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BIOTECHNOLOGY LABORATORY

PROGRESS REPORT

September 15, 1962

UPPER EXTREMITY PROSTHETICS RESEARCH

(Contract V1005M-2075 with U. S. Veterans Administration)

HUMAN TRACKING

(Contract N123(60530)2355.A with U. S. Naval Ordnance)

CONTROL LOGIC FOR A MYOELECTRIC SERVO-BOOST SYSTEM

(Purchase Order No. 2227 with Spacelabs Inc., Van Nuys, California)

HUMAN THERMAL STUDIES

(Contract AF 33(616)-6763 with U. S. Air Force)

Project Leader: John Lyman
Associate Professor of
Engineering and Psychology
Head, Biotechnology Laboratory

Engineering Dept. Report No. 62-57

20061018027

DEPARTMENT OF ENGINEERING
University of California
Los Angeles

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Best Available Copy

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FOREWORD

The research described in this report, Biotechnology Laboratory Report, by the Laboratory Staff, was carried out under the technical direction of John Lyman and is part of the continuing program in Upper Extremity Prosthetics Research, Human Tracking, Human Thermal Studies, and Control Logic For A Myoelectric Servo-Boost System.

The Biotechnology Laboratory is part of the Department of Engineering of the University of California, Los Angeles. L. M. K. Boelter is Dean of the College of Engineering and Philip F. O'Brien acts as his representative for research activities.

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UPPER EXTREMITY PROSTHETICS RESEARCH

Sponsor: U. S. Veterans Administration

PREFACE

Because of a drastic reduction of funds for the 1962-1963 fiscal year, it has been necessary to discontinue work on many of the subprojects of the UCLA fundamental studies program. New funding for reactivation of some of the more important discontinued research is being sought from other sources.

I. FUNDAMENTAL STUDIES TO ESTABLISH BODY CONTROL SITES FOR APPLICATION TO EXTERNALLY-POWERED PROSTHESES

A. Objective

To conduct studies which will permit an evaluation of the practical feasibility of surgical and non-surgical methods for providing severely handicapped amputees with satisfactory body control sites. Such control sites must be capable of permitting coordinated and proportional control of multiple prostheses functions.

B. Current status of studies leading to an evaluation of the feasibility of proportional prosthesis control by EMG signals.

Continuation of data analysis and preparation of an integrative technical report during the current fiscal year.

Comments: A reduction in the budget for the 1962-1963 fiscal year necessitated discontinuation of further research activity on this topic.

C. Current status of evaluation of surgical methods to establish new body control sites.

Phase 1: Completion of this phase is dependent upon histological examinations of the excised muscles of the experimental animals.

Dr. Bechtol has assumed responsibility for these analyses. No report has been received to date.

Phase 2: No further plans for experimental surgery to provide isolated "control bulges" have been made due to lack of funds.

D. Current status of experimental investigations assessing the various non-surgical methods to create proportional coordinated body control:
Development of suitable electro-mechanical transducers for coordinated prosthesis control.

This phase has been discontinued. The experimental data collected to date will be integrated into a technical report during the current fiscal year. No transducer development will be undertaken.

II. COMPONENT DEVELOPMENT STUDIES

A. Objective

To evaluate exist~~ing~~ing prosthetic components and derive design criteria for further development or modifications.

B. Current status

The following studies, initiated prior to July 1, 1962, have been discontinued:

1. Investigation of variable ratio coupling of muscles and loads to delineate design specifications for a general method of obtaining maximum energy transfer between natural or artificial muscles and their load.
2. An analysis of bellows for prosthetic elbow flexion.
3. Evaluation of the braided pneumatic actuator for prosthetic elbow flexion.

Comments: Available experimental data will be analyzed and integrated into a technical report during the fiscal year.

III. CONTROL ENGINEERING SURVEY

A. Objective

Continuing compilation of systems and components and evaluation of their feasibility for use in externally-powered prostheses.

Comments: The study has been resumed and is designed to result in a technical report covering the following:

1. State of the art of components and systems currently used in externally-powered prostheses with special emphasis on their technical inadequacies.
2. Description and evaluation of currently available components and systems better meeting the technical needs of externally-powered prostheses. The evaluation will cover specifications, availability, costs and maintainability.

