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A PHASE PLANE APPROACH TO STUDY THE ADAPTIVE NATURE OF A HUMAN --ETC(U)
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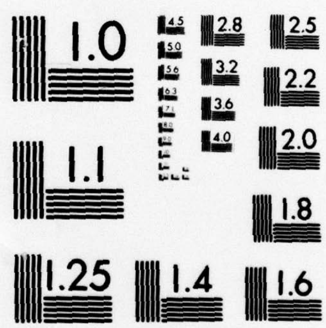
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One of the most complex and adaptive systems to study is a human involved in a closed loop tracking task. It is observed that when the forcing function of the closed loop system has a time varying velocity and acceleration profile, the human will track the input until it exceeds his physical (visual) limitation. When the input is changing too fast for the human to follow, adaptation (or regression) from tracking occurs. If, however, the input is not changing too rapidly, the human will reacquire the target and continue tracking. A study of this type of adaptability is considered here using the phase plane with a statistical analysis performed over a family of four input forcing functions.

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A PHASE PLANE APPROACH TO STUDY THE ADAPTIVE NATURE OF A HUMAN PERFORMING A TRACKING TASK*

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Abstract

One of the most complex and adaptive systems to study is a human involved in a closed loop tracking task. It is observed that when the forcing function of the closed loop system has a time varying velocity and acceleration profile, the human will track the input until it exceeds his physical (visual) limitation. When the input is changing too fast for the human to follow, adaptation (or regression) from tracking occurs. If, however, the input is not changing too rapidly, the human will reacquire the target and continue tracking. A study of this type of adaptability is considered here using the phase plane with a statistical analysis performed over a family of four input forcing functions.

1. Introduction

The study of a human involved in a closed loop tracking situation in which the task is to control the dynamical response of some mechanical device has been a problem of interest for many years. The use of phase plane analysis to study man-machine interaction is not new d has been considered previously, for example by Phatak and Bekey [1] . The approach considered here differs from previous approaches because here the problem centers on the identification of the human limitations and also on the performance index associated with the man-machine interaction. Figure (1) illustrates the typical man in the loop problem considered in this paper for the two operators involved in a two dimensional tracking task. Figure (2) illustrates one of the four input forcing functions in the horizontal and vertical axis for this two dimensional task. Each operator was required to track the forcing function in his axis (azimuth or elevation which correspond to horizontal and vertical, respectively). This type of simulation is typical of AAA (anti-aircraft-artillery) simulations as considered in [2,3] . As a result of this type of forcing function many non-stationary effects will occur in the closed loop interaction between the man and the machine. Figure (3) illustrates the velocity and acceleration profiles of the forcing function in the azimuth axis for the first input considered here. It is observed that large variations of the velocity and acceleration profiles may give rise to adaptive behavior of the man in the loop as he is required to perform this type of tracking task. Figure (4) illustrates a segmentation of the tracking task which has been observed to occur with humans as they are forced to track this type of input. From the time period t_0 to t_1, the velocity and acceleration of the input are sufficiently small in magnitude such that the tracker can maintain the plant's output to follow the input forcing function. From the time period t_1 to t_2, the input is too difficult to follow and the human regresses and no longer attempts to follow the input. During this period the error signal in the closed loop system is dominated by the signal f(t) and the system is essentially open loop. At the time t_2 the velocity and acceleration of the input are reduced in magnitude such that the human can then reacquire the target.

The experimental data used here came from a simulation study of male and female trackers which consisted of 5 teams of 2 trackers each who were trained for 3 weeks prior to the data presented here. The training period consisted of 24 runs a day on 4 different simulated flight trajectories (input forcing functions). The deterministic trajectories were presented to the subjects on a random basis. During the experimental period the subjects tracked 12 runs per day. The four forcing functions used in this study resembled the shape of figure (2) with differences in the shape and magnitudes of the velocity and acceleration profiles. These forcing functions were chosen based on known aircraft maneuvers which were of interest. The plant dynamics which appear in figure (1) can be represented by the following lumped transfer function:

$$H(s) = \left[\frac{s+1}{s}\right]\frac{64}{s^2 + 12.5s + 64} \qquad (1)$$

In order to study these tracking problems with this non-stationary behavior, it is of interest to observe these effects on behavior in the phase plane.

* The research reported in this paper was sponsored by Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright Patterson Air Force Base, Ohio 45433. Further reproduction is authorized to satisfy needs of the U.S. Government.

