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Modular Construction of a Balloon-Borne Apparatus*1

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Abstract: A few hundred batteries are employed to supply electricity to an experimental apparatus borne on a balloon. It is important to keep the batteries under good quality control. To facilitate such control, a modular architecture has been introduced to the organization of the batteries and the structure of the electronic system in the apparatus. The system comprises subsystems called modules. Electricity is supplied to each module by floating power supplies made from a dedicated portion of the batteries. The modules are electrically isolated individually. A local network is employed to enhance the modularity of the system. The modules communicate through a single twisted-pair cable, a party-line bus to which the modules are connected through isolation transformers.

Modular Construction

Recently, the experimental balloon-borne apparatus has increased in complexity[1]. The apparatus includes complicated detectors and a large amount of associated electronics[2,3,4]. A number of batteries are mounted on the balloon to supply electricity to the apparatus. It is important to keep the batteries under good quality control. To facilitate such control, a modular architecture has been introduced to the organization of the batteries and the structure of the electronic system in the apparatus.

Modularity is a leading principle to construct a large, complex system. By introducing the modularity properly, the system comprises modules which are integrated into the system in a well-defined way. The modules cooperate to realize the system functions. This cooperation is

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attained through interactions among the modules, where the interactions are explicitly defined. The modules can thus be tested individually under simulated interactions, which improves module quality and, therefore, the system. The modular architecture is essential to keep complexity under control. Otherwise, complexity might explode beyond practical feasibility. This article concerns the modular construction of the balloon-borne apparatus.

The electronic system in the apparatus is made of modules. The batteries are grouped so as to correspond the modules. Individual groups of batteries are dedicated floating power supplies and provide electricity to the corresponding modules. The domules are electrically isolated individually. A local network is employed to enhance the modularity of the system. The modules communicate through a single twisted-pair cable. The cable is a party-line bus to which the modules are connected through isolation transformers. Such isolation has many advantages aimed at operating the system stably. A power failure of a module does not effect the operation of other modules. Similarly, isolation localizes damage due to accidents involving high voltages which are generated in the apparatus. Furthermore, ground loops which often induce noise are eliminated by the isolation. The system is shown schematically in Figure 1.

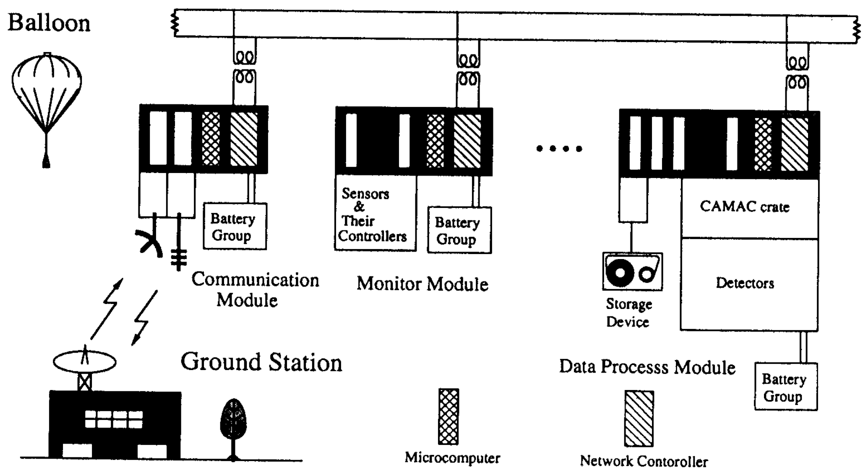

Figure 1 Schematic Diagram of the Apparatus

Modules

The experimental apparatus launched by our group includes a communication module, a monitor module and a data-process module. Communications between a ground station and the balloon-borne apparatus is controlled by the communication module. Many types of sensors are incorporated into the apparatus in order to monitor both the status and environmental conditions. The sensors are under the control of the monitor module. The sensors are connected to corresponding dedicated controllers. The monitor module accesses the controllers and gathers sensor data.

The data-process module is a large module and is provided with extensive functions to process signals from the detectors. The module includes various components: selection logic to trigger data gathering, analog and digital circuitry to process the signal, and a data-storage device. A microcomputer is employed to coordinate the components. The selection logic tests trigger conditions of events and initiate data gathering for the selected events. The signal from the detectors is amplified and digitized. The digitized data of the signal is supplied to a special hardwired logic for further processing and is then stored in a storage device.

