ROBERTO SAUCEDO
Manager, Command and Control Systems
International Business Machines, Inc.
and
University of California at Los Angeles

EARL E. SCHIRING
Staff Engineer
Logicon, Inc.
and
University of California at Los Angeles

INTRODUCTION TO CONTINUOUS AND DIGITAL CONTROL SYSTEMS

THE MACMILLAN COMPANY
COLLIER-MACMILLAN LIMITED, *London*

PRINTING 3456789 YEAR 3456789

Library of Congress catalog card number: 68-12075

THE MACMILLAN COMPANY, NEW YORK
COLLIER-MACMILLAN CANADA, LTD., TORONTO, ONTARIO

Printed in the United States of America

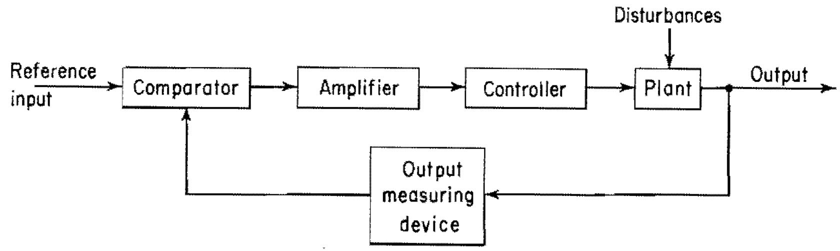


FIGURE 1–3. *Block diagram of closed-loop system.*

and direction of the side winds, the accuracy of the compass instrument, the engine thrust magnitude, and the accuracy of the controller all contribute to errors between the desired flight path and the actual one.

A closed-loop control system is one in which the output quantity is fed back for comparison with the input, and the difference, or error quantity, is then applied to the amplifier, as shown in Figure 1–3. In such a feedback system, if the output is not the desired one, an error is sensed by the comparator and the control system will act in a manner to reduce the error to zero, or to maintain the output equal to the desired input. Thus the feedback system has the ability to correct for load disturbances and inaccuracies in the controller. If in the aircraft navigation example the pilot can see the ground, and if he is familiar with many landmarks along his flight, then he has the capability of correcting his flight-path errors by this visual feedback, as shown in Figure 1–4.

In general, open-loop control systems are characterized by moderate accuracy, high sensitivity to environmental conditions, and slow response. The advantages of open-loop control are simplicity and low cost. In contrast, closed-loop or feedback control systems are characterized by high accuracy, rapid response, and relative independence of environmental factors.

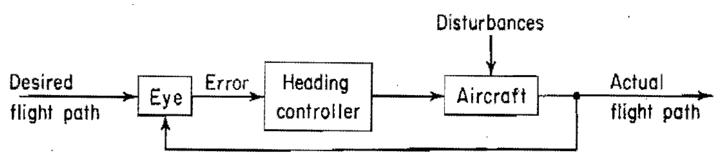


FIGURE 1–4. *Closed-loop aircraft navigation system.*

1.3 NOMENCLATURE

The functional block diagram of a closed-loop system in Figure 1–5 shows the nomenclature that is in common use. The *command input* is transformed by the reference input element, or *reference selector*, into a signal that is calibrated in terms of the output. This signal is called the *reference input*. The *actuating signal* and plant of Figure 1–1. The output of these feedforward elements is the *control system output*. This output is sensed by the *feedback element* and is fed back to the comparator as the *feedback signal*, where it is compared with the reference input to form the *actuating error signal*. In addition, an *output element* may exist such as an output indicator.(2)

Common terms for control systems that are widely used in the literature are *servomechanism* or *servo*, and *regulator*. A servomechanism is a control system in which the output is the position, velocity, or acceleration of a mechanical shaft, such as that corresponding to a motor. The term *regulator* usually applies to a control system wherein the output quantity is desired to be maintained constant despite unwanted disturbances to the system. An electric generator is an example of a regulator, in that it is desired to maintain constant the generator voltage regardless of the load fluctuations on the generator.

If control systems are classified according to the nature of the signals at the various points of the feedback loop, then the three kinds of systems are continuous, sampled-data or pulsed-data systems,‡ and relay-type systems. A continuous control system is one in which all the signals in the control loop may be considered as continuous functions of time, and an example of a continuous system is the regulation of speed of a motor using tachometric feedback. In such a system, the tachometer feeds back a signal proportional to the motor shaft speed to be compared with the desired speed.

A sampled- or pulsed-data system is one in which one or more signals in the loop are in the form of a pulse train or a numerical code, such as the output of a digital computer. An example of a sampled-data system is that of a radar tracking system. The signals sent and received are in pulse form, and are used to position an antenna to track some desired object.

