

DST Project

**Computerization of the
Control System of the
University
Planetarium**

Project Completion Report

June 2003

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1. Introduction

1.1 Origin of the Project

The Sri Sathya Sai Space Theatre was established in November 1985, a gift from the Sathya Sai Society of America to the Sri Sathya Sai Institute of Higher Learning. This Deemed University thus became the first one in the country to have a Planetarium of its own. The Sri Sathya Sai Space Theatre incorporates the Planetarium System 512 from Spitz Space Systems Inc., USA. All the Planetarium equipment was installed and commissioned by Spitz Inc. as a turnkey project.

The Planetarium functioned well, providing instruction to the students and general science introductions along with entertainment for the general public. Just as free education is provided at the Institute, Planetarium shows are also free, for the students as well as for the general public.

However, with the passage of time, frequent breakdowns interrupted the smooth functioning of the Planetarium. Repairs were found to be tedious due to the complexity of the control system. Spares were also becoming scarce due to obsolescence.

Though the system was kept operational with increasing effort, it was clear that a major overhaul would be necessary.

The Planetarium display system includes a large number of slide projectors, special effect projectors, video projectors and the Planetarium Instrument. The latter includes the star sphere projector and projectors to simulate other celestial bodies like the Sun, the Moon and the planets. A Planetarium show involves the control of all these resources to produce an aesthetic impact. Manual control of resources is feasible if the number of resources is not too large. But as the number of resources increases, if their control is done manually, complexity of the show is limited by the dexterity of the operator. The creativity of the show designer cannot find full expression. Controlling more than a hundred switches and sliders in a time-critical manner is no trivial task. Hence, automation of the control system is highly desirable. Thus, a total solution for the control of the Planetarium System was required to implement automation features also.

Spitz Inc. was contacted in this regard and they gave an informal estimate of US\$ 70,000 to US\$ 80,000 for a turnkey contract for upgrading the Planetarium. This much expenditure on this count could not be made by the Institute. Yet, the Planetarium was a valuable asset that had to be kept in good working condition. A detailed study of the problem and

discussions with experts in the field of control systems made it apparent that an innovative PC-based solution was feasible.

1.2 The original system

Our Planetarium has eighteen carousel slide projectors, more than thirty special effect projectors, and more projectors incorporated in the Planetarium Instrument. Special effect projectors include such effects as Space Shuttle launch, Comet, Rainbow, Ylem, Saturn Rise, various unveiler and ripple effects and planetary rotators of the Earth and Jupiter. It had an automation system supplied by the manufacturer, Spitz Space Systems Inc. This was based on a 4-track spool tape recorder and a dual track cassette recorder.

Our Planetarium's dome has a tilted design, so that the audience faces only one direction. The 15-metre diameter dome is tilted by 10 degrees. The images from the various slide projectors and special effect projectors are projected from ports located at the rear of the Theatre, to cover the front 180 degrees of viewing area. The Planetarium Instrument located at the centre of the Theatre projects the star field over the entire 360 degrees of the dome using the star sphere projector. The Instrument also projects heavenly bodies like the Sun, the Moon, and the planets.

To control all the equipment, the operator stood at the rear of the Theatre at a 4-metre long console with around a hundred knobs, switches and sliders. For recording automation signals onto the 4-track spool tape recorder, the operator actually went through the motions of controlling all the resources in real time, synchronised with the sound track. Even when the show was running using the automation signals, the operator could manually override the automation, taking over control of individual resources.

1.3 The limitations of the original system

1. Equipment failures

The 4-track spool tape recorder used for automation has now become obsolete. Spare parts for it are not available. The 4-track also experienced frequent failures. The cassette recorder was a customised type, incompatible with standard consumer products. Spares for this were also not available.

2. Cumbersome automation

Making new shows with the original automation system involved switching on all the resources with central air-conditioning and practising repeatedly for correct cueing. This approach was very cumbersome. Students could not easily take part in the show creation process due to its complexity.

3. Inability to depict animation and video

The Spitz 512 Planetarium System did not have the facility of projecting video or animation sequences. The only dynamic images in the Planetarium were created with the special effect projectors and the Planetarium Instrument. Newly available media like Laser Discs (LDs) and Digital Versatile Discs (DVDs) of Computer Generated Animation (CGA) and other astronomy related material available in the public domain from sources like National Aeronautics and Space Agency (NASA) of the United States of America and the European Space Agency (ESA) could not be easily incorporated into the Planetarium shows.

1.4 The envisaged solution

A PC-based control solution avoids the failure of the 4-track during playback. The control signals are sourced from the PC, and hence the 4-track could be dispensed with. The PC-based control system was to be developed in modular form. With the newly developed system, new shows were to be created on any multimedia PC that has the show creation software loaded. Thus, both the equipment failure and the

cumbersome nature of the automation system could be overcome.

It was also envisaged to upgrade the Planetarium system with the addition of a video LCD projector, which would be capable of projecting videos as well as CG animations from a Computer Workstation. This would enable the incorporation of the latest space imagery in new Planetarium Shows.

