JSC-08973

NASA TECHNICAL MEMORANDUM

NASA TM X-58135
August 1974

NASA

TECHNOLOGY EVALUATION OF CONTROL/MONITORING SYSTEMS FOR MIUS APPLICATION

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MODULAR INTEGRATED UTILITY SYSTEMS

improving community utility services by supplying electricity, heating, cooling, and water/ processing liquid and solid wastes/ conserving energy and natural resources/ minimizing environmental impact

(NASA-TM-X-58135) TECHNOLOGY EVALUATION OF CONTROL/MONITORING SYSTEMS FOR MIUS APPLICATION (NASA) 65 p HC $3.75

N74-32715

CSCL 09C

Unclas

G3/13 48746

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM X-58135		

4. Title and Subtitle	5. Report Date
TECHNOLOGY EVALUATION OF CONTROL/MONITORING SYSTEMS FOR MIUS APPLICATION	August 1974
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
L. Marion Pringle, Jr., JSC	JSC-08973
	10. Work Unit No.
9. Performing Organization Name and Address	386-01-00-00-72
Lyndon B. Johnson Space Center Houston, Texas 77058	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, D.C. 20546	Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report is a first look at potential ways of providing control and monitoring for the Modular Integrated Utility System (MIUS) Program. Control and monitoring hardware and operational systems are described. The requirements for the MIUS Program and the development requirements are discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
· Automation Control Equipment · Control Boards · Electronic Control · Measuring Instruments · Instrumentation	STAR Subject Category: 14

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
None	None	63	$3.75

NASA TM X-58135

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PREFACE

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program devoted to development and demonstration of the technical, economic, and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid-waste treatment, and solid-waste management. The objective of the MIUS concept is to provide the desired utility services consistent with reduced use of critical natural resources, protection of the environment, and minimized cost. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by the organization, private or public, selected by a given community to provide its utilities.

Under HUD direction, several agencies are participating in the HUD-MIUS Program, including the Atomic Energy Commission, the Department of Defense, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Bureau of Standards (NBS). The National Academy of Engineering is providing an independent assessment of the Program.

This publication is one of a series developed under the HUD-MIUS Program and is intended to further a particular aspect of the program goals.

COORDINATED TECHNICAL REVIEW

Drafts of technical documents are reviewed by the agencies participating in the HUD-MIUS Program. Comments are assembled by the NBS Team, HUD-MIUS Project, into a Coordinated Technical Review. The draft of this publication received such a review and all comments were resolved.

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TECHNOLOGY EVALUATION OF CONTROL/MONITORING SYSTEMS FOR MIUS APPLICATION

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SUMMARY

The Urban Systems Project Office at the NASA Lyndon B. Johnson Space Center has conducted a general survey of possible systems and hardware required for control/monitoring in a Modular Integrated Utility System (MIUS). This survey was scheduled for completion early in the MIUS Program because its purpose supports early events in the program sequence. The purpose of the survey is to familiarize aerospace engineers who will undertake the design and analysis work specific to MIUS with appropriate techniques and hardware for monitoring and control of individual processes that are applicable to MIUS; that is, power generation, solid-waste treatment, et cetera.

This report gives a general description of control/monitoring hardware, including logic controls, central control stations, subsystem hardware, and actuators. Several operational control/monitoring systems were visited during the survey and are described herein. The requirements for a control/monitoring system for the MIUS are given. The results of the initial survey show that only one major hardware development is required - the automatic monitoring of waste and water treatment processes. Computer modeling of MIUS subsystems is a required software development. In keeping with the directive for use of articles of commerce in the development of the MIUS design, the survey has shown that a wide range of capabilities exists that will provide the MIUS a control/monitoring system for which equipment exists as off-the-shelf hardware. Baseline systems have been selected.

This report should be considered as a first look at the control/monitoring system technology. It is not intended to be the final assessment nor an economic assessment of this technology. It is anticipated that the Department of Housing and Urban Development (HUD) MIUS project will continue an in-depth study of the control/monitoring subject.

INTRODUCTION

The optimization of the overall Modular Integrated Utility System (MIUS) operations and the individual subsystem processes is provided by the control/monitoring equipment. Techniques for monitoring and control of individual processes that are applicable to the MIUS - that is, power generation, waste processing, and air-conditioning - have been demonstrated in various implementations. Examples of these techniques are included in this report. Many of these examples are advanced to an operational state that requires no technological improvement or further research to meet the expected MIUS requirements for these types of subsystems. For example, the operational control of pumps, valves, motors, and switches on offshore oil well platforms by using remote control and monitoring devices provides techniques that can be used in the MIUS Program. The requirements to control flow, pressures, temperatures, and mixtures of liquids and semiliquids on these platforms can be applied directly to the MIUS water and liquid-waste treatment subsystems. Some developmental efforts funded by the Department of Housing and Urban Development (HUD) and the Environmental Protection Agency (EPA) should also be considered as MIUS candidate subsystems. These efforts incorporate control and monitoring techniques that are similarly advanced beyond the conventional approaches. Total-energy plants for power generation and heat/cooling functions and for solid-waste pickup and incineration techniques are some of the examples that are summarized in this report.

The design definition of the MIUS control system will be accomplished through a consideration of the individual techniques implemented in applicable areas; however, an extensive correlation of these techniques will be required so that the integrated systems approach to the overall operations can be achieved. This report identifies the available techniques for controlling individual subsystems and points and gives examples of supervisory control implementations on related system applications.

In some of the cases - for example, power generation controls - individual controllers are dedicated to particular motor generation units with a master control unit supervising the overall operation. This illustrates the direction in which the MIUS control system definition is proceeding; that is, toward a central control station that is cognizant of the several processes. This type of control center concept will allow for the optimization of each individual subsystem performance, based on its effect on the overall operations.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

GENERAL DESCRIPTION OF CONTROL/MONITORING HARDWARE

LOGIC CONTROLS

The following discussion of control/monitoring hardware is based on the current state of the art.

Logic controls are remote sensing and actuation devices that will provide the MIUS control/monitoring system with the input and output signals from the subsystems. A general description, the interface range, the relative cost, and the advantages and limitations of each type of controller are presented.

Electromechanical Relays

Relays are the first generation of logic controls. They are available with normally open and/or normally closed contacts, on-off or off-delay timers (using motor, thermal, radio-controlled circuit, and dashpot techniques), and magnetic latching. Relays range from general-purpose commercial to high-performance industrial relays to military and special-purpose types. They are available in sizes from miniature to large and can be mounted on panels or used in plug-in sockets. The enclosures for the relays are both standard (dustproof and hermetically sealed) and open types. A wide range of current and voltage levels is available in direct current and alternating current. Generally, the relays are 2 to 10 amperes with voltages as large as 600 volts.

Relays provide controls at a very low relative cost. A small control system can be only a fraction of the cost of other systems if the logic is simple and can be done with relatively few relays.

Advantages.- Electromechanical relays are a good choice for simpler systems with a moderate number of inputs and outputs and a moderate number of logic decisions. They provide good reliability at lower cyclic operating rates. Maintenance personnel are most familiar with this type of control, and electromechanical relays are relatively easy to maintain. Wide flexibility in selection of contact arrangements and ratings is possible. Low contact resistance, generally a few milliohms, is typical. Relays are least sensitive to underrating. The breakdown voltage is generally many times the operating voltage because of the rugged construction of the relays. Fairly standardized configurations are available. Wiring to pilot and output devices is easily facilitated because inherent voltage and power levels are sufficient. Relays generally can be used in ambient temperatures as high as 343 K (70° C). Other types are available for higher temperatures. Relays do not generate a large amount of heat, and they provide high noise immunity. The inputs and outputs are completely isolated. There is rarely a requirement for auxiliary power supplies or for input/output voltage converters. Because input logic and output voltages are usually the same, cost advantages can result. Relays can have low thermal electromotive force (emf) characteristics. The relay control system is custom designed and wired uniquely to fit the specific design. Its operation can be detected audibly and visually.

Limitations.- Electromechanical relays have limited life if the operating rate is high. The variability of operating time on alternating-current wave shape complicates control for radiofrequency interference (RFI) suppression. These relays are slow in switching time (generally 15 to 20 milliseconds) and comparatively large in size. Relays consume more power than equivalent electronic systems and can be adversely affected by vibration, heat, or caustic atmosphere. External suppression of the coils may be required to avoid inadvertent solid-state triggering if the relays are used in proximity to solid-state devices. The response time in cascaded circuits may place inherent limitations on production cycle times. Response times for similar devices within a given system can vary.

Solid-State Relays

Solid-state relays are made from thyristors, silicone-controlled rectifiers, Triac switches, or power transistors and are used for power switching. They are available with normally open and normally closed contacts. On-off delay timers generally use remote-control circuits and are also available. It is technically possible to match voltage and current capabilities of electromechanical relays; however, the availability of off-the-shelf solid-state relays that do this is limited.

Solid-state relays are more expensive than electromechanical or hybrid relays. List prices for solid-state relays c· › "un about torr times more than those for electro-mechanical relays.

Advantages.- The power needed to drive solid-state relays is compatible with low-driving capabilities of solid-state logic elements. The low-level input requirements ease interface problems with complex solid-state control systems. Solid-state relays are useful for high-cycle-rate controls and can accept a wide range of alternating- and direct-current input voltages. Units are available that are interchangeable with electromechanical relays, relative to application, wiring, and maintenance. Solid-state circuitry can eliminate RFI on opening; zero-crossing circuitry can eliminate RFI on closing. These relays can operate at high speeds (microseconds). The lifetime of solid-state relays is generally considerably longer than that of electro-mechanical relays. Transformer or optical coupling provides complete isolation between input and output, as well as between poles. Poles can be made convertible by inverting plug-in units. Solid-state relays can be used in temperatures as high as 343 K (70° C). Excellent shock and vibration resistance is provided. They are easy to maintain if not potted. Phase control of silicone-controlled-rectifier (SCR) or Triac firing can minimize surge currents caused by inductive or other loads. This type of relay generally has good surge current handling capability, typically 10 times the rated current for one alternating-current cycle.

Limitations.- Solid-state relays have a junction voltage drop of approximately 0.7 to 1.5 volts. They require built-in or external heat sinking to curb heat dissipation caused by junction voltage. They also require built-in or external suppression circuits on input and output sections to counteract electrical noise that could cause inadvertent triggering. For smaller ratings, their size is comparable to that of other types; but as ratings increase, their overall size (size of unit plus size of heat-sinking accommodation) comparatively increases. There is limited availability of standard characteristics. Whereas functions from a given manufacturer generally are compatible, logic from two different vendors usually is not compatible. The design procedure is similar for all vendors, but the symbols, voltage levels, and functions available differ among manufacturers. The breakdown voltage is fairly close to operating voltage (operating voltage plus approximately 100 volts). Surge voltages can cause conduction for one-half of an alternating cycle. When driving an inductive load, solid-state relays are subject to a secondary breakdown of the power semiconductor unless there is diode suppression. These relays require a precisely designed system because underrating can cause failure.

Dry-Reed Relays

Dry-reed relays can perform all relay functions but are generally used at lower power levels. They are available packaged as shift registers, or flip-flops, that use magnetic latch relay and thus have retentive memory. Special logic units are also available. As many as six poles are readily available; the number depends on the form (A, B, or C) selected. Special combinations can exceed the number of generally available poles - those available with normally open contacts, normally closed contacts, magnetic latching, and time delay (using solid-state driver and reed relay output). Dry-reed relays are used for electronic process control equipment in low-level switching applications, including instrumentation, logic switching arrays, high-frequency switching, control of other relays and solenoids, high-voltage switching, and current and voltage sensing. Applications include electrostatic copiers and computers, transfer machines, and conveyors.

Dry-reed relays are available in typical levels to 250 volts; the upper limit is generally 1000 volts. The maximum current is 3 amperes for all types. High-voltage dry-reed relays are also available to 20 kilovolts and 1 milliampere of current for direct-current resistive loads.

The component cost can be equivalent, but it is generally more expensive to implement dry-reed relays in special logic units rather than standard electromechanical relay systems because direct-current power is required. In single-throw applications, dry-reed relays can be competitive with the electromechanical relays. They are less expensive than mercury-wetted, hybrid, or solid-state relays.

Advantages.- Contacts in dry-reed relays are sealed in glass to provide increased environmental reliability. Routing of wiring to pilot and output devices is facilitated. Compared with solid-state relays, dry-reed relays are less susceptible to overload. They can operate mounted in any position. They are approximately 3 times as fast and have 20 times the life of standard electromechanical relays. Operating speeds range from 1 to 6 milliseconds, depending on contact configuration and coil driving power. Operating temperature ranges to 358 K (85° C). Maintenance personnel can be trained in a short period of time because the basic theory, symbols, and test techniques of electromechanical relays apply. Inputs and outputs can be made to the reed system without a need for signal converters or simplifiers. Reed relays have very low contact noise and can exhibit very low thermal emf characteristics. They are generally rated for 100 million operations at signal level loads and 5 to 10 million operations at rated loads. Complete input/output isolation is provided. Complex interface problems involving a wide range of signal and power levels can be solved through the use of dry-reed relays. They operate with very low coil power requirements (generally in the millivatt region). Breakdown voltage, when compared with operating voltage, can be very much higher. These relays are available with integrated circuit-compatible (standard 5-volt diode transistor logic/transistor transistor logic (DTL/TTL) drives) low-profile packages designed for printed circuit board mounting. Dry-reed relays are generally immune to false triggering by overload transients and have less contact bounce and greater resistance to shock and vibration than electromechanical relays.

