Project Summary

Open Source Instruments Inc. (OSI), in collaboration with Texas A&M University (TAMU), will demonstrate a new design of multi-object spectrograph that provides a higher density of fiber positioners than any competing design, and lends itself to the construction of spectrographs with tens of thousands of fiber positioners.

Overview

This Phase II project will assemble a spectrograph equipped with eighty fiber positioners, each occupying a footprint of no more than five millimeters square, and install this spectrograph on the Otto Struve telescope at the McDonald Observatory in Fort Davis, Texas. No modifications to the existing telescope will be required. The applicants will demonstrate the spectrograph by observing celestial objects.

Keywords: multi-object spectrograph, fiber positioner, universe expansion, dark energy
Topic Name: Space (SP)

Intellectual Merit

This Small Business Innovation Research Phase II project will demonstrate the accuracy and reliability of a new design of fiber positioner, called the Direct Fiber Positioning System (DFPS). One of the long-term goals of the astronomical community is to construct a multi-object spectrograph equipped with fifty thousand, independent fiber positioners. They refer to this instrument as the Stage Five Spectrograph, and their plan is to use this instrument to measure the spectra of one billion distant galaxies every ten years. The DFPS is the only fiber positioner design capable of providing fifty thousand positioners within the focal plane of a telescope. The DFPS will make it possible for astronomers to construct the Stage Five Spectrograph.

Broader Impacts

The success of this Phase II project will establish a new, versatile, fiber positioner for multi-object spectrographs. Unlike fiber positioners that have come before it, the DFPS is mechanically simple and self-contained. The design is easy to adapt to new telescopes, and easy to install. It requires no modifications to a telescope before installation, nor does it require that any auxiliary instrumentation be placed within the optics of the telescope. In place of mechanical complexity it substitutes electrical complexity. The DFPS can be manufactured with relative ease. The DFPS will be accessible to observatories that have never been able to contemplate the purchase and installation of a multi-object spectrograph in the past.

Results of the Phase I Project

Our Direct Fiber Positioning System (DFPS) uses the slight bending of a piezo-electric actuator to move an optical fiber at the end of a mast. Each positioner consists of a cylindrical, piezo-electric actuator, a slender carbon fiber mast, and one or more optical fibers running to the mast tip. Each positioner is accompanied by a control circuit that generates the ±250-V potentials that deform the actuator. Seen from above, each positioner occupies a 5-mm square. Each control circuit fits beneath the same 5-mm square and shares the same power and communication signals as its neighbors.

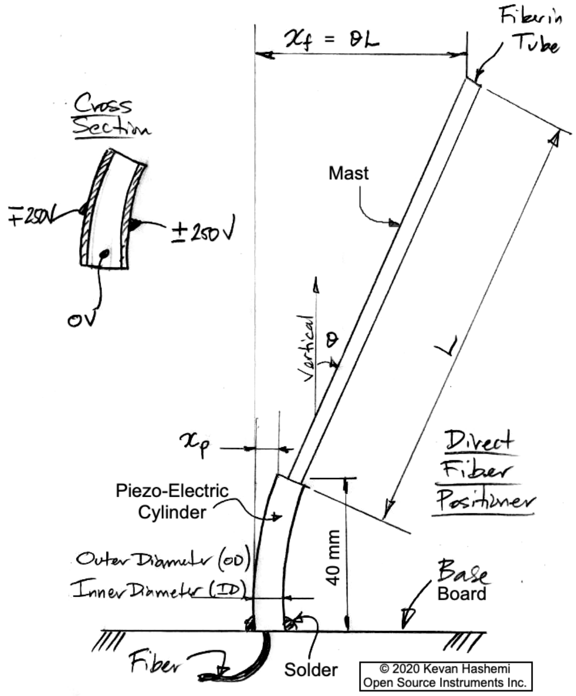

Figure 1: Sketch of a Direct Fiber Positioner. By exaggerating the bending of the actuator, we show how the mast and actuator move the fiber tip.

In our Phase I work, we constructed a prototype DFPS, the DFPS-A16, that provides sixteen positioners on a 20 mm x 20 mm raft. The combination of the raft and its positioners we call a *cell*. At the tip of each mast is a guide fiber. The purpose of the guide fiber is to allow us to measure the position of the mast tip. A Fiber View Camera (FVC) looks down upon the guide fibers as well as four fiducial fibers fixed to the DFPS-A16 mounting frame. The FVC takes pictures of the guide fibers as we shine light into the fibers from the other end. We mounted the DFPS-A16 in a gimbal so that we could rotate it from vertical to horizontal and measure the deformation of its masts as we did so.

