

Optimization of Control Gain by Operator Adjustment

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Abstract

Initially, an optimal gain was established by measuring errors at 5 discrete control gain settings in an experimental set-up consisting of a 2-dimensional, first-order pursuit tracking task performed with an isotonic fingerstick. This optimum gain was also judged least loading by subjects (S's). In addition, no significant experience effect on optimum gain setting was found in the first experiment. During the second experiment, in which control gain was continuously adjustable, high experienced S's tended to reach the previously determined optimum gain quite accurately and quickly. Less experienced S's tended to select a marginally optimum gain either below or above the experimentally determined optimum depending on initial control gain setting, although mean settings of both groups were equal. This quick and simple method is recommended for selecting control gains for different control systems and forcing functions.

Introduction

In complex high performance manual control systems, control can be performed sufficiently well only if the man-machine interfaces are designed with respect to the psychological and physiological characteristics and limitations of the human operator. For optimizing a man-machine system, we have to take into consideration two main aspects:

1. The performance of the entire system with regard to certain performance criteria, and
2. The workload of the human operator.

When an operator is part of a continuous control loop he tends to adapt to the machine system by adjusting his own describing function and gain in order to get the desired output. This adaptability is one of the advantages of the human controller. His adaptability, however, is not infinite. Considering that operator corrective movements and actions are performed by internal human control loop processes, real system optimization can only be attained if system control characteristics are adjusted to be compatible with human control characteristics. In a continuous tracking task e.g. VINCE found out that any adaptation difficulties by the operator lead to higher control frequency in order to keep control error within a certain range through increased operator effort.

In a machine system with a fixed describing function an optimization can most easily be done by adapting system gain to the human operator. With regard to the man-machine interfaces we make a distinction between display gain and control gain. Assuming display gain to be fixed, control gain remains an optimization variable. What are the influences of control gain on a pursuit tracking task?

1. With low control gain settings a wide manipulation range is needed. Large control movements through this wide range result in relatively small changes in the controlled element. Such a control has low sensitivity and high stability. It has the advantage of high accuracy, but the disadvantages of large amplitudes, long adjustment times and high velocities of motion.
2. A high control gain means high sensitivity and low stability so that slight control movements produce a big change of the output signal. Advantages are small manipulation area and slow velocities of motion. A disadvantage is reduced accuracy.

The choice of the right control gain should therefore be some compromise between accuracy and a convenient velocity of motion depending on the specific task or unique requirements on the system.

In earlier experiments where tracking errors were measured with various control gains the curve of tracking errors as a function of control gain was found to be rather u-shaped, with a broad range of minimal errors. Since the operator adapted

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regardless of workload it did not seem to be worthwhile to put much effort into the task of optimizing control gain.

In previous experiments, not reported here, only with the more difficult tasks were gain set optimized. It was necessary to consider both objective performance measurements and subjective ratings in determining optimum control gain settings. The method seemed to be rather complicated. Few proposals for control gain settings can be found in literature ; usually only for zero order systems.

Results of a previous experiment concerned with operator selection of alternate control gains in a step tracking task, indicated that the human operator is capable of selecting from two different control gains so as to improve his performance and reduce his workload. The experiment reported here was conducted to test the capability of the human operator of optimizing his own gain with a continuously adjustable control gain.

The following questions had to be examined :

1. Is there an optimal range of control gain for all S's ?
2. Do control gain optimization results obtained with objective error measurements agree with subjective rating results ?
3. Are the individual optimal gains obtained by repeated adjustments of control gain by the S himself within a narrow range (sharp or broad optimum) ?
4. Is there a relationship between operator experience and his choice of an optimal control gain setting ?

Experimental Set-up

A two-dimensional continuous first-order pursuit tracking system was designed for this experiment (see figure 1).

Gaussian noise was filtered to .3 Hz and used as the forcing function. This was done to avoid the possibility of operators learning and anticipating the forcing function, and perhaps affecting optimum control gain settings. The used frequency is near .5 Hz, which HAMMERTON proposes is the maximum frequency for unpredictable signals that human operators can follow. The resulting high difficulty level should also lead to a narrow range of optimal control gain.

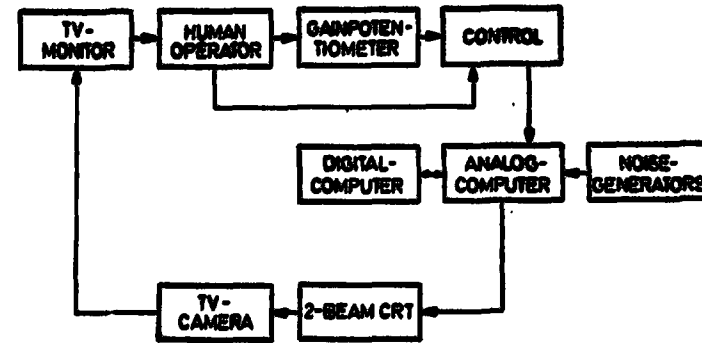


Figure 1 : Flow diagram of the experimental set-up

Target and cursor were displayed on a 24 " tv-monitor. The target was displayed as a small circle, the cursor as a dot. A light centering fingerstick with nearly no friction was used for control. Maximum stick deflection in all directions was 16 °.