2. A Phase Plane Analysis of The Tracking Task

Figure (5) illustrates phase plane trajectories of the closed loop error signal during typical segments of tracking (from t_o to t_1), during the regression period (from t_1 to t_2), and during the reacquisition of the target and final tracking period (from t_2 to t_f). During the time period the human is seriously tracking the error signal, the phase plane is elliptical in shape. During the regression and reacquisition period the trajectories spiral out from the origin (and return to the origin) as if the system were first unstable and then stable. Tracking behavior in the final segment is elliptical in shape similar to the behavior in the initial tracking segment. The elliptical shape in the phase plane has a physical interpretation which implies that greater importance is placed on reducing the position value of the error signal with less importance placed on reducing the derivative of the error signal. One may interpret figure (5) in a performance index sense. Consider the following performance index:

$$J = \int_0^T \left[e^2(t)\, R_1 + \dot{e}^2(t)\, R_2\right] dt \qquad (2)$$

with $R_1 > 0$, $R_2 > 0$, and T is the period of time it takes an ellipse to encircle the origin. It is noted that the scalar variables e(t) and $\dot{e}(t)$ are weighted but no penality weighting is assigned to the control vector u(t) generated by the man. The performance index (2) implicitly weights the control vector u(t) due to the closed loop dependence between e(t) and u(t). The elliptical shapes which appear in figure (5) imply that $R_1 > R_2$ or that more penality is associated with minimizing the position state of the error signal and less penality is associated with minimizing the rate of the error signal. An approach will now be introduced to investigate the weightings R_1 and R_2 in equation (2) and to test statistical hypothesis concerning them.

3. An Approach To Identify The Performance Index

In order to identify a performance index of the form (2), consider the equations of an ellipse with respect to the variables e(t) and $\dot{e}(t)$:

$$\frac{e^2(t)}{R_2} + \frac{\dot{e}^2(t)}{R_1} = 1 \qquad (3)$$

or

$$e^2(t)\, R_1 + \dot{e}^2(t)\, R_2 = R_1 R_2 \qquad (4)$$

But:

$$\text{Constant} = \int_0^T R_1 R_2\, dt \qquad (5)$$

$$= \int_0^T \left[e^2(t)\, R_1 + \dot{e}^2(t)\, R_2\right] dt = J \qquad (6)$$

Therefore J can be determined knowing only R_1, R_2, and T. Since J is explicitly expressed by equation (6) over the time period [0,T], then it is required to identify T as the time necessary for the ellipse to encircle the origin. Therefore it is only necessary to identify the variables R_1, R_2, and T during the various stages of tracking and also to study how these variables change as a function of the velocity and acceleration characteristics of the input forcing functions. The consistency (measured by means and variances) of the performance index parameters R_1, R_2, and T can be investigated as a function of different velocities and accelerations of the 4 different input forcing functions. From equation (3), R_1 and R_2 become the axis of the ellipse and the time period T can be read off parametrically in the phase plane. Regression was defined as a trajectory whose distance from the origin is in excess of twice the largest axis of ellipse.

It is interesting to investigate if the regression from tracking is due to the velocity or acceleration of the input or possibly to both effects taken together. The following statistical section will describe the manner in which these type of hypothesis can be investigated.

4. A Statistical Analysis of The Adaptation Effects

In an effort to identify the performance index of the form (2) from the data, it is necessary from equation (4) to identify R_1, R_2, and T from the elliptical phase plane plots. The variables R_1, R_2, and T will vary over the initial and final stages of tracking and also over all four forcing functions. The following table is constructed based on data from as many as 18 replications of the four forcing functions for the best team in this study. The criteria for the selection of the best team from the five possible candidate teams was based on the maximum time during the 45 second run that the error signal was within a specified error window size. Table (1) illustrates the results obtained for this experiment during the time period $[t_o, t_1]$.

Table (1)-Performance Index Coefficients $[t_o, t_1]$

	FF#1		FF#2		FF#3		FF#4	
	Az	El	Az	El	Az	El	Az	El
R_1(mean)	.25	.09	.38	.11	.23	.13	.29	.11
R_1(s.d.)	.02	.01	.07	.02	.04	.03	.04	.02
R_2(mean)	.06	.03	.12	.04	.06	.03	.07	.03
R_2(s.d.)	.01	.01	.03	.01	.03	.01	.02	.01
T(mean)	2.7	2.5	3.3	2.8	3.2	2.9	3.2	2.8
T(s.d.)	.93	.48	.88	.50	.59	.70	.80	.75

where Az and El stand for Azimuth and Elevation axis, respectively.The same results are determined for the time period $[t_2, t_f]$:

