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Technical Note

Development of an Instrument Control System: Automation of MFOSC-P Instrument to Facilitate Remote Operation at Mt. Abu

by

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Development of an Instrument Control System: Automation of MFOSC-P Instrument to Facilitate Remote Operation at Mt. Abu

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Abstract
The instrument control systems are integral part of any scientific instrumentation, as the automation of various sub-systems would provide substantial reduction in overhead time and ease in instrument operation. Here we describe the development of an instrument control system to cater the need of an in-house developed imager-sepctrograph (Mt. Abu Faint Object Spectrograph and Camera - Pathfinder, MFOSC-P) for PRL 1.2m telescope at Mt. Abu. The control system has been built around two off-the-shelf motion system controller units as well as several additional electronic modules (e.g. motor drivers). Some of the purpose specific modules (e.g. lamp control electronics) have been developed in-house. The graphical user's interface (GUI) of the control system has also been developed and it can be easily configured as per sub-systems' requirements. The controller aids the operation controls of MFOSC-P e.g. precise positioning of slits, gratings and filters, operations of calibration lamps etc. MFOSC-P has five motion systems, viz. filter wheel, grating, slit, calibration mirror positioning and auto-guider unit. These motion systems are driven by stepper motors with encoder feedbacks, limits and home sensors. These motion systems and the lamps in the calibration unit are operated with this control system via the GUI. The control system is successfully being used since February 2019 as a part of MFOSC-P instrument. The required positional accuracy, repeatability etc. for various motion sub-systems and other control aspects have been achieved and demonstrated through repeated scientific observations on the telescope. Here, we present the hardware & software design architectures and implementation of the control system. The performance of the control system, evaluated through various laboratory tests and with scientific observations on the telescope, is also discussed.

Keywords
PRL Telescope, MFOSC-P, Control System, Instrumentation, GUI

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Contents

1. Introduction

Modern optical telescopes and their back-end instrumentation pose some of the critical requirements in terms of instrument's stability, alignment , positioning, motion repetition, calibration etc. As such telescopes and their back-end instrumentation are often operated remotely, the role of a robust control system to provide critical automation for their functioning is paramount[Stoll et al. [2010],Ramiller et al. [2010],Ferguson et al. [2020]]. In recent times, several large astronomical facilities with 8-10m primary mirror diameters (e.g. Keck telescopes, ESO-VLT, South African Large Telescope etc.) have revolutionized the astronomical research. The scale of such facilities and their back-end instruments require a complex system consisting of hardwares and software , which can only be operated by a trained set of personnel. Mid and small sized telescopes (1-3m) like IUCAA Girawali Observatory [1], Himalayan Chandra Telescope [2], Mount Abu Infrared Observatory[3] etc.; on the other hand, offer a great advantage due to the availability of more amount of telescope observing time, and the presence of larger number of such facilities. Operations of such small-mid size telescopes, however, are usually done by a small set of engineers and observers. Thus, the instruments on such telescopes demand a rather simple and easy to use control system which could also be used by the general users of the observatory. A suitable instrument control system in such observatories with attributes like flexibility, great precision, robustness, reliability etc can enhance the effective duty cycle of the observing facility and minimize the time overheads during observations. Such control systems have been successfully developed in the past[Srivastava et al. [2009]] using the then available micro-controllers and other electronic components. However, in recent times, due to the availability of off-the-shelf controller devices and other sub-system level components, the development of such control systems is greatly simplified, provided suitable hardware and software environment is created. Here we describe one such effort to develop an instrument control system with commercially available components and in-house designed and developed software. Though the system is designed for the requirements of an in-house developed instrument named Mt. Abu Faint Object Spectrograph Camera- Pathfinder (MFOSC-P)[Srivastava et al. [2021]] on PRL 1.2m Telescope at Mt. Abu, India, it can also be adapted for various similar applications with minimal hardware and software modifications.

MFOSC-P is an optical instrument which provides imaging in various filters and spectroscopy in visible waveband using three different plane reflection gratings [Srivastava et al. [2021]]. Thus, the instrument has various moving elements (e.g. filters, gratings, slits, calibration mirror etc.) where the precise positioning is extremely necessary to achieve the designed performance. The instrument also uses several calibration lamps which are to be operated as per need. MFOSC-P is mounted on the PRL 1.2m telescope and can not be physically accessed during its operation in the night, therefore the control system architecture has been designed to consist of two separate modules: (1.) Hardware control system consisting of controllers, motor-drivers, encoders, limit switches and power supplies - which are mounted on the telescope along with MFOSC-P; and (2) a software user interface with several configuration options for MFOSC-P - which is accessed on the desktop PC in the remote location. The hardware part of the control system along with the software interface work in tandem to provide the required automation for precise motion control and other instrumentation requirements.

The control system is modular in its core and provide the flexibility of scaling up the number of motion axes as per the requirements. A complex motion control application thus can be derived by simple configuration of the hardware and software settings. The control system has been developed around commercially available motion controller, stepper motor driver modules and in-house developed electronics for switching operations. It can facilitate the operations of up to eight stepper motors along with their encoders and limit sensor feedback. It also has provisions to control several switching operations of the instrument. The multiple stepper motors within the instrument can be driven in a coordinated fashion along a defined trajectory. The hardware and software interface allow the precise position tracking of the moving component during the operation of the instrument. The user's interface is developed using open source Python-qt framework and has two layers (1.) An instrument specific front window interface and (2.) A general-purpose engineering interface. While the front window is instrument specific and can be designed as per the instrumentation requirement, the back-end engineering interface window provides a low-level interface to various hardware settings. A simple instrument specific editable configuration file provides the link between the two interfaces.

This technical note is organised as follows: In Section 2, general requirements of a typical analytical instrument control system - which are also the requirement of MFOSC-P instrument -are discussed. In section 3, detailed hardware architecture using commercially available components for an actual system is discussed. The Software architecture of the system is described in section 4. The implementation of the whole scheme for the control operation of MFOSC-P is given in section 5.

2. Control System Requirements

The essential technical requirements of MFOSC-P control system arose from the objective to accommodate high-level controls of various motion control systems, encoder & limit feedback, and switching operations of calibration lamps in a single scheme. A user friendly graphical user's interface (GUI) would be provided to the end user for easy operation of the instrument. The system needs to be built in such a way that the end user should be able to take the observations through the GUI without any pre-requisite in-depth knowledge about the instrument functioning. The hardware of the control system is thus designed with the following basic building blocks:

[1] https://instru.iucaa.in/index.php/igo?view=featured
[2] https://www.iiap.res.in/iao/cycle.html
[3] https://www.prl.res.in/~miro

1. Controller processor unit with motion control interface
2. Motor drivers for stepper motors
3. Additional electronics e.g. switch controls, limit sensors etc.

These sub-units are described below.