2. Design Philosophy in Project Execution

The original Planetarium control system's "back-end", consisting of high-current drivers, bipolar motor drivers and the like, was fairly rugged. The "front-end", consisting of a control panel with mechanical switches and the 4-track, was unwieldy and prone to failure. Making the best use of available resources, it was decided to retain the "back-end" and substitute the "front-end" with a PC-based control system. Further upgrading of the facilities was also planned, by the addition of video projection capabilities.

Such a design would entail the interfacing of the computer control PC with the original control system. The TTL circuitry of the original control system fortuitously provided many uncomplicated interface paths. Interfacing could be done with parallel data paths or a serial data path, depending on the interfacing scheme chosen. The original control system was studied to bring forward the various options in carrying out the interfacing.

Another factor to be borne in mind during the execution of the Project was that the Planetarium was a valuable resource of the Institute and had to be kept in working condition,

minimising the disruption of regular shows scheduled. The execution of the circuit interventions had to be designed and carried out during the lean period of the summer months.

3. The original control system

3.1 Schematics

The controlling of resources was originally done using a control panel of mechanical switches and sliders. This panel was attached to the 4-track reel-to-reel tape deck of TASCAM make, and logic circuitry called ATM2. In simple terms, the system had a “recording mode” and a “playback mode”. In the recording mode, information about switch/slider settings on the control panel is recorded on the automation track of the 4-track spool recorder. The resources reflect the settings on the switches and sliders as well. In the playback mode, this information is played back from the 4-track and used to control the Planetarium resources. The playback mode has an additional feature, “manual override”. When override is enabled, changes made on the control panel during playback override recorded signals for the relevant resource.

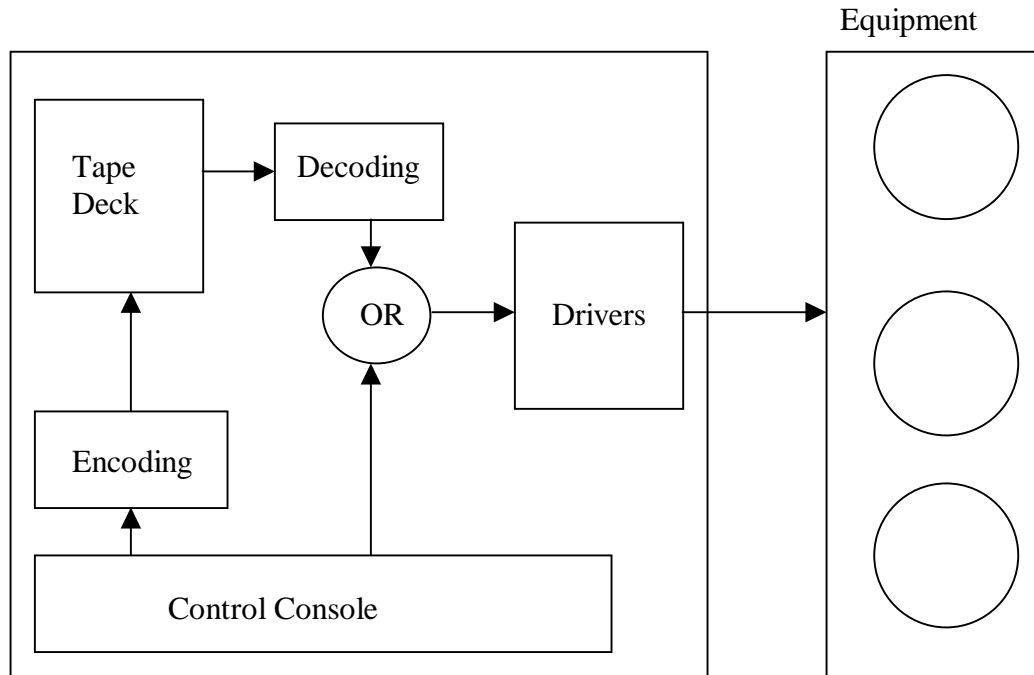


Fig. 1: Schematic of the original control system

3.2 Circuitry

All the relevant circuitry on the control panel, along with the ATM2 logic circuitry, is TTL compatible. In other words, 0-5V digital signals only are used. Each switch/slider is associated with one or more digital signals, called channels. A simple on/off switch controls a single channel. A slider controls three or four channels. These channels form the bits of a binary number representing the level of the slider. All the channels from the control panel, 384 in number, are sampled three times a second and multiplexed into a serial bit stream by the logic circuitry. This stream is recorded on the automation track of the

spool tape as an analogue signal after suitable wave shaping and modulation. On playback, the analogue signal from the automation track is converted to a serial bit stream by wave shaping. The serial bit stream is demultiplexed and sent to the various resources. Digital to analogue driver circuitry is located near each resource. This circuitry then controls the functions of each resource. Thus, the long runs of cable from the control panel console to the remote resources handle only low voltages and currents.

4. The new control system - design

4.1 Designing the interface

In the interfacing of the control system with a PC, signals from the PC could be injected in various ways, as follows:

1. Analogue signal input to the logic circuitry
2. Multiplexed digital signals in the logic circuitry
3. Demultiplexed digital signals after the logic circuitry
4. Demultiplexed digital signals before the logic circuitry

Each of these options was studied one by one.

1. Analogue signal input to the logic circuitry

In order to input a suitable analogue signal to the logic circuitry, the original signals were to be reverse engineered. This was an attractive idea, since if the control computer could mimic the analogue signal, only a single pair of wires would be needed for the interface. Cabling requirements would then be reduced to a minimum.