Table (2)-Performance Index Coefficients $[t_2 , t_f]$

	FF#1		FF#2		FF#3		FF#4	
	Az	El	Az	El	Az	El	Az	El
R_1(mean)	.29	.11	.29	.10	.23	.14	.30	.11
R_1(s.d.)	.03	.03	.11	.02	.04	.03	.04	.02
R_2(mean)	.07	.03	.10	.03	.07	.03	.07	.03
R_2(s.d.)	.02	.01	.04	.01	.04	.01	.02	.01
T(mean)	2.4	2.7	3.2	2.6	3.3	2.8	3.2	3.1
T(s.d.)	.64	.68	.96	.50	1.1	.57	.69	.72

It is necessary to now test whether the tracking performance index that was used in the closed loop system changed significantly from the time period $[t_0 , t_1]$ to $[t_2 , t_f]$. Table (3) represents this aspect of changes in tracking strategy of the human:

Table (3) - An Investigation of Changes in The Performance Index prior to and after Regression: (Fly-By # 3)

		Mean Prior to t_1	S. D. Prior to t_1	Mean After t_2	S. D. After t_2	N	t stat.	α level
R_1	Az	.2264	.0427	.2346	.0378	13	-.519	.609
	El	.1318	.0275	.1355	.0266	14	-.357	.724
R_2	Az	.06	.033	.0659	.0356	13	-.439	.665
	El	.0277	.0085	.0309	.0089	14	-.966	.343
T	Az	3.19	.59	3.33	1.16	13	-.3879	.702
	El	2.88	.70	2.78	0.57	14	0.4145	.682

In order to determine the source of regression (velocity and/or acceleration), table (4) was computed from the data to study this effect:

Table (4)- An Investigation of Regression Characteristics Over The 4 Inputs:

	FF#1		FF#2		FF#3		FF#4	
	Az	El	Az	El	Az	El	Az	El
t_1(mean)	None	17.5	11.8	14.1	14.5	12.5	14.0	20.2
t_1(s.d.)	None	0.5	2.47	1.1	2.40	1.47	1.2	2.54
vel. at t_1(mean)	-	.68	.40	.50	-1.3	.25	-3.1	2.75
acc. at t_1(mean)	-	-.23	-.70	-.10	-.90	-.60	-.60	-0.8

Table (5) was computed from the data in order to study velocity and acceleration effects in the reacquisition of the target:

Table (5) - An Investigation of Reacquisition Characteristics Over The 4 Inputs:

	FF#1		FF#2		FF#3		FF#4	
	Az	El	Az	El	Az	El	Az	El
t_2(mean)	None	22.0	30.1	28.1	33.2	30.0	30.0	27.5
t_2(s.d.)	None	1.5	2.2	1.1	1.5	0.5	1.5	0.8
vel. at t_2(mean)	-	-.60	-3.1	-.1	-.3	-1.3	-3.0	-3.5
acc. at t_2(mean)	-	-.23	1.16	-.13	.2	-.20	0.7	.18

Finally to study the variability of velocity and/or acceleration as the primary factor in causing regression, t-tests were made against zero for the mean (over all four forcing functions) of the velocities versus zero and the accelerations versus zero. These t-tests were also conducted for the reacquisition task and the results are displayed in table (6). A higher α level indicates that this variable has greater variance if the human is using this variable in his decision making process. In other words, if the human is a minimum variance estimator, he will use the variable which gives rise to the smallest α level.

Table (6) - An Investigation of Velocity and Acceleration Effects At Regression and Reacquisition:

		Mean	S.D.	N	Mean	S.D.	N	t stat.	α level
Regression Velocity	Az	1.6	1.37	3	0	0	3	2.02	.114
	EL	1.05	1.15	4	0	0	4	1.82	.119
Regression Acceleration	Az	.733	.153	3	0	0	3	8.31	.001
	El	.433	.324	4	0	0	4	2.67	.037
Reacqusition Velocity	Az	2.13	1.59	3	0	0	3	2.33	.081
	El	1.38	1.49	4	0	0	4	1.83	.116
Regression Acceleration	Az	.687	.480	3	0	0	3	2.48	.068
	El	.185	.042	4	0	0	4	8.80	.0001

5. Summary and Conclusions:

The results of tables (3), (5), and (6) indicate the following (based on the α levels and the data base used here):

(1) The performance index which describes tracking prior to and after regression does not change statistically in its weighting coefficients or the time necessary for the ellipse to encircle the origin. In other words, the tracking prior to regression and after reacquisition remains the same in a statistical sense.

(2) There is a significant less variability if the human were to use acceleration of the target as his decision mechanism in the regression from the task and reacquisition of the task as compared to the velocity of the target. In other words, the factors which determine regression and reacquisition seem to be more closely tied to acceleration (with less variance) as compared to the velocity of the target.