2.1 Controller Processor Unit with Motion Control Interface

The controller processor unit is the core of the whole system which works in tandem with rest of the components. This unit communicates with the GUI and performs following basic functions:

- It serves the operations of motion control for various motors by taking the input from user and providing the number of pulses, enable and direction control signal to the stepper motor driver which would be digitally interfaced to it.
- Motion profile for each of the stepper motors can be set here separately with appropriate low speed, high speed, acceleration and deceleration. In general, each of the stepper motors would be having different motion profiles, depending on their loads, micro-stepping modes etc. Determination of proper motion profiles is essential to achieve less vibration, noiseless functioning and precise positioning of the stepper motor.
- It receives the feedback signal about the real time angular position of the shaft of the motor via the encoders, in order to take informed decision for further action of motor.
- It receives feedback signals from limit sensors which indicate the terminal positions reached by motors viz positive limit, home and negative limit and take immediate necessary action to avoid any damage to the instrument.
- It has provisions for digital input and output signals for controlling additional switching circuitry operations which may be needed for some additional tasks apart from motion control.
- The controller has provisions to establish a communication over USB or RS-232/RS-485 serial interface to a PC based user interface.
- It has a dedicated ASCII command set to enable the above mentioned properties in a designed way.

2.2 Stepper Motor Drivers

The instrument uses several stepper motors and/or stepper motor based translational stages. Each of these would require its own driver circuitry to provide sufficient current for its movement. The motor driver units are used to interface the

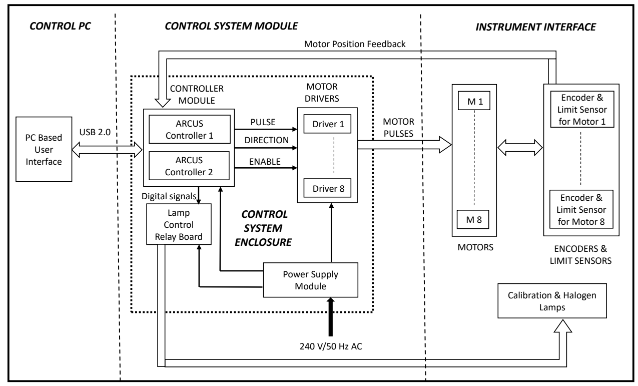


Figure 1. Block diagram for various interfaces of the hardware components.

motors. The driver units act as a buffer and regulate the current profiles in the stepper motor coils through necessary electronic circuits. The drive units also have provisions to set-up the peak coil currents and micro-stepping modes to control the motor's torque and resolutions. These drive units digitally interface with the controller unit to receive direction and step pulses for the movement of the stepper motors. The details of motor drivers in mentioned in 1.

2.3 Additional Electronics

Along with the motion control aspects, the system should be versatile enough to take care of other aspects of the instrument e.g. interfacing with various digital/analog sensors, limit switches, calibration lamps and power control etc. To facilitate this, apart from the controllers and motor drivers, the control system is augmented with additional electronics to support various other functionalities like operating relays, accepting various sensor outputs etc.

3. Hardware Architecture of the Instrument Control System

Based on the subsystem characteristics mentioned in section 2, an instrument control system has been developed. Block diagram of the hardware setup is shown in Figure 1. Though the preliminary application of this system is for MFOSC-P instrument, it can very well be adapted and used for any other similar instrument as well with minimal configuration changes. This section provides detail about the actual hardware components used for this purpose.

As discussed in section 2 above, the control system is designed around two controller units, eight motor driver units and some peripheral electronics. These parts and their interfaces are described below:

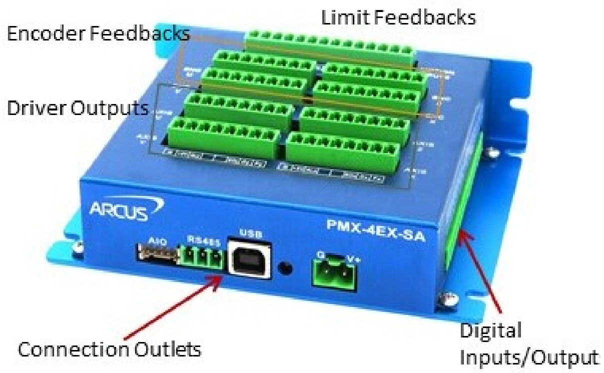


Figure 2. Arcus PMX-4EX-SA advanced 4 axis Stepper Motor Motion controller

3.1 Stepper Motor Motion controller

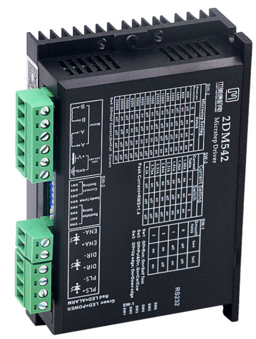
The control system hardware architecture is built around two PMX-4EX-SA[arc] series of motion controller units from Arcus Technoloy, Inc [4]. PMX-4EX-SA is an advanced 4 axis stepper standalone programmable motion controller operated at 24V supplied by a fixed voltage power supply Figure 2. Communication to the PMX-4EX-SA can be established over USB or RS-485. It is possible to download a standalone program to the device and have it run independent of a host. The controller supports the baud rates of 9600, 19200, 38400, 57600, 115200 bps. One such controller can be used to drive 4 motor drivers, 4 set of encoders and 12 limit switches (3 per motor). The maximum frequency supported for differential encoder inputs is 5 MHz. It also has a provision to accept and give digital and analog input/output signals for the additional auxiliary tasks.

Table 1. Motor Driver Electrical Specifications

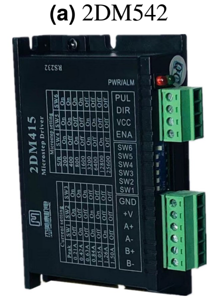
Specification	**2DM542[mot [a]]**	**2DM415[mot [b]]**
Input Supply Voltage	18-50VDC	24-36VDC
Peak Coil Current Range	1A to 4.2A	0.21A to 1.5A
Microstepping (per rotation for a 1.8deg stepper motor)	upto 25000 steps	upto 25600 steps

3.2 Motor Drivers

In an application, there can be different requirements in terms of load and motion profile for moving different components. Commercially available stepper motor drivers are used in the control system viz. 2DM542[mot [a]] and 2DM415[mot [b]] for driving the NEMA 13[nem [a]] and NEMA 17[nem [b]] stepper motors. These drivers have programmable output currents and micro-stepping modes through a simple selection of hardware switches. Considering different load and speed requirements of motors inside MFOSC-P instrument, two different kinds of driver modules are used. These are shown in Figure 3 and their basic specifications are given in Table 1 below.



(a) 2DM542



(b) 2DM415

Figure 3. Commercially available micro-stepping stepper motor drivers

3.3 Additional Electronics for Switching Operations

MFOSC-P uses three different types of spectral calibration lamps which are also being operated with this control system. These are M/S Newport make pencil style Neon and Xenon lamps [5] for wavelength calibration and a halogen lamp for flat field calibration of the recorded spectra. Power supplies of these lamps are routed through the control system. Four electro-mechanical relay based current switching circuit is designed and is being used in the control system to provide automation to the operation of these lamps.