IV. ANALYSIS OF EXISTING EXTERNALLY-POWERED PROSTHESES AND DEVELOPMENT OF ADVANCED DESIGN SPECIFICATIONS

A. Objective

To make an engineering and performance evaluation of existing devices to assess their capabilities and limitations and derive specifications for further development.

B. Current status of experimental investigations

1. Engineering analysis of the French electric hand:

Modifications and exploratory engineering investigations had changed the characteristics of the hand to such an extent as to make further functional testing meaningless.

Dr. Brooks from the Child Amputee Project kindly loaned us a model of the hand that is identical to ours, except for containing improved spring leaves and a later model motor.

The following engineering tests have been completed:

a. Force on bellows transducer vs prehension force:

- 1) for varying volumes of air in transducer
- 2) for varying prehension spans
- 3) for varying velocities of force applied to the transducer.

b. Bellows displacement vs prehension span at varying
m volumes of air in the transducer.

2. Engineering analysis of the Heidelberg pneumatic arm:

Data have been collected to ascertain maximum velocity of
elbow flexion through various degrees of movement.

3. Engineering evaluation of the Northwestern University
attitude-controlled electric elbow

The following information was obtained:

- a. circuit diagram
- b. ranges of motion
- c. maximum velocities through specific degrees
of flexion

Two changes had to be made to render the arm operational:

a. After breaking two limit switches, the position of
the extension limit switch was modified so that on full
extension the activating cam would not crush the switch.

Reliability of limiting remained unimpaired.

b. Installation of a tension spring.

Full extension of the arm would righten the turn
screw to such an extent that during flexion an extra
load was placed on the motor and excess current drawn

through the mercury switches to overcome the friction.

This problem was eliminated by the tension spring.

4. Performance analysis of the French electric hand.

Continuation of experimental testing with amputee subjects.

5. Performance analysis of externally-powered elbow lift-and-lock systems.

Amputee testing is in progress for the Northwestern University and Heidelberg prostheses.

A considerable amount of time is necessary for fitting and training, making data collection relatively slow.

V. DEVELOPMENT OF ELECTRO-PNEUMATIC LOCK-AND-LIFT SYSTEM

A. Objective

Development of an externally-powered "meet-the-load" electro-pneumatic elbow flexion unit.

B. Current status:

This project was interrupted from July 1 until September 15, 1962.

Comments: Employment of an electromechanical engineer in mid-September will enable a critical evaluation of the development of this system to date and recommendations as to the direction of further work.

This project will be concluded during the current fiscal year.

VI. SELECTED APPLICATION STUDIES

A. Objective

Evaluation of control problems in available special amputee cases.

B. Current status:

Mr. G. Gwynne has promised to make some arrangement to complete the report on work accomplished even though his employment has changed.

Comments: No material has been received to date.

RESEARCH ON THE PERFORMANCE OF
HUMAN OPERATORS OF TRACKING SYSTEMS

Sponsor: U.S. Naval Ordnance

I. PERFORMANCE EVALUATION OF VARIABLES OF THE OPTICAL SYSTEM ON THE
NOTS TRACKING SIMULATOR

A. Objective

Systematic evaluation of variables of the optical system on target acquisition and tracking accuracy. Design specifications for optimum performance shall be derived. Handbooks or tables will be ultimately developed to aid tracking system designers.

B. Current status of experimental investigations

Phase 1:

A pilot study using three subjects has been completed. This study was undertaken to evaluate the importance of TV vs monocular viewing displays and on-mount vs off-mount proprioceptive cues for tracking performance.

The data collected with the Integrated Error Scoring System have been analyzed and the following preliminary results can be reported:

1. The monocular viewing mode seems significantly superior to both the on-mount and the off-mount viewing modes. The on-mount is superior to the off-mount viewing mode. We tentatively conclude that the monocular viewing display is superior to a TV display and that proprioceptive cues are important to tracking performance. These results, however, are not consistent for all subjects and conditions, indicating

that interactions may be present.