Trials were carried out by which the signals from the spool tape were recorded as an uncompressed PCM file on a PC and played back using a commercially available sound card. Piping these signals from the sound card to the automation

logic could trigger the circuitry correctly under certain conditions.

1. The signal had to be sampled at 48 kHz.
2. The level of the soundcard output had to be high enough to trigger the circuitry – around 5V peak.
3. The soundcard had to have a clean high frequency response.

It was found by trial and error that a certain type of sound card (ESS Solo) was suitable, while another type (Yamaha DS-XG) was not – presumably because of the noisier output of the latter card.

Even though this much progress was made, mimicking the analogue signal proved difficult. Generating suitable signals without the signals originating from the control logic proved too complicated in the limited time frame of the project. In this situation, if replacing the spool tape recorder was the only objective, this path could have been followed, with the computer with the sound card replacing the spool tape recorder. But our objective was to enable show creation remotely. With this objective in mind, this approach was abandoned and the next option was explored. The automation signal is illustrated below.

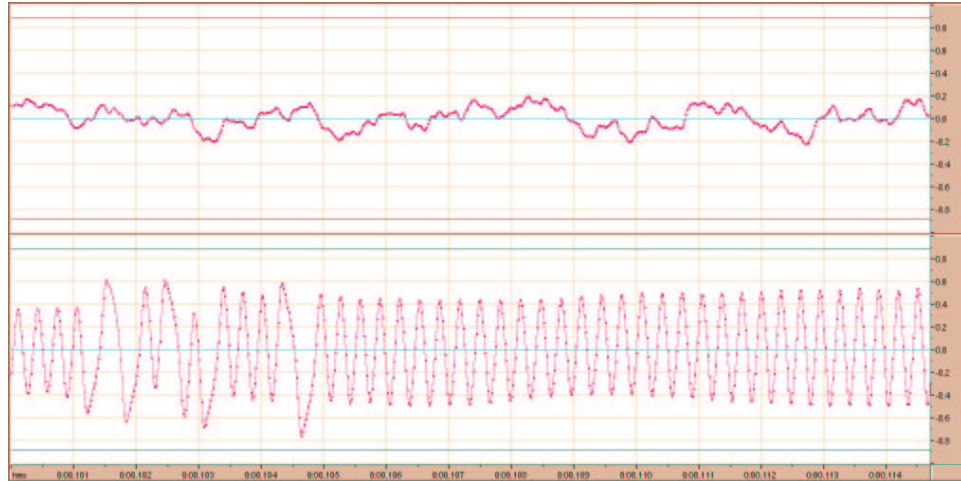


Fig. 2: The automation signal is the one in the lower pane. The signal on the upper pane is the audio track. The horizontal time axis is incremented in milliseconds.

2. Multiplexed digital signals in the logic circuitry

The other option with minimal cabling was the injection of a multiplexed digital bit stream into the logic circuitry. This idea was actively pursued and a test circuit was breadboarded based on this concept. It was found by experimenting with breadboarded TTL ICs that the PC interface needed to send the bit stream based on the console's internal clock, and that the time lag between the receipt of the clock pulse and the sending of the relevant bit had to be less than 10 microseconds. Any delays greater than 10 microseconds would prevent the interface from working satisfactorily. This circuit is described below.

Breadboarded test circuit

At one point of the original control circuitry, the multiplexed bit stream is read bitwise into buffer memory. A 9-bit read address register cycles through its 512 states 3 times in a second, and bits corresponding to the channel represented by the address register are sent serially into the buffer. Intercepting the signal at this point, injecting our own bits at this point, was the aim of this breadboarding trial.

The relevant part of the original control circuitry is shown below.

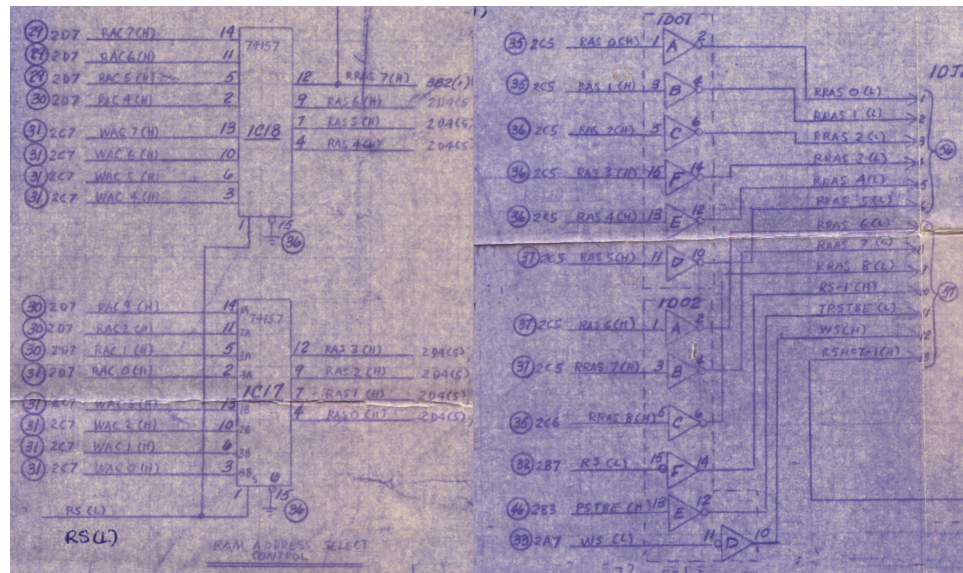


Fig. 3: This is one fourth of one sheet of nine sheets that describe the ATM automation control.