<u>Limitations</u>.- Dry-reed relays are more susceptible to an overload than are electromechanical relays. They are slower than solid-state switches but are as fast as the fastest of the electromechanical switches. The dry-reed relays are relatively larger than switching transistors, and their open construction is more fragile than that of transistors. Contact protection is required for most reactive (capacitive or inductive) loads and for tungsten lamp loads. These relays are susceptible to stray magnetic fields and therefore need shielding. They are usually built for direct-current operation but can be used on alternating-current circuits with proper filtering.

Mercury-Wetted Contact Relays

The mercury-wetted contact relays switch on a film of mercury. The contacts are glass-encapsulated fixed under gas pressure with a movable reed armature. The fixed contacts are continuously mercury wetted through capillary action. The switch action is produced by an electromagnetic field that moves the armature from the normally closed contact to the normally open contact. These relays can operate in 1 millisecond in single-pole forms. The lifetime of these relays is approximately 100 million to 10 billion operations, depending on the load. Contact relays are available as plug-in units for printed circuit board enclosures. They can easily switch low-level or logic loads and system power load levels. There is a very wide range of permissible operating voltage in addition to nominal voltage. The high repeatability afforded by mercury-wetted relays makes them useful in data transmission, telephone, and telegraph applications. Two-pole relays are most common for printed circuit mountings; four poles are most common for plug-in types.

Operating-condition maximums for mercury relays are 500 volts direct current or peak alternating current and 5 amperes direct current or peak alternating current; the temperature range is 235 to 378 K (-38° to 105° C). Mercury-wetted relays are generally more expensive than electromechanical and dry-reed relays. They are comparable in price to hybrids and less expensive than solid-state relays.

Advantages.- Mercury-wetted relays offer low and stable contact resistance. The speed ranges from 1 to 6 milliseconds, with high repeatability. They are good switches for level signals and require less power to operate than other electromechanical devices. Mercury-wetted relays can be driven by solid-state circuitry because of low power input requirements. They have low contact noise and high input/output isolation. The constant contact resistance variation is typically ±2 milliohms. They can withstand transients better than solid-state relays can. These relays provide positive on-off switching with relatively no bounce of contacts because of the cushioning effect of the mercury film. This capability makes possible a very wide drive-power range. The film and pressurized hydrogen atmosphere also dissipate heat and minimize contact erosion.

Limitations.- Mercury-wetted relays are position sensitive. The pool of mercury must be at the bottom of the capsule for capillary action. They are not as resistant to overloads as electromechanical relays are but are more resistant than reed relays. Contact protection is required for most reactive (capacitive or inductive) loads.

Hybrid Relays

The hybrid generally consists of reed relay input and semiconductor output but can be the opposite. It is available with built-in amplifiers to directly interface low-level signals (DTL/TTL) and output power control requirements. A lifetime of approximately 10 million operations (the same as for the reed device) is normal. Voltage and current capabilities depend on the solid-state device used and on the mounting and enclosure methods.

The input to the hybrid relays ranges from 6 to 48 V dc or 24 to 115 V ac. Current ratings range from approximately 0.5 to 7 amperes rms at 60 hertz and 298 K (25° C). Higher current ratings can be achieved with additional heat sinking.

Hybrids are three times as expensive as electromechanical relays, but their lifetime is considerably greater.

Advantages.- Hybrids combine the long life of solid-state relays with the input/output isolation of reed relays. They can interface semiconductor logic circuits with inductive loads (motors, solenoids, tungsten lamp loads, and transformers). They can accept a wide range of input voltages. Interference is inherently eliminated on opening and closing by use of a zero-crossing circuit. With load derating and/or improved heat sinking, they can be used in temperatures above 298 K (25° C). Because of reed relays on inputs, hybrids are generally more immune than all solid-state devices to inadvertent triggering by input transients.

Limitations.- There is little standardization of hybrid relays. Built-in or external heat sinking is required to dissipate heat from junction voltages. Maintenance personnel must be highly trained. Auxiliary power supplies are needed if precise regulation is required on amplifier-driven units.

Functional Systems (Special Electronic Logic Packages)

Special electronic packages find application where system complexity is moderate - between that of electromechanical control systems and that of wired logic, printed circuit card systems. They generally consist of 1 to 10 self-contained modules. Each module consists of input sensors and sensor interface, decision logic and time delays, an output section, and a power supply operating from standard 117 V ac. Basically, each module is equivalent to one or two lines of a relay ladder diagram. The modules are coupled to proximity and photoelectric sensors to provide a complete electronic system to meet special needs for reliability, high-speed response, and noncontact sensing. Inspection, sampling, counting, synchronization, confirmation, protection, flow control, and operation validation are available in standard functional systems. Functional systems use a maximum voltage of 115 volts for inputs and outputs. Low-level direct-current voltage of a few millivolts to 24 V dc is used for the logic.

A solid-state-type control system can be configured in this manner at relatively low cost. The overall cost falls between that of a relay system and that of a more complex hardwired solid-state system.

Advantages.- Each module is fully independent with its own power supply, and modules are easily tied together for more complex requirements. They usually find application in fairly simple systems in which limit switches and electromechanical relays suffer from comparatively short lifetimes because of high operational rates and in which complex timing, time delay, and logic processing are not economical with the use of relays. They can be used in combination with relays and limit switches in specific areas where special requirements indicate the use of a functional solid-state "package." These packages are vibration resistant.

Limitations.- Functional systems are not flexible in that they must be specifically tailored to the application. Plant personnel are not experienced in the maintenance and use of these systems. The costs increase rapidly for systems larger than the equivalent of 10 to 20 relays.

Hardwired Solid-State Controllers

Hardwired solid-state controllers are the second generation of logic controls. They are used for controlling a large number of functions in such applications as automotive, packaging, food processing, multistation transfer lines, injection molding machines, metal casting, and materials handling equipment. They use integrated circuits and discrete components (diodes and transistors) for logic circuitry. The controllers include functional cards for basic logic gates, up and down counters, shift registers, range timers, flip-flops, retentive memories, and assorted inputs and outputs. Generally, card-mounted logic functions are plugged into rack-mounted connectors or panel-mounted receptacles. The cards are classified as input interface, logic, and output interface; their interconnections are wired according to a logic diagram or a systems logic equation.

The solid-state controllers operate on 115 volts, input or output, whereas logic circuits make use of low-level signals (5 to 24 V dc). Solid-state controllers comprise fewer components (only needed functions are purchased) and are less expensive than the more universal programmable units. Although engineering, assembling, and documenting costs must be considered for tailor-made systems, they can often be spread over multiple applications to produce a large system for a reasonable overall cost.

Advantages.- Solid-state controllers are custom designed, have long lifetimes, and have no moving parts. They operate at high speeds, are compact in size, and are very reliable. Their control actions are highly repeatable. They can be easily protected against adverse environments. Cards from which a solid-state controller is built generally contain more function types than are available from relays, and they are easily removed for use in a new system. Functionally, solid-state controllers are the most direct equivalent to relay systems. The modularity of the cards reduces inventory. Repair or maintenance often involves only replacement of plug-in logic cards. The logic voltages are compatible with computers, but actual interfacing requires custom design.

Limitations.- There are no standard configurations for solid-state controllers. Functions from different vendors are compatible but their logic usually is not. These controllers operate at lower voltage and power levels than electromechanical relays; effects of electrical noise on the system thus must be considered. Electrical noise can be minimized by grounding of the chassis, by use of electromechanical shielding, and by physical separation of solid-state controls from electromechanical devices such as starters and solenoids. Other methods include using high-noise-immunity logic elements; these have increased noise immunity by a ratio of more than 10 to 1 over commonly used computer-type logic elements. Maintenance personnel are less familiar with this type of system, but assistance from manufacturers is available. Solid-state logic symbols are not as familiar as are relay circuit ladder diagrams.

Solid-State Programmable Controllers

Solid-state programmable controllers are the third generation of logic controls. They perform control functions like relays or hardwired solid-state controllers. They provide basic logic functions, timing, and counting and readily accommodate different types of inputs and outputs. These controllers can incorporate hardwired solid-state logic for specific inputs and outputs for auxiliary functions. They can contain memory and computer monitoring capabilities. These controllers are in packaged systems (such as in National Electrical Manufacturers Association (NEMA) 12 enclosures) and accept inputs from limit, pushbutton, pressure, or proximity switches. Operations of output devices in machines or systems are controlled according to a predetermined control sequence, as established by a program. This programing, and a specified number of inputs and outputs, tailors the control to a specific application. Programmable controllers are available with read-write (alterable, generally magnetic core) and read-only (ROM, hardwired or programmable diode matrix) memories. Machine operating logic is softwired (programed) to control machine sequence. This avoids the necessity for custom design and unique hardware configuration for each control application; instead, different control applications can be performed from standard hardware configurations. These controllers use sequential (serial) scanning. The memory unit scans inputs in a cyclic fashion and determines whether outputs should be turned on or off. These controllers are used in industrial applications, including severe environment. They replace magnetic relays or conventional solid-state controls for machine tools, conveyors, and parts handling. They are useful for controlling large, complex systems or several related systems.

The input and output voltages for these controllers are the same as for hardwired solid-state controllers: 115 volts input/output logic level, 5 to 24 V dc.

The initial cost of these units is generally higher. The wiring for external interfaces such as computers is integral to the package; it is this flexibility that makes programmable controllers the most expensive type of control for most applications initially. They become practical with increasing numbers of circuits. The crossover point is approximately 30 to 50 circuits; they then begin to provide space-saving flexibility and maintenance advantages.

Advantages.- Solid-state programmable controllers provide flexibility for increased automation and control system complexity. Control can be expressed in Boolean statements for machine flexibility. Changing systems is less expensive and faster than changing hardwired solid-state controllers or relays. These controllers have long lifetimes and greater reliability. Most programmable controllers have computer interface options for supplying status information to a monitoring computer. All basic control elements in a factory can be optimized through the software and then implemented with similar hardware. A basic hardware complement meets all control requirements. Programmable controllers provide fast control response in moderate-sized systems; however, because of the sequential nature of control in moderate-sized systems, the control response decreases as the system gets larger. Programmable controllers are compact. They replace relay logic and permit the design of a control system using relay circuit techniques, including conventional ladder diagrams. Programing generally is done with a tape reader or a programing keyboard, using conventional control rather than computer language. The use of programmable controllers facilitates future addition of a computer monitoring system (because of the ease of interfacing). Debugging and maintenance are simplified because of indication lamps on all input and output functions. Some systems have debugging programs and maintenance aids.

Limitations.- The logic design must be translated into a form acceptable to the memory of the controller. Some restrictions are imposed on a ladder diagram format as applied to the controller. The possibility of electrical noise pulses causing erroneous changes in the read-write memory may require protection in these units. A sequential scanning requirement can be a time response limitation in certain high-speed applications. An auxiliary unit (such as a programing panel or minicomputer) is required for programing.

Fluid Controllers

Environmental conditions and machine, material, and manual motions, as well as measurable process parameters, are converted to fluidic input signals through sensors and transducers by control of airflow (or fluid flow) into or out of fluid circuits. Moving-parts sensors and transducers, as well as nonmoving-parts and noncontacting fluidic sensors and transducers, accomplish these conversions. Circuit logic components use low-power pneumatic (fluid) signals to redirect fluid streams to selected output signal ports within such elements. Logic elements (OR/NOR, AND/NAND, FLIP-FLOPS, etc.) are interconnected with tubing formed in the basic structural material at the time of fabrication. Logic elements are available in plastic, ceramic, and metal. For higher speeds, output devices can also be fluidic devices at a higher power level. For low speeds, output is usually through a moving-part interface valve. The format includes plug-in elements, bolt-on elements, integrated circuits, and stacked laminations to form a circuit block. Systems can be quoted according to the logic diagram of the user. The usual packaging, in conventional heavy electrical boxes, is standard. Fluidic controllers are used in liquid-level control, sequencing, safety and interlock control, selected gaging, flow monitoring, air-conditioning, leak detecting, and liquid-waste management applications. Advanced systems have the capability for digital multiplexing and two-way signal transmission over a single pneumatic line. In addition to digital controls, fluidic analog systems are available for conventional process control applications.