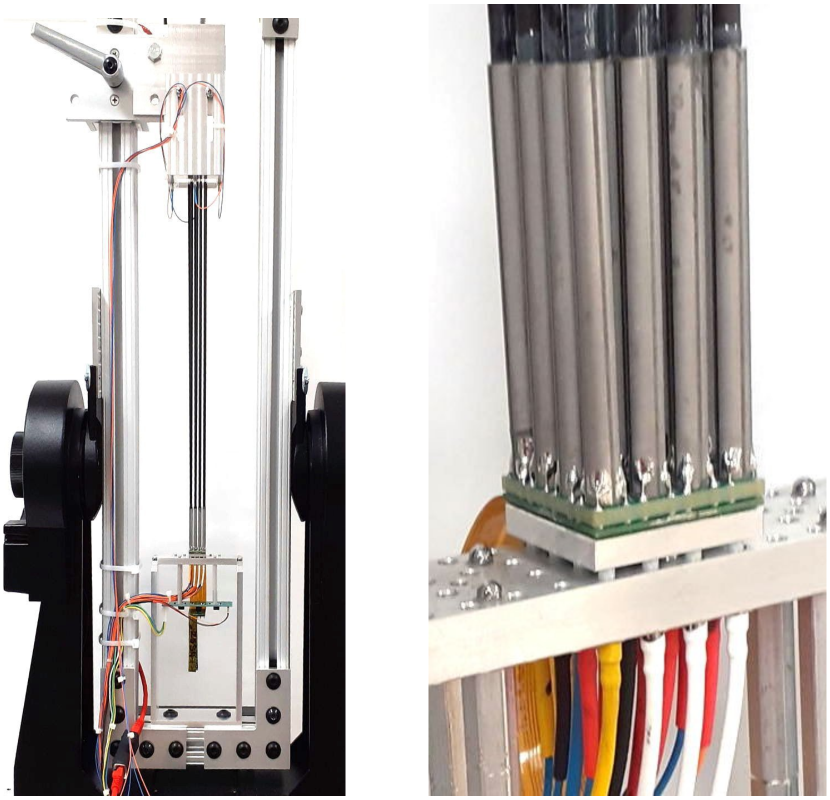

Figure 2: DFPS-A16A in Gimbal (Left) and Closeup of the Base of a Fiber Positioner Cell (Right)l.

In any practical application of the DFPS, each mast would present a detection fiber in the focal plane of a telescope. This fiber would be used to collect light from one celestial object and transport that light to a spectrometer. The DFPS-A16's purpose was not to observe spectra, but to show that we could assemble positioners on a 5-mm grid, and that these positioners could deliver sufficient precision for astronomical observations. A study of the plate scale and resolution of a selection of large telescopes leads us to conclude that a precision of 10 μm is adequate for all likely DFPS applications, and this is the precision we set out to demonstrate. Before we constructed the DFPS-A16A, we built a series of prototypes with one, three, and four fiber positioners to study range of motion, hysteresis, creep, and long-term stability of the direct fiber positioner.

The positioner's range of motion is affected by the manner in which we fasten its actuator to its mast and base board. When we dedicate two millimeters of the 40-mm actuator to the mast joint, and another two millimeters to the solder joints at the base, the tips of our 300-mm masts move in a 3.8-mm square [1, 2, 3]. When we dedicate 4 millimeters at each end to the glue and solder joints, the range of motion reduces to 3.4 mm [3]. But even a 3.4-mm square range of motion, when combined with a 5-mm square footprint, is more than adequate for multi-object sky surveys [3].

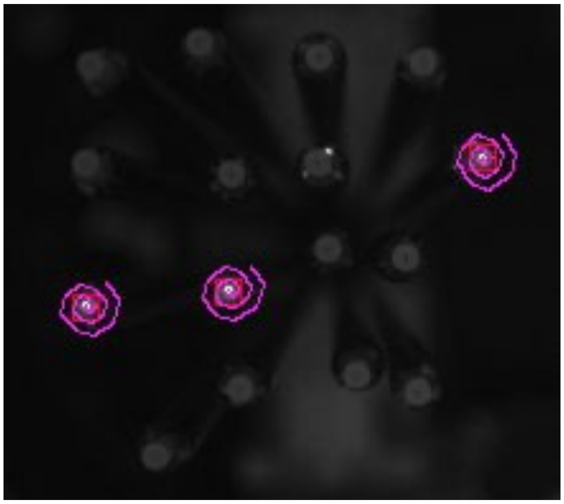

Figure 3: DFPS-A16A Fiber Tips Seen in Fiber View Camera. Three are executing spiral reset, their movement traced by magenta lines.

We overcome the hysteresis inherent in piezo-electric actuators by executing a ten-second reset procedure prior to re-positioning a mast. We move the mast to the edge of its range and then drive it in a spiral towards the center, as shown in Figure 3. After performing the spiral reset, we can move the mast to any position without taking into consideration its position before the reset [2, 3]. All piezo-electric materials creep after an initial displacement. The creep we observe in fiber position follows a logarithmic progression with time. In the ten seconds following an initial movement of 1 mm, the mast tip creeps another 50 μm. In the next one hundred seconds, it creeps another 50 μm, and so on. We compensate for actuator creep by adjusting the actuator control voltages to keep the fiber in the same location [1, 3, 4]. The stability of fiber position is also affected by the stability of the actuator control voltages. With our ±250-V control voltages stabilized to ±0.5-V, our fibers are stationary to 10 μm rms [2, 3] for weeks.

Having demonstrated that the direct positioner is capable of providing the stability and precision necessary for astronomical observation, we began construction of the DFPS-A16. We designed discrete, low-power, ±250-V amplifiers, as well as a micropower, reconfigurable embedded processor for the fiber controller circuit. We assembled and tested sixteen fiber controllers. We assembled sixteen positioners, each consisting of an actuator, a 300-mm carbon fiber mast, an optical fiber, and two zirconia ferrules glued at either end. Assembly of the positioners was delicate. Our yield from start to finish was only fifty percent. By far the greatest challenge we faced was loading sixteen positioners onto a twenty-millimeter square raft. We ended up hand-soldering the positioners, which was hindered by the fact that every positioner was already fully-assembled. We succeeded in loading all sixteen, but the alignment of the mast tips was no better than ±1 mm.