2. As would be expected, tracking done on the smooth, low-velocity trajectory is superior to that with the rapidly changing, fast trajectory for each of the conditions.

3. After a very short initial learning period the five degree, 5 X field of view is superior to the 13 degree, 1 X field of view for each of the conditions.

4. The rate plus displacement dynamics give smaller errors than the rate dynamics when averaged over all the conditions. There is, however, considerable interaction, and it is actually a hindrance on the easiest condition-5 degree field of view on the smooth, low-velocity trajectory.

5. Two other important effects were observed during the pilot study. Tracking in the azimuth direction is markedly superior to tracking in the elevation direction, and tracking performance is better when the target moves from left to right than when it moves from right to left.

Comment: The results of the pilot study seem promising and work (described in Phase 3) is being carried out to extend the experiment and more fully control variables not isolated in the experiment.

Phase 2:

Certain equipment and methodological malfunctions occurred during the course of the pilot study, resulting in degradation or loss of data. The following modifications will be completed by the end of September.

1. At present there is considerable lack of reliability in the visual display portion of the Integrated Error Scoring System. This condition is primarily caused by interaction between the supposedly independent azimuth and elevation axes. This unit is in the process of being rebuilt.
2. The off-mount TV viewing station proved unsatisfactory. An isolation booth has been built where such factors as chair height, parallax due to differences in head position, and subject's comfort can be more readily controlled.
3. Problems have been encountered in tape recording the runs, as several distinct actions must be made by the experimenter at specific times for each run. In an experimental situation with very little light this is quite often hard to do. The problem has been solved by the development of a master timing-switching mechanism. This will also allow greater time uniformity throughout the experiment.
4. The data from the taped Sampled Error Scoring System have not been reduced as yet. The data are handled by an analog to digital conversion system at NOTS, China Lake, California. Several problems have been encountered by the personnel there, including the problems of noise and ghost or echo images. These are currently being remedied and the data of the pilot study will be compared with those taken with the Integrated Error Scoring System. Both error scoring systems will be used in the expanded experiment described in Phase 3.

Comment: These improvements and changes should be finished in time to start Phase 3 during the fall semester.

Phase 3:

Six subjects, including two of the three used in the pilot study, are currently being extensively trained under each of the experimental conditions. Training will continue until learning has reached a plateau. This will mean a minimum of thirty hours training per subject. At that time data will be taken for the experiment.

Comment: Complete analysis of the experimntn will be done and the results will be published in a technical report.

II. MULTIMAN TRACKING STUDIES

A. Objective

Investigation of the operating chracteristics of tracking teams are expected to be developed.

B. Current status of experimental investigations

Phase 1:

The first phase of the multiman teaching studies has been completed. A written report of the experimental work has been prepared and submitted as a Ph.D. dissertation: "System Variables affecting Team Performance in a Visual Tracking Task" by G. Weltman. Preparations are presently under way to bring this manuscript out as a technical report. An abstract of the dissertation is included in the section on Academic and Student Activities.

Phase 2:

Continuation of investigations of team tracking.

The present study involves a tracking task performed by two subjects in a serial configuration. The object of the study is to try to improve serial tracking performance by eliminating high frequency noise which is injected into the system by the lead tracker. Two methods of accomplishing this are now under consideration

1. giving the lead tracker a rate control as suggested by Zierler¹ and
2. filtering the lead tracker's response to eliminate his high frequency output.

Comment: Experimental design, equipment design and construction are in progress.

III. LITERATURE REVIEW: AN INTEGRATION OF VARIOUS AREAS OF VISUAL PERCEPTION APPLICABLE TO TARGET ACQUISITION AND TRACKING PROBLEMS

A. Objective

To formulate testable hypotheses for investigations of the effects of the total field of view and frames of reference on target acquisition and following.

B. Current status of review

The survey has been completed and a manuscript for a technical report has been submitted to the project leader. A review of the manuscript indicated that an extensive revision of the material will be necessary before publication.

Comment: This work will be reactivated during the fall semester.

¹ Zierler, Neal. A Preliminary Report on the Theory of Tandem Tracking, OMB Report No. 10, 1948.