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2. Kleinman, D.L., and Perkins, T.R., "Modeling Human Performance in a Time Varying Antiaircraft Tracking Loop", IEEE Transactions on Automatic Control, Vol. AC-19, No. 4, August, 1974.

3. Hartzell, E.J., "Eye Movements During A Compensatory Tracking Task", Preprints, Aerospace Medical Association Meeting, May, 1976.

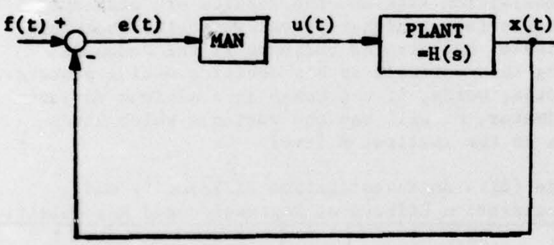

Figure (1) - One Operator

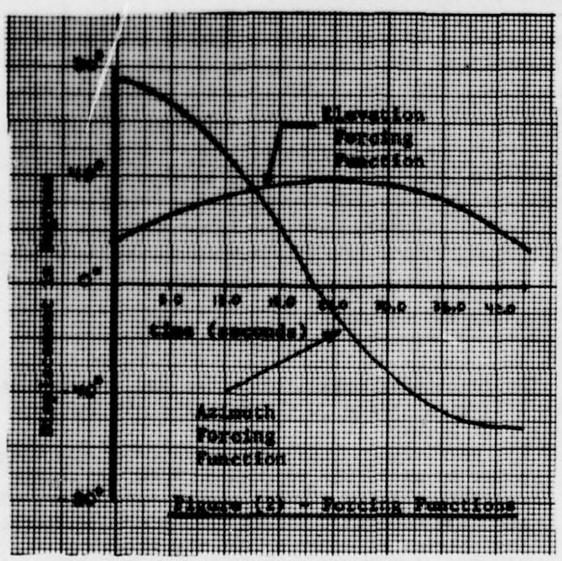

Figure (2) - Forcing Functions

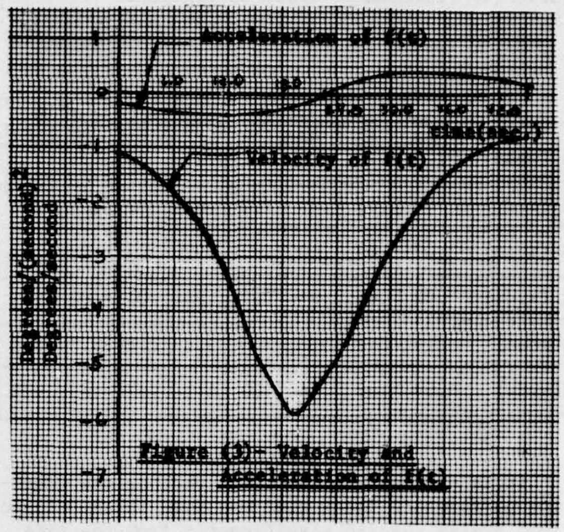

Figure (3)- Velocity and Acceleration of F(t)

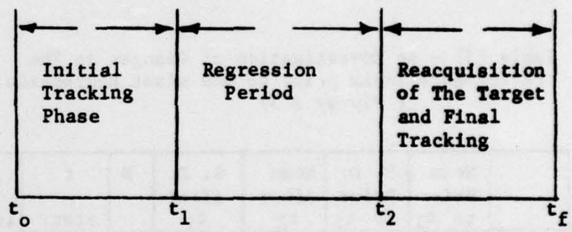

Figure (4)- Segmentation of The Tracking Task

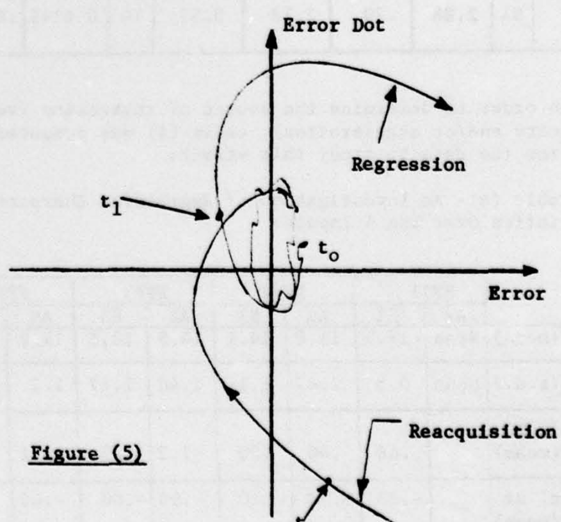

Figure (5)