January 1970

Fourth Quarterly Report

Covering Period of 1 October 1969 to 1 January 1970

The Study of Synchronization Techniques For Optical Communication Systems

Robert M. Gagliardi
Principal Investigator

Department of Electrical Engineering
University of Southern California
Los Angeles, California 90007

This work was sponsored by the National Aeronautics and Space Administration, under NASA Contract NGR-05-018-104. This grant is part of the research program at NASA's Electronics Research Center, Cambridge, Massachusetts.

This document represents the fourth quarterly report of a NASA Research Program to study synchronization techniques for optical communication systems. The work is being carried out at the Electrical Engineering Department at the University of Southern California, under NASA Contract No. NGR-05-018-104, with Professor R. M. Gagliardi as principal investigator. This grant is part of the research program at NASA's Electronics Research Center, Cambridge, Massachusetts.

This study program is devoted to an investigation of problems associated with synchronizing an optical communication system. The objective of the effort is to indicate design procedures, assess system performance, and predict future areas of needed study in synthesizing and improving system operation. The organization and guideline of the study, the particular problem areas, and their applications are covered in the first quarterly report, March, 1969.

The research effort is primarily analytical in nature, and is divided into two categories. The first involves tasks with direct application to the synchronization problem, while the second involves related areas also being studied under the grant. This document reports technical progress during the fourth quarter, but detailed results will be published in separate interim reports, and are omitted here.

Current Progress

Three published papers have recently appeared in the literature stemming directly from work associated with this contract.

1) "M-ary Poisson Detection and Optical Communications" R.M. Gagliardi (with S. Karp), IEEE Transactions on Communication Technology, Vol. Com-17, April 1969 pp. 208-216.

Abstract. This paper presents an investigation of the problem of maximum likelihood detection of one of M Poisson processes in a background of additive Poisson noise. When the observables correspond to counts of emitted photoelectrons, the problem models a discrete version of a coherent M-ary optical communication system using photon counters in the presence of background radiation. Consideration is given to an average distance and a detection probability criterion. The advantages of an M-ary pulsed intensity set (Poisson intensities wholly concentrated in a single counting interval) are demonstrated. The performance of such intensity sets is exhibited in terms of error probabilities, pulse widths, signal-to-noise ratio, and channel capacity. Behavior as a function of number M of intensities is also discussed. By appropriate conversion these results may be used for determining power requirements in an optical pulse position modulation system.

2) "The Design of a Pulse Position Modulated (PPM) Optical Communication System" R.M. Gagliardi (with S. Karp), IEEE Transactions on Communication Technology, Vol. Com-17, December, 1969.

Abstract. In recent literature the advantages of an idealized narrow width pulse position modulated (PPM) optical communication system, using coherent sources and direct photo-detection, have been shown. In this report, the practical design of such an operating PPM link is considered. System performance, in terms of error probabilities and information rates, are derived in terms of key parameters, such as power levels, number of PPM signals, pulse width, and bandwidths. Both background radiation and receiver thermal noise are included. Design procedures utilizing these data are outlined. Whenever possible, optimal design values and parameter trade-offs, in terms of maximizing information rate or minimizing transmitter power, are shown. The effect on performance of photomultipliers and their inherent statistics is also presented. Although the basic analysis is derived in terms of photon "counts," the necessary system optics equations are introduced to allow for overall optical hardware design. The primary underlying assumption is that synchronization is maintained at all times between transmitter and receiver.

3) "On the Representation of a Continuous Stochastic Intensity by Poisson Shot Noise" R.M. Gagliardi (with S. Karp), IEEE Transactions on Information Theory, March, 1970 (to be published).

Abstract. In many applications a poisson shot noise (PSN) process is said to statistically "represent" its intensity process. In this paper an investigation is made of the relationship between a PSN process and its intensity, when the latter is a sample function of a continuous stochastic process. The difference of the moments and the mean square difference between the two processes is examined. The continuity assumption on the intensity permits the development of a sequence of moment relationships in which the effect of the PSN parameters can be seen. The results simplify, and afford some degree of physical interpretation, when the component functions of the PSN are "rectangular," or when the intensity process does not vary appreciably over their time width. An integral equation is derived which defines the component function that minimizes the mean square difference between the two processes. It is shown that a "degenerate" form of component function induces complete statistical equality of the two processes. The problem has application to optical communication systems using photodetectors.

The following reports summarizing recent technical work are presently in progress.

1) "Shot Noise processes" and "Digital Communications" (Contributions to review articles in special issues of the Proceedings of the IEEE).

2) "Phase Locking with Shot Noise Processes and Applications to Optical Synchronization"

3) "Effect of Imperfect Synchronization on Error Rate in Optical PPM Systems"

4) "Information Rate of Optically Detected Gaussian Fields"

The present study effort is primarily devoted to consideration of the particular areas.

a) Statistical properties of tracking errors in optical trackers

b) Study of the statistical characterization of the photon count at the output of a photodetector observing an optical field, considering both time and space effects

c) Optimal detection, estimation, and filtering of optically detected fields

This work effort is being carried under Professor R. Gagliardi, with 3 graduate students.