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Application prospects of the augmented reality technology for improving safety of machine operators

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1. Introduction

Basing on the results of industrial accident analysis (Dzwiarek, 2004) one can arrive at the conclusion that every year accidents happen because a warning signal is either not heard or not heeded (Haas & Casali 1995). Therefore, one of the important measures to prevent undesired events consists in informing a machine operator about the appearance of hazardous situation quickly and effectively enough. Standard ISO 12100-2:2003 recommends employing warning signals as an additional means for risk reduction, especially in the cases when other safety measures are not effective enough. This additional means plays an especially important role in the courses of machine regulating, maintaining and repair since in those cases the protective devices are usually disconnected and a direct access to dangerous zones is required. One can deal with such a situation also when maintaining an assembly line, where the operator should work during the line standstill and has to leave the dangerous zone before the line moves on. The warning signals are of crucial importance also in the cases when it is impossible for the operator starting a machine for control all the access zones. In such a case there arises the necessity for signaling the intention of starting a machine in the way ensuring that all the persons present nearby will be warned against the danger early enough.

Therefore, the warning signals are employed for emergency event alert e.g., in case of unexpected machine start or sudden increase in a tool speed. Those signals can be used for warning the operator before the dangerous situation could have activated the safety devices. Those signals should:

(a) be generated before a dangerous event occurs,
(b) be unambiguous,
(c) be clearly distinguishable from other signals generated within the workplace.

Nowadays, visual and acoustic warning signals are most common. However, their main disadvantage consists in the fact that they may be received by many people instead of a person in danger alone. That may distract many people causing disturbances in other workstations. Additionally, visual signals can be seen only when displayed within the visual area of the person in danger. The operator usually focuses the attention and sight on the operations he/she is carrying out, therefore often neglects those signals.

The Augmented Reality (AR) devices satisfy all the requirements imposed on warning signals and suffer from no drawbacks mentioned above, therefore, the development in technology will bring about broadening of the scope of their applications covering also the field of safety at work.
The main aim of the paper consist in on presenting and discussing of the methodology of proving (by means of the perception assessment) that the warning signals generated using the AR approach reveals the same effectiveness as standard visual signals coming from an industrial signaling device that is of common use in machinery (Dzwiarek at al., 2007).

2. Case studies of emergency signs applied to machinery

In order to analyze thoroughly a possible applicability of the AR warning signals to machine operation several factories were visited for case studies. Six workstations were analyzed, and four of them indicated the applicability of the AR signals.

2.1 Automated production line

Each automated production line comprises several work centers. In each center the products are processed automatically. On the considered case production cycle takes about 10 minutes.
After a cycle has been completed the operator should enter a work centre and remove waste material. Then after leaving the work centre he/she should start the next cycle of automatic processing. Usually, the line is operated by two operators. Each work centre is supplied with a device signaling dangerous situations and warning the operator against entering the work centre area after the signal of processing cycle start has been generated. The signal can be seen only outside the centre area. A person working inside the work centre area has no possibilities of catching the signal that actually caused an accident during the line operation. The accident could have been prevented if the operator was warned about the danger early enough; e.g., using the AR signal.

2.2 The workstation of automated press forming in the „SETUP" mode

Two workers make a replacement of extrusion dies in an automatic press line. The extrusion dies are stored in piles next to the line. One of the workers makes a chosen extrusion die ready to be lifted by an overhead traveling crane, while at the same time the other worker is lifting the extrusion die that has been prepared before. An accident happened during the operations since the worker standing behind the pile extrusion dies did not notice the approaching overhead traveling crane that crashed the pile of extrusion dies. The only way of prevention such accidents consists in warning a worker against the approaching traveling crane. The warning signal applied in the case had failed since it was generated to forbid the outsider to approach the crane operation zone while the workers replacing the extrusion dies were inside the zone during work. The AR signal could be an effective in the case since it would be received by the person in danger.