During the final stage of construction, more experimental instruments will be incorporated into the apparatus. Therefore, modules to control the instruments will be also installed into the system. Furthermore, the data-process module will be divided into several smaller modules for improved performance. The system will include a module to measure the attitude of the apparatus, a module to accelerate even selection and some additional modules.

Batteries

The batteries are arranged into groups so that each group can be a dedicated power source of a module. Groups of batteries are floating power sources. This group supplies the entire electric power of the corresponding module; it is therefore unnecessary to hold the power return of the module common among the modules. The potential of the power return is refered to the frame potential of the gondola for safety.

Switchover of Power Sources

The battery generates electricity through an electrochemical reaction, and the response of the battery is slow compared to the speed of the system. The batteries are far from ideal power supplies. The output voltage of the battery may change largely due to the amount of output current. Furthermore, an instantaneous increase of the output current causes a larger drop of the output voltage, even though the same amount of slow increase does not lower the output voltage to such an extent.

The apparatus is turned on at the launching site before flight. The electrification of the system involves a rush current. This transient current is far beyond the rating of the battery. The batteries suffer shock when the batteries electrify the system, and the system is liable to latch-up due to CMOS IC's which are widely employed in the system. The shock might result in a power failure during the flight. The batteries must be managed so as not to be shocked by an excess current.

Switchover of the power sources is therefore introduced to eliminate the shock[5]. Auxiliary power supplies are prepared which are provided with electricity by a commercial electric line. In place of the batteries, the auxiliary power supplies electrify the system. Then, power source is switched over from the auxiliary power supplies to the batteries. The procedure to turn on and off the system becomes long and cumbersome because of the many battery groups. The isolation of the modules simplifies the switchover of the power sources, since the switchover can be applied to individual modules independently.

Voltage Regulators

The batteries supply electricity during a flight, and the output voltages of the batteries droop as time elapses. Voltage regulators are employed in order to stabilize supply voltages to the circuitry. A regulator requires a voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate. The dropout voltage is the input-output voltage difference at which the regulator ceases to function normally against a further reduction in the input voltage. The batteries necessitate supplying the sufficient voltages to compensate for the dropout voltage. A reduction of the dropout voltage extends the time interval, while the batteries afford a sufficient voltage and leads to a reduction of the power consumption in the regulator. For these reasons, reducing the dropout voltage is important for the battery powered system.

Several manufacturers are now producing such regulators that will operate for a dropout voltage of less than 100 m V. The dropout voltage is reduced by a novel circuit where the output of the regulator is modified from the emitter to the collector of a series pass transistor. The regulators are widely employed in the system. The dropout voltage depends on both the load current and the temperature. The dropout voltage increases with an increase in the the load current. Then, the regulators are distributed in the circuitry, lest the load current of each regulator should exceed the prescribed limit. The dropout voltage of the individual regulators are kept smaller than a few hundreds of millivolts.

The digital circuit uses +5 V and ground as supply voltages. A bank of batteries supplies electricity for +5 V. In the bank, units are repeated where two batteries are connected in series and a schottky barrier diode is inserted to protect the batteries from any reverse bias. The current capacity of the bank is augmented by connecting the units in parallel. The output of the batteries are nominally around 3.4 V. Then, the output voltage of the bank ranges from 6 V to 6.5 V on account of the voltage drop due to the diode. The dropout voltage due to the regulator reduces the margin of the output voltage further, making the estimated margin to be 1 V at most.

Capatitors

Gates fabricated by CMOS technology do not consume power while the gates stay quiescent. The power dissipation is caused by state transitions in the gate; advancing technology is reducing the power consumption further. CMOS IC's are, therefore, favorable for the battery powered system and are employed as widely as possible. In particular, most of the digital circuits in the system are made of CMOS IC's. Some digital circuits stay inactive until they are activated by a trigger circuit. The power consumption then rises suddenly when the circuits enter into the active state. The current drawn by a certain circuit increases by a few tens of times[6]. If such an increase of the load current were applied directly to a bank, the output voltage of the bank would decrease beyond the margin. The regulator would then not work entirely well and the regulation would deteriorate.

Capacitors are introduced so that any decrease could be kept within the margin. A capacitor is connected in parallel with the bank. The capacitor is charged while the circuit is not active, and electricity is discharged while the circuit is operating. The capacitor affords a sudden increase in the load current by discharging electricity. The voltage across the capacitor, which is applied to the regulator input, decreases along with the discharge of electricity. The capacitor is so large that the voltage decrease stays within the margin during the active state of the circuit. The amount of capacitance required depends on the triggering rate, the active time interval and the active load current. A capacitor of a few millifarads is used in a circuit where the active load current is 30 A and the active time interval is 10 microseconds. The triggering rate is a few kilohertz.

