First steps towards a low cost, automated stellar interferometer.

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This paper reports on work done in the Physics Department of UPRM to construct an automated interferometer for stellar astrophysics, whose optical delay lines, under computer control, automatically search for the interference fringes produced by a large spectral bandwidth artificial source. The automation of the mechanical controls is achieved through the use of inexpensively built stepper motors and driver cards, controlled by slave PCs through their parallel ports. The primary purpose of this system is to demonstrate the positioning precision that is possible with low cost instrumentation and to maximise the reuse of decommissioned component systems.

Key Words: Interferometry; Stepper motor control; Optical Delay Lines.

1. Introduction

Optical stellar interferometers are used to make measurements of the fine angular detail in the visible and near infrared emission from celestial sources. The angular resolution of single optical telescopes (at best this is of order 1 second of arc, given the effects of atmospheric turbulence) is insufficient for a number of astronomical objectives. Despite the advent of adaptive optics, which is able to correct to a large extent the aberrations caused by the atmosphere, even the largest of today's telescopes are only 10 metres in diameter. To be able to see detail as yet inaccessible to us, on the order of a millisecond of arc, we require telescope baseline diameters at least an order of magnitude larger.

So, the principal motivation to build a stellar interferometer is that such instruments provide access to high angular resolution information. This comes at a small fraction of the price of a single-aperture telescopes with similar angular resolution, even if such single-aperture items were feasible.

A traditional interferometer geometry is shown in Figure 1, where the instrument consists of two telescopes, two optical delay lines (ODLs) and a beam combining plane.

In order for this interferometer to produce interference fringes (the signal) the system must be correctly aligned such that the optical path lengths of its arms are equalised. The optical path is defined to be the refractive index of the medium (usually air) multiplied by the physical path length traversed by the light beam through an optical instrument. In addition to this, the polarisation vectors of the light beams coming from each telescope must be the same.

Figure 1 shows many of the instrumentation subsystems required to align and manoeuvre the system components prior to observing “on-sky”. Many of them will be controlled in real-time, while others have to be adjustable from a remote station so as not to introduce extra turbulence into the beam combining plane.

Briefly, the various components within
the instrument that need to be computer controlled are:

- A set of artificial sources to align the interferometer components.
- Optical Delay Lines to equalise the arms; one is needed per arm of the instrument.
- Detector positioning system(s) to ensure the fringes are brought into focus on the detection camera.

Asides from the requirement that the subsystems be motorised and therefore controllable directly, there is also a need for feedback sensors, such as limit switches. This is so that the central control station can respond appropriately, although the inclusion of said sensors is being left for the second stage of the project.

2. Experimental setup

The basic prototype laboratory based interferometer with its computer controllers is shown in Figure 1. In order to be able to control the system remotely, we have had to construct an ethernet network within the laboratory. This serves as the backbone of computer communications for the interferometer’s subsystem controllers. The controllers themselves are Intel 386 and 486 PCs that have been reconstructed from decommissioned parts. They run a cut down version of Linux (Slackware v8.0) and are slaved to a number of master Pentium IIIs, which were loaded with both Windows 98 and RedHat v7.1 Linux operating systems. The eventual aim is to have the whole system running off real–time Linux kernels, although for the present the standard RedHat distribution is employed. Windows 98 is currently required because drivers for the video capture equipment is not yet available under Linux.

3. Mechanical motorisation

In order to motorise the subsystems that have been indicated in Figure 1, the philosophy of “the simpler the better” was adopted. Many older 5.25” floppy disk drives come with unipolar stepper motors as their workhorse motor. Three were rescued, to be used for the driving of stages and optical mounts. Having removed them from their disk drives, in–house driver boards were made so that the steppers could be controlled through the standard parallel (printer) ports of PCs. The circuit design used is shown in Figure 2. As shown, the driver circuit for a single unipolar motor uses four control pins of the parallel port. Since there are a total of twelve output pins per standard non–Centronix port, this means that we may simultaneously manage three unipolar motors with our design from a single port, depending on the
complexity of the controller program. PC architecture is designed in such a way that up to three parallel ports may be accessed from a single motherboard, giving even more flexibility.

The physical drive shaft of the test stepper motor was connected to a pulley by a small rubber belt. These belts are those used in VCRs and cassette recorders. The pulley itself was mounted on a micrometer screw drive, designed to push a single-axis optics mount.

3.1. Motor Calibration

To properly ensure the correct operation of the mechanism, a number of calibration measurements on a test rig were carried out. A control program was written in C which was executed remotely by a master computer to run the stepper motors through the parallel port of the slave. Figure 2 (right) shows the calibration mount controlled by a stepper motor and a sample linearity plot of steps applied versus displacement measured. The resulting linearity of the movement was found to be in a range of 0.47-2.05% in a single directional sweep. Bidirectional sweeps were less accurate, because of the backlash in the micrometer screw. An oscillating mode is yet to be calibrated. It is anticipated that the maximum travel speed for mounts will be on the order of a few cm/sec.

4. Basic Interferometer

As mentioned, the stepper motor systems are being made to drive the mechanical stages of an interferometer. These stages will control the positions of the ODLs, the artificial alignment sources and the detectors. As a test platform, a simple two beam interferometer using a monochromatic HeNe laser source is under construction. This is shown in Figure 3. The present incarnation of the interferometer does not incorporate the optical delay lines or all the required alignment sources as yet. The first fringes that have been acquired from the vanilla system are shown in Figure 4. They have a markedly lower contrast than expected. The loss of the fringe contrast\(^1\) is attributed to unequal polarization vectors in the arms of the instrument, asymmetries in the system geometry and the unequal optical paths between the two arms. The optical delay line will be added as a next step to the work. It is anticipated that this will augment the fringe contrast. If possible polarizers will be acquired for each arm.

\[^1\text{Fringe contrast or Visibility } V := \frac{I_{\text{max}}-I_{\text{min}}}{I_{\text{max}}+I_{\text{min}}} \text{ where } I_{\text{max}}, I_{\text{min}} \text{ represent the maximum and minimum intensity values.}\]
of the instrument, for although they affect the instrument transmissivity, by rejecting the out–of–phase components the signal–to–noise of the final fringes will be improved.

5. Conclusion

We have reported on the first phase of construction of a low–cost stellar interferometer. This system, if proved in the laboratory environment to be robust enough, will be used at the UPRM–Los Alamos National Laboratories observatory site of Fenton Hill.

References


