MIDI: Controlling a Two 8m Telescopes Michelson Interferometer for the Thermal Infrared

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ABSTRACT

MIDI is a two channel mid-infrared interferometric instrument developed for the Very Large Telescope (VLT) Interferometer (VLTI). A control system with real-time capabilities integrates the various VLTI subsystems. Based on the VLT control architecture and its interferometric extension, the VLTI control system, the MIDI control system will use synchronized VME computers running Tornado to control time critical subsystems such as delay lines and detector control electronics. Standard Unix workstations run high-level coordinating, monitoring, and data pre-processing tasks as well as graphical user interfaces. We describe the MIDI control architecture, the data flow and storage concept, and the self fringe tracking option. Furthermore we introduce a software package currently under development to simulate observations with MIDI.

Keywords: control system, interferometry, fringe tracking, simulation software

1. INTRODUCTION

MIDI is a Michelson-type interferometric instrument[1,2] to be operated at a wavelength of 10 μm, combining the beams of two 8-m telescopes on Paranal, Chile. The instrument's most challenging tasks from the point of view of control are the high detector readout frequencies (40–250 Hz) which will be processed in a (near) real-time environment. The wish for setting up a feed-back system with a bandwidth of approx. 1 Hz to stabilize fringes (in case without common external fringe tracker), sets increased demands on data acquisition, real-time processing, and near real-time processing capabilities. Fast and delay-less synchronizations between different subsystems (chopping control systems, external fringe tracker, VLTI delay line controller, PRIMA,[3,4] VINCI,[5] etc.) introduce further strong requirements on all involved software components.

The MIDI control system architecture (see figure 1) is a multi-platform, distributed, network-based control system. Local Control Units (LCUs) perform real-time control of MIDI subsystems and synchronization with other VLTI subsystems. LCUs typically respond to external events within a few microseconds. Unix workstations (WSs) run graphical user interfaces (GUIs) and high-level coordinating tasks with approx. 10 ms response times. The entire MIDI system architecture has been designed to conform with the standard hardware and software platforms supported by ESO.[6]

2. CONTROL SYSTEM REQUIREMENTS

MIDI is equipped with a mid-infrared sensitive detector (320 $\times$ 240 pixel) which yields — output of the readout control electronics (ROE)[7] — a data stream up to about 51 MB/s (burst/test mode at 333 Hz full frames with 16-Bit per pixel). Although the processing of those data rates is only necessary for maintenance (detector characteristics) or test purposes, the control system has to be designed to handle them. In science mode, the MIDI control system must be able to process about 14 MB/s in Fourier mode and 2.3 MB/s in a so-called precise ABCD mode.[2] The latter one shall be considered the typical MIDI observing mode. That means the maximum average data rate that MIDI will produce is 2.3 MB/s or about 100 GB a night.

The current phase of development foresees that MIDI will always acquire full (complete) detector frames. Sub-array modes or selected areas or windowed frames (a window is typically smaller than the detector geometry) can be handled by the ROE — and obviously this hardware pre-processing (if functional) will be a major relief to the subsequent data pipeline.