Fluidic controllers operate with a supply pressure that ranges from 1.4×10^3 to 3.1×10^5 pascals (0.2 to 45 psig). A typical range is 6.9×10^3 to 21×10^3 pascals (1 to 3 psig). The air (or fluid) consumption depends on the size of the power nozzle (ranges from 0.1 by 0.2 millimeter

(0.004 by 0.008 inch) to 0.5 by 1.0 millimeter (0.02 by 0.04 inch) for logic elements) and on the supply pressure levels.

The cost of fluid controllers is generally lower than that of other types of pneumatic control systems. These controllers are more competitive for simple systems, especially where hazardous environments, pneumatic sensing, or high-output power levels are involved. They are not presently competitive in very large, extremely complex systems.

Advantages.- Fluidic controllers are easy to maintain; reliability and electronic skills are not needed for servicing. They are very suitable for hazardous or extreme environmental conditions because they are explosionproof. Fluidic controllers offer new or improved sensing capabilities in the areas of airspeed at low velocity, flowmeters, noncontacting sensors for gaging, location, and presence or absence of the element being monitored. They withstand a reasonable amount of abuse, operate at low pressures, use no electricity, and are not damaged by accidentally incorrect input/output connections. They react at higher speeds than moving-part pneumatic devices. Also, they interface easily with high-force-level pneumatic and hydraulic actuators.

Limitations.- Fluidic controllers work at much lower speed than electronic types. Clean air is required (filtration from 0.5 to 5 micrometers, depending on element nozzle size). Moving-part interface devices are needed for low-duty-cycle, high-power-level outputs. There is a lack of personnel acquainted with fluidic capabilities. The logic components from available manufacturing sources are not interchangeable; hence, one must return to the original source of logic components for replacement parts.

Pneumatic Moving-Part Logic

Pneumatic moving-part logic (MPL) controllers use pilot actuators to operate one or more control valves from a compressed-air power source. Pilot control provides such options as remote or multiple control; interlocking control; power-level changes; isolation (separation of inputs and outputs); simplified piping and component placement; and interfacing to pneumatic, hydraulic, or electronic systems. They can function in control enclosures or in the open on many machines. All types of directional control valves, flow control valves, and special-purpose valves are available in plug-in modular systems and manifold varieties.

The MPL controllers typically require 207×10^3 to 1034×10^3 pascals (30 to 150 psi) for the pilot control valves. System power levels range in pressure from 0 to 2068×10^3 pascals (0 to 300 psi). Power levels must be high enough to operate sizable cylinders, yet low enough to be easily handled in control circuits.

These controllers are generally available at low initial cost and are generally comparable in cost to electromechanical relays. Miniaturization reduces cost. Pneumatic controls can be lower in cost than other electromechanical and solid-state relays.

Advantages.- A wide range of compatible pneumatic control components is available for control circuit designs. The components can be miniaturized to save space. Pneumatic controls seldom fail unexpectedly; there generally is an advance indication of a potential malfunction. In industries with high downtime costs, this is important. Basic functions, despite variance in size and speed of units from different manufacturers, can be interchanged. The MPL controllers are explosionproof and sparkproof and present no shock hazards. They are suitable for severe industrial environments. Being sealed from within, pneumatic controllers resist dirt, dust, and moisture and will tolerate much of the usual contamination found in air lines. They can also operate underwater. Pneumatic controllers operate directly from the readily available plant air supply. They are dependable and compact and require minimum maintenance skills. They do not require flow to maintain position and memory. Pneumatic devices of the "bubbletight" variety can remain activated indefinitely, with no interim loss of power. Hardware, fittings, and accessories are available for installation and maintenance. Pneumatic control valve shifting (response) times are in the low milliseconds (50 to 500) range. Pneumatic controllers typically have very long lifetimes (5 to 100 million operations).

Limitations.- Compressed air is required. Although generally not a problem in industrial applications, this could be a problem in other areas. Air power consumption can be high, but miniaturized systems can alleviate this. The operating temperature is limited to approximately 383 K (230° F) because of temperature limits of seals and standard lubricants. If pressures in the compressed-air power source vary, the response time and time delays can be affected. Moisture contamination in the air supply can deteriorate lubrication.

CENTRAL CONTROL STATIONS

The following discussion of control/monitoring hardware is based on a review of current operational control centers. The technology level that has been implemented in the central control stations is sufficient to provide optimization of integrated MIUS systems with respect to manpower, hardware, and overall performance. Available control centers are based on two primary concepts - the analog control center and the digital control center. The following general discussion describes each.

Analog Control Centers

Central control provides observation of operations from a vantage point that allows maximum communication with all subsystems. Information is provided through individual wires from the sensors and actuators to panel-mounted meters, gages, controllers, and switches in the central control station. The status lights, meters, and switches can be arranged on the viewing panel in a schematic format of the operational system that will show flows, valve positions, engine status, and pressures in relation to the overall system. Banks of gages, meters, and switches supplement the schematic display. A panel of this sort is commonly called a mimic display, and the name is indicative of the functional use. These control centers serve well to bridge the gap between manual control and automation. Not all analog control centers include mimic displays because, in many situations, the operator's familiarity with the overall operation preceded the trend toward automated control.

The techniques of operating the system are the same as if it were under manual control. The equipment incorporated in the subsystem is generally capable of being automatically controlled without modification. An exception is the sole use of pneumatic controls in a subsystem; these must be replaced with electromechanical devices.

The cost of central control stations is higher than that of individually controlled subsystems. Furthermore, it is an expensive endeavor to innovate a central station in such a manner, because the same amount of electronics is necessary for the basic operation of the equipment in addition to the hardware required to relate the performance of each component to the operators. The cost advantage is in reduced manpower. This is not evident at first glance and does not usually get much publicity; however, the number of operators required at a central analog control station in a local refinery was reduced from 36 men working in 3 shifts (average of 8+ men/shift) 7 days a week to only 8 men working 1 shift/day for 5 days a week. This amounts to a 4.5:1 reduction in manpower that occurred as experience was gained in the use of the control station over a 2-year period.

Advantages.- The obvious advantage of an analog control center is the overview of the operations that is provided. The inherent savings in personnel costs become very significant as the use of the system matures. Typically, the added costs of the central control station are returned in manpower savings in 2 to 3 years.

Another advantage of the analog control center over the digital system is the acceptability of the techniques of control. Essentially, the same equipment that was locally used at the subsystem for monitoring and control is used in the central control station; only the location has been changed. Hence, the experienced operators can easily make the transition to automation and operation from the central control system. This is not true with more advanced digital control techniques in which pushbuttons and cathode-ray-tube displays are used and computers make most of the decisions.

Limitations.- The size of the panels that display the sensor information can become very large. Refineries have panels that are 200 feet long. Obviously, there is a point of diminishing return in centralization of this sort merely from the standpoint of unwieldiness because of size. A further limitation is the maintenance of such a control center. Failures caused by wiring problems must be traced through complex arrays of cables, trays, junction boxes, and harnesses.

This technique of control is also limited in the degree of automation that can be achieved. Interrelationships between the subsystems are controlled by the operators, and recognition of impending problems and expeditious corrective action are strictly their responsibility.

Digital Control Center

The desire for centralized control with an absolute minimum of operator decisionmaking and with improved communication within operations has established a field for computerization of the control/monitoring effort. Data are taken from sensors and transmitted to the computer through communications channels (such as standard telephone lines). The computer compares sensor data with prestored limits; if tolerances are exceeded, they are displayed on a televisionlike tube called a cathode ray tube (CRT). Colors are frequently used to depict alarm levels. The computer provides visual and auditory alarms; with prestored programs, it can initiate corrective action to normalize the operation. This is accomplished in the same manner as if the operator initiates the change through a pushbutton or switch after reading the alarm. The computer determines the actuator that is to be stimulated and transmits updated control signals to the unit over the same type of communication channels. A check of the status is then made to verify that proper operation has been achieved. These systems are typically implemented in addition to the conventional subsystem analog controllers. In the event of a failure of the central station equipment, t subsystem analog controls allow operations to continue fail-safe mode.

The range of input/output parameters that are acceptable by the remote units is usually limited to the logic levels of the units. Standard logic levels of 0 to 5 V dc and 10 to 50 milliamperes are commonly used. These ranges are compatible with most of the sensors and actuators that are implemented in the subsystem hardware. In those cases where further signal conditioning is required to match the input/output characteristics, it is a simple matter to include this capability as required. Developmental programs for space-flight units have centered around programmable signal conditioning that allows multiple users to share the same unit, with switching and control by the computer. This is not done to any degree in industrial or commercial applications because of the lower cost of individual units.

The cost of digital control centers is distributed over four major areas: displays, computer system, remote units, and software for the overall system. These cost areas are directly related to analog systems only with respect to the displays, which are the operator interface and, like the control panels, serve to convey the performance of the overall system. A CRT-type display represents about one-eighth of the total system hardware costs. The computer system, which includes the auxiliary memory and interfaces with the remote units, comprises about three-eighths of the costs. Approximately one-half of the hardware costs are for the remote units that interface with the subsystems. The cost of these remote units is dependent on the quantity of signals. The hardware costs are generally equaled by the cost of the software required to operate the system. Operating system and minimal decisionmaking software is supplied by the computer system suppliers; however, the cost of programing the automated procedures, display formats, and remote unit control is significant, and this cost must be borne by the user.

Digital control systems can be supplied at approximately the same cost as analog systems. In most cases, a minimal set of analog controls is included on each subsystem, and this cost is added to the total cost.

Advantages.- A digital control system provides a significant advantage over an analog system in that management by exception is provided. The decisionmaking capabilities of the digital computer allow for message communication of exception data, which minimizes operator duties. When exceptional conditions are detected, the operator intervention is concerned only with that particular problem. The control system digital supervisor will coordinate all other related decisions; in cases in which it is predetermined and programed, the digital supervisor will verify and assure correctness of all the operator decisions as he intervenes.

Limitations.- The provision of fail-safe control/monitoring necessitates either a totally redundant digital control system or an analog control system for backup operations in the event of a failure in the digital system. The totally redundant system is expensive to implement, and the switching of the failed components is a major control job itself; hence, an analog control system is generally used to allow continued operations after failure of the digital system.

SUBSYSTEM CONTROL/MONITORING HARDWARE

The following discussion of subsystem hardware concerns various types of sensing elements and actuators, which are the pieces of equipment that interface with the logic control and then in turn with the control center. Sensors and actuators are commonly well integrated into the subsystems in off-the-shelf configurations.

Sensors

Sensors are transducers that transform the energy of a given condition, state, or value of a process variable into another type of energy that is relatable to the controlling logic. The more frequent energy transformation is from physical to electrical; however, physical-to-physical transformation (as heat to pressure) is frequently used in pneumatic control systems.

Motion sensors.- Linear and angular motion sensors are used to detect slight degrees of motion. They are implemented by the use of potentiometers, variable capacitors, or variable transformers with a physical link to the equipment where movement is to be detected. The voltage output is proportional to the movement of the slider, plate, or core of the potentiometer, capacitor, or transformer, respectively. Linear motion is limited by the length of the sensor in the arm connection linkage technique. The angular motion is limited to less than a full revolution by most sensors of this type. A potentiometer can sense as much as 300° of angular rotation. A variable capacitor is limited to a maximum of 180° of angular motion, and a variable transformer can sense from 0 to ±45° of angular motion.

Speed of rotation is a widely used sensing requirement in industry. A centrifugal governor is one of the earliest sensors of speed of rotation. This device consists of a rotating shaft directly coupled to the unit being monitored. As the shaft spins, centrifugal force causes counterweights to spin outward. The outward motion moves an arm connected to an indicator needle showing revolutions per minute. When the indicator needle is connected to a potentiometer, the output voltage is proportional to the speed. This voltage can then be used to control the current or fuel to the engine, and a constant speed is achieved.

<u>Force sensors</u>.- Pressure or compression sensors are usually based on the use of bonded-wire strain gages. As wire in the device is stretched or compressed, its length and cross-sectional area change; hence, its resistance changes. A current transmitted through the wire will then vary in proportion to the pressure or compression. These devices are implemented with diaphragms to sense fluid pressures in engines.

<u>Sensors for fluids</u>.- Fluid sensors are devices to detect the pressure or differential pressure of both static and flowing fluids. They include the bourdon tube, mercury columns, bellows, diaphragms, and differential pressure cells, each of which can indicate, transmit, record, and/or control fluid actions. Turbine meters and rotameters are used for fluid flow measurements only.

A bourdon tube is a thin, partly flattened tube made of springy metal in a curved arc and closed at one end. Fluid is fed into the tube in the form of a liquid or gas, and increasing pressure tends to straighten the tube. The slight movement of the closed end causes a coupled indicator to move over the pressure scale. Bourdon tubes can also be spiral or helical to provide greater movement as pressure changes. Bellows and diaphragms function in much the same manner and can be coupled with linear or angular motion sensors to provide electrical outputs.

In fluids, pressure differential across an orifice plate or venturi tube is the most common parameter used to measure flow. Mercury columns with high- and low-pressure inputs that feed motion sensors such that the motion is proportional to the pressure difference are used in many standard configurations.