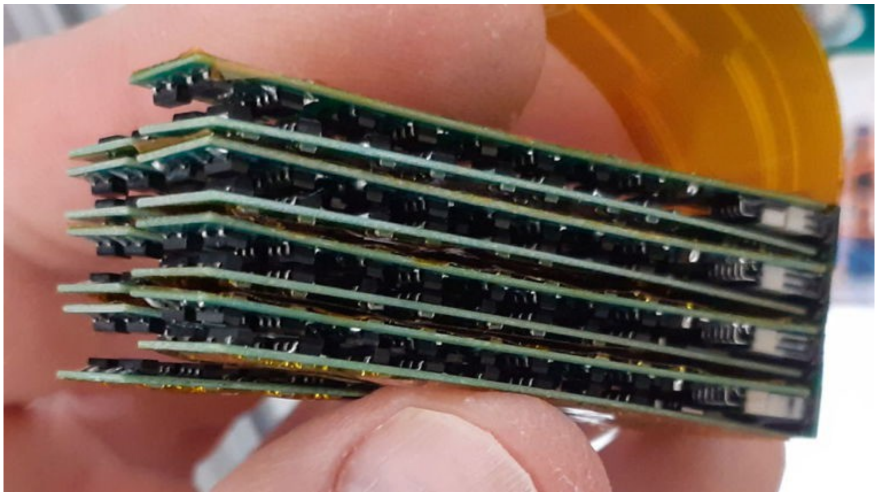

Figure 4: Fiber Controllers Plugged Into a 19-mm Square DFPS-A16 Service Board.

Packing sixteen fiber controllers beneath our array of sixteen positioners requires a connector small enough to fit within the available space, while at the same time capable of maintaining isolation between ±250 V signals and providing enough insertion force to hold each fiber controller in place on the service board. To our knowledge, only one company makes connectors that meet these requirements [5]. The connectors performed perfectly, but we made several mistakes during the construction of our DFPS-A16 service board [3]. Only seven actuators ended up being connected correctly to their controllers. Despite these mistakes, the DFPS-A16 demonstrates that we can pack all necessary electronics in the footprint available, and control all actuators individually. The seven actuators to which control signals were connected moved as we expected them to.

Our Phase I work demonstrated that it is indeed possible to construct a direct fiber positioner on a 5-mm grid, and that the positioners provide sufficient range of motion and precision for astronomical use. Our next step is to build a DFPS spectrograph for deployment on a telescope, and see if it can perform useful measurements. That is what we plan to do in Phase II.

Phase II Technical Objectives, Approach and Work Plan

In Phase II our company, Open Source Instruments Inc. (OSI), will collaborate with the Astronomical Instrumentation Laboratory at the Texas A&M University (TAMU) to construct an eighty-fiber, multi-object spectrometer, and install this spectrometer on the Otto Struve telescope at the McDonald Observatory in Fort Davis, Texas. At OSI, we will build the front-end of the instrument, consisting of eighty fiber positioners, two fiber view cameras, four guide sensors, and a fiber illumination system. At TAMU, our collaborators will build the back-end of the instrument by upgrading, refurbishing, and modifying an existing spectrometer so that it will accept eighty optical fibers at its entrance slit. The front-end and back-end will be integrated and tested at TAMU for the first time. They will later be transported to the McDonald Observatory for installation, commissioning, and observing.

Self-Contained Front-End

The front end of our Phase II spectrometer will be packaged in a metal-walled enclosure with a viewport at one end, a power over ethernet (PoE) socket on one side, and five sixteen-way optical fiber connectors on another side. We will call it the DFPS-A80. To install the DFPS-A80 on the Otto Struve telescope, we bolt its viewport to the viewport on the telescope. To power it up and communicate with it, we plug it into a PoE switch. To integrate it with the back-end, we connect it to the spectrometer slit using five sixteen-way optical fiber cables. Each DFPS-A80 fiber positioner will be equipped with two fibers. One is a detector fiber, the other a guide fiber.

Figure 5 shows the arrangement of components inside the DFPS-A80. The blue cone shows the angle subtended by rays from the primary mirror of the Otto Struve. The orange cone shows the acceptance angle of the detector fibers. The detector fibers will have numerical aperture 0.12, this being the smallest aperture available. The low numerical aperture minimizes focal ratio degradation (FRD) [6], and also ensures that the detector fibers cannot see light reflected off the walls of the enclosure. The yellow cone shows the spread of the light emitted by a guide fiber. The guide fibers will have numerical aperture 0.37, so that they emit light in a cone so wide it is visible to the fiber view cameras (FVCs). The FVCs measure the location of each guide fiber by triangulation. Light injectors within the same enclosure illuminate the guide fibers. To minimize atmospheric glow caused by the guide illumination, we will coat the interior of the enclosure with an anti-reflective black paint [7]. The fibers we thread through the positioner masts must be connected to the fibers that run to the DFPS-A80's injectors and feedthroughs. We will make these connections with a fusion splicer. The DFPS-A80 enclosure provides space to coil excess fiber, so that fibers may be spliced outside the enclosure, then stored inside the enclosure.

Once the DFPS-A80 is installed on the telescope, we can start reading out the guide sensors. The telescope control system will use the guide sensor images to focus and guide the telescope during observation. As we will describe in the next section, the guide sensors, fiducial fibers, guide fibers, and fiber view cameras housed inside the DFPS-A80 will allow us to deduce the location of each detector fiber in celestial coordinates, and so place the detector fibers on celestial targets. We will build two DFPS-A80 front ends. We will complete assembly and calibration of the first DFPS-A80 in Month 14, and ship it to TAMU in Month 15. We will complete the second DFPS-A80 in Month 18. We will keep the second DFPS-A80 at OSI to help us duplicate and diagnose problems encountered by the first DFPS-A80 during commissioning at the McDonald Observatory.