Supply voltages to the the module are to be applied or removed simultaneously. Otherwise, the circuits in the modele might be damaged or destroyed by unbalanced applied voltages. Now, capacitors are being provided to buffer any sudden increase in the load current. The capacitors are then charged or discharged quickly when the module is turned on or off. Any quick charge or discharge of large capacitance involves a large transient current. Difficulties associated with this current is resolved by the switchover of power sources.

A Network

Interaction are implemented in various ways in the system. Components are integrated into a module by the interactions; the efficiency has priority in the implementaion at the level of components. Interactions among the modules are implemented so as to enhance the independence of the individual modules. A local network is employed for this purpose. The modules communicate through a single twisted-pair cable. The cable is a party-line bus to which the modules are connected through isolation fransformers. The rate of data transmission in the network is 4 M bits per second.

Network Controller

A network controller is installed in each module. The controllers are connected to the cable and access the network. The controllers cooperate to communicate with one another. The controller on the network has a unique network address. This address identifies the controller and, thereby, the module where the controller is installed. A packet is a unit of transmission on the network. Data and control information are encoded into the packet. The control information includes the addresses of the source controller which puts out the packet and the destination controller to which the packet is addressed. The packets are classified into message packet, acknowledgement packents and synchronization packets. The source controller encodes data into the message packet and puts it out on the network. The packet on the network is watched by the controller and is taken in by the destination controller. The destination controller returns either an affirmative or negative acknowledgement packet according to whether the controller receives the packet without errors.

Upon receiving the packet, the controller tests the soundness of transmission by an error check code included by the packet. An acknowledgement packet is put out immediately following the completion of the message packet, lest a third controller should put out a packet meanwhile. When the source controller does not receive the affirmative acknowledgement packet, retrial message packets are sent repeatedly until the controller receives an affirmative acknowledgement packet or until the repetition reaches a prescribed number. The retrial message packets are identical with the original message packet, except for the control information. The control information is modified on every repetition lest the destination controller should receive the message packet in duplicate.

The only controller is allowed to put out a packet once. The controllers sense the cable and ascertain the network being available before putting out a packet. Two of the controllers may happen to send packets at the same time. In such cases the packets collide on the network. The collision is not detected by the source controllers. Namely, the colliding packets are sent to the end and are then processed in the same way as the packet to which the controller does not receive an acknowledgement packet. It therefore takes time to recover from a collision. The performance of the network may decrease if collisions occur frequently. To reduce the possibility of a collision, the controller calculates an algorithm when the packet is put out on the network. The calculation is based on a timer incorporated in the controller, where the timers are synchronized among the controllers in the network. Synchronization among the controllers is attained through synchronization packets which are received by all of the controllers in the network.

The controller executes "carrier sense multiple access with acknowledgement" or the Omninet[1] protocol autonomously as far as possible, therby minimizing the intervention of a microcomputer. What is required for the microcomputer to transfer a block of data is to provide the controller with a destination network address and the block data. The controller then transmits the block data to the destination controller and returns results to the microcomputer. It errors occur, the controller reties the transmission automously without disturbing the microcomputer for service. Receiving a message packet correctly, the destination controller generates an interrupt and requests the microcomputer to retreieve the received data.

Microcomputers and Interfaces

Microcomputers are installed in the individual modules. The microcomputer controls the module. It supervises the network controller and manages communications among the module. Components in the module are kept under its control. The microcomputer is constructed on a single board. Additional RAM's and ROM's exist on a separate board. A nucleus residing on the microcomputer realizes a real-time multi-task environment. Tasks run concurrently under the nucleus.

[1] Registered trademark of Corvus Systems, Inc.

The network controller is also implemented on a single board. The controller chip[2] is mounted on the board. The controller chip frequently accesses a network buffer. The microcomputer also reads and writes the network buffer. The buffer is allocated on a local memory, lest frequent accessing by the controller chip should interfere with the memory cycles of the microcomputer. The local memory and an arbitration circuit are implemented on the board. The arbitration circuit makes the local memory emulate a dual-port memory. The local memory is accessed independently by both the microcomputer and the controller chip. Synchronization between the microcomputer and the controller is attained by interrupts which are prepared by the controller chip.

