DYNAMIC READING OF ANALOG AND DIGITAL DISPLAYS: A COMPARATIVE STUDY

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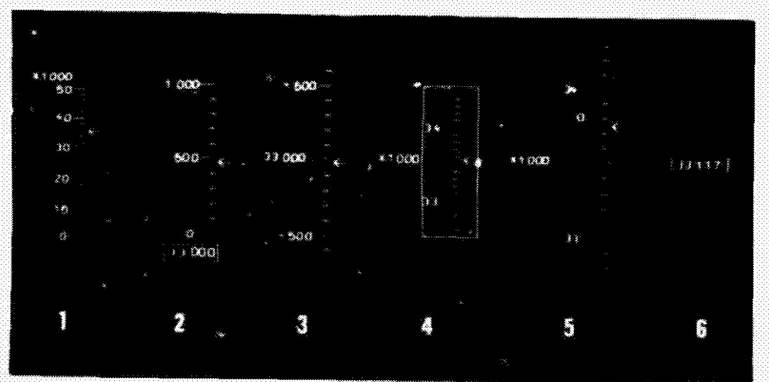
Introduction

Analog and digital meters are used to present the actual value of a parameter to an observer. The selection of a suitable display format for a special task depends essentially on whether accurate (digital) or quick (analog) reading is demanded. To combine both properties - accurate and quick reading - within one display, analog and digital elements have to be presented simultaneously in a way, that is most suitable for human perception.

Since this problem can not be solved by theoretical means, several display - formats were compared by a comparative experimental study (see fig. 1). Beside analog (1) and digital (6) scales, some hybrid (analog-digital) formats were taken into consideration. System 4 is a moving scale meter.



analog hybrid digital

fig. 1 : Examined display formats

Experimental procedure

The meters are presented subsequently to the subjects. During this time, the indicated value was changing with constant rate and statistically alternating direction. At the end of a presentation interval an acoustic signal was

3) A mixture of the two systems mentioned before represents a third possibility. A section of the total range ist indicated by an analog scale and a digital display indicates the range of the actual value. The measured variable is shown by the pointer on the scale and by the digital indication. In the following this display is called "hybrid display" (see figure 1, display No. 2-5).

In the present research various display systems had to be compared as to their readability. For that purpose, the rate of change of the displayed value is varied over a large range, in order to obtain quantitative data in the transition range between static and dynamic use.

The reading-error is selected as a measure. The introduction of the pointer-velocity as an independent variable in these experiments leads to the problem of a suitable research-method. Until now only static methods (e.g., by means of the tachistoscope) are known form literature. For this experimental study a new"dynamic procedure" was developed which I will describe later on.

2. Experimental set-up

Figure 1 shows the various displays, which were presented to the subjects. All systems had the same range of 50 000 units. Four hybrid displays (No. 2 through 5) were examined in addition to one analog (No. 1) and one digital display (No.6). The length of the scale was the same for the displays No. 1 through 5. The scales subtended a visual angle of 8°, with the lin-of-sight perpendicular to the display surface. As a scale-form the line-scale was selected and arabic figures were chosen for numbering of the scales and the digital display. The geometric dimensions of these display characteristics correspond to the rules available in the literature.

The displays, which are presented on a CRT, are generated by means of a symbol-generator developed in our institute. The location of individual symbols, for exampel the pointers position on the scale, can be changed by an external analog voltage, and individual symbols, for example the figures of a scale, can be changed by digital information externally supplied (see figure 2).

Figure 2 : Experimental set - up

The screen observed by the subject was installed in a cockpit. The CRT is sloped such that a subject of average size looks vertically upon the projection screen.