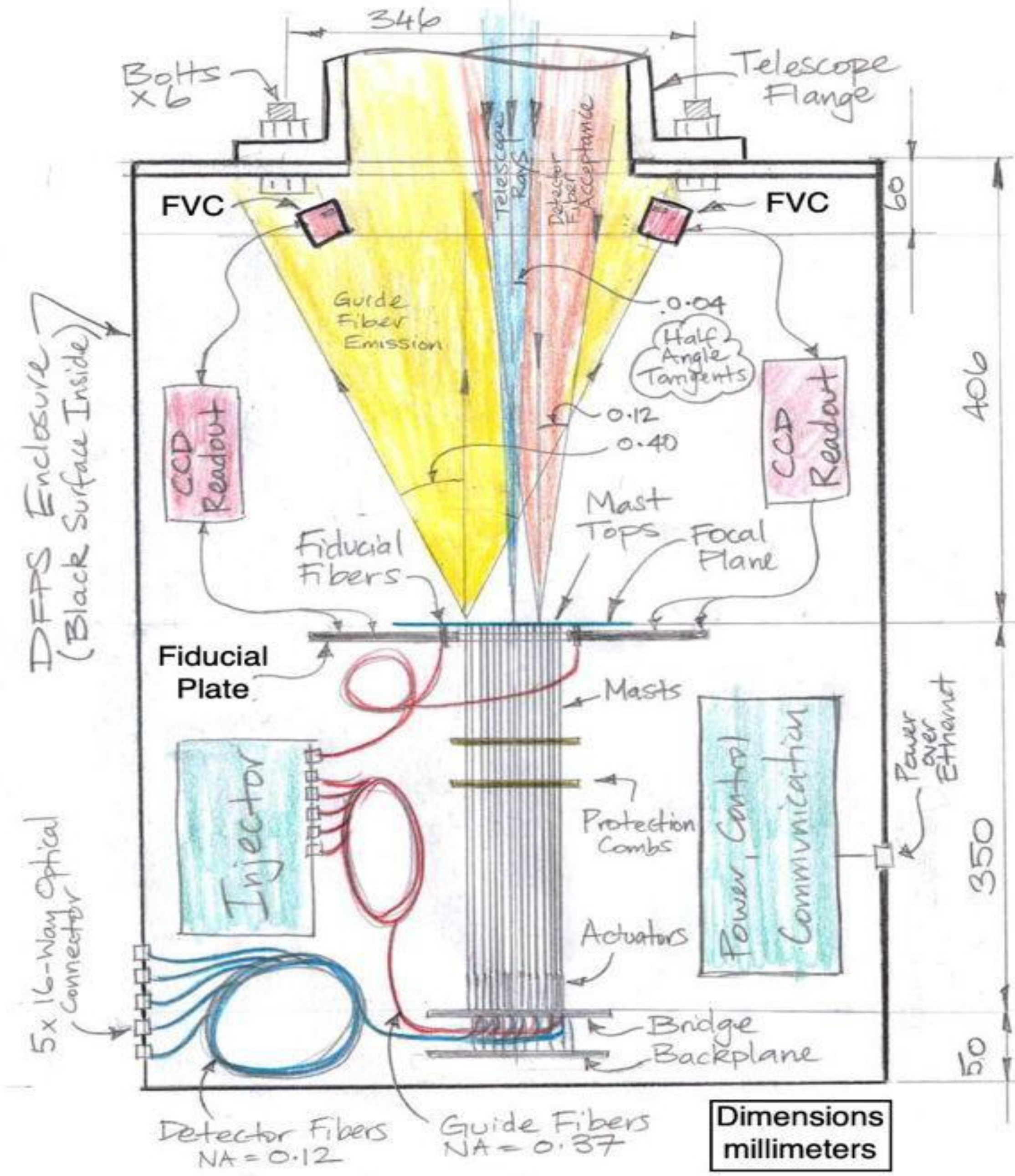

Figure 5: Sketch of the Self-Contained DFPS-A80. Fiber view cameras (FVCs) look down upon an array of eighty fiber positioners. A fiducial plate supports star-guide sensors and fiducial fibers. An injector illuminates the guide fibers. Optical connectors carry the detector fiber light out through the blackened walls of the enclosure.

Detector Calibration

The DFPS-A80's array of eighty positioners will consist of five cells of sixteen positioners each, arranged in a cross, as shown in Figure 6. We note that the central cell is surrounded on all sides by neighboring cells, thus demonstrating that a cell needs no additional space around it for installation. Each positioner presents both a detector fiber and a guide fiber. The DFPS-A80's fiducial plate surrounds the fiber array. Mounted on the fiducial plate, around the perimeter of the fiber array, are four guide sensors and twelve fiducial fibers. Viewing the guide fibers and fiducial fibers from above are two fiber view cameras (FVCs). All these elements must be calibrated so that we can deduce the position of each detector fiber with respect to the stars during observation. In order to permit us to measure the locations of ferrules, mounting balls, and calibration targets during our Phase II work, we will purchase a 10-μm accurate, portable measuring arm with a radius of 60 cm. Our objective is to determine the locations and orientations of all DFPS-A80 optical elements in a coordinate system defined by its fiducial plate. (For this coordinate system, we might take one edge of the plate as the x-axis, its surface as the x-y plane, and the normal to the surface as the z-axis.)