The components in the module are connected to the microcomputer through interface circuits fabricated on individual boards. The boards are housed in a crate. Interconnections among the boards are attained through buses on the backplane of the crate. The crate in each module includes a microcomputer board and a network controller board in common. The interface boards in the crate may vary among the modules, depending on the components under controll. The crate uses +5 V and ground for supply voltages. Electricity is supplied to the boards through power buses on the backplane. The amount of current required by the crate depends on the configuration of the interface boards, and ranges from 0.5 A to 1.5 A. A single voltage regulator affords sufficient current for the crate.

Remote Process

Commands

The experimental apparatus borne on a balloon is linked by radio with the ground station[7]. The apparatus is kept under the control of a terminal placed at the ground station. Control is achieved through commands typed to the terminal. The command includes a module code which identifies the addressed module. The command transmitted from the ground station is received by the communication module and is then guided to the addressed module through the network. The command is processed in the addressed module. Individual modules issue messages when the modules require commands. Brought to the communication module through the network, the results of the commands and the messages are telemetered to the ground station and displayed on the terminal. The terminal at the ground station emulates the console of each microcomputer in the module.

Commond Decoder and Radio Transmitter

The communication module includes both a command decoder and a radio transmitter. They are controlled by the microcomputer in the module. Commands are received by the command decoder. The output of the decoder is fed to the microcomputer through an interface board. A radio transmitter is connected to the output of a transmission controller residing on an interface board. The transmission controller converts data prepared in a transmission buffer

[2] μPD72105: a product of NEC Corporation.

to the serial bit stream which is supplied to the radio transmitter. The transmission buffer is allocated on the memory and is shared for common use between the transmission controller and the microcomputer. Data are prepared in the transmission buffer before the transmission controller is initiated. Once initiated, the transmission controller operates autonomously on a direct-memory access basis.

Remote Process

A network routine is a task unde the nucleus and is concerned with inputs and output through the network. The network routine keeps the network controller and the network buffer under control. The controller and the buffer are accessed through the routine. When data and the network address are submitted, the routine begins to operate. The routine arranges data and the address information in the buffer and initiates the controller. A message packet for the data is then created and put out on the network. When the controller takes in a message packet, a network routine is initiated. The routine moves the data in the buffer into the input queues of a dispatcher. Thus, the network buffer is made ready for receiving the next packets.

A remote process is supported where a procedure residing in one microcomputer is called from another through the network. This process is realized through request blocks carried by the message packet. The request block contains sufficient information to execute a remote request. The request block includes a task identifier by which the dispatcher queues the request block to the specified task. The request block also includes the data to be processed by the task. When the request involves the return of results produced by the task, the request block contains a network address and a task identifier to which the results are to be returned. The results ars then encoded into a request block and transmitted to the module of the given network address. The request block for the results is then submitted to the specified task.

When the commands are received by the communication module, a request block for the command is created in which the task identifier points to a command interpreter. The command interpreter is a task under the nucleus. The module code of the command is then converted to the network address in order to determine which module the command is addressed to. If the command addresses to the communication module, the request block for the command is submitted to the command interpreter. Results of the command are put into the transmission buffer and then telemetered at once. Otherwise, the request block for the command is submitted to the network routine.

After the message packet for the command arrives at the destination module, the request block is routed to the command interpreter. The command interpreter then processes the command. After completion of the command, the results are encoded into the request block, where the task pointer points to a transmission interface in the communication modele. The request block is submitted to the network routine and carried to the communication module. The request block is then guided to the transmission interface where the results in the block are moved to the transmission buffer.

Concluding Remarks

The experimental apparatus was launched in the early summer of last year. The flight was successful and the system described above operated as designed without any trouble. Switchover of power sources was applied in order to turn on and off the system excellently while proving its effectivencess.

The data-process module is a large module which includes many components. The data-storage device is among such components. The components are controlled by a microcomputer under a real-time environment, and many tasks are run concurrently. The program in the microcomputer thus becomes complicated and neccessarily wastes time. To improve the performance, the data-storge device which until now has resided in the data-process module will be moved to the data-storage module, which has been newly added to the system to control the device. A fast data path between the data-process module and the data-storage module will also be implemented. A new configuration of modules will hopefully simplify the programs in the modules and improve performance.

A single terminal now emulates the consoles of the three microcomputers. It is confusing and cumbersome to use such a termical in which plural microcomputer share their console. Furthermore, the number of the modules will increase soon. It will then be convenient that the indiviual microcomputers have their own console at the grount station.

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