2.3 Workstation of fork lift truck operation

The operator of fork lift truck provides workstations with materials. While driving from a store there are many places of possible impacts to both pedestrian and other equipment. According to the rules followed in the whole factory the fork lift trucks have the right of way. All the employee know the rule and should follow it. Despite the fact the accidents happen at the cross-roads, mainly due to missing the approaching fork lift truck by a distracted person. If the safety glasses, the workers wear, were supplied with the AR signal systems warning against the approaching trucks, at least some of the accidents could have been avoided.

2.4 Workstation of car roof assembly

The workstation is operated by two workers (Fig.1.). They should put on manually the car body sides and start an automatic car roof assembly. After the tasks have been executed the assembly line travels a little – the car body is shifted to the next workstation, allowing space for another car body.

Fig. 1. Workstation of car roof assembly.

During the assembly line travel as well as when the car roof is put on the body both the operators should be outside the zone marked on the floor with a yellow line. The zone is controlled by a laser scanner that stops the assembly line when anybody is present within the area. The time allowed for the task is 1 min. 43 s. During their work the operators wear the safety glasses.

In the course of normal operation no warning signals appear. The dangerous situations, about which the operators should be warned, consist in the events when due to a failure or fault, the production line starts its travel or the automatic car roof assembler starts its work at the instant when the operators are within the marked area. Such situations are extremely rare, however, do happen and for that reason the standard warning signal device was mounted (see Fig. 1). The signal, however, is not effective enough and supplying the safety glasses worn by the workers with the AR systems would considerably improve the protection.

The Hierarchical Task Analysis (HTA) has been conducted using the workstation considered above. The warning signal is generated when the automatic machine starts unexpectedly at the instant when the workers are executing their tasks. The event is completely independent of the operators' activities (and therefore, needs additional warning) and might occur at an arbitrary instant during any operation. One cannot, therefore, distinguish any particular operation that would be associated with the risk.

3. The Augmented Reality in a workplace

Some information about the attempts made at application of the augmented reality approach to workplace in industry has been available from the literature for the last few years. To the best of our knowledge, however, those attempts consisted in employing the AR systems for improving the efficiency of inspection and maintenance as well as for training purposes.

A general analysis of the AR systems serviceability when applied to inspection and maintenance was carried out (Kyung et al., 2002), as well as the possibilities of the AR system application to trainings for maintenance technicians were examined (Bound et al. 1999). A way of AR system application to periodic inspection of machinery was presented (Chung et al. 1999; Weidenhausen et al., 2003). Same authors (Anastassova et al., 2005) presented primary results of currently conducted investigations into AR system application to improving the work efficiency in automotive maintenance and the possibility of AR system application to manufacturing system design was discussed (Dangelmaier et al., 2005). A large scale application of the AR technology has allowed for solving many important problems in the field of car service. Car mechanics in many garages in the USA are provided with portable AR systems supplied with semi-permeable glasses that are connected with a central computer managing the expert software packages, supporting that way proper conducting of particular repair/service operations. The garage owners have estimated that the application of AR systems allows for shortening the repair time by 1/3.

All the aforementioned applications were characterised by the following features:

(a) AR images were directly associated with the executed task;

(b) AR images were displayed continuously and should have been situated in the vicinity of the devices the operator kept his sight on;

(c) Operator's attention was concentrated on the images he expected to appear.

Therefore, the investigations were planned basing within the HTA approach and, where possible, conducted on the real workstations.

3.1 Requirements for the AR warning signals

As far as we know, there is lack of information available in the literature about the investigations into application of the AR systems to generation of visual warning signals used in machinery operation for warning operators. The results of analysis presented in chapter 2 have proved that the AR systems can be applied in the cases where standard warning systems are not effective enough; especially in the cases of: warning about the machine start, when the operator's sight of dangerous zones is limited, warnings in transportation operations – e. g. in the case of overhead cranes and warning signals in semi-automatic manufacturing systems.