The switching circuitry uses relays, opto-isolators, current amplifier IC, buffer IC, DC to DC step down transformer, resistance pack and a voltage divider circuit. The pin interconnection diagram is shown in Figure 4. A step down transformer is used to convert input 24V from the power supplies to 5V to be given to various components. The digital output signals from ARCUS controller serve as driving inputs for this additional circuitry as shown in the circuit diagram

[4] https://www.arcus-technology.com/, Accessed: 2021-20-21

[5] https://www.newport.com/f/pencil-style-calibration-lamps

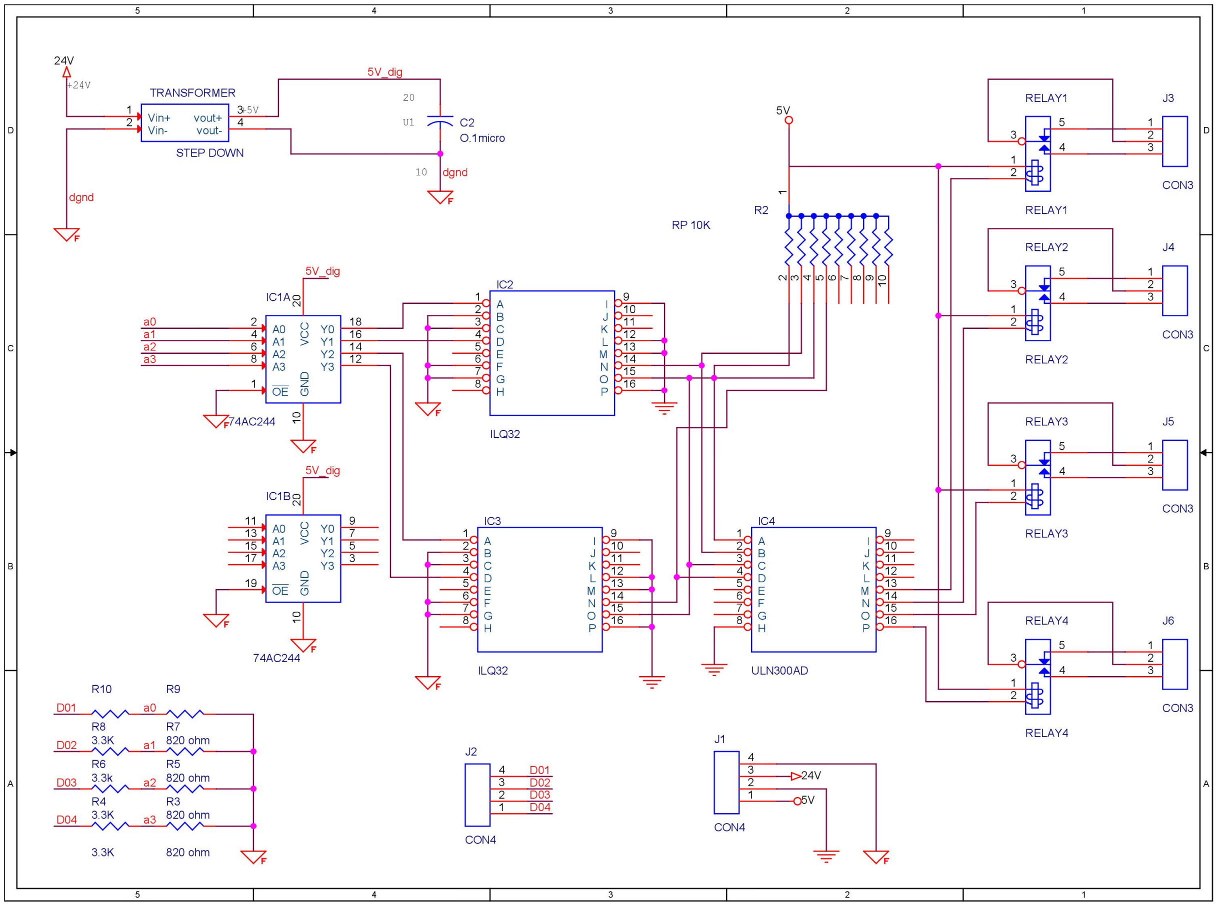


Figure 4. Pin Interconnect Diagram of the lamp control electronics

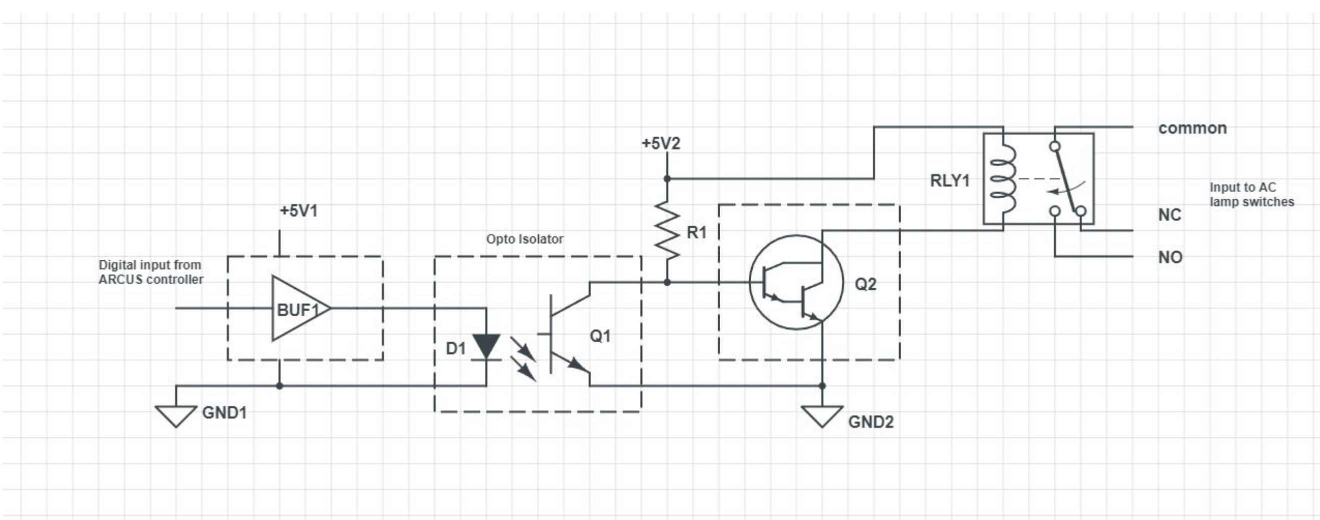


Figure 5. Circuit Diagram of the lamp control electronics

Table 2. Specifications of various power supplies used in the control system

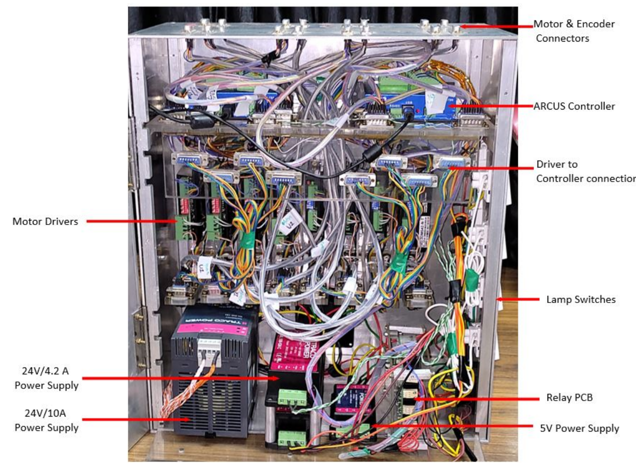
Manufacturer and Product Number	Specifications	Purpose
Traco Power TML 100-124 C	Input: 100-240 VAC/2 A, Output: 24 VDC/4.2 A	Supplies power to the two Arcus controllers.
Traco Power TML 100-124 C	Input: 100-240 VAC/2 A, Output: 24 VDC/4.2 A	Digital power supply for switching circuitry and power supply for Arcus controller's opto-isolted I/O pins.
Traco Power TCL 240-124	Input: 187–264 VAC/1.7 A, Output: 24 VDC/10 A	Power supply for motor driver module.
Traco Power TML 20105 C	Input: 90 – 264 VAC/270 mA, Output: 5 VDC/4 A	Power supply for the analog power to be given to relay circuit.

Figure 5. The digital output is given to the voltage divider circuit present at the input to produce 5V. This is then fed as input to the buffer IC (SN74AC244 OCTAL BUFFER)[BUF] which is used for impedance matching. The output of buffer IC is given to the opto-isolator IC(ILQ32 from Vishay Semiconductors)[ilq]. Opto-isolator are used to isolate low-power circuits from higher power circuits and to remove electrical noise from signals. The output from opto-isolator goes to a current amplifier IC (ULN2003A)[ULN]. It consists of the Darlington arrays which provide a large current to drive the coils of the relays. The output of current amplifier IC is given to one of the input coil terminals of the relays. OMRON make relay (G5LE, 5V-10A)[REL] are used in the circuit. The output normally open and common terminals of the relays are connected to the lamp sockets.

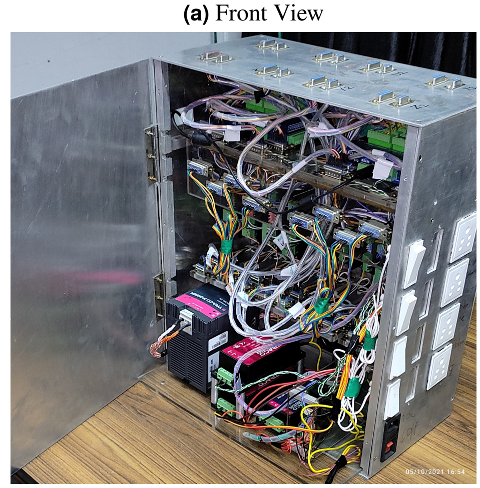
3.4 Power Supply Unit of Control System

The instrument control system uses four different kind of power supplies. These power supplies are used for different subsystems present in the control system.