3. Experimental procedure

In the following I'll describe the dynamic method, I used in this experiment. At the beginning of a given trial one preselected display is presented on the CRT screen and the subject has to read this display (figure 3). The pointer starts at a statistically determined position of the available range and then moves up or down with a constant velocity according to the chosen rate of change for the displayed value, as you can see here. After a few seconds an accoustic signal is given and the subject has to read the value at that moment. Simultaneously the pointer and other parts of the display, which are important for the reading, are turned off. The subject reports the detected value to the experimenter verbally. The latter writes this reported value into an electronic memory coupled to a digital display, which is situated above the CRT-screen for confirmation by the subject. This "reported-value-display" was switched

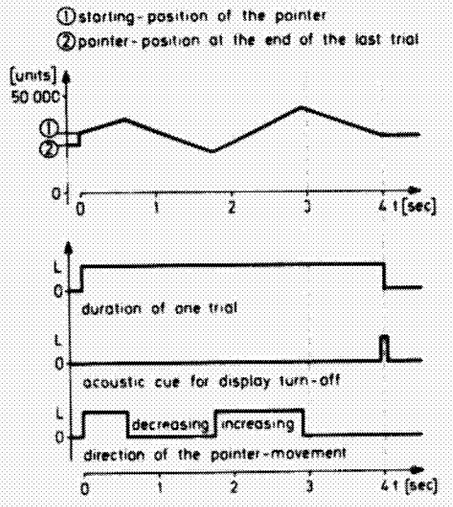


Figure 3 : Experimental procedures diagram

off during the trial run. The duration of one trial was stochastically varied among three fixed-time periods so that the subject could not predict the required moment of reading. The starting-position of the pointer, the rate of change of the displayed value, and the time of presentation are fixed for each trial. The direction in which the pointer moves is controlled by a random-generator. An electronic control prevents the pointer from changing the direction in the last second before the turn off. The rate of change of the displayed value is systematically varied for each trial. The speed values are logarithmically graduated and cover a range of 20 to 5000 units per second for the displays No.1 through 5. The rate of change can also be expressed as a pointer velocity in degrees per second. For a scale viewing angle of 8^{o}, as mentioned before, values between 0.0032 and 40 degrees per second are obtained. In display No. 6 the numbering frequency was varied over a range from 5 to 1000 units per second. On the average the readings were made half at increasing and half at decreasing tendency of the displayed value.

The difference X between the value reported by the subject and the displayed value was chosen as the performance measure and is called the "reading error" :

$$X = V_R - V_D$$

4. Experimental results and discussion

For these experiments a readability index for a display is derived from proportional "correct readings". Contrary to the digital display an accurate reading is hardly possible in analog displays. For that reason a certain range of tolerance needs to be chosen, in my case ± 50 units, and the proportion of answers is determined, for which the reading error X is situated within this limit. This evaluation method proved to be advantageous, especially for the comparison between analog and digital forms of displays and enables a comparison among the distributions of the reading errors X.

Concerning the diagrams, which I'll show in a moment, it should be noted, that the rate of change is always shown in logarithm units, whereas the ordinate, which represents the readability index, shows a linear subdivision.

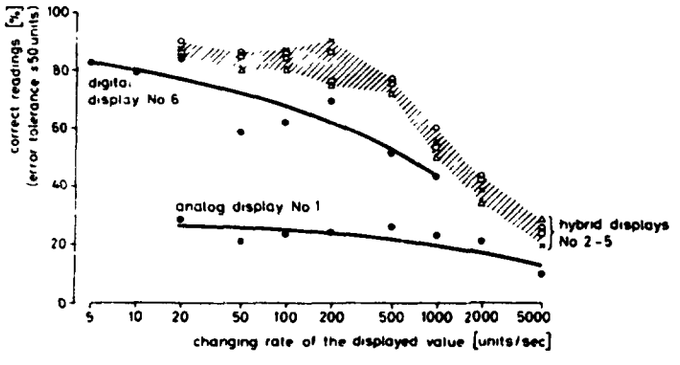


Figure 4 : Correct readings as a function of the changing rate of the displayed value

The results in terms of proportional "correct readings" are shown in figure 4. As you can see, the hybrid displays No.2 through 5 present the best readability, when the answers are interpreted as "correct" with a reading error criterion of maximal ± 50 units. As the hatched surface shows, these displays are approximately equally well read. Comparing the hybrid displays with the digital display performance was about 10 % worse than the hybrid display performance. The pure analog display (No. 1) shows the worst result as could be expected form the scale-resolution used (2 000 units per scale division with a scale spacing of 20 arc-minutes).