Some basic features have been specified to distinguish between the warning and information signals, respectively:

(a) usually, warning signals are hardly ever connected with the current operations;
(b) warning signals appear only occasionally in unusual situations and are displayed far enough from the device the operator keeps his/her sight on;
(c) warning signals appear unexpectedly, when the operator's attention is focused on other operations.
Due to the aforementioned features of warning signals, as well as the fact that there is a broad variety of workplaces they can be used it is impossible to determine using the HTA approach the operations typical for all users of the warning signals. It is possible, however, to determine special categories of psycho-motoric and cognitive skills as well as other abilities the workers should have that are necessary for safe and efficient operation in workplaces equipped with machinery. After analyzing the characteristics of respective occupational groups and workstations equipped with machinery it was stated that main abilities necessary for efficient machine operation consisted in reaction time and attention (Luczak, 2001).

4. Some AR system designs suggested for warning signal generation

The considerations presented in the previous chapter have proved that the AR systems occur to be extremely effective within a broad scope of their applications. Up till now, the AR systems were employed for providing additional information useful for the operator. Comparative analysis results have proved that work efficiency in the case of AR signal support is much higher as compared to the standard warning methods, improving the efficiency indicators; like number of mistakes and reaction time (Chunga et al., 2002). However, special characteristics of the warning signals require special AR systems for signal generation.
Special equipment has been designed and constructed at the Wrasaw University of technology in co-operation with the Central Institute for Labour Protection - National Research Institute (CIOP-PIB). The background information was collected basing on the analysis of available systems and taking into consideration the following assumptions (Dzwiarek et al., 2003; Dzwiarek et al., 2004; Dzwiarek et al., 2006):
(a) it should be a system of the see-through type. In such systems in case of no warning signal the real workstation is being observed. While in the systems, which provide additional signals emitted by a camera, the surrounding area is being displayed on a monitor screen. However the at present stage of technology development those systems should not be used for industrial applications due to their inaccuracy and low reliability (Hagele et al., 2002).
(b) the glasses on which the AR signal is generated should be as comfortable as possible.
(c) in case of no warning signal the glasses should limit the sight area in the slightest possible way and involve the minimal number of disturbances, distortions and fading of the image displayed.
Additionally, since the systems are to be used in machine operation, the requirements specified in standards EN 981:1996 and IEC 61310-1:1995 should be satisfied as well, because recommendations on visual warning signal features are specified in the standards. The designed glasses are shown in Fig.2.

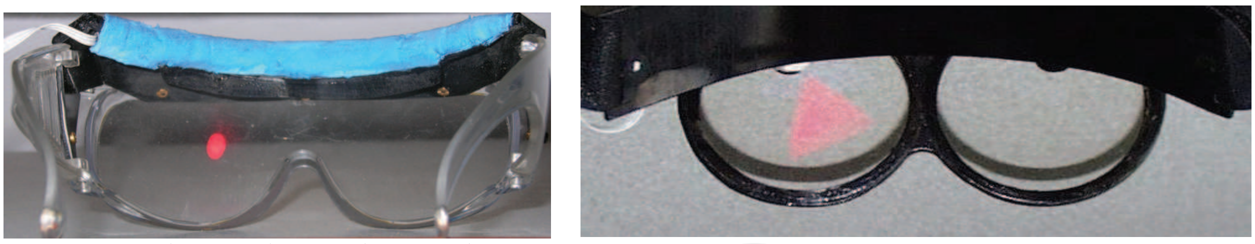

Fig.2. Sample AR glasses designed

Moreover, to introduce alphanumerical signs into the images displayed, the LITEYE-500 (see Fig. 3) glasses available on the marked were used

Fig.3. “Stop” signal displayed on the external side of LITEYE-500 eyepiece

5. Methods

The AR systems can be applied to generation of visual warning signals provided that perception of such signals is effective enough in the considered case. The main aim of the research consists in examination of the AR signal perception in the context of applicability of AR approach to warning signal generation in case of hazard in workplaces equipped with machinery. To this end we have decided to verify experimentally the following hypotheses:

Hypothesis 1

There is a substantial difference in perception of warning signals generated using the AR and standard (ST) approaches, respectively, in view of both objective and subjective indicators assessment.