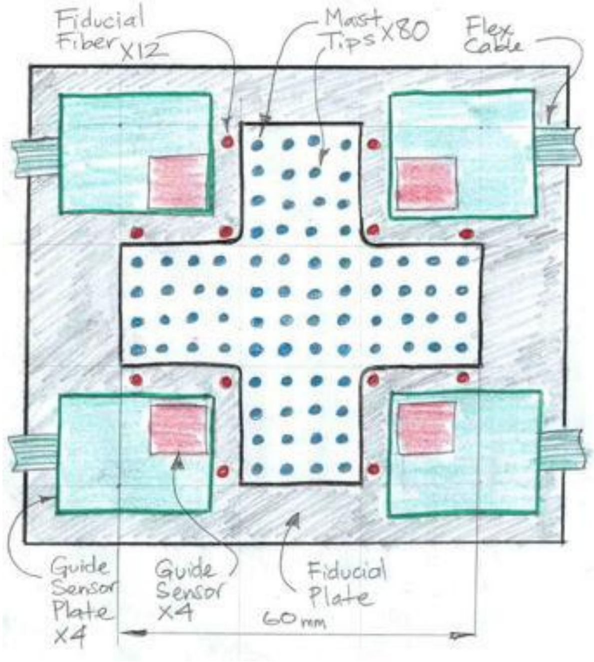

Figure 6: Sketch of the DFPS-A80 Fiducial Plate, Looking Down on Positioners. The fiducial plate is equipped with four guide sensors and twelve fiducial fibers. Width of the cross is 6.6 arcmin on the sky.

The silicon surface of the guide sensors will occupy a plane slightly below the plane of the detector fibers. The window on the sensors makes them appear closer to the primary mirror. Taking this effect into account, we will ensure that the tips of the detector fibers will be optically coplanar with the guide sensors to within ±100 μm.

The guide sensors will mount kinematically on three steel balls glued to the fiducial plate. On a separate calibration stand, we will mount the guide sensor in several orientations while projecting a chessboard mask onto its surface [12]. By this means, we will deduce the location and orientation of its pixel array with respect to its mounting balls. On the fiducial plate, we will measure the positions of the mounting balls and fiducial fiber ferrules directly. The fibers will be held in zirconia ferrules that center the fiber to within a few microns.

We can, in principle, calibrate the FVCs using the fiducial fiber array. But we will calibrate the FVCs separately, because we have been performing such calibrations for over twenty years [8]. Each FVC will consist of an 18-mm focal length lens, a 1-mm aperture, and an image sensor roughly 20 mm from the aperture. The FVC will behave like a pinhole camera, providing linear projection over a wide field of view. Each FVC will mount on three steel balls. We will measure the location of these three balls with respect to the balls on the fiducial plate. The FVC mounting plates and the fiducial plate itself will both be bolted to a stiff metal plate that will make up the back wall of the DFPS-A80 enclosure. We will measure the location of these mounting balls and combine them with our calibration of the FVCs. We will know the location of the FVC apertures to within 10 μm in the coordinates of the fiducial plate. We will know the direction of their optical axes to 50 μrad and the rotation of their image sensors to within 100 μrad.

The FVCs triangulate the position of the fiducial and guide fibers in a single exposure from each camera, in which all the guide and fiducial fibers are illuminated at once. Our calibration of the guide sensors, fiducial fibers, and cameras will allow us to measure the location of every guide fiber with respect to the guide sensors with an accuracy of 10 μm in all coordinates. But we still do not know the locations of the detector fibers. The detector fibers and guide fibers are mounted together in a dual-bore ferrule at the tip of each positioner mast. So we know their separation to within 10 μm. But we do not know the exact direction of this separation in the coordinates of the fiducial plate. To measure this direction, we will build a calibration camera. This camera will mount in the viewport of the DFPS-A80 and look straight down upon the positioner array. For the calibration, we back-illuminate the detector fibers and view them in the calibration camera. We then illuminate the guide fibers and view them in the same camera. By this means, we obtain the direction of the displacement between each pair of guide and detector fibers. We will demonstrate accurate calibration of the DFPS-A80 by Month 14. With these calibrations in place, the guide sensors and fiber view cameras provide all the information we need to drive each detector fiber to a target location in the celestial map.

Construct Positioner Cells

The greatest challenge we faced in Phase I was loading sixteen fiber positioners onto a twenty-millimeter square cell. These actuators must be soldered securely at the base so as to provide both electrical and structural contact with their four electrodes.