Fluid sensors that measure rate and quantity of flow are based on several combinations of sensors. A typical quantity-measuring device is the watermeter. This device works on the basis of incoming pressure against an oscillating disk. As the disk oscillates because of the pressure, a quantity of water (constant in proportion to the oscillations) is released to the exit pipe. The disk is coupled to a counter that is calibrated in terms of quantity of water per oscillation.

A direct-sensing rate-of-flow device is the turbine flowmeter. A small line-mounted rotor with propeller blades that turn as the fluid flows through the line senses the rate of flow. The rotor contains a magnet that spins with the blades and induces in a pickup coil a current that is proportional to the speed of rotation and hence to the fluid flow.

Another device that is commonly used to indicate flow of a liquid is the rotameter. It consists of a tapered vertical glass tube in which a metal float moves up with increasing flow and down with decreasing flow. Size relationships between the tapered-tube diameter and length and the metal float determine the range of flow covered by a given rotameter. For transmission of the flow measurement to another location for indicating, recording, and/or control, the float is equipped with a position-sensitive electromag[illegible] pickup arrangement.

Liquid-level sensors.- In any process involving the flow and storage of liquids, the measurement and control of the level become important parameters. Although many types of level-measurement hardware are readily available, only the basic methods for level detection, transmission, and control will be discussed in this report.

Wide-range level-measurement units are the tape-float and differential pressure types. In the tape-float unit, a tape moves over a digital indicator/transmitter as the float moves up and down with the liquid level in the tank. Output signals can be telemetered to remote stations for readout and control of the level. Differential pressure cells can sense pressures above and below the liquid through the use of bubble tubes and can transmit electronic or pneumatic signals to remote stations for readout and control of the level.

Narrow-range level measurements can be made with displacers, capacitance probes, and gamma radiations. In the displacer unit, buoyance variations that occur with liquid-level changes operate through a torque tube to reposition a flapper nozzle; this repositioning produces an output air signal proportional to the level. This pneumatic signal is transduced to an electric current for readout and control of level-adjustment hardware. A capacitance probe mounted in the liquid to be gaged and controlled gains capacitance with rising liquid level and furnishes an output of 4 to 20 milliamperes of current for remote indicating and control of the level. A radiation level device uses cobalt-60 gamma radiations to "look" through container walls and across the liquid surface to detect and control level. The gamma rays are absorbed by the liquid as it rises between the radiation source and detector, and a sharp change occurs in the output from the detector, which is registered in appropriate indicating and control hardware. Most level-measurement equipment can be arranged to operate alarms and/or switches at preset high and low levels for reasons of safety, assured performance, or preservation of liquid supplies.

Temperature sensors.- Both temperature level and temperature differences are important parameters in the control of processes involving consumption, transmission, or production of heat (or energy). Changes in volume of confined liquids, length of metals, resistance of semiconductors, emf of bimetallic junctions, and heat radiations can be used for measurement and control of temperature (temperature changes) and temperature differences. This discussion will include only the basic and more easily applied techniques for monitoring, indicating, recording, and controlling temperature.

The simplest device for temperature sensing is a filled system such as the mercury-in-glass thermometer because the glass thermometer is not readily used for purposes other than indicating temperature. The same principle is used in a filled-bulb system. As temperature changes, the confined fluid expands or contracts; this movement operates through levers to position indicating and controlling systems. Because of the unequal linear expansion of two dissimilar metals, bimetallic strips bend with temperature changes and constitute a near universal method of thermostatic control for both large and small temperature systems.

The functional capability of resistance thermometers is based on the fact that most metals experience an increase in electrical resistance with a rise in temperature. For a metal like platinum, the temperature/resistance relationship is very near linear from 5 to 3000 K. Conversely, semiconductor elements such as thermistors have a negative temperature coefficient that is nonlinear and quite large in the 273 to 423 K (0 to 150° C) range and that decreases to nonusefulness at temperatures above 473 K (200° C). Both the resistance thermometer and the thermistor element are relatively expensive and require Wheatstone bridge circuitry to obtain voltage output signals at a useful level. Both of these temperature-sensing elements are small in both size and heat capacity; however, both are also fragile and require adequate shielding and protection in all applications.

Thermocouples, or junctions of two dissimilar metals, are the "workhorses" of the temperature measurement industry, whereas radiation thermometers are very special temperature sensors and their discussion in this report is unwarranted. Operation of the thermocouple is based on the facts that electron pressure within a metal varies with temperature and that the electron pressure/temperature relationship is different for any two dissimilar metals in good thermal contact. What this means is that as the junction between two metals increases in temperature, an emf or difference in potential is produced in the two metals that is proportional to the temperature rise above some reference temperature. Although the accuracy, linearity, and range of the thermocouple as a temperature sensor are somewhat less than those for the resistance thermometer, its application in industrial processes is far more extensive than that of the resistance thermometer. Both low cost and rugged construction contribute to the extensive use of the thermocouple in all phases of temperature measurement and control. If greater emf output is needed than is available from a single-junction thermocouple for a given temperature, increased response per degree of temperature change can be achieved by use of multiple-junction thermocouples. These units are called thermopiles and may contain as many as 20 junctions for a twentyfold increase in output voltage.

Visible-light sensors.- Photoelectric effects produced as light strikes a material are classified as three types: (1) photoemissive, wherein electrons are released from the material; (2) photovoltaic, wherein a voltage is generated; and (3) photoconductive, wherein the resistance to electrical current is reduced by the light. All these are based on emission of electrons, although they are listed separately.

Phototubes are light-sensing devices that contain a light-sensitive cathode that emits electrons when struck by light. The anode collects the emitted electrons, and a current results if a positive voltage is kept on the anode. Gas ionization within the phototube is used to cause a greater current with respect to a given light intensity. Phototubes are widely used in industry as on-off switches, such as for lighting control or alarm systems for intrusion or smoke. Automatic door openers, counters, and conveyor belt controls generally use light beams to shine into the phototube.

Photovoltaic cells produce a voltage proportional to the light incident upon an iron disk coated with photoemissive selenium on one side. The coating allows electrons to flow readily from the selenium to the iron but not in the other direction. When light strikes selenium, free electrons flow to the iron. This transfer gives the iron a negative charge and leaves the selenium positive; thus, a voltage is established that can be used to produce current flow to an indicating meter. Light meters or exposure meters work on this principle.

Photoconductive cells also use semiconductors such as selenium to reduce resistance in the presence of light. A voltage source across the cell will cause more current to flow as increased light is applied. Cadmium sulfide crystals (in very small sizes) react to ordinary room lighting in somewhat the same way.

Phototransistors combine transistors with a lens to focus light on the base opposite the collector. In this case, light energy breaks down covalent bonds to produce a free electron for each bond broken. This process causes a reverse current through the transistor that is proportional to the intensity of light rays falling on the lens.

Radioactivity sensors.- Radioactive materials emit one or more of three types of radiation: alpha particles, beta particles, and gamma rays. Alpha particles are helium atoms that have lost two electrons; hence, they are positively charged and have four units of mass (two protons and two neutrons). Beta particles are high-speed electrons; they have a negative charge and negligible mass. Gamma rays are electromagnetic; they have energy but have negligible mass and no charge. Gamma rays are of the same nature as light rays and X-rays but have shorter wavelengths and higher frequencies. Because of their extremely short wavelengths (10^{-6} micrometers), gamma rays are more penetrating than X-rays (and much more so than beta particles); hence, they are the type of radiation normally used in radiation sensors.

Beta particles can be used for thickness measurements only on very thin materials, and alpha particles have no measurement applications. Gamma rays, however, are used extensively in the measurement and control of level and density. Level measurement by gamma rays was discussed in the section on liquid-level sensors. Density is measured in terms of energy absorbed from the penetrating beam of gamma rays as they pass through a fixed thickness of the material in question. Density measurements may be made inside process pipes or containers with wall thicknesses to 5.08 centimeters (2 inches) of iron.

The most common type of radiation sensor is the Geiger-Muller tube, which consists of a long anode and cathode and contains a small amount of a gas such as argon. Potential difference between the positive anode and the negative cathode is increased until the gas ionizes. Current flows through the tube as electrons move toward the positive anode and positive ions move toward the negative cathode. Voltage on the tube electrodes is held just below the ionization level of the gas; as gamma radiation penetrates the detecting lens, it causes the gas atoms to ionize. As a result, a current pulse flows through the resistance in the anode circuit and produces an output voltage drop across this resistance. This voltage drop opposes the applied voltage and causes deionization of the gas and hence a stoppage of current until additional gamma rays penetrate the tube and the cycle is repeated. The output pulses can be amplified to register on indicating devices such as lights or loudspeakers. Counting the pulses gives an indication of the number of photons received, which is the relative intensity of the radiation level.

Proximity sensors.- A magnetic pickup that has a stationary field about it is used to detect the presence or absence of an object on the assembly line or conveyor. As the object passes through the field, the field is distorted; this distortion induces voltage in the coil. Rate of rotation can be sensed by using this technique to sense gear teeth movement as a shaft revolves. Each tooth will interrupt the field, and the resultant pulse train permits the determination of the speed of rotation.

Capacitive relays are also used as proximity switches. The body of the operator acts as one of the plates of the capacitor connected to ground. If the operator places his hand or body in a hazardous position, the absorbed energy of the electrical circuit is sufficient to stop a radio-frequency oscillator that controls current to an electro-magnetic device that shuts power down and prevents the hazard.

Moisture-content sensors.- The sling psychrometer is a dry-bulb/wet-bulb sensing thermometer that registers two temperatures when it moves through air in which the water content is less than saturation. The lower the water content of the air, the greater the difference in temperature between the wet and dry thermometers; thus, the cooling effect of evaporation is a function of relative humidity. The difference in the two temperatures permits determination of relative humidity from a chart or calibration curve.

The functioning of a hair hygrometer is based on the principle that hair (human, for instance) will stretch as it absorbs moisture (hygroscopic). This stretching with spring backup can cause a needle to move over a scale calibrated to read directly in relative humidity.

Moisture-sensitive chemicals that change resistance as more moisture is absorbed are also used to detect relative humidity. Moisture content of powdered or granular solids can be determined by inserting two capacitance prongs a fixed distance apart. If the resistance of the dry material is known, then the change in resistance with moisture added (which will vary inversely) may be obtained. The dielectric constant of water is approximately 15 to 20 times that of most materials; therefore, small changes in the quantity of water produce relatively large changes in the dielectric constant of the material. If a wet sample is placed between the plates of a capacitor for measurement of dielectric constant before and after drying, the measurements provide data from which moisture content can be determined.

Other noteworthy methods by which moisture can be measured include infrared absorption, electrolytic hygrometry, heat of adsorption, and piezoelectric adsorption. Although the devices employing these methods provide moisture measurements in the parts-per-million range, they are expensive and often require rather extensive preparation of samples before the measurement.

<u>Density sensors</u>.- Some of the simpler methods and hardware by which the density of liquids (and some solids) can be measured and transmitted for control of an operation are the transmitting hydrometer, displacer with torque tube, displacer with electromagnetic suspension, chainomatic displacer with magnet, static head, and gamma ray absorption techniques. The principles of the torque tube, static head, and gamma ray methods for density measurements were discussed earlier in this report.

The hydrometer sinks deeper into a fluid as density decreases, and its vertical position is sensed by an attached metal rod and an external magnetic coil. In the displacer electromagnetic-suspension unit, the displacer weight is adjusted to barely sink in the fluid with the highest density to be measured. Current required in the electromagnetic coil to maintain support (suspension) of the displacer increases as the density decreases and therefore becomes an inverse signal for measurement and control. In the chainomatic displacer, three metal chains are connected loosely between the displacer and the walls of the container. As the chainomatic displacer moves upward with increasing fluid density and downward with decreasing fluid density, it supports more or less chain weight, respectively. The vertical location of the displacer is detected by a magnet internal to the displacer and a pickup coil external to the nonmagnetic container.

pH sensor.- The acidity or alkalinity of a solution can be determined by immersing special electrodes in the solution and measuring the voltage developed. The pH scale ranges from a value of 1 for highly acidic solutions to 7 for neutral solutions to 14 for strongly alkaline solutions. The pH of a solution is really an exponential measure of the concentration of hydrogen ions versus the concentration of hydroxyl ions. At a pH of 7, the solution is neutral and contains 6.02×10^{16} hydrogen ions and 6.02×10^{16} hydroxyl ions per liter of solution. For each one-unit decrease in pH, the concentration of hydrogen ions increases tenfold and the concentration of hydroxyl ions decreases by a factor of 10.

Measurement of pH in industrial streams and chemical processes is important because of its effect on corrosion of metals, deposition of solids, and rates of reactions. Liquids with pH values from 5 to 3 are highly corrosive and require special alloy metals (such as stainless steels) for handling. Liquids with pH values above 8 rapidly deposit solids (salts) when heated, and this deposition will cause plugging of transmission lines. Chemical reactions such as the polymerization of butadiene and styrene in the manufacture of synthetic rubber require careful control of pH to produce the best reaction rates for the desired product quality.