Hypothesis 2

The perception of visual warning signals generated using the AR approach varies in view of the assessment of objective indicators – for different types of the AR signals.

5.1 Most common methods for examination of warning signal perception

Basing on the available literature one can conclude that a typical method for examination of perception of industrial warning signals consists in application of the „criterion task set” (CTS) (Shingledecker, 1984) while version 2.1 i.e., „probability monitoring task”, is most common in the case of machine operation. In the course of experiment throughout the tracking task (Burt et al., 1995), a warning against the hazard of system failure was displayed at 30 s intervals and the circular target changed into a square. If the square target then went out of the joystick control and started to drift outside the specified rectangular boundaries, the tracking system had failed. The subjects were required to press the push-button in order to resume tracking. The reaction time was recorded from the instant when the tracking system failed until the push-button response moment. A similar experiment was described by others (Cohn, 1996), where due to accommodation accompanying warning signals: (a) the icon jumped from side to side, (b) the curved arrow moved circularly, (c) wavy lines marched across from left to right. In the course of the experiment aiming at the perception assessment of visual and acoustic warning signals generated in both the synchronous and asynchronous ways (Chan & Chan, 2006) the subjects sat in front of a computer screen wearing stereophonic headphones, through which acoustic signals were emitted. The visual signals had a form of red circles of 20 mm in diameter displayed on the computer screen at a distance of 80 mm to the left or right of a green circle of the same diameter. The subjects were required to keep their sight on the green circle and respond to the visual or acoustic signals appearing in the left or right hand side through pressing of one of the two buttons. The response time was measured. The response correctness was registered as well. In al the aforementioned experiments the perception indicator of warning signals consisted in the response time and possibly in the number of mistakes made in the course of task execution.

5.2 Experiment

Due to the features of warning signals concluded in chapter 3.1, as well as the fact that there is a broad variety of workplaces they can be used it is impossible to determine using the HTA approach the operations typical for all receivers of the warning signals. It is possible, however, to determine special categories of psycho-motoric and cognitive skills as well as other abilities the workers should have that are necessary for safe and efficient operations in workplaces equipped with machinery.

Therefore, when planning the experiment it was decided that the task should be simulated in view of engaging the specified mental processes and abilities, shared by the broadest possible group of workers instead of taking the performed operations into consideration. After analyzing characteristics of different professions and trades, also in the cases when the work is done in an assembly room (Widerszal-Bazyl, 1998; Łuczak, 2001) and the characteristics of respective occupational groups and workstations equipped with machinery it was stated that main abilities necessary for effective machine operation consisted in reaction time and attention. It was then planned that, the task executed by the operator during the experiment would involve those abilities. The requirement is satisfied by the „criterion task set" (CTS), in its „dual task" form (Shingledecker, 1984), on the basis of which the experiment was planned. The task executed during the experiment by the tested subjects consisted in putting the element of one colour into the hole of the same colour made in a palette, e.g. blue-to-blue, green-to-green, etc. After all holes in the palette had been filled a tested subject put it aside in the place of console situated within two strips. Then he took the next palette and repeated the whole cycle of putting elements into the proper holes. Each session lasted for 20 minutes. During the whole session time a robot standing in the vicinity was simulating the movements made usually when measuring the element size. The aforementioned sequences were repeated consecutively until the session ended. In the course of experimental task execution visual warning signals were generated using either a standard industrial signalling device or augmented reality glasses. The tested subject had to press a push-button as soon as a signal was generated. The warning signals were randomly generated during the test session. Each warning signal lasted for 10 seconds and if during