The block diagram of the breadboarded circuit is shown below.

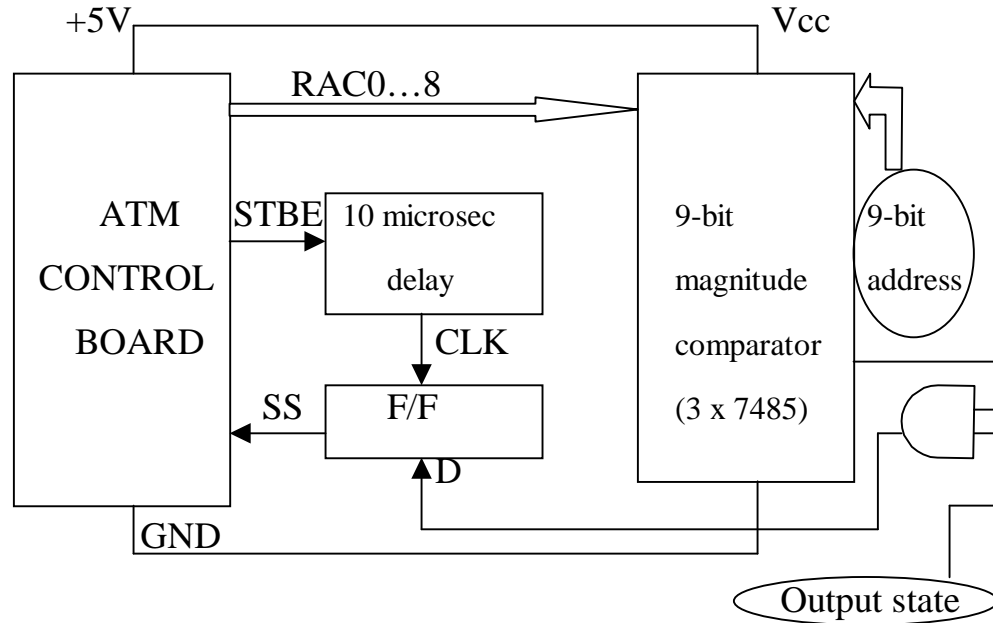


Fig. 4: The comparator triggers an AND gate when the RAC 9-bit address matches the preset 9-bit address set for the comparator. This AND gate then signals the D change of state for a D flipflop (F/F). The Strobe (STBE) and SS signals are as documented in the original circuit diagrams from Spitz Inc.

The circuit was actualised according to the circuit diagram in the next page.