Electrode potentials are both zero at a pH of 7, and a potential difference of approximately 59 millivolts is developed for each unit pH value above and below 7. Because of the extremely high impedance between the special electrodes and the solution for which pH is being measured, a special voltage amplifier is required; even the best voltmeter or potentiometer will not measure pH in a satisfactory manner.

Actuators

An actuator is a device that converts a signal input into a mechanical motion. The input signal may be electrical, pneumatic, hydraulic, or mechanical. The mechanical motion may be linear, rotary, or reciprocating. Gears and linkages may be used to change one type of motion to another. Actuators are to be considered as control devices rather than as sensing devices.

Solenoids and motors - electrical actuators.- The most common type of electrical actuator is the solenoid. It is an electromagnet that is energized by an electrical signal and consists of a coil and a movable iron core or plunger. As the coil is energized by the input signal, its magnetic field pulls the core into the coil. A spring pulls the core back out of the coil when the coil is deenergized. The actuation is accomplished by attaching the element to be moved to the core. Solenoids are on-off devices in that they are capable of producing only two movements (push, pull). They are useful in such applications as valves, brakes, gates, doors, and dampers, where a mechanical force in a straight line is required.

Rotary solenoids are constructed by suspending the core on bearings so that the result of the electrical field causes the core to rotate in output strokes from 5° to 90°, depending on construction.

Electric motors can be considered actuators of a sort in that they convert electrical input signals into mechanical motion. They are useful in providing power to drive fans, pumps, and tools. When coupled with gears, clutches, or drive trains, motors can be used for opening and closing doors, valves, and so forth.

Clutches and brakes: A solenoid actuator can be used to engage two friction disks to produce a clutch arrangement. This method is useful in connecting an output shaft to a rotating motor for production of force for a controlled period of time. A brake is made by using a solenoid actuator to engage a rotating shaft and a stationary friction plate.

Torque and force motors: Torque and force motors are particular applications of solenoid techniques that are used to produce a few degrees of rotary motion or deflection at the end of a lever arm.

Position controls: Electrical actuators are designed to position the actuated device in response to input signals. Because solenoids are on-off devices, it is evident that they must be designed in complex fashion to operate proportionally for production of the required few degrees of control; hence, motors are used as actuators and may be coupled with generators to produce an output shaft motion representative of input signals. The counter electromotive force of the generator serves as a brake on the motor. Combinations of motors and generators, called synchrosystems, can be used to provide the stepping power required to move or rotate valves, dampers, or doors in any increments required by the process.

Fluid power actuators.- The pressure exerted by a fluid can be used to operate a plunger to produce a push or pull force as required. Actuators operated by a gas (generally air) are called pneumatic, and those operated by a liquid (generally oil) are called hydraulic actuators. Cylindrical actuators can produce a push or pull and may be backed by a spring or dual-part system that reverses the plunger direction when pressure is reduced to a preassigned value.

Rotary actuators are made by attaching a shaft to a fixed set of vanes. Usually, rotary actuators are limited to less than a full revolution (maximum 270°) by a barrier in the chamber around the shaft and vanes.

The operation of diaphragm motors is based on the application of pressure to a diaphragm that pushes against the device being actuated, such as a valve stem. The area of the diaphragm and the amount of pressure applied depend on the force required to close or open the valve, door, and so forth. When pressure is reduced, a return spring causes the actuating rod to move back to the normally open or normally closed position. Motion of these actuators can be controlled proportionally because the pressure exerted on the diaphragm moves the actuator in a proportional manner, so that indicators or electrical sensing devices can be used to show relative positions of the actuator.

Valves.- A valve is a variable-opening device used to control flow of fluids or semifluids such as powdered material. They can be either on-off or throttling devices and, as discussed previously, can be controlled by either electrical or pneumatic actuators. Most common valves are plug and seat arrangements that are sometimes called throttling or needle valves. Gate valves slide a plate into an opening to stop flow and move the plate out of the opening to permit flow. Butterfly valves have gates that rotate to control the flow and are especially effective for materials that will foul or clog plug-type or slide-type valves. Actuation of butterfly valves is accomplished with electrical, pneumatic, or hydraulic actuators, and positions of the valve can be sensed by various methods.

OPERATIONAL CONTROL/MONITORING SYSTEMS

The determination of the applicable level of control systems technology commensurate with the HUD direction for the MIUS Program was based on a survey of many types of operational systems with functions similar to those of the MIUS. Power generation, heating and cooling, water distribution, solid-waste handling, fluid flow, and building system (fire alarm, elevators, and security) installations were visited, and their control systems were studied.

Examples of control/monitoring system functions and descriptions are given in this section. Several installations for liquid-waste-treatment control and monitoring were also visited; however, the technology used in these operational systems was advanced only to a point that would provide a design baseline for the MIUS, and it was not considered of sufficient interest to include. Motor control for pumps and valves was found to be quite conventional. Detention time in processes was based on operational experience and manual tests. Hence, this effort of the MIUS design remains the most significant technological development area. The instrumentation requirements for the MIUS liquid-waste-treatment control and monitoring have been included in the section entitled "MIUS Control/Monitoring Systems."

CHILLED WATER SYSTEM
NASA LYNDON B. JOHNSON SPACE CENTER

The chilled water system at the NASA Lyndon B. Johnson Space Center (JSC) supplies chilled water at 278 K (40° F) through pipelined utility tunnels that serve centrally located air-conditioned buildings. The chilled water system is designed for the return water to reach a maximum temperature of 286 K (56° F). The system includes seven centrifugal refrigeration units operating in parallel; each unit is driven by a steam turbine. Each unit has 1814 x 10^3 kilograms (2000 tons) of refrigeration capacity and is designed to cool 0.1893 m^3/sec (3000 gal/min) of circulating water from 286 to 278 K (56° to 40° F).

The system operates under either automatic or manual control. During normal operation, the capacity of each unit is controlled automatically to maintain a preset chilled water temperature at the evaporator outlet. The control system senses the temperature of the chilled water and adjusts the speed of the turbine and modulates a damper in the suction line to compensate for heat removal requirements. This is accomplished at all loads from full to 25 percent. Loads from 25 to 10 percent require manual operation of a bypass valve to supplement the automatic techniques.

In off-normal operations when manual control is used, both the turbine governor speeds and compressor suction damper positions are adjusted with manual switches. Some chillers are equipped with electric motor-driven speed changers that are manually controlled from a display panel. These speed changers override pneumatic temperature controllers and allow manual operations to set turbine speeds above or below normal set points.

In addition to operational controls for the chilled water system, safety cutout devices are incorporated to protect the system under extreme conditions. Examples of safety cutout parameters are as follows:

Parameter	Affected Area
High temperature	Compressor main bearing (both ends), compressor oil, turbine main bearing (both ends), and turbine oil
Low temperature	Chilled water and refrigerant
Pressure	Refrigerant, compressor oil, turbine oil, low differential pressures, chilled water, and condenser water
Overspeed	Turbine

The safety devices make up the interface to an advanced alarm system to alert operators before shutdown of the system. They also provide failure indications on a status panel after shutting down the system.

OPERATION BREAKTHROUGH - AUTOMATIC CONTROL SYSTEM JERSEY CITY SITE

The Jersey City total-energy site contains five engine-generator units. Each of these units uses an individual control cabinet. The functions of speed control, real-load division, reactive-load division, voltage regulation, engine and electrical system start sequencing, alarms, and protection from undesirable operating conditions are controlled by these separate units. To attain the desired system performance, a master control unit is implemented to coordinate all the units in operation. This master control unit supervises the automatic starting and stopping of all units in response to the load demand. Preselected sequences and variations to the sequences are provided in this control of start/stop. Automatic paralleling with capability of manual paralleling is also a requirement that the master control unit must accommodate. Any or all units can be operated in a manual mode. The failure protection monitor and control features incorporated on the engine-generator units are normally not overridden during manual operations.

The individual unit controller will sense the following undesirable operating conditions:

- Low oil pressure (with lockout during startup)
- High water temperature
- High oil temperature
- Overspeed
- Underspeed
- Excessive vibration
- High oil-coolant temperature
- Lubrication filter high differential pressure
- Fuel filter high differential pressure
- High exhaust temperature
- High intake-air temperature
- Circuit breaker trip
- Excessive start time
- Overload
- Failure to parallel
- Reverse power protection
- Generator underspeed
- Overvoltage
- Undervoltage

An occurrence of any of these undesirable conditions will result in the shutting down of the engine-generator unit by the unit controller. Some of these conditions are transmitted to the master controller in two stages: an alarm is issued first and then a signal is sent that the unit has been shut down as a result of the malfunction. In any event, the shutoff notification must be sent to the master control unit. A lockout key is manually operated to bring the engine-generator unit back on line after the malfunction has been corrected. Individual-unit malfunction and status indications are reported to the master control unit from each of the five generators. The indications are unit selection in either manual or automatic control, gross unit malfunction, unit ready, unit starting, unit stopping, unit on line, and 40 and 90 percent load adjustable signals. The five generators can be automatically controlled from the master unit to be brought on line or dropped off as the load demands. A required minimum number of units on line at any time will override such dropoff in the load-sensing circuit.

Manual control for a given unit allows start, stop, and paralleling from the master control unit. The protective features of the automatic system operate in the normal manner during this manual control mode. No automatic control is provided from the individual unit controllers. The overall operational performance of the power generation functions can only be monitored and controlled from the master unit. The master unit incorporates a single meter to read line voltage, a single meter to read total current in any phase, and a single meter to read the frequency of any unit or bus. A recording wattmeter, a totalizing watt-hour meter, and a power-factor meter provide system output information at the master control unit.

The provision for terminals for additional engineering instrumentation has been specified. These terminals will allow laboratory tests of voltage control, frequency control, overspeed on startup, real-time and near-real-time load divisions during paralleling, and load dumping. They can also be used to verify the functions of the protective devices on the engines and the sequencing procedures of the master control.

OFFSHORE PLATFORM WELL CONTROL SYSTEM
LAKE CHARLES DIVISION, CONTINENTAL OIL COMPANY

The offshore platform well control system provides computerized control and monitoring of offshore gas wells, including well testing, production shut-in, turn on, and the hurricane emergency timer. Approximately 158 wells on 13 platforms are monitored and controlled by the computerized system. The data are transmitted by mi[illegible] wave transmission from Lake Charles to the Gulf, and [illegible] telephone cable is run from the Gulf to each platform.

Remote terminal units located on each platform serve as the interface between the computer system and the well hardware. Electrically controlled valves, regulators, and monitoring points are tied into the remote terminal units. These units can serve as "stand alone" remote control units irrespective of the computer system. Through a series of switches and control knobs, the operator can perform manual control electronically at a console on the platform.

The control system central hardware complex is based on a Control Data Corporation (CDC) 1700 computer with minimal peripherals (i.e., teletype, card/reader/punch, and disk). A special console for communications allows a highly trained operator to control the wells from the control room.

THE CPU-400 PILOT PLANT
COMBUSTION POWER COMPANY, INC., MENLO PARK, CALIFORNIA

The automatic control system for the CPU-400 pilot plant monitors and controls a solid-waste preparation and storage subsystem, a solid-waste combustor and gas preparation subsystem, and a turboelectric subsystem. This pilot plant system is a development item, and the control subsystem is presently tailored to the precise control of the gas temperature and flow rate delivered by the combustor. These factors affect the energy output of the gas turbine, which in turn produces the electrical energy. This electrical energy is the primary output of the pilot plant and is the primary parameter being controlled.

The control subsystem consists of a manual control system and a computerized control system. The manual control system is composed of signal transmitters, analog controllers, toggle switches, and relay logic networks. The computerized system includes portions of the aforementioned items, the computer main frame, operator terminals, and input/output and storage devices.

Operating modes of the combustor system are manually controlled with five mode switches that select one and only one of the following modes: (1) backhead, (2) fluidized operation on diesel fuel, (3) fluidized operation on diesel fuel and solid waste, (4) fluidized operation on solid waste, and (5) fluidized operation without fuel.

Valves are automatically controlled by analog controllers. The valves are electrically operated proportional valves (positions proportional to the input signals) that are controlled automatically by the analog controller. Set-point adjustment is by thumbwheel, with a meter reading for indication of the signal being transmitted.

In the automatic mode, the analog controller compares signals from the system parameters with anticipated (by operator selection) levels. The output signal is then increased or decreased based on the difference between the measured value and the selected value.

The computer system consists of a 16-bit word length minicomputer with 20K words of semiconductor main memory, a battery pack for memory refreshing during power outages, an internal communications register for input/output, and a control panel with a keylock.

The computer accepts 30 channels of low-level analog measurements from thermocouple-type devices and 80 channels of high-level analog measurements from pressure, speed, position voltage, flow rate, and other types of transducers. It uses 160 channels of discrete contact sensing measurements to monitor contact closures and alarm conditions and 32 bits of digital data to monitor mode selection.