Two 24 V power supplies are required for the ARCUS controller itself; one for the digital power supply of the controller and other for various digital inputs/outputs pins, which are electrically insulated via opto-isolators. A separate 24 V power supply is used for motor drivers to drive the motor's coils. As their current requirements are higher than the controllers, they are also kept isolated with the previous two power supplies. The relay board for lamp controls uses the same power supply as for the controller itself for the digital logic signals. However, a fourth 5V power supply module is used through opto-isolators for controlling the relays which are directly connected to the AC and hence must be kept isolated with the rest of the circuitry.
So keeping in view all these requirements, four power supplies are used. Their makes, specifications, and purposes are given in the Table 2.

3.5 Signal Flow Within the Control System



(a) Front View



(b) Perspective View

Figure 6. Hardware box of the Instrument Control System

The hardware box of the instrument control system is shown in Figure 6 which includes power supply module, motor driver module, two controller units, and the lamp circuitry module. The system architecture has been designed while keeping all the safety precautions in mind.The routing of wires is done such that low current wire section is separated from higher current carrying wires. AC wires are placed at a distance from communication cable to avoid any interference. Proper insulation is provided via cable sleeves. Different power supplies are used for subsystems having varied current requirements. Moreover,the isolation of different signals has been ensured via opto-isolators and EMI filters to avoid any kind of interference. Hence power sources for driver and controller are separated. The system draws AC power from the mains power supply which is fed to different AC-to-DC power supplies as discussed above. Figure 7 shows the sample block diagram for the hardware connections within this hardware set-up.

Digital outputs for Enable, pulse and direction of stepper motors are given to motor driver module from Arcus controllers. The coils connections of the motors are connected to the outputs of the motor drivers. The encoder and limit feedback from the motors are given directly to Arcus controllers. The digital I/O signals from an Arcus controller is provided to the lamp control circuitry/Relay PCB. AC supply is directly given to the cooling fan and NO (normally open) terminal of the relays. The output of the power supplies is given to the controllers, motor drivers and the relay board.

During operation, controller can send signals to the motors and relay board and receive feedback from encoders and limit switches. When the driver is turned on, it can send pulses, direction and enable signals to the stepper motor, which in turn runs the motor accordingly. The digital output signals from the Arcus controller drives the power supply relay of the particular lamp.

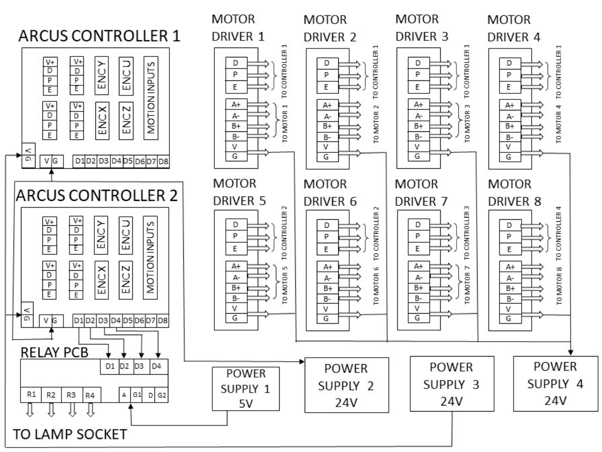
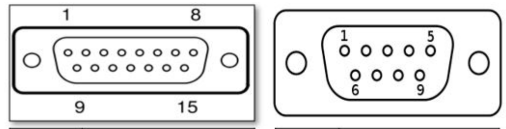


Figure 7. Sample block diagram for controlling eight stepper motors using two Arcus controllers along with additional functionality to operate four lamps.