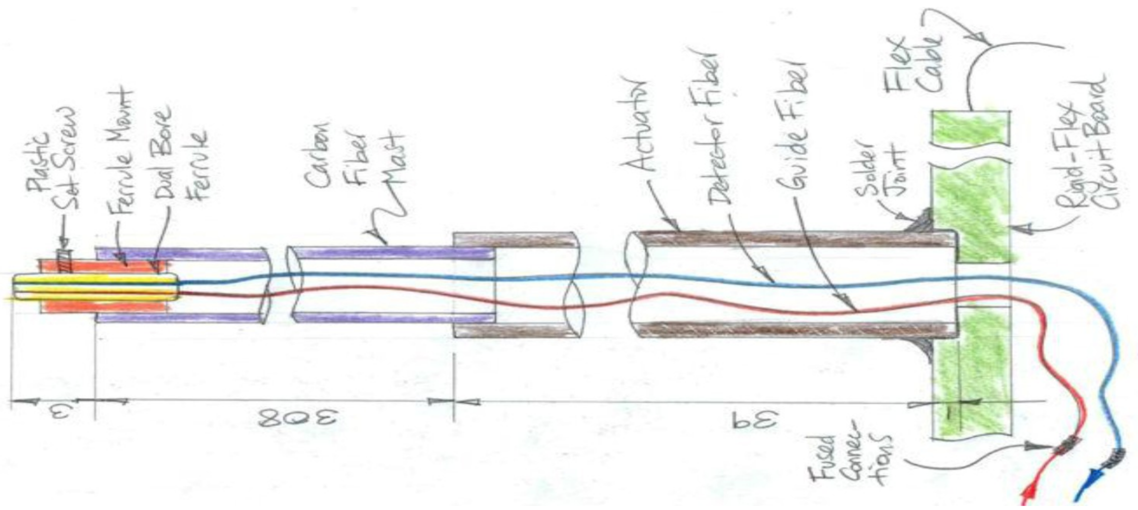

Figure 7: Sketch of the DFPS-A80A Fiber Positioner, Cross Section.

When our Phase II work begins, we will order the actuators required by our two DFPS-A80 front ends. We will have to wait fourteen weeks for the actuators to arrive. During that time we will use the few actuators we have left over from Phase I to perfect our means of loading actuators onto cells of sixteen. Our current plan is to load the piezo-electric actuators onto the cell's base board, apply solder paste, and solder them in our reflow oven. Once all the joints are inspected and tested, we glue the carbon fiber masts into the actuators with the help of an assembly fixture. We will glue ferrule mounts into the tips of the masts using the same fixture.

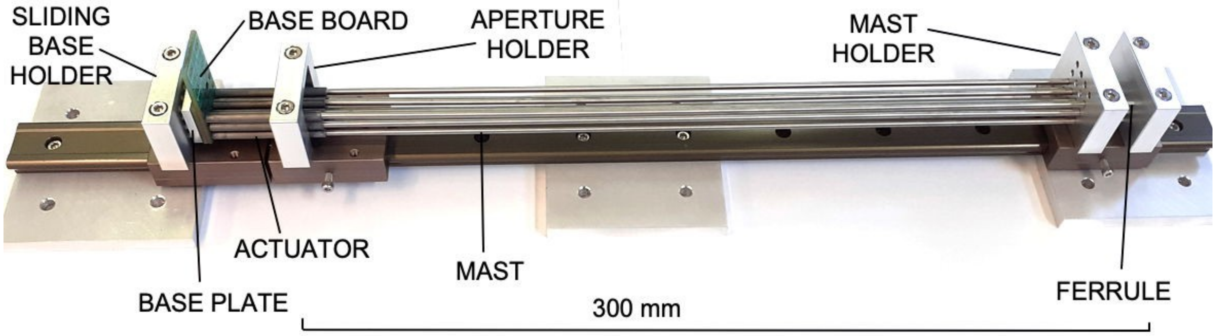

Figure 8: DFPS-A16 Cell Assembly Fixture. Here we see stainless steel masts, later rejected in favor of carbon fiber. We will use a similar fixture to glue the DFPS-A80 masts to their actuators.

Each DFPS-A80 positioner will be equipped with two fibers: one detector fiber and one guide fiber. We load these fibers into a dual-bore ferrule and polish them at the same time, leaving one meter of each fiber attached to the ferrule. In the DFPS-A80, we will restrict ourselves to two fibers per positioner, but we could load seven fibers into a multi-bore ferrule [13], polish them all at once, and so provide six detector fibers clustered together at the tip of one positioner for celestial observation. Once we have prepared the ferrule, we thread the guide and detector fibers down through the mast and out through a hole in the base board. We fasten the dual-bore ferrule into the top of the mast with a set screw. We will complete construction of five positioner cells, sufficient for our first DFPS-A80, by the end of Month 8.

Construct Fiber Controllers

The DFPS-A80 will use the same fiber controller design as the DFPS-A16. The design worked well and we expect no problems with assembly and testing. We will complete the assembly of one hundred and sixty fiber controllers, sufficient for two DFPS-80s, by the end of Month 5.

Telescope Control Interface

The DFPS-A80 readout and control system will be based upon our existing Long-Wire Data Acquisition (LWDAQ) hardware and software [9]. The DFPS-A80 image sensors will be CCDs we have on the shelf, for which the LWDAQ already provides readout and control [10]. The light injectors will be similar to our existing Thirty-Six Way Contact Injector [11]. The telescope control interface will run on a computer provided by the observatory. It will communicate with the observatory's control system through a TCP socket. Commands delivered through the socket will cause the program to return the position of all the detector fibers in fiducial coordinates, read out the guide sensors, or drive a detector fiber to a particular location in fiducial coordinates and keep it there. The interface will monitor all positioners and adjust their control voltages to maintain their positions. We will complete the first version of the telescope control interface by the end of Month 10.

Modification of Existing Spectrograph

The McDonald Observatory Otto Struve 2.1-m telescope is a classical Cassegrain design with *f*/13.7 focal ratio and 7.23 arcsec/mm plate scale. Several features of this telescope make it a practical choice for testing the Direct Fiber Positioning System. When compared to other potential telescopes, the 2.1 m is relatively under-subscribed and the Texas A&M Instrumentation Lab has a history of being awarded significant time for both engineering and scientific activities (~80 nights in the past two years). The plate scale of the telescope is such that a widely available fiber optic diameter of 100 microns is equivalent to 0.723 arcseconds, which is a good size for sampling point sources as well as physically fitting in the fiber positioners and with sufficient flexibility to easily route the fibers through the positioner. This also means that additional fore-optics are not required to adjust the plate scale, which simplifies the instrument and enables more flexibility when determining the location of the fiber view cameras.