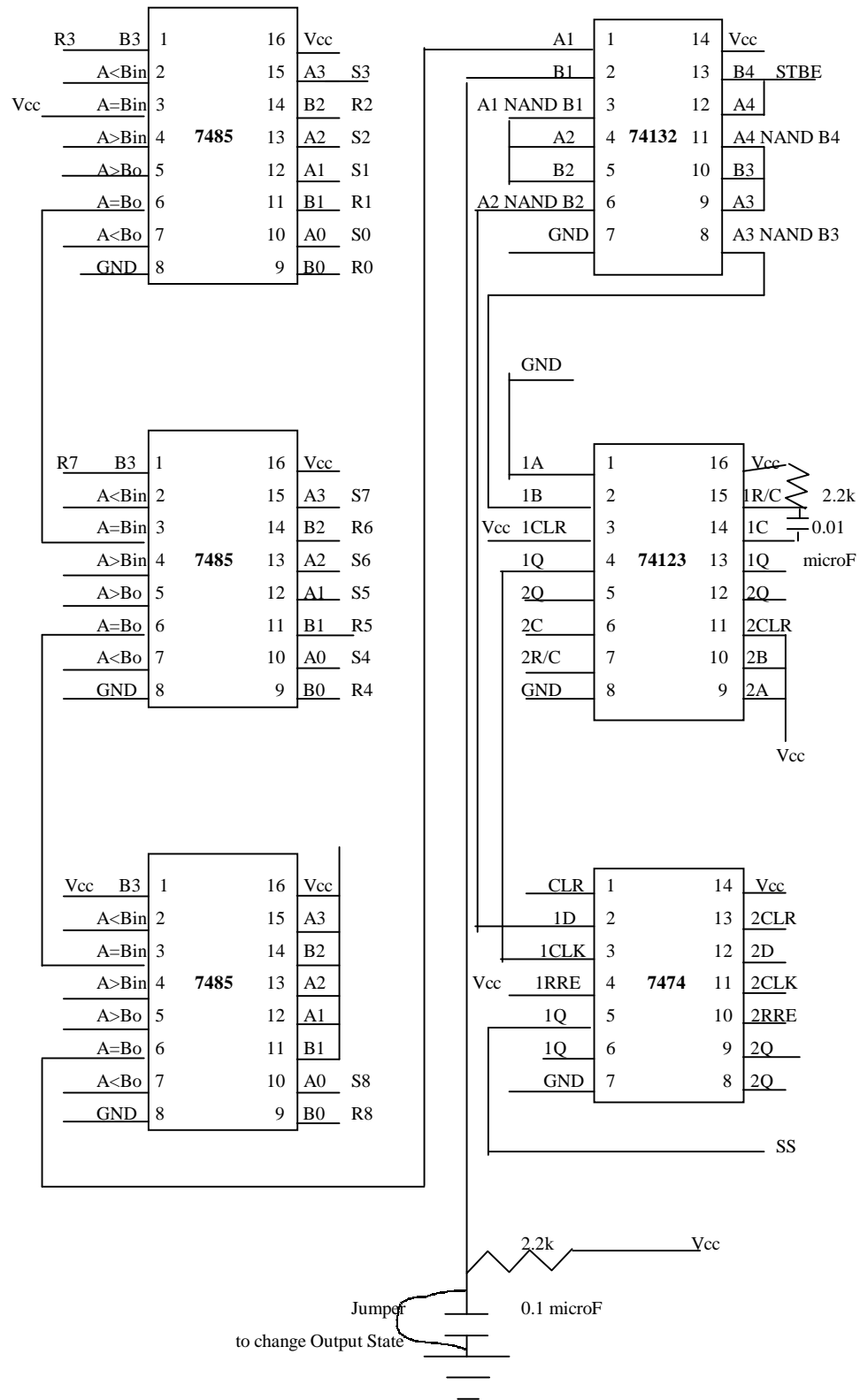


Fig. 5: Circuit diagram of bread-boarded test circuit

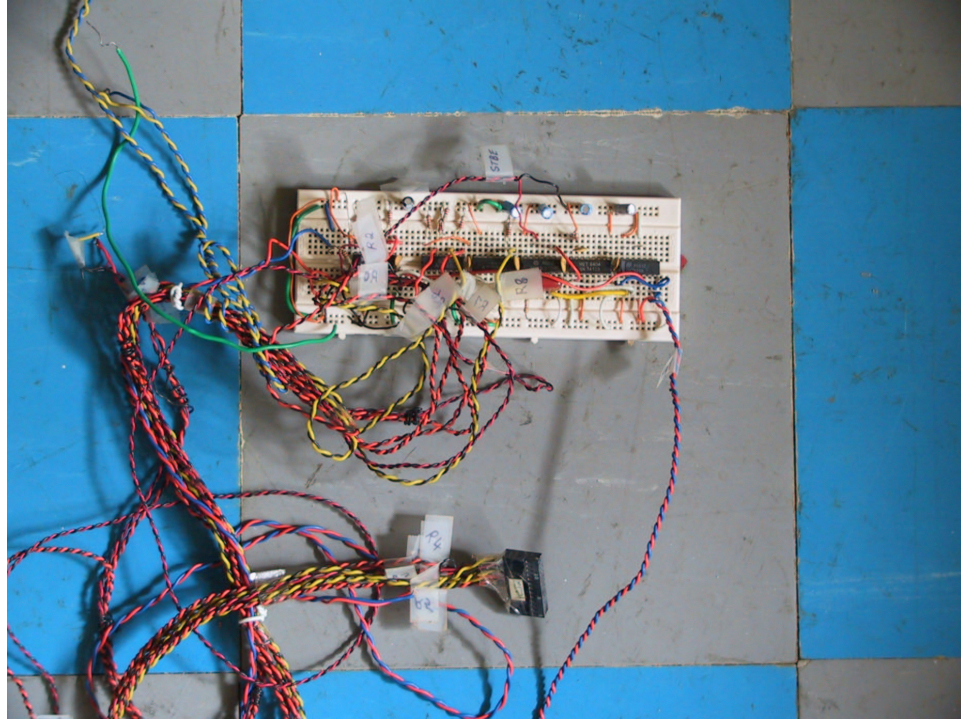


Fig. 6: The bread-boarded test circuit

This method of injecting signals into the Planetarium control system was found to have some drawbacks. The original control system was found to be sending some initialisation signals on power-up. These were presumably being sent in the channels described as being reserved for “framing” in the system documentation. These signals could not be suitably mimicked. This would then require the original system to be connected initially, and then control to be shifted to the new control system after the initialisation had been performed. This would lead to addition of complexity in the design.

Also, a test routine running on the PC showed that just the two byte input statements and the one bit output statement

was taking 12 microseconds, even without taking into account programming overheads which would be added in the case of an actual control program. This ruled out the generation of the bits one by one by the PC in response to interrupts from the control circuitry. Hence, it was decided to inject demultiplexed signals from the PC into the control system.

3. Demultiplexed digital signals after the logic circuitry

The signals emerging from the logic circuitry were not completely documented in the manuals provided by Spitz Inc. Moreover, these signals were located on connectors that were physically difficult to access. Hence, the approach to interfacing by injecting signals after the logic circuitry was abandoned in favour of the final option, that is

4. Demultiplexed digital signals before the logic circuitry

The signals from the control panel to the logic circuitry were neatly available in 72-pin and 104-pin connectors. The pin-outs of these connectors were also available from the manuals supplied by the manufacturer. Hence, it was decided to inject signals before the logic circuitry, replacing the signals from the control panel. This needed 384 digital lines from the PC to the control system.