The computer uses 18 channels of high-level analog output for set-point commands and 160 channels of discrete contact closure outputs to control the relays and contactors for programed sequences.

An annunciator panel containing lights, a CRT, and a schematic provides status indication to the operator during automatic computer-controlled operations. For manual operations, a schematic that is back-lit will indicate operating functions. When a parameter goes out of tolerance, indicator lights flash. The computer will provide a hardcopy output of alarm conditions and a CRT status indication during computer-controlled c ration.

Special-purpose gas sampling and recording equipment provides particle removing, gas cooling, drying, temperature, and flow control. These specific analyzers monitor oxygen, hydrocarbons, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxide, and hydrochloric acid. They are not connected to the manual or automatic control system. An outline particle size and count using photoluminescent techniques is being developed; however, this development is not yet complete and a more complex technique is being used. This method forces a sample through a calibrated orifice that has a given current passing through it. The change in resistance caused by the particles is proportional to the size of the particle.

WATER DISTRIBUTION CONTROL SYSTEM
SAN ANTONIO

The water distribution control system (fig. 3) consists of control equipment, telemetering equipment, a system map, and communications facilities. The system covers 466 square kilometers (180 square miles) and is divided into 6 service levels, 9 major pump stations, 13 elevated storage tanks, 27 secondary pump stations, and 57 monitoring sites.

The computer system used is the IBM 1800. The computer monitors more than 600 points and controls 350 variables. It allows for one operator to manage both water distribution and a chilled-water/steam pla The computer monitors all points every 50 milliseconds, ..gs all transactions, sounds alarms for out-of-tolerance conditons, and performs statistical data processing functions such as billing.

The IBM 2260 computer furnishes display equipment. The operator uses the IBM 2260 to request status. He may also request a special printout. Two IBM 1053 printers are used: one prints alarm messages and the other prints hourly transaction logs. A printer keyboard (IBM 1816) prints a full-day log each midnight.

Chilled-water billing is achieved by monitoring the flow and converting it to ton-hour billing units. Punched cards are output daily.

Transmissions are made over leased telephone lines. Tone signals, sent once every 15 seconds, have a maximum length of 12 seconds; the length is proportional to the value of the parameter being sampled. The computer system samples the tone signals that have been discriminated through passive filters to represent individual channels. Each parameter is sampled every 50 milliseconds. The computer is simply looking for the presence of the tone. On receipt of a null period (indicating end of transmitted value), the computer totals the counts received. A maximum of 600 counts is representative of a full-scale value (i.e., 12-second signal sampled every 50 milliseconds and tone detected each time). Hence, a 6-second tone indicates 50 percent of full scale, which is interpreted by the computer to be a half-full tank or a pressure of only one-half of full force.

All variables are converted to engineering units every minute and checked against preset limits every 2 minutes. Operator decisions are made on the basis of processed data. Priority interrupts alert the computer to evaluate critical quantities. Audible tones on alarm horns are used with printed alarm messages and alternative actions messages to indicate emergency procedures.

Coded schematics of the water and heating/cooling systems are graphically shown on a computer-controlled slide projector. This setup allows the operator to interface with the system through the computer without using unwieldy textbook-type procedures.

AUTOMATIC CONTROL AND MONITORING SYSTEM
DISNEYWORLD, FLORIDA

The automatic control and monitoring system at Disneyworld (fig. 4) provides a communications-oriented monitoring and management system for the following areas:

- Fire alarm and suppression
- Sewage treatment
- Solid-waste handling
- Domestic water
- Central energy
- Energy distribution
- Drainage
- Elevator emergency procedures
- Air handlers
- Fuel loading
- Refrigerated storage
- Security
- Secondary power

There are 1300 sensing and control points with plans for extension of these as existing services are expanded and additions are incorporated.

The system is comprised of six data terminals, called Centri, which are located geographically. These terminals scan the various parameters in their area once each second. Critical measurements are implemented on two or more terminals. The data are scanned, and any significant change is reported to the computer system. The computer system, under operator command, can request data at any time. These remote terminals are centered around minicomputers that, through software, operate the terminals. It is possible that all the required processing for a given area could be accomplished at the Centri terminal. Each terminal contains the necessary digital/analog logic to interface with the sensing points in the Disneyworld system. Six remote terminals were chosen as a result of cost trade-off studies. Primarily, the cost of installation and integration of cables (wires) compared to that of digital equipment pointed to more remote terminals rather than a single one as being cost effective. The consideration of growth through addition of functions also affected the choice of several remote terminals rather than a single one.

There are four types of displays in each of seven locations. They consist of (1) CRT data terminals, which provide the working interfaces with the operator, (2) teletypewriters for hard copy, (3) audio alarms, and (4) lamp display panels. In those instances wherein a dual display of a single critical parameter is implemented, it is driven by separate computers.

The two central computers are used to implement redundancy for critical operations. A concept of standby redundancy is used wherein computer B performs all operations while computer A does self-test programs on the entire system (including computer B). The computers are located separately to avoid common catastrophies that would cause failure of both systems. In high-activity processing periods, the standby computer takes over some of the processing load. Either computer can serve in either role.

The total software system for the Disneyworld automatic control and monitoring system consists of the following categories: executive, applications, self-test, data base, and utility. These software packages are self-descriptive.

The Disneyworld system probably represents the most forward approach to overall utilities monitoring and control that has been implemented to date. As an application to the MIUS, it contains all the functions of the hardware and most of the software. The area of the MIUS in which development data and demonstration are lacking is the physical integration of the various subsystems and their associated control and monitoring software.

SPACE SHUTTLE AVIONICS
LYNDON B. JOHNSON SPACE CENTER

The avionics subsystem of the NASA space shuttle consists of guidance, navigation, and flight control; data processing and software; communications and tracking instrumentation; displays and controls; and electrical power distribution and control. The application of the space shuttle avionics technology to the MIUS is most beneficial from a functional consideration rather than an actual implementation. The functions of onboard systems management, integration, and simulation are of particular interest. Technology requirements for the NASA space shuttle are centered around the use of proven equipment and/or techniques. Many of the concepts that are to be implemented in the shuttle avionics have been well demonstrated in the electronics laboratories at JSC. Because the detailed shuttle design is currently being formulated, no particular configuration can describe it; however, those functions related to the MIUS have been treated in the following manner.

The systems management provisions include onboard functions required by both flight and ground crews to determine vehicle status, configuration, performance, and operational readiness. These provisions include caution and warning, performance monitoring, and in-flight data recording for later ground analysis. The primary features of the onboard systems management are used in airline systems and are based on the following criteria.

1. The cockpit is the center of both in-flight and ground activities, except for hazardous servicing.

2. Operational displays and controls are used to the maximum extent for checkout.

3. Automatic fault detection is provided for flight-critical functional paths.

4. Built-in test equipment is incorporated in avionics and nonavionics equipment.

5. Previous flight subsystem performance is the basis for most ground checkout activities.

The performance of subsystems is monitored at the subsystems management station and center and at the pilot consoles. Although some systems contain provisions for automatic switching of redundant elements or for automatic safing of failed elements, most redundancy management is accomplished manually. It is generally based on data made available through the performance monitoring function and dedicated cockpit displays.

The hardware for the performance monitoring function consists of the following elements:

1. Computer and associated input/output switching

2. CRT, keyboard, and annunciator panel displays

3. Pulse-code-modulated (PCM) data bus system

4. Data acquisition system (includes remote units with stored program format controller)

5. Special-purpose recorders for ground and in-flight playback

SUMMARY OF OPERATIONAL SYSTEMS

The control/monitoring systems that have been generally described could have been implemented in several basic ways. These systems were chosen to illustrate the technology level of existing systems. The instrumentation techniques available have been discussed in earlier sections of this report. The choice of computers in these types of systems can be made from a multitude of applicable candidates. A survey of the minicomputer market and a compilation of selection advice for minicomputer users are presented in reference 1. Prices for central processors with a standard complement of memory (usually 4K to 24K maximum) are shown in reference 1 and in most trade advertisements. The added cost for peripheral equipment must be considered before price comparisons are meaningful. Reference 1 outlines the most significant selection criteria for this field of technology and lists 65 suppliers of minicomputers and associated hardware.

THE MIUS CONTROL/MONITORING SYSTEM

SELECTION CRITERIA

The selected system for the MIUS control and monitoring function will provide the information necessary for each subsystem and for the overall MIUS to accomplish intended goals. Each subsystem and the interfaces among subsystems will be monitored for those parameters that determine safe and optimum operational levels based on load requirements. To achieve these levels, switching of the subsystem components off the line or to a different operating level will be accomplished as required. A functional block diagram for the MIUS control/monitoring system is shown in figure 5.

Automatic controls shall be implemented into the MIUS design such that more effective operations can be achieved. The diversion of flows and loads and the addition of chemicals in treatment processes shall require only general supervision by a single operator.

Valve controllers, pump switches, motor controls, and automatic loaders shall be implemented into the MIUS design such that an individual or a group of measured or sensed quantities within a subsystem will provide sufficient information to the control center so that compensation can be made for changing operational situations such as flow diversion, pump control, and so forth. This requirement does not eliminate the need for regular maintenance crews that periodically service the controllers and manually fill the hoppers.

A centrally located control room will provide space for all controlling, computing, and recording equipment, as well as for operator personnel. All signals shall be routed to the control room for indicating, recording, and/or controlling from one location. Noncontrolled measurements shall be available for monitoring only in this room. In addition to housing control equipment, the control room should provide suitable and proper (quiet) space for discussions of problems as they may arise in the MIUS facility.

The control system shall be capable of operation in three different modes from the control center: (1) manual control by the operators from control center valve positioners, (2) automatic controller operation with signal output based on value of signal received, and (3) automatic signal output by digital computer based on received signals and processed associated values. In addition to these console operations, manual positioning of valves must be possible at service positions independent of the control center.

Control techniques for the types of subsystems used by the MIUS are advanced to a state of computerized conventional control. Conventional analog controllers mounted on panelboards can be adjusted by the operator or by a computer.

Continuous monitoring from a control room of the MIUS subsystems and the interfaces among subsystems shall be provided as a part of the MIUS installation. Sufficient instrumentation shall be included as a part of each subsystem and on the interfaces among subsystems so as to provide a continuous status to the operator in the central control room. Operation of the MIUS shall be conducted without the necessity of the operator having to routinely read gages, meters, and other indicators around the equipment room floor. The equipment room environment for the MIUS, like that of similar system installations, is expected to be such that routine manual operations can be performed without the need for extensive physical protection for eyes, ears, and so forth.

The MIUS control and monitoring equipment shall be capable of logging and recording selected measurements. Certain operational parameters that are of interest for long-term status reports and that are of daily or even hourly interest to operator personnel shall be logged. Strip-chart recorders and a printer output shall serve as the logging devices. Selection of data to be logged shall be by patch panel or keyboard input at the control console. Automatic logging of parameters that vary unusually and of alarm conditions shall be a function of the digital supervisor and its interface to the printer. Daily operator logs can be supplemented or fully furnished by the digital supervisory output to the printer.

SUBSYSTEM INSTRUMENTATION

Performance of a MIUS subsystem shall be monitored and controlled with sensors and control techniques that are conventional in control systems for utility and petrochemical industries. The measuring and control techniques discussed in the following sections shall be used.

Temperatures

Thermocouples shall be used to sense temperatures in heating and cooling water lines and across heat exchanges in engines, pumps, incinerators, and process tanks where temperature control enhances the operation. Amplifiers, controllers, and transmitters shall be implemented as necessary for the controlled responses to valves, pumps, and so forth, such that the optimum range of temperature is maintained.

Pressure

Fluid pressure sensor transmitters with local readout shall be used to determine pressure in the various components of the MIUS. A 4- to 20-milliampere signal that is proportional to the sensed pressure shall be transmitted to the control room. Controllers are required for those parameters for which the pressure must be regulated within high-low limits, at a specified rate of change, or for other predetermined conditions.

Flow

The flow of water in various loops of the MIUS shall be monitored with rate-of-flow devices such as orifices or flow, venturi, or Pitot tubes. Differential pressure cells that transmit 4- to 20-milliampere signals representative of the flow rate shall be used to provide the signal from the device to the control room.

The flow of conductive materials that are thick, corrosive, turbulent, or solids-bearing (such as sludge) shall be monitored with magnetic sensors. These sensors shall produce millivolt signals that are transduced to a 4- to 20-milliampere current output proportional to the flow rate.

Controllers for both categories of flow-rate sensors shall be used where the flow is to be modulated or diverted, based on predetermined factors associated with the rate. The valves or pumps that alter the flow shall contain interfaces that will accept a signal from the controller for position or start/stop control.

Level

Liquid levels in tanks shall be monitored by using float, buoyancy, or differential pressure sensors to transmit either the volume on a continuous basis or an indication of high or low levels as alarm signals. The transmitter output shall then be used to turn pumps on or off or to position valves as necessary to adjust the level to the proper volume.

Water Quality

Instrumentation for determining the effects of and the requirements for treatment of waste water and potable water shall be included in the MIUS. Examples of sensors that are to be used to determine the quality of such water follow.