CONTROL LOGIC FOR A

MYOELECTRIC SERVO-BOOST SYSTEM

Sponsor: Spacelabs, Incorporated

Van Nuys, California

A. Objective:

To assist in the development of a myoelectric servo-boost system for application as a control mechanism in aerospace vehicles under accelerative flight patterns.

B. Current status of experimental investigations

The data obtained from the experimental investigation of myoelectric activity patterns observed during six arm maneuvers, at six arm positions, during three simulated 'G conditions, and for five male subjects, have been analysed. A report describing the experimental procedures and conclusions has been written and submitted to Spacelabs.

Myoelectric control of a limited set of servoed arm-brace movements appears feasible on the basis of the experimental data. The subject group demonstrated myoelectric signals of acceptable strength under the simulated high-G conditions. Furthermore, it was possible to formulate control logic tables from the recorded myoelectric data which unambiguously identified four arm movements by means of "on-off" activity detection at three or four muscle sites, and which were not in conflict with observations made on individual members of the subject group. The limitations of the present study are outlined in the report. Several suggestions are made for continued investi-

gation, the two most important being the construction of a static, four-movement task simulator and visual-feedback training device, and the simultaneous construction and evaluation of a one-dimensional, up-down, dynamic task simulation.

Comment: Planning for future phases of work will be initiated with remaining funds in the contract.

HUMAN THERMAL STUDIES

Sponsor: U. S. Air Force

I. Physiological measurements of human thermal tolerance

Comments: The final draft of a technical report, "Arm Water Losses Under Disparate Arm and Body Thermal Conditions," has been submitted to the contracting agency for publication.

The report concludes the research obligations for this phase.

II. Development of a rationale for psychomotor tests measuring performance decrements in extreme heat environments

Comments: A manuscript of a technical report, "Measuring Performance Changes in Highly Transient Extreme Heat Stress: Rationale, Problems and Experimental Procedures," has been submitted to the contracting agency for review.

III. Construction of a high transient rate environmental chamber

Comments: To complete the report it has been necessary to develop solutions for the heat transfer equation on an iterative basis. The equations have been prepared for programming on a Bendix G-15 computer to accomplish this.

ACADEMIC AND STUDENT ACTIVITIES

Dissertation

Weltman, Gershon: "System Variables Affecting Team performance in a Visual Tracking Task"

In partial fulfillment of the requirements for the Ph.D. degree in Engineering, June 1962. Committee: John Lyman, Chairman; T. W. Brown, T. A. Rogers, I. Maltzman, and T. H. Bullock.

Abstract:

Team tracking is of interest both as a mean of reducing system error below that produced by the individual operator, and as a means of examining team behavior in a situation incorporating both strong intra-group interactions and a high degree of response specificity. This report describes an experimental investigation in which two-man teams, arranged in various configurations, operated on random-appearing uni-dimensional and bi-dimensional inputs in a visual compensatory tracking task. The objective of the experiment was to examine the relation of tracking system parameters, training, team makeup, and team operating modes to team performance.

The investigation was organized into two studies. In the first, thirty-six subjects forming eighteen teams tracked a uni-dimensional input problem. The teams operated as individuals as well as in serial and parallel configurations. Knowledge of team situation, configuration, controller gain, and input frequency spectrum were treated as experimental variables. The second study utilized four subjects forming six

teams, incorporated a bi-dimensional input problem, and focused on learning effects within the parallel situation and its derivatives. A log mean squared error measure served as performance criterion for both studies. Analog and digital techniques were used to obtain, reduce, and statistically analyze the error data. A subsidiary analysis, utilizing digitized analog records, applied cross-correlation techniques to estimate the relative dynamic reaction times of team members, and provided estimates of the error function spectral densities characteristic of independent and parallel tracking.

The results indicated that with a proper choice of system parameters it was possible for the serial and parallel team to improve error performance not only over the average, but also over the better team member. Team superiority was seen for bi-dimensional as well as uni-dimensional inputs, and was accentuated with training for the parallel, bi-dimensional situation. Two methods of X-Y response allocation proved inferior to completely parallel operation with the bi-dimensional input. Knowledge of team situation appeared to be a prerequisite of purposeful team action. Both serial and parallel teams reacted adversely to the introduction into the tracking loop of high-frequency components caused by the high-gain controller conditions. Spectral analysis of individual error functions provided verification for a sampled-data model of tracker performance.