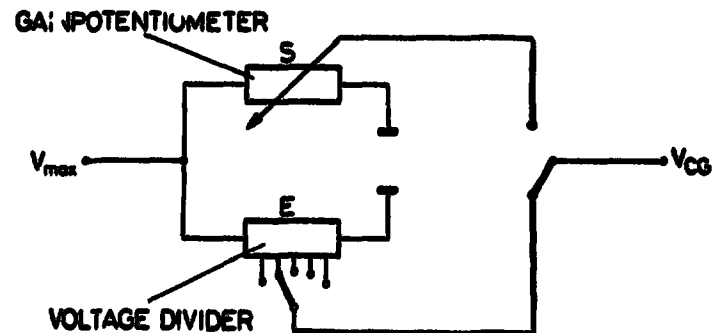


Figure 2 : Circuit for adjustment of control gain

To investigate question 2, listed above, an apparatus (see figure 2) was designed to permit control gain to be set either by the experimenter or by the operator. Settings were first fixed by the experimenter to generate performance curves. In later procedures , a 10-turn potentiometer was used by the operator himself.

Control of the experiments, data collection and processing was done by a hybrid computer.

Experimental Procedure

The experiment was performed with two groups of S's. The first group consisted of 10 low ranking enlisted men from a communications battalion. They had nearly no tracking experience. The second group consisted of 5 engineers with extensive tracking experience. During a training time of 15 minutes, S's became acquainted with their task and practised the self-adjustment of control gain with the potentiometer.

The experiment was divided into two parts :

1. Recordings of performance curves, characterized by RMS-tracking errors and TOT-measurements, were made in 5 trials of 2 1/2 minutes each with different control gain settings in a range of 1 to 10. After each trial, subjective data were collected using rating scales and questionnaires of operator workload and controllability of each setting.
2. During these trials, S's could adjust their control gain to any value they wanted by turning the potentiometer knob. After initial maximum setting by the experimenter, S's were able to select control gain settings during the first 2 1/2 minutes which were adjusted more finely during the next trial. The same experimental sequence was repeated with an initial setting of minimum gain.

Experimental Results

a) Control gain - error characteristics

RMS-Tracking error was used as the performance criteria. In figure 3 control gain-error curves of both groups are shown. Although typical u-shaped curves resulted, a significant minimum error was seen with the unexperienced group.

The rather big standard deviations did not result from different individual optimum gain values as it could be demonstrated with the TUKEY-test of non-additivity. That test showed : There is an optimum range of control gain for all members of this group.

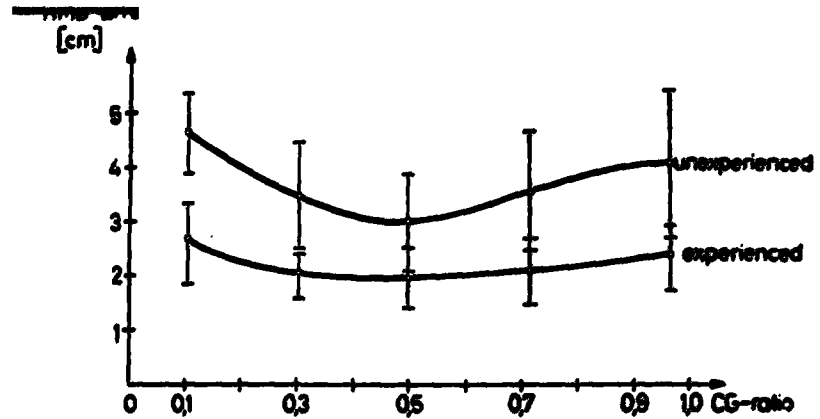


Figure 3 : RMS-error as a function of control gain ratio and tracking experience

The results of the experienced S's were similar. A control gain range of minimum error was demonstrated as well, but there is no significant difference between the 3 middle settings due to the higher degree of experience.

In answer to experimental question 1 these experiments showed that with objective measures there is almost no difference in optimal gain settings between the two groups.

Subjective judgements were obtained from S's after each control gain setting using Cooper rating scales and direct comparison ratings of each setting with preceding ones. The Cooper rating scale, developed for experts, was too finely subdivided for our S's. Therefore all ratings were transformed to rank orders by which the mode of each setting was computed. A comparison of the modes of subjective and objective ranks is shown in figure 4.