1. Chlorine - Ion probes for chloride detection and total chlorine monitoring, using reagents such as orthotolidine, provide continuous chlorine levels in the stream or tank.

2. Carbon - A total organic carbon (TOC) analyzer shall be used as a continuous monitoring device to detect the immediate organic loading.

3. Conductivity - The monitoring of total dissolved solids in cooling towers and boilers shall be required. A continuous blowdown procedure that uses a conductivity cell, a transmitter, and a controller to operate the dump valves shall be implemented.

4. pH - On-line control of the pH of treated water shall be implemented through the use of electrodes, transmitters, and controllers to add acid, carbon dioxide, or other substances to change the pH as it varies above or below the optimum level for proper treatment.

Subsystem Instrumentation Summary

The instrumentation techniques specified in this section have been proved through their uses in industrial chemical and refining operations and in utilities operations during the past 15 years. The general overall acceptance of these types of instrumentation techniques at such major industrial installations qualifies them as being equally acceptable for MIUS installations. Major hardware suppliers, architectural and engineering firms, and mechanical contractors will have no difficulty in supporting the project efforts with respect to the instrumentation called for in this specification. In addition, the aspects of operation and maintenance will be accomplished with relative ease because the techniques are universal.

SYSTEM ACCURACY

The instrumentation for the MIUS control/monitoring system shall have an overall accuracy of at least ±3 percent of full scale. The following accuracies (maximum errors allowed) for the various components of the control and monitoring instrumentation shall be met as a minimum requirement.

Sensors	±0.5 percent of full scale
Transmitters	±0.5 percent of full scale
Panel meters	±2 percent of full scale
Multipoint readout devices	±0.5 percent of full scale

Off-the-shelf instruments provide these accuracies in standard configurations.

REDUNDANCY

The MIUS instrumentation shall be implemented redundantly in accordance with the following guidelines (minimum redundancy requirements).

1. No primary element or associated hardware redundancy is required for flow measurements. Failure of a given instrument will not result in degraded system performance as long as related pressure and temperature parameters are still available.

2. All temperature measurements that are transmitted to individual indicators, recorders, or controllers shall originate from a duplicate set of temperature probes. Redundant probes shall be mounted in the same thermowell as the temperature sensors that supply measurements for logging, multipoint readout, and digital supervision.

3. No primary sensor element or associated hardware redundancy is required for pressure and level measurements. However, local gages shall be implemented to provide system backup.

4. For transmission wire, 15 to 20 percent of redundant (spare) wire pairs shall be included in all multiconductor cables in conduit or trays that lead from the control center terminal boards to junction boxes in the subsystem equipment area.

5. All onstream water analysis instruments must be backed up by laboratory capabilities for periodic verification of calibration, performance, and measurement data.

These recommendations for backup or redundant instrumentation are the minimum requirements for effective continuous operations.

SPARE PARTS

A spare parts inventory of the control and monitoring system hardware shall be maintained. The following minimum quantities of spares should be kept in stock.

1. Spare panel meters with percent-full-scale faces shall be kept in inventory to represent 5 to 10 percent of the total number of meters in use.

2. Analog controllers (three mode) shall be spared at a level of 10 percent.

3. One three-pen strip-chart recorder should be kept as a spare for every five used in the control center.

4. Multipoint temperature indicators shall be installed redundantly. No sparing is required.

5. Discrete indicators (alarms and lights) shall be spared at a 10-percent level.

6. Ten to twenty percent spares or at least one of each type of plug-in circuit board for all field-replaceable digital hardware shall be required to be kept in stock.

Installation of these types of spares can be performed as a part of the normal duties of the operator.

CONTROL CENTER DISPLAY

The control center shall contain sufficient panelboard space for the display of the sensed measurements and their associated controllers. The control center shall provide display for as many as 150 temperature measurements. No more than two of these measurements need be displayed simultaneously. Selection of the particular temperature measurements to be displayed shall be made from the control panel. Temperature measurements that are continuously displayed on indicating controllers shall also be included redundantly on the selectable display.

Pressure, flow, and level indications shall be displayed on individual panel meters or on indicating controllers. Panel space shall be allocated for as many as 120 such meters.

Individual discrete measurements (on/off, high/low) shall be indicated on dedicated control panel lights, controllers, and alarms. The changing status or alarm condition shall be recognizable from the operator's station. An acknowledgment of an alarm or a discrete-level change shall be initiated by the operator by pushbutton or keyboard control. Panel space for 50 such discrete indicators shall be included in the control center.

Analog controllers with indicating meters and discrete lights shall be a part of the control center equipment. Panel space shall be reserved for as many as 100 controllers. As pointed out previously, these controllers will delete the necessity of some of the panel meters and discrete lights mentioned earlier.

Digital-supervisor-processed data (data processed by the computer system) shall be displayed on a computer-output-compatible electronic display screen. Control center space allocation for a single such device is required. Format selection by alphanumeric or functional keyboard will allow multiple usage in various operational modes.

The arrangement of these display meters, indicators, and controllers on the control panel shall be organized such that related components or subsystems of the MIUS hardware can be monitored by observing a certain section of the control panel rather than the entire panel.

ADMINISTRATIVE SUPPORT

The digital supervisory equipment shall support the project management in performing the administrative duties pertaining to logistics, payroll, rental availability, and similar factors that promote more economical operation of the overall project. The computer system shall contain auxiliary memory and programs that support the consumables usage and reorder effort for fuel, oil, treatment chemicals, and filters. The relative values of energy generated in the form of electricity and heat/cooling and the value of water/waste-treatment process operations as opposed to fuel consumption shall be computed regularly. The additional equipment required to perform these specified functions is not extensive in that only additional memory modules are necessary to allow the computations to be run concurrently with the normal operations of the control system.

DEVELOPMENT REQUIREMENTS

TECHNOLOGY ADVANCEMENT

The results of the initial survey of control and monitoring techniques applicable to the MIUS have revealed only one major hardware development requirement: the automatic monitoring of water and waste treatment processes. Organic, chemical, and biological measuring techniques require slow, detailed analysis procedures that are not readily adaptable to automation because results are not obtainable for as long as 5 days after samples are taken. Hence, electronic techniques of detecting and analyzing the constituents of processed water and treated waste effluent need to be pursued. There are several candidate concepts that provide a technology baseline for the effort.

Computer modeling of MIUS subsystems stands out significantly as required software development. The algorithms development for applications programs required to operate the MIUS must pace the hardware production schedule. Only through a modeling effort can the various expected subsystem configurations be analyzed in minimal time and at minimal expense such that the development of the algorithms can proceed.

These items of control/monitoring technology are suggested as fiscal-year 1974 budget items and are a part of the overall MIUS development program.

LABORATORY EVALUATIONS

Many of the control/monitoring system integration problems that are directly related to the integration of other MIUS subsystems will be resolved during the MIUS integration and subsystem tests (MIST) development program. The use of the MIST as a tool for furthering concepts of systems integration will especially enhance the control/monitoring techniques development.

CONCLUSIONS

In keeping with the HUD directive for use of articles of commerce in the development of the MIUS design, this survey has shown that a wide range of capabilities exists that will provide the MIUS a control/monitoring system for which equipment for sensing, actuation, local and remote control, processing, and display exist as off-the-shelf hardware. Enhanced, more automatic operation of water and liquid-waste treatment processes seems achievable with a concentrated development of biological or bacterial sensors. The monitoring and control techniques for other subsystems have been well demonstrated in operational systems throughout the United States.

Baseline systems for the MIUS control and monitoring equipment have been selected for the purposes of minimizing operator personnel and optimizing performance. Techniques employed in everyday usage in refineries, petrochemical processing plants, and utilities installations have been combined and specifically tailored to meet the MIUS applications.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, April 12, 1974
386-01-00-00-72

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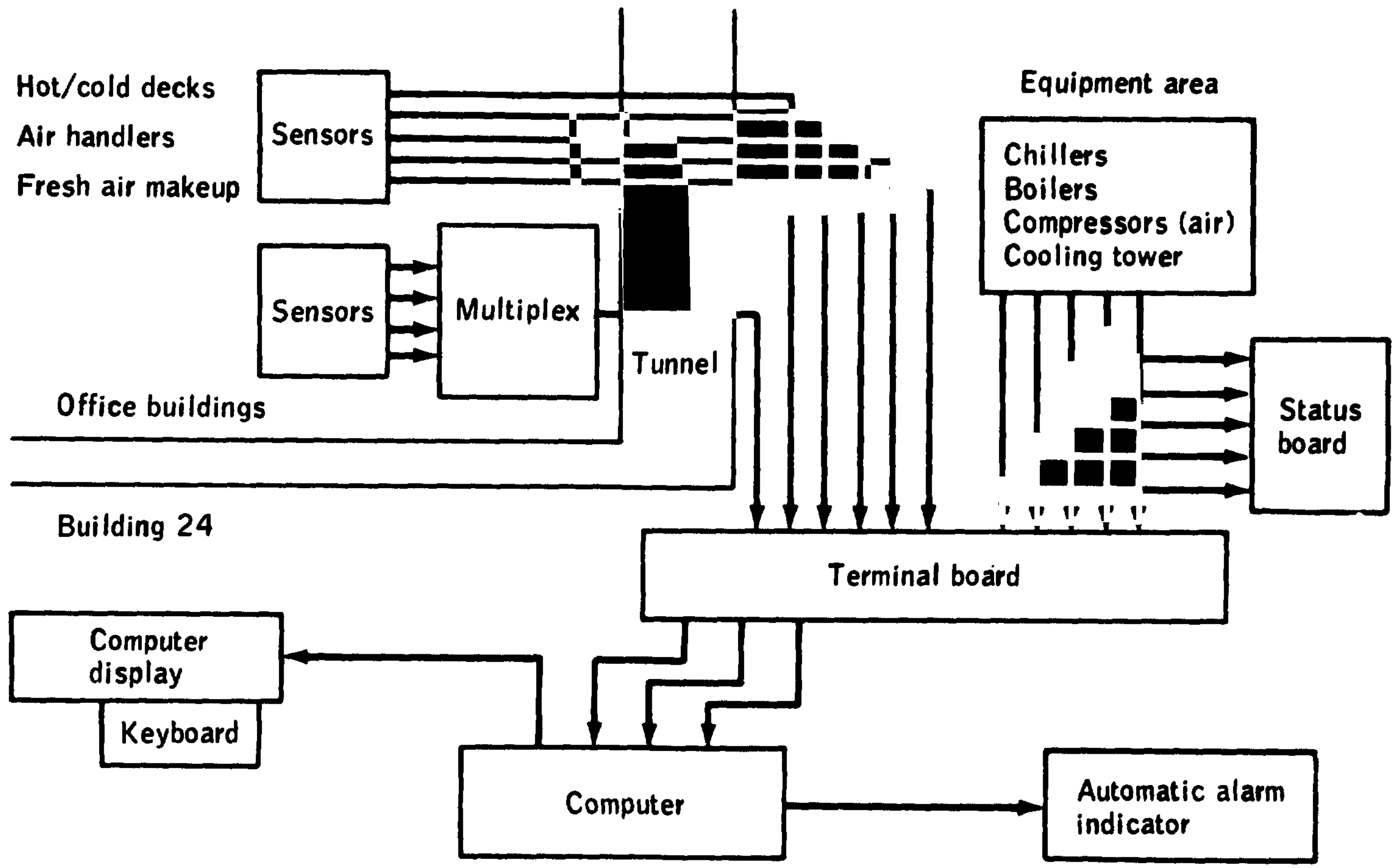

Figure 1.- Block diagram of JSC utilities control system.

