEW BY: PROF. DR HAB. INŻ. ADAM KLICH, KRAKÓW

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