The load on the subject, associated with reading the individual display systems, was examined in a second experiment using an additional secondary task (see figure 2). A fixed circle and a cross, which is movable in the image field, are presented toward the right of the displays. The subject must bring the cross back into the circle by means of a control stick, which can be moved in two dimensions during the run of trial. The subject has to try to keep the cross at the null point. At the beginning of each trial the cross is displaced form the null position in the circle with a certain initial acceleration.

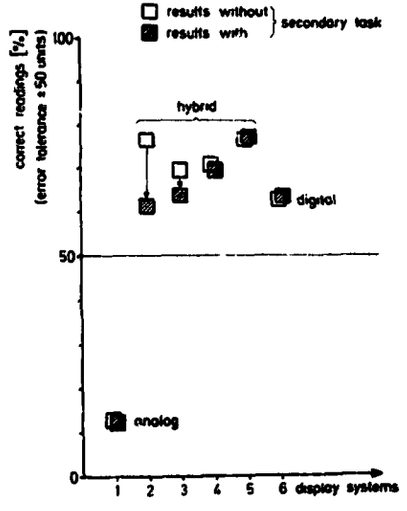


Figure 5 : The influence of the secondary task

In figure 5 the influence of the additional secondary task is shown. The open square represents the mean value of the correct readings for each system corresponding to the experiments without secondary tasks. The corresponding results with the additional secondary task are marked by the shaded squares. For the second experimental run, differences now can be noted in the reading performance of the hybrid displays. Whereas the displays No. 4 and 5 show almost no influence, the number of correct readings for display No.3 is about 5 % lower. Display No. 2 clearly shows that the subjects already were very much stressed with their main task of reading the display so that the number of correct answers became nearly 15 % less when simultaneously executing the secondary task. Altough the digital display No. 6 shows no change compared to the results of the first series, i.e. without secondary task, now it is read better than display No. 2 by about 3 %.

In the figure 6 the mean error of reading $\bar{X}$ for the six displays are represented. About 200 answers were given by the subjects for the analysis of one velocity-step in one display with increasing or decreasing tendency. The mean values $\bar{X}_{IN}$ and $\bar{X}_{DE}$ as well as the variances σ^2_{IN} and σ^2_{DE} were calculated from these data.

In the upper diagram the relationship between $\bar{X}_{IN}$ and changing displayed value rate is shown for the various display systems under the experimental condition of "increasing tendency". The lower diagram shows the simular relationships except for the "decreasing tendency". As the results show, the reading performance depends not only on the display system and on the rate of change of the displayed value, but also clearly on the direction of movement (or tendency).

It is generally true that toolarge a reading is made during an increasing tendency ($\bar{X}_{IN} > 0$), whereas during decreasing tendency the mean error $\bar{X}_{DE}$ is smaller than zero ($\bar{X}_{DE} < 0$). That means : in an increasing tendency the subjects always tend to read higher value - compared to the actual value - and they read a lower value in a decreasing tendency. Furthermore it was found that the absolute mean error $|\bar{X}|$ is somewhat smaller during the decreasing tendency ($|\bar{X}_{DE}| < |\bar{X}_{IN}|$).