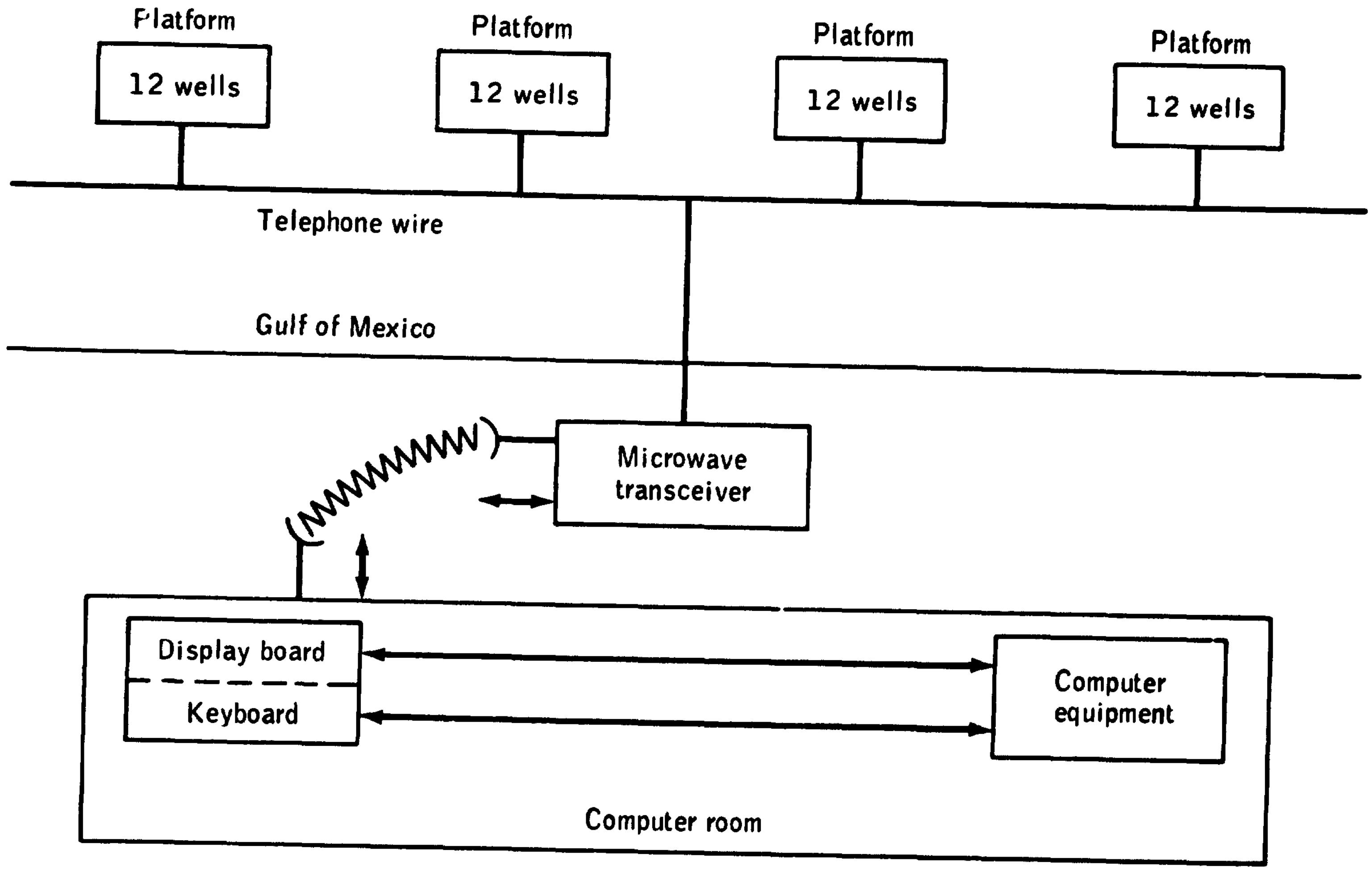

Figure 2.- Block diagram of offshore platform well control system.

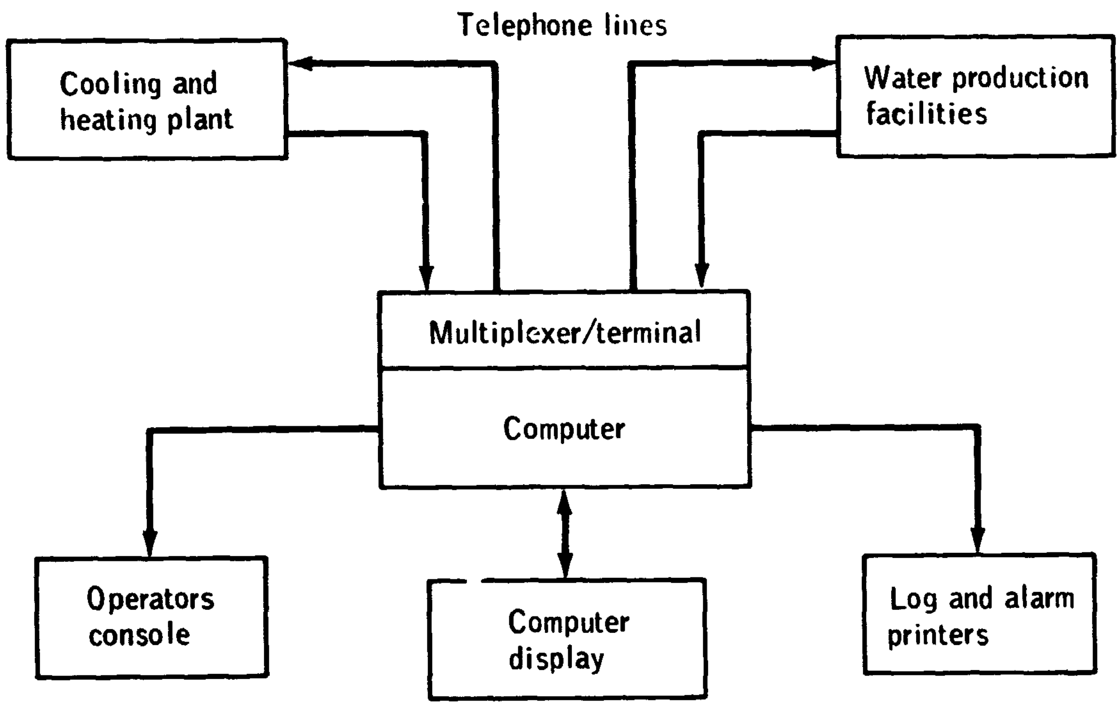

Figure 3.- Block diagram of San Antonio water distribution control system.

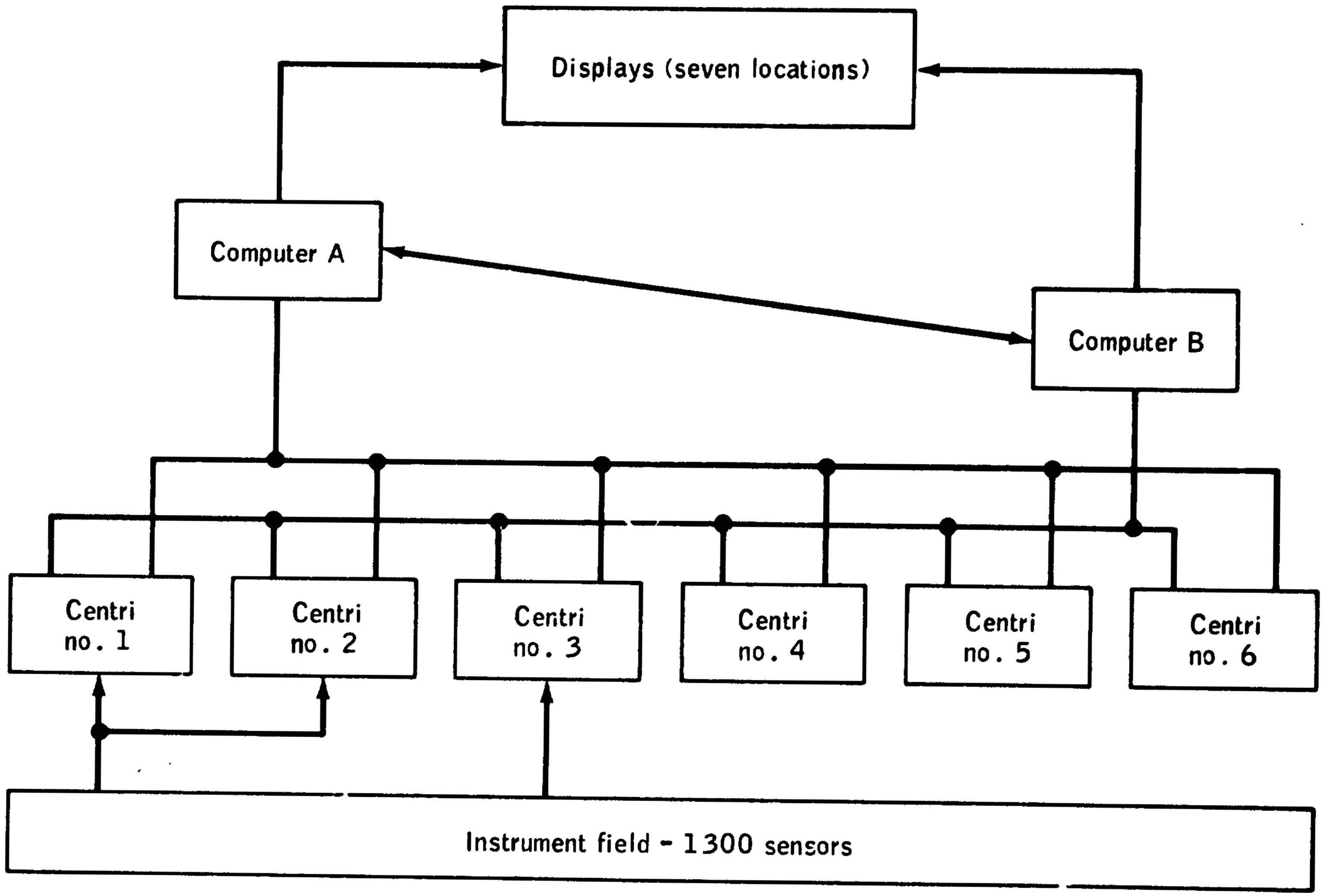

Figure 4.- Block diagram of the Disneyworld automatic control and monitoring system.

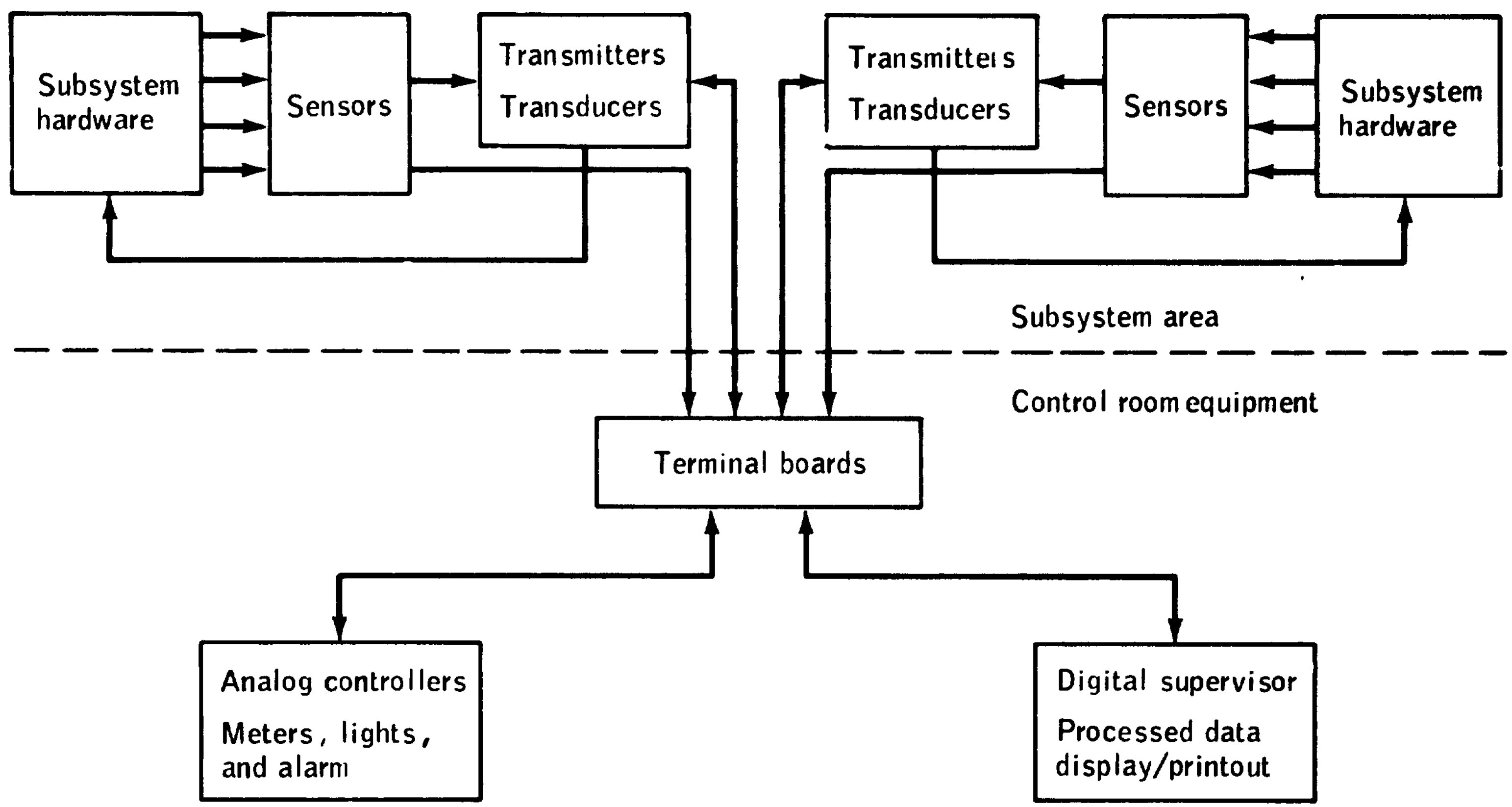

Figure 5.- Block diagram of the MIUS control and monitoring system.

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