The circuit diagrams used for this work are similar to the ones shown below.

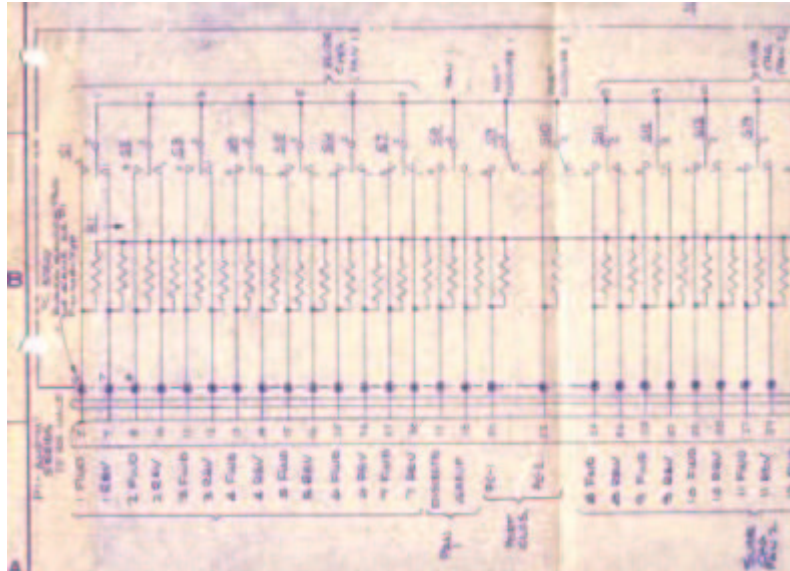


Fig. 7: This is a sample circuit of part of the control panel.

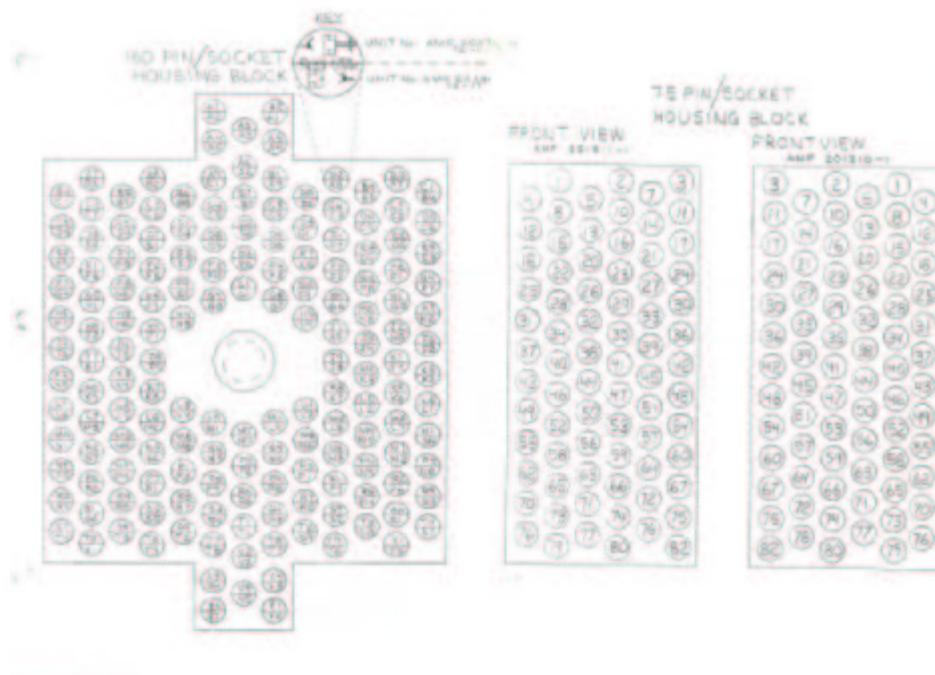


Fig. 8: Pin-outs of connectors used in injecting signals from the PC in place of signals from the original control panel.

5. The new control system – execution

5.1 The choice of hardware

Initially, interfacing work was started with a C-programmable micro-controller card from Zilog, the BL1700. This had up to 32 digital outputs, and could be interfaced with a PC using the RS-232 serial port. An MTech student of our Institute did a project on the development of a Planetarium control system using the BL1700. The abstract of the project report is included as Appendix B. Unfortunately, running the entire Planetarium system with the interfacing scheme of choice, viz. the injection of de-multiplexed digital signals before the logic circuitry, needed 384 digital lines. Having multiple BL1700s was an option, but was unwieldy and expensive. The micro-controller would have to be reprogrammed for every new Planetarium show, hence a PC would also be needed near the control system. Hence, a simpler PC based solution was explored.

Low cost 144-line digital I/O cards based on IC8255 were commercially available off the shelf. Three such cards were used to provide the required digital output capabilities to the PC. Multiple lengths of 25-core cable were used to connect the I/O cards on the PC to the control console. This wiring involved more than two kilometres of wire and more than 700 solder and crimp connections. The final solution included a TouchScreen monitor for the ease of use of the operator.



Fig. 9: The control console after the wiring – the TouchScreen monitor is on the left.