A system in which a relay type of element is present in an otherwise continuous type of system is called a *relay*, or *on-off, system*. The thermostat home-heating system is an example of an on-off system. When the temperature at the thermostat is below a preset value, the full force of the furnace is suddenly applied to

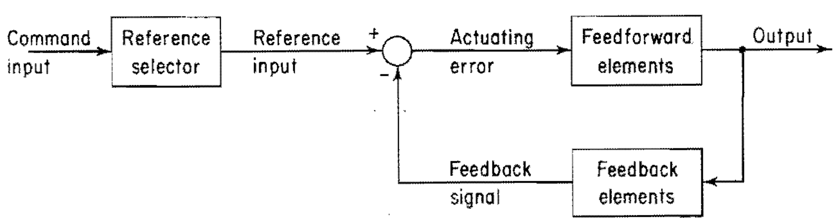


FIGURE 1–5. *Functional block diagram of closed-loop system.*

‡ The terms "sampled-data," "digital," and "discrete" are used interchangeably in many instances throughout the text, although fine distinctions are made by many researchers. The term "sampled-data" is the most general term, and includes all systems which contain signals in pulsed form. The term "digital" implies that a digital component such as a digital sensor or a digital computer is used in the system.

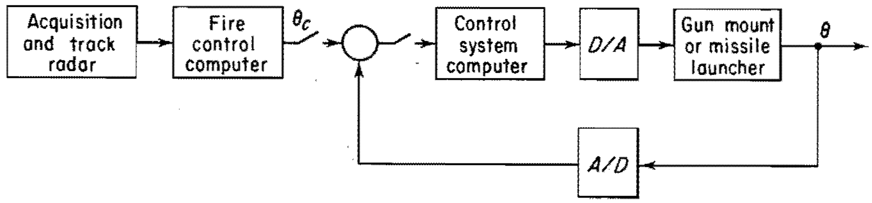


FIGURE 1–10. *Sampled-data fire-control system.*

or missile launcher is commanded for the gun control system. The error signal in pulsed form is converted to a continuous signal and applied to the gunmount drive motor, and the gun is positioned accordingly. The angle of the gun is sensed and converted to digital form and fed back for the error comparison. While the diagram shows a simple single-axis representation, two separate channels of azimuth and elevation are positioned simultaneously in the actual equipment. In addition, if the fire-control system is on board a naval vessel, the ship is subjected to sea motion that must also be accounted for in the fire-control computer.[6]

Another example of a sampled-data system is the control of an electro-optical telescope to effect automatic tracking of a star. The telescope must be continuously repositioned if the star is to remain in the field of view of the telescope, owing primarily to the rotation of the earth. This system is illustrated in Figure 1–11. A television camera is mounted on the telescope and an image is generated on the screen. The set is aligned such that the center of the raster is coincident with the optical axis of the telescope. Additional tracker electronics determine the displacement of the image with respect to the center of the raster and furnish a signal proportional to the pointing error of the telescope. Since television is by nature a repetitive scanning device, it is also by nature a sampled-data component. The pointing error is amplified and shaped by stabilization electronics, and is then applied to the servomotor, which positions the telescope in a direction to decrease the pointing error. While a standard television applied to this problem has a sampling rate so high in comparison to earth rate that the system appears to operate as a continuous control system, the same system applied to automatic tracking of a high speed missile or aircraft could have system time constants of nearly the order of magnitude of the television sampling rate, so that a sampled-data analysis would be required.[7]

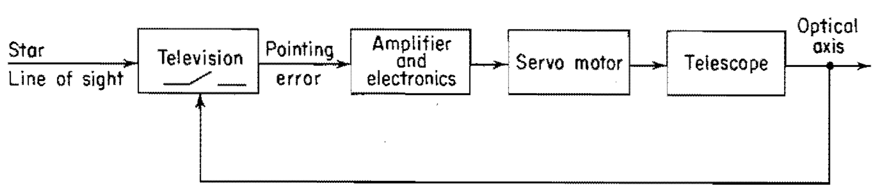
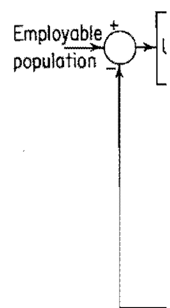


FIGURE 1–11. *Electro-optical telescope tracker.*

Numerous c
occur naturall
system compo
human body r
more general s
The oculomotc
discussed prev
object, such as
the retina fron
muscles are coı
in the center o

In ecology a
of Canada. In
territory under
constitute the
the lynx popul
population wil
rabbits. To co
overpopulation
complete.[9]

Another nat
1–12. This part
(10), which is
income is the s
these quantitie



DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.