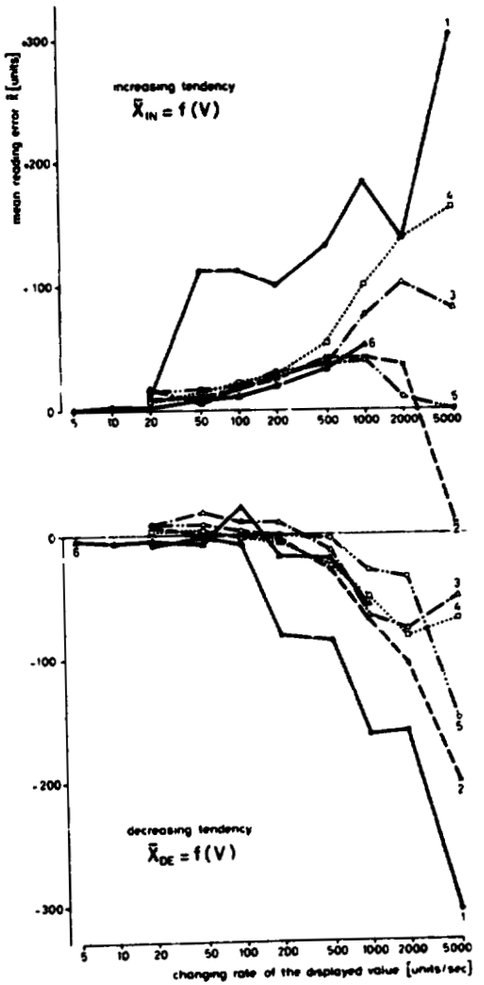


Figure 6 : Mean reading error as a function of the changing rate of the displayed value

The same effect is observed for the corresponding values of the variance. That means : the subjects tend to read more accurately under conditions of decreasing tendency. Regarding the results for display No. 6, the digital display, *it should be noted that - contrary to statements in the literature* - subjects did perceive the change of direction of the displayed value, especially at high rates of change.

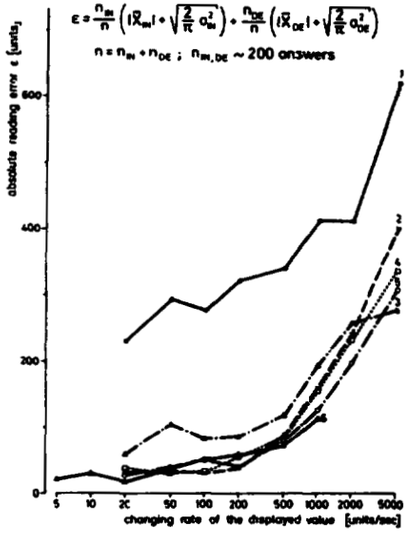


Figure 7 Absolute reading error as a function of the changing rate of the displayed value

A further possibility for defining an index of readability of a display is given by the "absolute reading error". This error was formed from the values mentioned before by the equation in the upper part of the diagram in figure 7.

The significant influence of the velocity is quanlitatively the same for all displays and grows with the increasing values for the rate of change. In the hybrid displays (No. 2 through 5) the corresponding values of the pointer-velocity vary between .08 and 40 degrees per second. Even in the analog display (No. 1) in which the pointer moves with a maximal velocity of .8 degrees per second, a clear influence can be seen. As results from literature have shown this dependence of the reading error on the pointer-velocity cannot be argued for by the "dynamic visual accuity".

5. Conclusion

To recapitulate the results of this investigation I would like to state the following :

the experimental method used has proved to be useful for showing differences in the performance of dynamically reading several display systems.

The results of this research can be summarized under three aspects :

1) The effect of the several displays on the reading performance in terms of correct reading shows, that the hybrid displays are superior to the digital and the analog displays. The analog display shows the smallest number of correct answers, as should be expected by the small scale-resolution. Whereas *in the first experiments without the secondary task nearly the same results* were obtained for the hybrid displays, differences were obtained in the experiments with an additional secondary task.

2) The influence of the tendency of the displayed value shows, that during the increasing tendency a reading error greater than zero is obtained, *during decreasing tendency the error is smaller than zero.*

3) The effect of the changing rate of the displayed value on the reading performance is qualitatively the same for all examined displays.

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