A characteristic team behavior, termed response dominance, emerged in the parallel situation. This phenomenon, involving

a greatly diminished response by one team member, was demonstrated in both studies. Its severity decreased with training in the bi-dimensional case, where, for the well-trained team, response sharing rather than response dominance was associated with successful parallel tracking. Response dominance appeared closely related to differences in team member in-loop reaction time, but was not completely explainable on this basis. It was felt that the phenomenon was of general importance to systems involving shared tasks.

The implications of these results are discussed in the report, and suggestions made for subsequent investigations.

Thesis

Boni, Giovanni: "Feasibility Study of Some Radical Approaches to the Design of an Artificial Hand."

In partial satisfaction of the requirements for the degree Master of Science in Engineering, May 1962. Committee: John Lyman, Chairman; Charles Bechtol, and Walter Karplus.

Abstract:

Following an historical synthesis of the development of artificial hands from 1500 till the present time, pointing to the fundamental ideas so far applied in this specialized field of prosthetics, a new approach first proposed by Dr. R. Tomovic of Belgrade (Yugoslavia), is introduced and examined.

Up to now the hand prostheses were characterized by the necessity for deriving signals used to control their movement from the amputee's body. This was also true when an external source of power was employed to substitute for the muscular one.

According to the new approach presented, the artificial hand is considered as a self-adaptive mechanism which can react automatically to certain external stimuli. In this way the amputee's task is simplified and he can better utilize the limited communication links between his nervous system and the prosthesis.

According to this principle a model of a hand was built in order to investigate the feasibility of the project. Signals derived from special pressure-sensitive pads fixed to the fingers and the hand body were fed to a servomotor mechanically connected to the fingers, so that a pressure applied to the pads produced through a positive feedback loop, the movement of the fingers. From this initial setup a new concept was developed of dividing the hand into sensitive zones with a one-to-one correspondence to each of several hand functions, such as grasping prehension or tip prehension.

Means for overriding the reflex arc and therefore voluntarily inhibiting the hand function were provided. Possible developments and the application of these principles to other fields were considered.

PROFESSIONAL ACTIVITIES OF STAFF MEMBERS

Dr. John Lyman has been appointed a member of the Education and Training Committee of the Aerospace Medical Association and a member of the NAS-NRC Advisory Committee to the U.S. Army Research Office, Durham. Both appointments are for the years 1962-1964.

July 9-20:

Dr. Lyman was in charge of a special two-week summer course entitled "Human Factors in the Design of Tasks and Environments."

July 16-17:

Dr. Gershon Weltman was a guest lecturer at a special course on "Human Factors in the Design of Tasks and Environments" given at UCLA. His two-day presentation covered the topics of human structure-function and mechanical force fields.

July 24:

Dr. Lyman gave a lecture entitled "Psychological Interfaces --Industrial and Otherwise," at San Diego State College, San Diego, Calif., as part of the lecture series on Contemporary Problems in Psychology.

August 25:

Mr. Peter Kaiser visited Dr. Eugene Murphy and members of the staff at the Veterans Administration Prosthetic Center in New York City. He also talked to Dr. S. Weis and Mr. N. Kay at the New York University Prosthetic Research Center.

August 27 - September 1:

Dr. Hilde Groth received a grant from the U.S. Department of State to attend the International Symposium on Application of Automatic Control in Prosthetics Design, Opatija, Yugoslavia,

as an American specialist. Dr. Groth presented two papers entitled "Practical Transducer Problems in Electro-mechanical Control" (J. Lyman and G. Weltman, co-authors) and "Electrical and Mechanical Properties of New Body Control Sites for Externally-powered Arm Prostheses" (J. Lyman and G. Weltman, co-authors).

Abstract

Practical transducer problems

Limitations of transducers used in currently available externally-powered prostheses are discussed.