3.6 Peripheral Connectors and Components

The electrical connections of MFOSC-P instrument are physically attached to the hardware box of the instrument control system through various connectors as discussed below:

- The Arcus controllers use USB 2.0 communication mode with the control PC. Thus, two USB cables are used to connect each of them to the control PC.



Pin No.	Description
1	Limit +
2	Home
3	Limit-
4	Encoder V-
5	Encoder V+
6	Encoder Z
7	Encoder B
8	Encoder A
9	Limit Vs
10	Limit Vs
11	Limit Vs
12	Not Connected
13	Limit Vg
14	Limit Vg
15	Limit Vg

Pin No.	Description
1	Not Connected
2	Not Connected
3	Not Connected
4	Not Connected
5	Not Connected
6	Motor Coil B+
7	Motor Coil B-
8	Motor Coil A-
9	Motor Coil A+

Figure 8. Electrical Interface Diagram of Motor and Encoder Connectors

- Lamp connectors: There are four 5A power plug points present to facilitate the connection of halogen and spectral calibration lamps with the control system. The halogen lamps are connected to these sockets via a Halogen LED Lamp Electronic Transformer, outside the control system. These plug points are internally connected to the relays which are eventually controlled by the Arcus controller.
- D type connectors: 8 number of 15 pin D type connectors are used to provide connection to encoders and limit switches. Additional 8 number of 9 pin D type connectors are used to provide connection to windings of the stepper motor. The electrical interface pin connections are mentioned in Figure 8.

4. Software Architecture

Block diagram of the software architecture of the instrument control system is shown in Figure 9. The software has been designed while keeping in mind various fundamental requirements like modularity, scalability and reliability. The software would communicate with Arcus controller on one side and user on the other. The user need not be exposed to the complex firmware environment of the controller but with rather help of some graphical user interface(GUI) buttons, should be able to carry out the designated tasks. The software is coded in Python 2.7 with GUI developed using PyQt4 framework. The software is platform independent and easily scalable in nature.

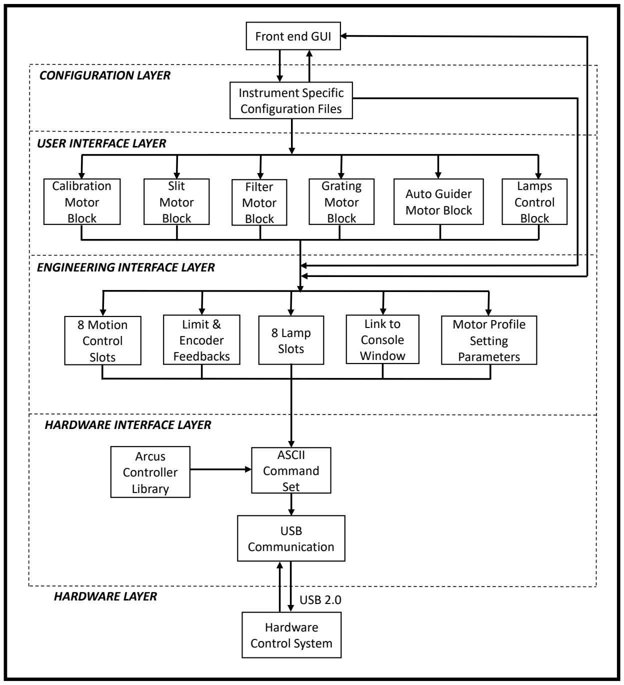


Figure 9. Block diagram of the software architecture of instrument control system showing various interface layers.

4.1 Software Overview

The software has been developed using Anaconda[con] platform which is a free and open source distribution of Python. Anaconda makes package management and deployment across different operating systems very easy. The software utilizes several standard general purpose Python packages which are easily available as open source.

The graphical user interface consists of two modules which are discussed below:

4.1.1 Engineering Interface

The engineering interface provides a low level control interface to various motors and switching operations. This interface window is used to monitor each module separately. The motors can be moved to any of the user desired positions as per the requirement while maintaining all the terminal constraints set by the limit switches. Figure 10 shows engineering interface for the control system with two controller units having four motors and four switches each. Functionality of various push-buttons of the engineering interface are given in table 3.

4.1.2 Set up Window

Software has been developed such that all motion related parameters (e.g. low speed, high speed, acceleration, deceleration, pitch etc.) can be set at one place. A dedicated set

Table 3. Functionalities of various push-buttons of the engineering interface as shown in figure-10

Button Name	Button Functionality
CONSOLE Button	To access the console terminal to directly communicate with controller using command line interface, for debugging errors.
SETUP Button	To access the setup window, where we can set and change various motor parameters.
CONNECT Button	To establish the communication link with the controller units.
Current position line edit	It displays the current encoder based position status of the motor (if motor has encoder attached to it), or the current position value of the motor determined by the number of pulses (if encoder is not attached).
Distance Entry box	It gets enabled when connect button is pressed. Here user enters the desired distance to be moved by the motor. It accepts fraction or integer value (in degrees or mm).
Limit Switches	L+: Positive limit sensor If the positive limit status is high, corresponding motor is stopped, limit status is cleared and positive limit button glows. Any further motion in positive direction is restricted. H: Home sensor If the home limit status is high, home limit button glows. There is no effect in the motion of motor. L-: Negative limit sensor (otherwise similar as L+)
Enable Checkbox	It activates the currents in the motors coils, thereby energizing the corresponding motor. ABS, INC, SET ZERO, STOP push buttons are activated. When enable box is unchecked: Corresponding motor is disabled (de-energized). ABS, INC, SET ZERO, STOP push buttons are deactivated.
ABS Button	It sets the move mode to absolute and then moves the motor up to the desired distance as entered by the user.
INC Button	It sets the move mode to increment and then moves the motor by the desired distance as entered by the user.
SET ZERO Button	It sets the encoder value and position value of the corresponding motor to zero.
STOP Button	It immediately stops the corresponding motor by sending command to controller.
Lamp Switches	When lamp box is checked: Digital output of controller corresponding to the lamp is set high, which acts as the input for the relay boards. The corresponding lamp will turn-on. When lamp box is unchecked: Digital output of controller corresponding to the lamp is set low, which acts as the input for the relay boards. The corresponding lamp will turn-off.
CLOSE Button	It closes the GUI window, it also disconnects the controllers, thereby halting the communication.