The decision to not include an atmospheric dispersion compensator does limit the practical use of the system to red objects and objects near Zenith. This was determined to be an acceptable trade in complexity and cost for a technology feasibility demonstration. Finally, the 2.1-m dome is very spacious, so there are no concerns with the instrument space envelope and potential collisions. Routing of the fiber optic bundle from the positioner to the spectrograph is straightforward and the Instrumentation Lab has previous experience with writing software interfaces to communicate with the telescope control system.

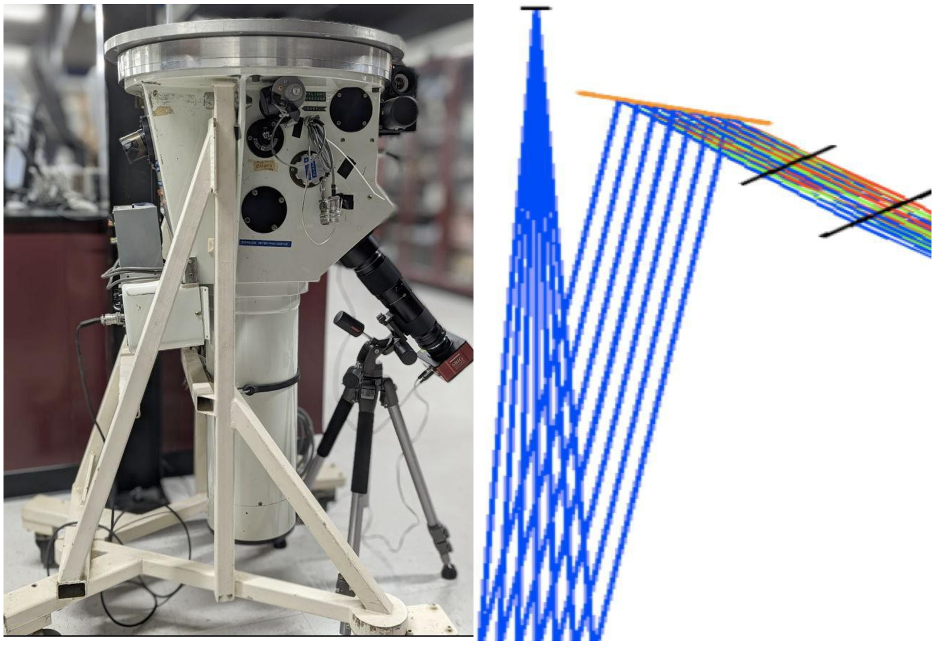

Figure 9: The spectrograph (left) and optical model (right). A tripod mounted camera lens with a CCD camera was used to verify the basic functionality of the spectrograph. The light from the fibers enters the top of the spectrograph, is collimated via an off-axis parabolic mirror and then dispersed by a reflective grating. The optical model includes a paraxial 300-mm focal length camera.

The primary goal of this proposal is to demonstrate the performance of a new fiber positioner design. In order to do this, a spectrograph is required, however the development of a purpose-built spectrograph from scratch would require a significant amount of engineering effort and production expense on a relatively short timescale to ensure the spectrograph is ready in time for testing the fiber positioner. Instead we propose to refurbish and modify a Boller and Chivens spectrograph that was installed on the CTIO 1-m telescope in mid 1975 and saw many years of productive service.

The spectrograph is complete, with the exception of a camera and detector system, so the primary effort will be focused on modifying the entrance slit to accommodate a linear array of eighty fibers and mounting a commercially available camera lens and detector system. The collimated beam is 90 mm in diameter, so we choose a Canon 300-mm focal length f/2.8 DSLR lens to replace the original f/1.4 reflective Schmidt camera. Instead of the original glass photographic plates, we will use a modern scientific CMOS camera (Hamamatsu ORCA-Quest qCMOS) which has 4.5-μm pixels in a 4096 (H) × 2304 (V) array. This detector is well-matched to the reimaged linear fiber array, enabling resolutions of ~1,000-20,000 and spectral bandwidth of 20-400 nm depending on the choice of grating. Several original gratings are still in good condition and additional gratings are readily available. A resolution element for a 100-μm fiber input is ~7 pixels. The high quantum efficiency (90% peak), low read noise (<1e-), and fast readout times (5 frames per second) will enable fast feedback while developing and validating the fiber alignment algorithms. The off-axis parabola reflective collimator in the spectrograph will be recoated and colored glass order sorting filters will be replaced with modern interference filters, which should result in efficiency gains of >10%. Basic functionality of the spectrograph has already been verified in the lab.

Figure 10: The Otto Struve Telescope and Dome. An astronomical instrument is installed at the Cassegrain viewport, in the same location we plan to install the DFPS-A80.

Assemble at TAMU

We will ship the first DFPS-A80 to TAMU in Month 15. In the TAMU laboratory, our collaborators will exercise our telescope control interface, connect the DFPS-A80 to their refurbished spectrometer, and take spectra of reference light sources. Laboratory testing at TAMU will be complete in Month 17.