Utilization of electromyographic signals as control inputs was investigated and data were presented which were obtained from exploratory studies of basic properties of complex bioelectric signals generated during muscle contractions. Effects of several electronically implemented transformations of the basic EMG signal were demonstrated. These changed the raw signal characteristics in such ways as to provide a more suitable control input.

Recorded patterns of myoelectric activity from six selected arm movements seemed to imply that isomorphic EMG control would not be feasible because of extensive overlap. A potentially more useful technique would utilize a pre-programmed control logic to interpret and integrate site signals.

Achievement of proportional EMG control appeared to be impossible since only a binary criterion of discrimination yielded unequivocal and reliable control signals.



Utilization of mechanical muscle output parameters, primarily change of forces and distances between specified points, presented the following technological problems for transducer development:

1. Inadequate means of stabilizing the transducer relative to the control muscle.
2. Lack of a sufficient number of independent body control sites to avoid cross coupling when attempting to achieve multiple coordinated functions.
3. Discriminative power of the transducer to distinguish between involuntary contractions (e.g. shivering) and intended control actions.
4. Miscellaneous problems of bulk, externally induced mechanical forces, etc.

Possibilities of surgical methods are discussed which could isolate small parts of a muscle and create localized well defined contractile bulges.

Abstract

Electrical and mechanical properties

An experimental investigation was conducted in order to obtain a preliminary indication of the mechanical and electrical outputs to be expected from functionally isolated muscles. As one approach photographic methods were explored as to their suitability for quantitative assessment of muscle bulge changes during contraction. Utility and limitations of the methods are discussed.

Another approach was an attempt to employ ultra-sonic echo measurements as a technique for assessing changes in

distance between the bone and the overlying muscle mass during contraction. The results showed promise that with refinement of the technique reliable measurements might be produced.

Extensive studies were undertaken for establishing probabilities of successful isolated muscle contractions in terms of EMG criteria. In general, for a "success-failure" criterion of the transformed electrical signal, the deltoid, the latissimus dorsi and the pectoralis muscles could be successfully isolated. The results are discussed with respect to their practical utility for developing functionally independent body sites which may permit multi-function coordinated prosthesis control.

September 3-17:

While in Europe, Dr. Groth visited the Federal Rehabilitation Institute in Belgrade, Yugoslavia and the Orthopedic Clinic of the University of Heidelberg, Germany.

September 3-5:

Mr. Kaiser attended the American Psychological Association convention in St. Louis, Missouri.

September 5-7:

Dr. Lyman participated in the Second Conference on Engineering Design Education, held at UCLA. He presented a paper entitled "The Role of Life Sciences in Design Education" and was chairman of the Thursday afternoon session on Graduate Research Programs.

PUBLICATIONS

R. Tomović and G. Boni

"An Adaptive Artificial Hand," IRE Transactions on Automatic Control, April 1962, Vol. AC-7, No. 3, pp. 3-10.

Hilde Groth, John Lyman, and Peter Kaiser

"A Synopsis of the UCLA Biotechnology Laboratory Functional Evaluation of Externally-powered Arm Prostheses. July 1962.

Gershon Weltman, Franklyn C. DeBiasio, and John Lyman

"Control Logic for a Myoelectric Servo-boost System."
August 1962.

Hilde Groth and John Lyman

"Measuring Performance Changes in Highly Transient Extreme Heat Stress: Rationale, Problem, and Experimental Procedures." August 1962.

R. W. Allen and John Lyman

"Arm Water Losses Under Disparate Arm and Body Thermal Conditions." August 1962

VISITORS TO THE LABORATORY

June 22:

Dr. Worden Waring, Head, Chemistry Section, Fairchild
Semiconductor, San Francisco.

July 5:

Mr. Ionnes Dennison, Executive Director, Committee on
Prosthetics Research and Development, NAS-NRC, Los
Angeles, California.

August 23-24:

Mr. Birger Roos, Civil Engineer Svenska Vanforevardens
Centralkommitte, Bromma, Sweden.

September 4:

Mr. J Raymond Pearson, Department of Physical Medicine
and Rehabilitation, University Hospital, The University
of Michigan, Ann Arbor.