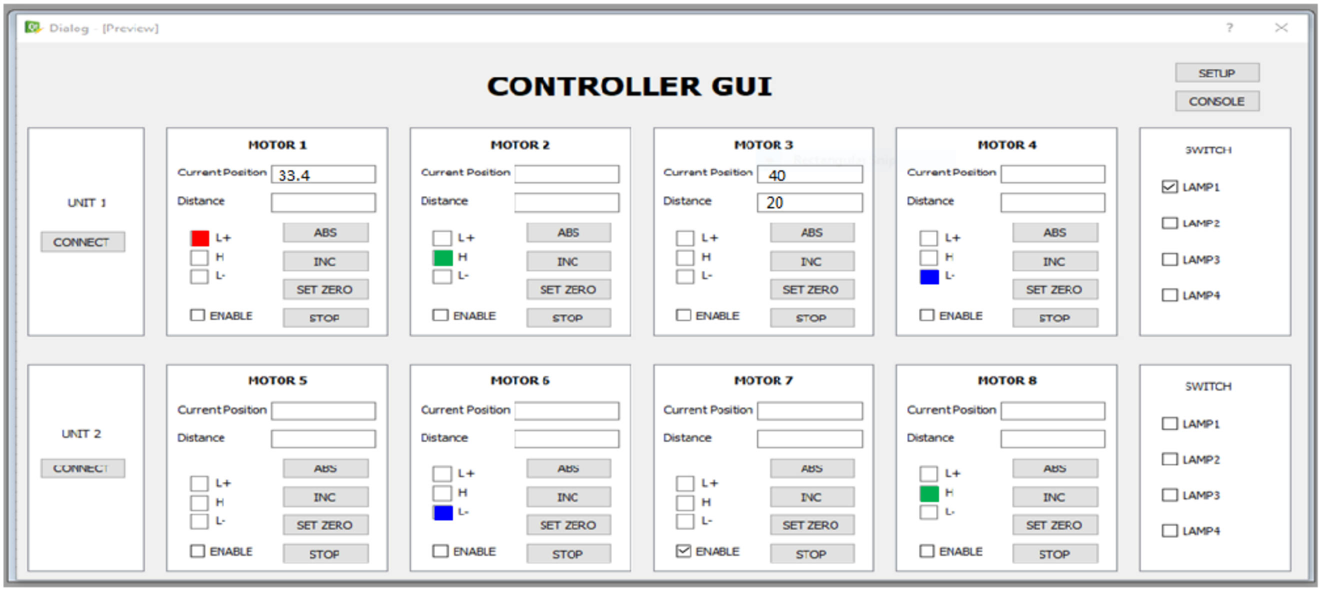


Figure 10. Engineering interface of the GUI. It controls all eight motors and eight switches with both the controller units. The functionality can be enhanced further to incorporate more degrees of freedom.

up window has been created for this purpose. As shown in figure 11, one can set up various motion related parameters with this window. It has two units corresponding to each of the controller. Each unit has four set of motors units. Each motor module has provision for setting the various motor parameters i.e high speed, low speed, acceleration, deceleration, number of pulses for one revolution and pitch of motor (if linear stages are used). These parameters are often needed to be adjusted to suit the load requirement and motion profiling.

"SAVE" push button will save these values in a text file and simultaneously pass on these values to the controller if it is connected. "RESET" push button will fetch the default values stored in a text file and display it. Whenever the setup window is launched, it displays the previously stored values in it. Further these values can be edited and stored in the memory.
The engineering interface is a back layer of the control software which is to be used by the developers or systems engineers for instrument's debugging purpose. A front end interface is to be added (see section 5) to provide instrument's control to the end user, who need not be familiar with the internals of the sub-system details. This front end GUI would be designed as per specific requirements of the instrument.

4.1.3 Command Line Interface

The engineering interface window also provides access to a command line terminal via CONSOLE push button, where one can directly interact with micro-controller using ASCII command sets [arc] which serves for error debugging and testing the controller parameters independently.

5. Application of the Instrument Control System for an In-house Developed Instrument - MFOSC-P

The instrument control system has been successfully used on fully in-house developed MFOSC-P (Mt. Abu Faint Object Spectrograph Camera- Pathfinder)[Srivastava et al. [2021]] instrument. MFOSC-P provides imaging and spectroscopy capabilities to PRL 1.2m telescope in visible waveband. It uses five astronomy standard optical Bessell's B-V-R-I and H-α filters in a filter wheel which is also having an open slot. Spectroscopy is provided with three different plane reflection gratings which are mounted on a turret mechanism along with a plain mirror for imaging mode. Filter wheel and grating turret are rotated by the stepper motors. A linear translational stage is used for slit/aperture movement on the instrument's object plane. Another translational stage is used to bring a calibration fold mirror in and out the path of instrument's optics axis, to fold the calibration beam in to the instrument. An off-axis auto-guider is also provided which scans a limited region of the sky with the help of a stepper motor. Except auto-guider motor, all the motors are equipped with optical quadrature encoders on the motor's shafts. All the motors are also equipped with limits and home sensors(only for linear stages).

Thus, the front end GUI of the control software was purpose designed to control the following aspects of the instrument:

- Motion of two stepper motor based linear stages for moving slit and calibration mirror.