5.2 The show creation software

For ensuring the end-user's familiarity, the show creation software mimics on the computer screen the layout of the original control panel of the Planetarium. A sound file can be loaded and played. Actions done on the screen, like moving sliders, etc, are stored as actions in a show data file. Clicking on the buttons toggles them on or off. A button in the "on" state displays its text in red. The sound file can be cued to start from any location using the audio slider. The show data file is a plain text file. This consists of two tab-separated columns. The first column has time in milliseconds, and the second, the channel number to be switched on. To switch off a channel, the number in the second channel is $512 + \text{the channel number}$. The text file format was chosen so that minor tweaking to shows could be done with just a text editor, even without opening the show creation software.

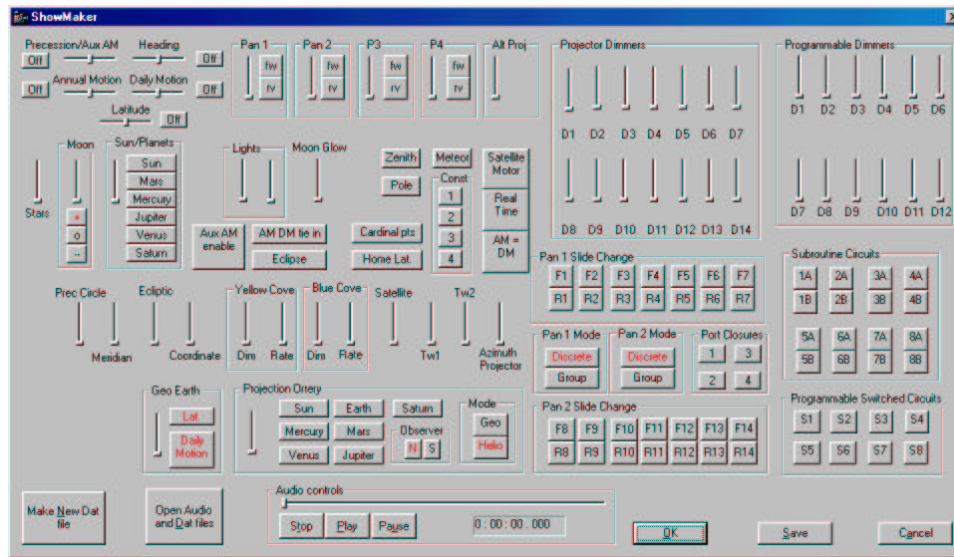


Fig. 10: The show creation software

A few lines of a sample show are included below for illustration.

Data to be sent to the controller.

```

100 176
100 188
100 190
100 241
100 243
100 56
100 574
100 575
100 689
100 701
100 703
100 752

```

100 754

1500 593

1500 594

1500 595

1500 596

1500 597

1500 598

1500 599

1500 600

..... . .

A simulation module was also developed. This module runs the Planetarium show on the computer screen, displaying bitmap images for slides and videos for special effects. This module is useful for the show designer in previewing the show under development.



Fig. 11: The show simulation software

The simulation software also incorporates a report generation feature. This assists the operator by generating a report text file listing the resources used in the show, with the on and off timings. A fragment of a sample report is shown below:

```
Pan1 Discrete at time      0:00:00.000 = 100 msec.
Pan2 Discrete at time      0:00:00.000 = 100 msec.
Proj11 On at time    0:00:03.300 = 3400 msec.
Proj11 Off at time   0:00:08.600 = 8700 msec.
Proj11 Fwd at time   0:00:10.100 = 10200 msec.
Proj9 On at time     0:00:13.900 = 14000 msec.
Proj13 On at time    0:00:22.500 = 22600 msec.
Proj13 Off at time   0:00:29.200 = 29300 msec.
Proj9 Off at time    0:00:29.400 = 29500 msec.
Proj9 Fwd at time    0:00:31.200 = 31300 msec.
Proj13 Fwd at time   0:00:31.200 = 31300 msec.
```

```
Proj11 On at time 0:00:32.800 = 32900 msec.  
Proj11 Off at time 0:00:40.500 = 40600 msec.  
Proj11 Fwd at time 0:00:41.900 = 42000 msec.  
.....
```

5.3 The show playing software

The show playing software incorporates a software component, the ActiveMovieControl ActiveX control from Microsoft™. This enables it to play audio files in many formats including uncompressed PCM (.wav), MPEG Layer 3 (.mp3) and others. To send control signals to the control console, this module uses the show data file created by the show creation software.

A tabbed interface is implemented in the show playing software to include manual override functions. Just as in the original control system, manual override can be activated at any time during the show. Control of individual resources can be overridden while the other resources continue to be controlled by the automated signals. The software is accurate to within 100 milliseconds, as it samples for actions to be done every 100 milliseconds. This is an improvement over the previous system that sampled inputs only three times a second. Provision is also made for the execution of multiple actions at the same instant in time.

5.4 The show creation studio

For the preparation of new shows, the audio track has to be recorded. For this purpose, audio editing capabilities have been acquired at the Planetarium under the DST Project. Software based multi-track editing has been implemented, in conjunction with equipment like mixers and microphones. The audio editing facility at the Planetarium uses a StudioMaster audio mixer along with a multi-track audio card DARLA from Echo Inc. This combination allows the recording of up to 99 tracks of audio, mixed down to stereo or to 8-track audio. Our Planetarium's audio system is stereo, so a stereo mix-down is very appropriate.