that time the push-button was pressed the signal was cut off and the reaction time was registered. In case the push-button was not pressed within 10 seconds the signal omission was registered. Each tested subject took part in 3 testing sessions. In one session two variants of the experiment were performed, each of 20 minutes in duration. In the first variant standard warning signals were generated, while in the second variant the AR signals were applied having one of six forms given below (AR1 - AR6). Between both the experimental sessions at least 20-minute-break was made so that the effect of fatigue could be eliminated.
Following the recommendations of EN 981:1996 i EN 61310-1:1995 and accepting the conclusions drawn by other researchers (Cohn, 1996; Gros et al., 2005) the following types of warning signals were employed during the experiment:
1. Standard warning signal; i.e., appearance of a red light signal (ST),
2. AR warning signal in the form of red circle displayed on the eyepiece (AR1),
3. AR warning signal in the form of flashing circle displayed on the eyepiece (AR2), of 4 Hz flashing frequency,
4. AR warning signal having the form of word „ STOP" displayed in red on the LITEYE-500 eyepiece (AR3).
5. AR warning signal in the form of yellow circle displayed on the eyepiece (AR4),
6. AR warning signal in the form of red flashing circle displayed on the eyepiece (AR5), of 8 Hz flashing frequency,
7. AR warning signal in the form of red triangle displayed on the eyepiece (AR6).
The experiment was performed in two cycles. The first one comprised the following sessions:
(a) Session E I – standard warning signal + AR1 warning signal (ST + AR1)
(b) SessionE II – standard warning signal + AR2 warning signal (ST + AR2)
(c) Session E III - standard warning signal + AR3 warning signal (ST + AR3)
While the second cycle of experiments was performed in the following three sessions:
(a) Session E 4 – standard warning signal + AR4 warning signal (ST + AR4)
(b) Session E 5 – standard warning signal + AR5 warning signal (ST + AR5)
(c) Session E 6 - standard warning signal + AR6 warning signal (ST + AR6)
That means that each subject during one session underwent the two types of experiments;, i.e. executing the task with the standard warning signal then executing the same task with one of the AR type signals.
All signals were generated against the same background. During the experiment the artificial lighting was employed with the colour rendering index of 82, which is typical for workstations. Within the task execution zone the luminance was measured continuously, and its change ranged from 440Lx to 550 Lx. Standard EN 12464-1:2004 recommends the lighting of luminance higher than 300 Lx at the inside work, while the investigations conducted at workstations (Pawlak & Wolska, 2004; Pawlak & Wolska, 2005; Pawlak & Wolska, 2006) have proved that actually at workstations the luminance changing within 350Lx – 600Lx.

5.3 Subjects

Subject were 21 to 25 years old, with a mean age of 23 years. Each subject having normal sight, with no needs for glasses and no sight defects (e.g. daltonism). Twenty three male volunteers constituted the paid subject population for the 1-sth cycle of experiment and 30 for the 2-nd cycle. Different groups of subjects underwent each cycle. The group of 53 people underwent tests, therefore during 159 experimental sessions the number of 318 different experiments (in view of warning signal combinations) were performed.

5.4 Results

To assess properly the perception of AR warning signals and standard warning signals both objective and subjective indicators were used. The following objective indicators were assumed: reaction time, number of signal omissions, number of mistakes made when putting elements into the holes. A subjective indicator has a form of questionnaire including four questions about the assessment of tested subject's reaction time to stimuli of both kinds and about preferences between the kinds of signal.

The results obtained were then analysed in view of the hypotheses that had been put forward before. The reaction times measured were subject to statistical analysis on the assumption of normal distribution. The results obtained from each experimental cycle were analysed independently of the other ones. Basic statistics were determined for each set of results:

(a) mean value T^i_m
(b) mean standard deviation σ^i
(c) maximal and minimal values (T^i_{max} and T^i_{min})

where "i" stands for the i-th subject.

The analysis results justified the hypotheses put forward. During the first experimental cycle the AR signal having the form of red circle was really better receivable as compared to the standard one, in view of both the reaction time and working speed. However, in view of the reaction time, the AR signal having the form of word "STOP" occurred to be visibly more hardly perceptible as compared to the standard one. During the second experimental cycle the AR signal having the form of yellow circle occurred to be significantly better in view if the working speed and visibly worse in view of the reaction as compared to the standard one. Additionally, during the same experiment the AR signal having the form of red circle flashing at 8 Hz frequency occurred to be visibly better as compared to the standard one since the scatter of the reaction times measured was narrower.