Installation and Commissioning

Our collaborators at TAMU will transport the first DFPS-A80 and their refurbished spectrometer to the McDonald observatory in Month 18. Both OSI and TAMU will take part in installation and commissioning. Figure 10 shows the telescope and its dome. We will be bolting the DFPS-A80 enclosure to the Cassegrain viewport of the telescope, and running optical fiber cables to the spectrometer on the floor nearby. We expect to make several trips to the telescope. We will complete commissioning by the end of Month 22.

Celestial Observations

We plan to demonstrate the effectiveness of the DFPS-A80 by executing several scientifically-interesting projects.

Lithium absorption in red giant stars

One project would be a survey of red giant stars in old open clusters for the presence of Lithium absorption at 670.7 nm. This absorption feature is unusual, since red giant stars typically have very low Lithium abundances in their atmospheres due to the deepening of convective envelopes during the stars post-main-sequence evolution (and consequent Li destruction at the higher temperature interior regions). Nonetheless, there are examples of these evolved stars with unexpectedly high Lithium abundance, thought to be caused by major disturbances of these stellar atmospheres in the recent past [15]. Identification of more examples, particularly with high signal-to-noise ratio, will help to disentangle the impact of the mechanisms responsible for these disturbances. We can observe many stars in appropriately chosen open clusters simultaneously; simulations of potential target stars using the proposed positioner geometry suggest we can observe as many as ~50 stars in many open clusters (leaving many to observe sky emission for accurate background subtraction). We will target several clusters at various ages and metallicities to obtain broadly useful information; the exact targets will depend on the assigned dates of the telescope time. We will configure the spectrograph to cover the spectral region around 670.7nm at resolution of approximately 0.05nm (resolution ~12,000), which will be sufficient to detect the absorption features [15].

Measuring the binary fraction of Globular Clusters

For many decades, Globular Clusters (GCs) were known to be simple stellar systems, with all member stars sharing a common age and iron abundance. Modern measurements, however, have revealed that not all of these systems are quite so simple, and have yielded further insight into these foundational systems in our Galaxy. As one example, unresolved binaries plague measurements of GC properties because they widen the stellar locus in a color-magnitude diagram, influence the mass distributions of these systems, and affect dark matter measurements. Typical velocity dispersions of GCs are in the range ~2 – 10 km/s. Because of this very low velocity dispersion, even a small contribution from binary stars can inflate the measured velocity dispersion relative to the true value. There exist in the literature radial velocity measurements for many stars in GCs, and the Gaia satellite has made these sorts of measurements as well, but only one epoch has been acquired for most systems. This yields a systemic radial velocity for the GC but not the ability to estimate its binary fraction. Repeated radial velocity measurements are required to assess the binary fraction of GCs. The system described in this proposal facilitates highly efficient multiple epoch, moderate-resolution spectroscopic measurements of many red giant branch stars in nearby GCs. The nearest GC, NGC6397, has many member stars having magnitudes $8 < G < 12$ mag, easily reaching adequate signal-to-noise using the system described here. Many additional nearby GCs may also be studied in this way. Even more compellingly, if we were to eventually deploy the system on a larger telescope we will then be able to reach fainter, more distant targets, enabling a similar study of other compelling stellar systems such as nearby ultra-faint dwarf galaxies.

Broader Impacts

Every astronomical observatory would like to own a multi-object spectrometer, and yet such instruments are rare. The existing designs are expensive to manufacture because they are mechanically complex. Most designs require modifications to the telescope, which makes them difficult to install. Our Direct Fiber-Positioning System (DFPS) is comparatively easy to manufacture because of its mechanical simplicity. It is easy to install because it requires only a viewport to bolt to. The DFPS integrates easily with an existing telescope control system because it contains its own calibrated guide sensors, and it performs continuous adjustment of its detector fibers without disrupting astronomical observation. The entire DFPS is controlled through a single ethernet port, and is supported by an open-source computer interface that runs on any operating system. The DFPS makes multi-object spectroscopy available to professional observatories of any size. If our DFPS proves itself during this Phase II project, the market for million-dollar DFPS installations at observatories across the world number in the hundreds.

The DFPS provides fiber positioners on a 5-mm grid, which is twice the density of positioners per unit area of any competing fiber positioner design. The design lends itself to the construction of multi-object spectrometers with tens of thousands of fiber positioners. The DFPS does not require separate sets of high-voltage signals for each positioner. Instead, these high-voltage signals are generated immediately beneath each positioner. The power-dissipation of the DFPS positioners is a continuous 40 mW, compared to peak dissipation of 1 W for competing technologies [14]. One of the long-term objectives of the astronomical community is to build a spectrograph with fifty thousand positioners. The DFPS is the only fiber positioner design capable of providing such an instrument. The construction of a fifty-thousand fiber positioner would be a contract worth tens of millions of dollars, and we believe our company is well-placed to receive that contract.

This Phase II project is a collaboration between a private company and an academic institution. It is not a transfer of technology from one entity to another, but rather a pooling of expertise to produce a working instrument. Astronomers are world leaders in the design of complex optical devices. They know their telescopes, and they don’t need a private company like ours to tell them how to design the back-end of a spectrograph. What they want from us is the electro-mechanical fiber positioner. Being academics, astronomers want to know how their instruments work. They prefer not to work with companies that keep secrets, because secrets can hide weaknesses. Assuming the success of our Phase II project, our DFPS marketing strategy will be to form a similar collaboration with every observatory for which we construct a DFPS. We will provide the front-end, they will provide the back-end, and we will cooperate openly on the design and installation of the final instrument.

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