CG - setting	Modes of ranks for each CG - setting				
	I	II	III	IV	V
objective error measurement	5	2	1	3	4
subjective rating	5	1	2	3	4

Figure 4 : Modes of ranks for each control gain setting determined by subjective rating and error measurement

Results obtained with direct comparisons with respect to controllability between each setting are similar. The difference between each setting is shown in figure 5.

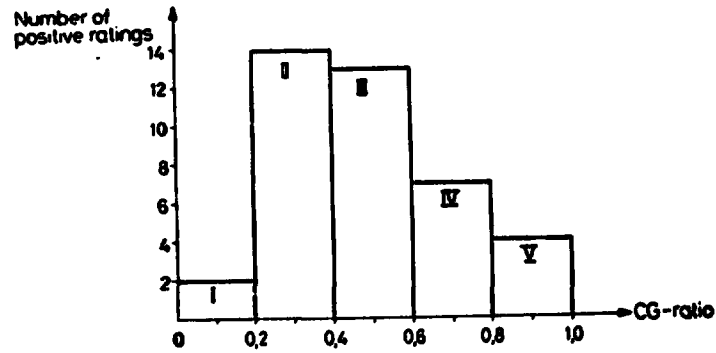


Figure 5 . Comparative controllability ratings of given control gain settings

The preference of S's for control gain settings II and III is pointed out very clearly. Operator's workload ratings show similar results (see figure 6).

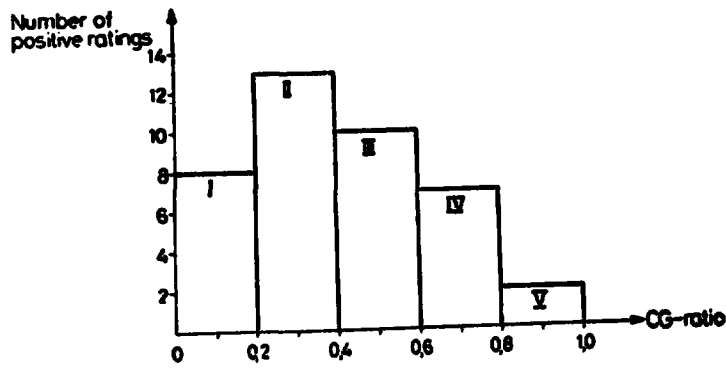


Figure 6 . Comparative workload ratings of given control gain settings

There is a slight but insignificant shifting of the optimum gain to lower control gains with the subjective ratings, but the question about agreement of objective with subjective optimum gain settings can be answered positively.

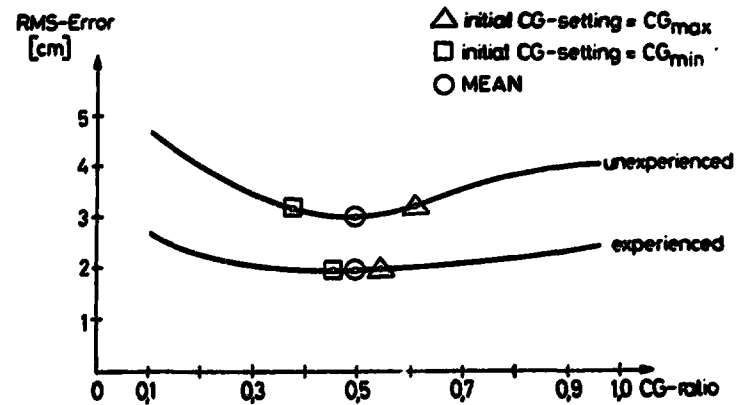
b) Continuous adjustment of control gain by the operator

In figure 7, means and standard deviations of final adjusted control gains are to be seen. These values are given for the different Initial setting conditions and degrees of experience.

Subjects	Initial CG-setting		mean
	CG _{max}	CG _{min}	
experienced	0,53 ± 0,175	0,48 ± 0,125	0,505
unexperienced	0,62 ± 0,254	0,38 ± 0,125	0,500

Figure 7 . Operator adjusted control gain settings as a function of initial control gain settings and experience

Contrary to unexperienced S's there is no significant influence of initial gain setting. Less experienced S's tend to adjust to the margins of the optimal range of the performance-optimized control gain settings determined in the first experiment (see figure 8).



The main result of this experiment is the congruency of the overall means of self-adjusted control gains of both groups with the experimentally determined optimal control gain setting.

The human operator seems to be capable of optimizing the control gain of a man-machine system by means of a simple additional manual device.

The essential advantages of this method are simplification of the measuring system and shortening of experimental time. Only the final value of the gain adjustment needs to be recorded, and it takes only about 1 minute for each adjustment. Subjective questioning may be omitted. The task can be done by experts, and the result will fit all persons.

It should be possible to determine optimal gain settings for various controls, systems and forcing functions by using this method, to help manufacturers design their products and to help operators in performing their tasks.

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