Substantial differences appeared in signal perception between the standard and AR warning signals also in view of subjective assessment of the perception quality. The comparative analysis of subjects' preferences have proved that the AR signals were received as the better ones in the case when they had the form of red circle, flashing or not, despite the flashing frequency. While during the task execution the red inscription STOP was considered to be more disturbing than the standard warning signal. The AR warning signal having the form of yellow circle was also considered as more disturbing, being however much easier to notice as compared to the ST one. In view of visibility the standard signal was consider to be better than the AR signal having the form of red triangle, that signal however, was considered to be noticeable much sooner than the standard one.

It can be concluded that in view almost every considered indicators, both objective and subjective ones, the AR signal occurred to be better as compared to the standard one. One of the reasons behind obtaining such a result consists in the fact that the AR signal, being displayed on the eyepiece, is always visible by the working person, while visibility of the standard warning signal changes, depending on the position the working person assumes or occupies.

It occurred, however, that the standard warning signal was more effective than the AR one having the form of red inscription STOP. The reaction time to the stimuli was really shorter. As far as we know, the results can be explained basing on the theory of perception, within which the two levels of perception are distinguished; i.e., sensomotor and semantic-operational (Tomaszewski, 1975). One can assume that perception of the standard warning signal take place on the sensomotor level (figurative perception), allowing for distinguishing geometrical objects (e.g. points, lines, solids). While perception of the inscription STOP takes place on the semantic-operational level (physical perception), and is not restrained to physical properties of singular objects (things, persons, events) but allows also for perception of their representations (models, diagrams, words).
Moreover, it can be assumed that following the whole perception process, i.e. impression phase (sensor registration), organisation phase (emotional assessment), recognition and metaphoric assessment; may in that case take much more time as compared to the red light generated by a signalling device, mainly due to the third phase (recognition) time (Kosslyn&Rosenberg, 2006).
At this stage of the perception process the semantic assessment of stimuli is carried out, allowing for its categorisation. Due to the set size effect the higher the number of stimuli to be compared the longer the perception process (Maruszewski, 2001) . In our case the inscription STOP is a more complicated stimuli than the red light.
The inscription STOP was considered as a more disturbing one, as well that subjective assessment may result from the fact that the inscription covers a larger part of the sight area than the red circle signal. Moreover, it was found that in experimental cycle 1 in view of the reaction time the red circle signal displayed on the eyepiece occurred to be the best one, while the inscription STOP – the worst signal. During experimental cycle 2, however, in view of the working speed the yellow circle signal displayed on the eyepiece occurred to be the worst one.
It can be concluded that the AR signal having the form of red circle was most advantageous: the reaction time to that stimuli was shortest and the working speed observed was most suitable. Additionally, it resulted from the subjective assessment that the red circle was considered to be best visible, most easy to catch and would be used most often at the actual workstations. When comparing between the signals differing in colour; i.e. red and yellow circles, more advantageous have occurred the red one. It seems that the reasons behind such assessment result from the social significance system, where the red colour usually means – "danger". The aforementioned system was detected e.g., in the course of investigations into perception of words and colours connected with danger, where it occurred that about 75% of subjects had considered the red colour to have meant "danger" (Baun&Silver, 1995; Borade et al., 2008). It was very important in view of the research completing also to find out what the subjects felt about different warning signals. Most of the subject population considered the AR signals as more "user-friendly" than the standard one. At the same time, however, almost everyone emphasized that the ergonomics of glasses was of crucial importance. Improving ergonomic properties of the glasses could make them more useful.