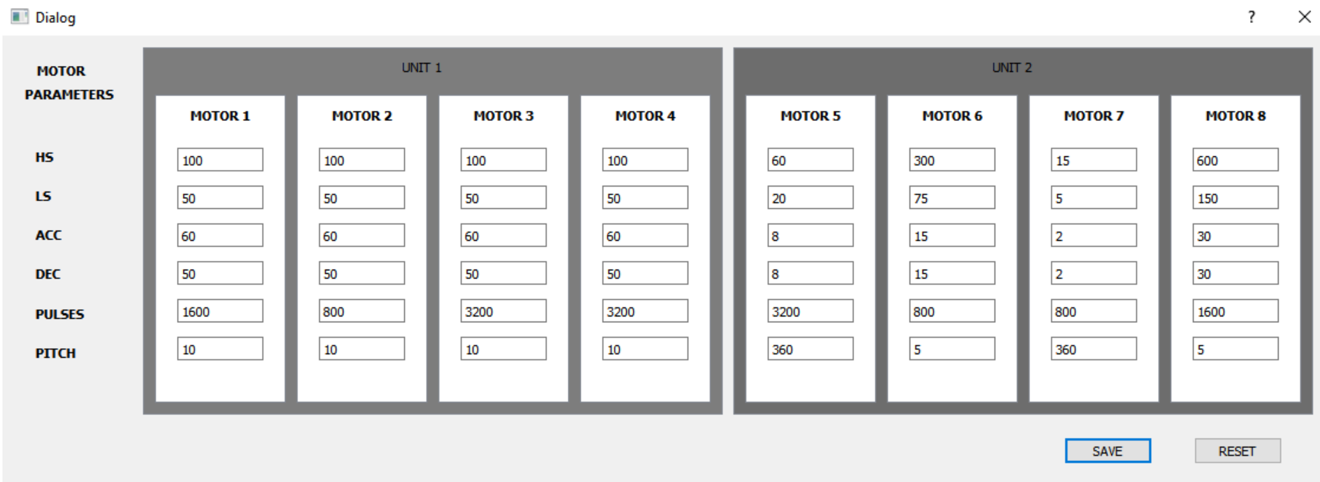


Figure 11. Motor Parameters Setup Window

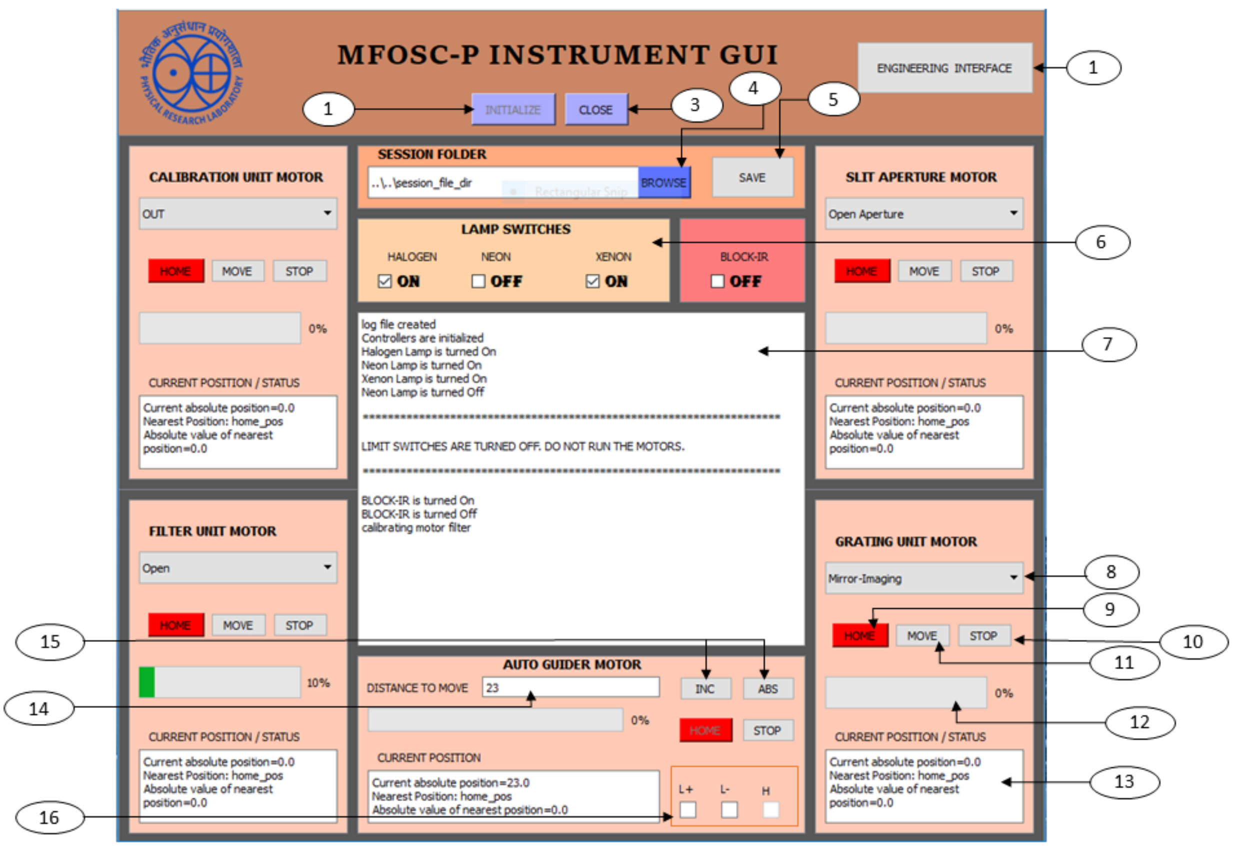


Figure 12. The front end GUI interface of the instrument control system software which is designed as per the requirements of MFOSC-P instrument

- Motion of three rotational stepper motors for moving grating, filter wheel and auto-guider.
- Reading the outputs of optical quadrature encoders of the motor units for providing precise angular and linear distances travelled by the motors.
- Reading the outputs of optically isolated limit sensors to detect the home and terminal positions (in case of linear stages) of motors.

- Relay based lamp controls for operating two spectral calibration and one halogen flat lamp.

Figure 12 shows the front end GUI of the software which is customised as per the above requirements of MFOSC-P instrument. The users communicate with the hardware set-up using this application specific interface window. This front facade would in turn communicate with the general purpose engineering interface to control movements of stepper motors, lamp's switching and feedback operations. An instrument specific *configuration file* is used to define the relationship of the required operation on the front end user's interface (UI) with the low level engineering operations of the engineering interface. The engineering interface is password protected and is not exposed to the common users of the instrument.

Separate interface modules are provided in the front end UI to operate each of the motors and lamps in a pre-designated way. In each motion module (e.g. grating, filter etc.), various motor positions can be selected from the drop-down menu and movement would be executed. The motion status of motor is indicated by progress bar above the status window in real time. The status window helps in obtaining the real-time position of moving element. All the actions performed by the user, get displayed in the central window and also simultaneously logged. Along with this status of all the motor and lamps can be saved in the session file at the user specified directory, as and when required.

Table 4. Application specific user interface functionality for MFOSC-P

Number in figure-12	Button Name	Button Functionality
1	ENGINEERING INTERFACE	Provides link to the engineering interface which is password protected
2	INITIALIZE	Initializes the controller units, creates log file, activates GUI, controllers and enables motors
3	CLOSE	Deactivate GUI,close communication channel with ControllerS, disables the motors
4	BROWSE	Allows browsing the folder to save the session file, a default path of the folder is displayed
5	SAVE	Current status of all the motor units and lamps is written to the session file.
6	LAMPS SECTION	Check and un-check to turn the lamps on and off.
7	DISPLAY WINDOW	Displays the functions performed,when user clicks any button. It keeps getting updated in real time, and data is stored in log file.

5.1 Functionalities of the MFOSC-P GUI

Functionalities of various buttons for the MFOSC-P user interface (Figure 12) are given in Table 4 and Table 5.

5.1.1 Motion Unit Modules

Five motor units of MFOSC-P viz. calibration motor unit, slit motor unit, filter motor unit, grating motor unit and auto-guider motor unit are provided their separate windows in the front GUI. All of them are mostly having similar functionalities therefore the similar interface buttons are provided. These are discussed in Table 5.

5.1.2 Homing Operation

Calibrating the motor position is an important task before carrying out any motion operation. Initially home button is red indicating that motor's home position has not been set. Once home button is clicked, it will check the number of limit switches connected (from the configuration file). The homing scheme is described below:

If only home limit is connected:

- Motor will start moving in positive direction (anti-clockwise) until home limit is reached.
- Then motor is allowed to overshoot a little beyond home sensor.
- Motor comes back in negative direction.
- It crosses the home sensor again.
- Again moves in positive direction slowly till home limit end is reached and stops.
- The position thus attained is indicated as the home position.

If all three limits are connected:

- Motor will start moving in positive direction, until positive limit is reached.
- Once positive limit is detected motor will stop.
- Then motor starts moving in negative direction till home sensor is reached.
- It moves a little beyond home sensor
- Motor again moves in the positive direction towards home sensor but at a slower pace
- As soon as home sensor is reached, motion is stopped.
- The position thus attained is indicated as the home position.