The new capabilities of the Planetarium include the projection of CG animation and full-motion video, using a video LCD projector acquired under the Project. In-house video editing capabilities have been built up to prepare suitable short clips for insertion into Planetarium shows. This has also been done using non-linear video editing software running on PCs. The Software-Hardware combination of Adobe Premiere and Matrox RT2000 is being used on a PC based video editing station in combination with the GV-D900 MiniDV video recorder from Sony. Edited video/animation clips are written on MiniDV tape using this editing station and played back at the theatre from the MiniDV video recorder.

6. Conclusion

A PC based Planetarium control system has been developed. This control system is helping us to develop new Planetarium shows easily at our facility. Collaboration with other Planetaria in the country could be done to customise this homegrown solution to suit their needs.

Many Planetaria in India are based on the erstwhile East German Carl Zeiss instruments, and have developed their own special effect projectors. These systems are predominantly manually controlled. Automating these Planetaria can be done using the technology demonstrated in this project.

This work was done with the help of a grant from DST, Govt. of India. The investigators would also like to thank the Revered Chancellor of the Sri Sathya Sai Institute of Higher Learning (Deemed University), Bhagawan Sri Sathya Sai Baba, for help and guidance during this development effort.

APPENDIX A

References

1. Spitz Space Systems Inc. 1977 System 512 Operation and Maintenance Manual.
2. Chandrasekhar N. 1999 Private Communication, Sri Sathya Sai Space Theatre.
3. Pandey P. 1998 Indigenous development of an automation system at M. P. Birla Planetarium, Calcutta. *Proc. of the 14th Int. Planetarium Society Conference*: 148-151

APPENDIX B

PROJECT REPORT ABSTRACT (II M.Tech)

STUDENT: P. Sathya Narayan (Reg No:97556)

SUPERVISOR : Dr M. Venkatesulu.

Project Title : SAI SRISHTI.

Area : Embedded Control System.

Software :

Dynamic-C (a patented product of Zilog,Inc) for the Embedded Software. VC++ on Windows 95 Operating System for the Show Simulation Software.

Motivation:

The project is undertaken in an effort to automate the control system at Sri Sathya Sai Space Theater, Prashanthi Nilayam.

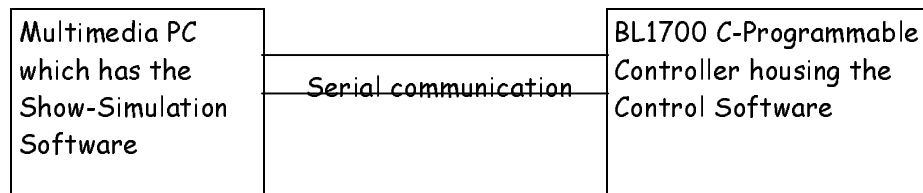
The present working system is such that production of shows is a very cumbersome and time-consuming process. Moreover, the entire show production requires the high Power-Consuming Air Conditioner to be on for long time.

Using a computer-controlled system would remove all the above-mentioned disadvantages.

Aim:

The main task is to design and implement the software which controls the planetarium equipments like Projectors, StarBall etc. Also, software support to work with devices like video-projector, which are planned for the planetarium, needs to be developed. This software is embedded in a Controller (BL1700, C-Programmable Controller, a patented product of Zilog Inc.).

In addition, the improvements required for the software already made previously should be completed. This software deals with the computer simulation of a planetarium show using multimedia interfaces. This software helps the Show-Producer to make a show and produce the commands, which are fed to the embedded software mentioned above through Serial Communication.



Methodology Adopted :

The design issues of the Control Software includes

1. Understanding the format of the data send from the Show-Simulation Software. The data sent to the controller contains information as to which device should be switched on and the timing information as to when the device should be activated.
2. Use the data and act accordingly. This is done through a giant switch loop which contains program code to issue the action as per the information.
3. The Dynamic-C software (provided by Zilog) contains API and Real-time constructs which enable the implementation of step 2.

The design issues of the Show-Simulation software includes

1. Graphical Interface of the Control Panel existing in the planetarium. For e.g. a projector is represented through a button.
2. Designing a proper structure to hold all the information regarding a device during the entire show duration.
3. The Show-Producer is provided with a preview of the Show. This enables him to view the show in the computer before making the presentation.

Tasks Accomplished :

- ♣ The format of sending the data from the PC to the controller is completed.
- ♣ The program logic to use this data and perform the required action was accomplished in a small manner where the input was hand-fed to controller.
- ♣ Many programs to get acquainted with the Controller was written and tested using LED's in place of the devices.
- ♣ The Show-Simulation software also has been simultaneously built. The Graphical Components representing the different devices in the Control panel was worked out.

- ♣ The information input by the user during the process of Show-making is processed and formatted as per the format specifications and sent to the controller through serial communication.
- ♣ The software to be embedded in the controller, which receives this data from the VC++ program and performs the needed action is developed completely and tested with the planetarium equipments. The hardware connections required from the controller to the devices form the last task in this module.
- ♣ The Show-Simulation Software which helps the Show-Producer in simulating the planetarium shows has been completed.