6. Conclusions

The considerations presented in Chapter 2, as well as the analysis results of the accidents that happened in machine operation (Dźwiarek, 2004) have proved that the appropriate use of warning signals is always the issue of crucial importance. The results obtained from the experiment conducted indicate that the warning signals generated using the augmented reality technology may occur much more efficient as compared to the standard warning signals. On the other hand thanks to the technological development signals of that type will soon be more easily available. Successful applications of the AR systems to solve other, not safety-related problems; like,

- supporting of service and assembly tasks in industry;
- training and supporting of diagnostics in medicine;
- "virtual guides" in museums;
- computer games;

also indicate the possibility of broadening the scope of AR system applications to improve the safety at work. Especially in the cases when standard warning devices occur to be ineffective and insufficient. Major drawback the standard warning systems suffer from consists in the fact that they are fixed, and therefore after the operator has moved they could be situated outside his/her visual area. The warning devices of that type can also be hidden from view by machinery elements or other equipment.

The AR signals are considered as the active visual ones. It is due to the fact that by means of changes in contrast, brightness, colour, shape size or location of a symbol they provide the information about any change in the state of machinery. If the information relates to risk changes they are warning signals.

To make the perception of visual warning signal easier the signal should be situated in the way ensuring that they will be seen from each place they should be. Active safety-related signals should be positioned so that they are visible to operators from working positions, and to exposed persons, and should have as wide a viewing angle as needed for safe detection. The examples shown in Chapter 2 have proved that when dealing with the standard visual warning systems it might be difficult. The idea of AR signal ensures that those requirements are satisfied since the signal will always remain within the operator's visual area. Moreover, it is very important that the AR signal is received only by a person in danger instead of involving any disturbances in the work of other people.

All safety-related signals should be designed in the way ensuring that their meaning is always clear, obvious, exact and unambiguous to the expected user. The safety-related information should be provided using means adapted accordingly to the perception capabilities of operators or other people in danger. The effective warning signals should be properly designed. The investigations conducted have proved that the type of applied signals is here of crucial importance. It is obvious that in warning signal design only "see-through" systems should be considered. In such systems in case of no warning signal the workstation is being observed. In the systems where additional signals are displayed the workstation is being observed on a monitor screen. That type of design is neither precise nor reliable enough to be applied in industry. Even most advanced systems can not reconstruct the real images in the way precise enough and supply the reality with virtual images.

The symbols as simple as possible should be used as warning signals. The results we have obtained have proved that most effective are circles, the reception of which does not require further semantic-operational analysis. Each additional sign considerably extends the perception time, which might reduce their effectiveness. One should consider also the risk of „sensory overwork" due to the information overload, which might cause that the operator misses the warning signals. A proper colour of sign is also important. Actually, our experiment has excluded the use of colours other then red, ehich agrees with the results obtained by other researches as well as with commonly accepted rules and standards on the warning signals. However, it is recommended to support the signal perception by means of flashing signals. From the experiment it was found that the signals flashing at 4-8 Hz were best received. Lower flashing frequency may cause reaction delays since the time between flashes is comparable with the operator's reaction time. Higher flashing frequencies are perceived as a continuous signal.

When designing the AR devices for industrial applications one should concentrate efforts on their ergonomics, which could be clearly seen from the subjects' remarks. It is recommended that the personal protective equipment used at the workstation be adapted accordingly for AR applications. If it is impossible, new designs should be as close to those being in use as possible, taking into consideration the conformity assessment with the relevant regulations on working equipment.

It can be concluded, therefore, that the AR devices can be successfully applied to warning against any dangerous event; like machine start, too high speed, etc; as the devices supporting standard warning signals. That concerns especially the cases when the operator should look in many different directions.

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The book consists of 20 chapters, each addressing a certain aspect of human-computer interaction. Each chapter gives the reader background information on a subject and proposes an original solution. This should serve as a valuable tool for professionals in this interdisciplinary field. Hopefully, readers will contribute their own discoveries and improvements, innovative ideas and concepts, as well as novel applications and business models related to the field of human-computer interaction. It is our wish that the reader consider not only what our authors have written and the experimentation they have described, but also the examples they have set.

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