Table 5. User interface functionalities for motion operations

Number as in figure-12	Button Name	Button Functionality
8	DROP DOWN MENU	Lists down the various positions available for the motor to move. Default positions are displayed initially.
9	HOME	Performs the homing operation, as explained in section-5.1.2
10	MOVE	Depending on the position selected in drop down menu, corresponding value is read from the configuration file and motor is moved to the indicated position. The motion algorithm is designed in such a way that motor always reaches the desired position from one particular direction, so as to avoid the backlash error.
11	STOP	Immediately stops the corresponding motor.
12	PROGRESS BAR	It keeps getting updated when motor starts moving, indicating its real time motion. Once the motor reaches the desired value, it will display 100 percent and resets to zero.
13	CURRENT STATUS DISPLAY	When the motor is in motion this window will keep displaying the numerical value of the current absolute position, the nearest position and position value of the nearest position.

After home position is attained, encoders are reset to zero indicating zero as home position. Once homing is done, home push button turns green indicating that home position is set.

5.1.3 Auto-guider Motor Module

Auto-guider motor is a special motor whose task is to search for a guide star in the nearby field. Since the normal operation involves searching in the nearby area, small steps are to be given to this motor as per user discretion. Unlike the rest of the motors, its functioning is little different. The buttons associated with this motor are described in Table 6.

Table 6. User interface functionalities of the auto-guider motor unit

Number as in figure-12	Button Name	Button Functionality
14	DISTANCE TO MOVE	User can enter the distance required to be moved by the motor in degrees.
15	INC and ABS BUTTON	These buttons have the same functionality as the move button present in other motor modules. Only difference is that in other modules by default motor are moved to the absolute position, but auto guider has the facility of moving in either increment mode or absolute mode as per the requirement.
16	LIMIT DISPLAY	There is visual display of L+, L- and H sensors. These will glow whenever any these limit switches are detected

5.2 MFOSC-P Motion Control Performance

MFOSC-P motion control performance has been successfully verified on several subsystems. A slit within MFOSC-P spans over ~3 pixels on the CCD detector and it has to be positioned with an accuracy of ~ $1/5^{th}$ of a 13μm a side pixel i.e. with ~2.6 μm. As MFOSC-P has a de-magnification factor of 0.57 at the image plane, this translate into required accuracy of ~4.6 μm on the slit plane. The slit is mounted on the a stepper motor driven linear translation stage, having a pitch of 5mm. Thus, this motor is operated at the $1/8^{th}$ micro-stepping mode, thereby giving 1600 steps for a full rotation or for 5mm pitch. This corresponds to 1 micro-step accuracy of ~3.1 μm on the slit-plane. Encoder associated with this stage has a precision of 4000 counts per revolution or 1.25μ per count which is sufficient to ensures the required positional accuracy. The positioning of the slit was measured repeatedly in the lab as well on the telescope and is found within requirements.

MFOSC-P uses three gratings of 150, 300 and 500 line-pairs per mm. The grating motor is set at $1/16^{th}$ microstepping mode corresponding to 0.11^0 per micro-step while its encoder gives an accuracy of 0.09^0 per count. MFOSC-P camera optics has a focal length of ~244.5mm which translate into ~36 pixels per micro-step. This accuracy is verified with the spectral calibration lamps by noting the position of known emission lines. Similarly, positing system for filter wheel is determined to be within specifications during laboratory tests of the instrument and subsequent science operations on the telescope.

Few other non-position critical sub-systems are the auto-guider and the calibration fold mirror. The off-axis guider system of MFOSC-P is designed with a rotary stepper motor with an off-axis 45^0 pick-up mirror coupled to the guider CCD camera. The 45^0 pick-up mirror selects the off-axis beam and image is formed on the auto-guider CCD. The neighbourhood sky is then scanned with this auto-guider CCD to search for the suitable guide star. This feature is successfully implemented in the instrument and have been used to interface with the guiding system of the telescope for auto-guiding purpose during observations. An oversized calibration fold mirror is used in MFOSC-P to feed light coming from spectral lamps into the MFOSC-P optics and to block telescope light during this process. This mirror is attached to a stepper motor driven linear translation stage. This mirror is routinely used for the spectral calibration of the science data frames. Table-7 provides a comparison of design and achieved parameter values with the MFOSC-P motion control system.

Table 7. MFOSC-P Performance Parameters

S.No.	Design Parameter Value	Achieved Parameter Value
1	Slit position within $1/5^{th}$ of 13μm pixel i.e. within ~2.6 μm	The positioning accuracy of the slit is verified through repeated observations.
2	0.11^0 angular precision for the grating rotation stage	Gratings are positioned within the instrument with required precision. This has been verified with repeated observations of the variety of astro-physical sources.
3	Filter wheel having 5 filters of size 50 mm and beam size 33 mm to be operated with an angular accuracy of ~ 0.45^0.	During filter wheel operation beam is found to be passing through the middle of filters without any vignetting.
4	Calibration mirror with size 31mm X 77 mm has to divert a beam of size 24.2 mm into the optical path.	Motor has an accuracy of 6.25 μm using which the beam is successfully inserted in the optical path whenever the calibration mirror is at "IN" position.
5	Scan off axis field for a guide star using autoguider system.	Autoguider system found to be successful in searching off axis guide stars.

6. Conclusion and Discussion

We have described the design architecture and development of an instrument control system in this technical note. Both the hardware and software aspects are described. Though the instrument control system is preliminary developed for MFOSC-P instrument, it is developed by keeping long term instrumentation need of the laboratory in mind. The control system has provided the desired flexibility and automation to the end-users in enhancing the utilization of the telescope observing time. It has been developed by keeping the general requirements of the back-end instrument of smaller and medium size observatories in mind. It provides a cost-effective and scalable solution with uncomplicated hardware and software architecture to control and monitor the instrument operation. The hardware and software architecture is modular in its core and hence can been extended to incorporate any number of degrees of freedom. The hardware architecture encompasses off the rack Arcus controllers, commercially available motor drivers, switching operation electronics module and various power supply units. The hardware has been designed such that each component can be dealt with individually, facilitating easy debugging and replacement in case of failure. The front-end of the software is based on PyQt4 Framework, whereas back-end is developed in Python. A user friendly interface and an engineering interface for the control software has been designed such that the motion profile can be easily adjusted in order to account for different motion and load requirements in different axes.

The instrument control system has been very successfully in use on PRL 1.2m telescope since February 2019 in the testing environment conditions of Mt Abu observatory without any error. It is mounted along with MFOSC-P instrument on the telescope and on a typical observing night it usually operates from 6:00 pm in the evening till 6:00 am in the morning (throughout the night) in open sky conditions. Thus, the control system has passed rigorous tests and can easily mitigate any inadvertent activity. Due to its generic architecture, design, development and interface approach, we hope that this instrument control system can find its application in other domains as well requiring similar precision applications.

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चुंबकीय क्षेत्र एवं विकिरण में
अनंत से अनंत तक
जिन्हे प्रकट कर सकती है
मानव की जिज्ञासा एवं विचारशक्ति