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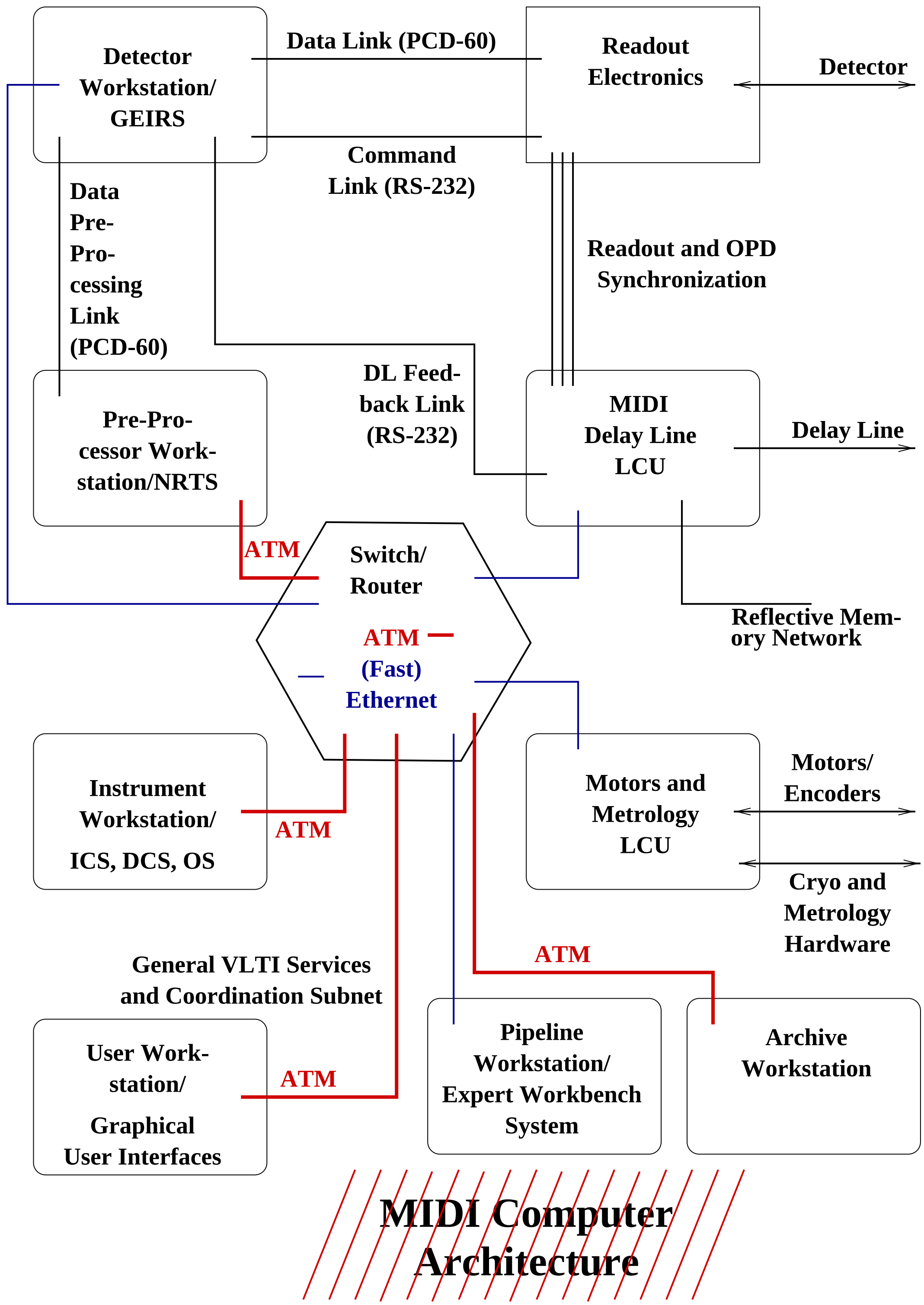

Figure 1. MIDI connectivity. Data collected by the detector are sampled by the readout electronics and transmitted to the detector workstation over a fast parallel data interface (PCD-60). The *general infrared software* GEIRS reorganizes the incoming data and sends them to the *near real-time system* NRTS running on the pre-processor workstation. NRTS creates the MIDI science data quality display and prepares the data for archiving. Data flow continues to the instrument workstation running MIDI *observation software* OS and hosting the instrument control system (ICS) and detector control system (DCS). OS takes care of data archival on the archive workstation. See text for further explanations.

The main scientific output to the observer will be visibilities, delivered in near real time. MIDI shall be capable to find fringes in near real-time and to track fringes in real-time. The difference between near real-time and real-time is easy to explain with the following examples:

- in real-time, fringe finding and tracking take place while receiving data at high data rates on the detector workstation (DWS).
- in near real-time, calculations of visibilities are decoupled from the data taking process, i.e. if the visibility calculator process hangs up, it does not disturb the real-time data acquisition process.

Some rather fundamental modes of MIDI science operation scan the optical path difference (OPD). In these delay scan modes, MIDI must synchronize its data taking process with the MIDI delay line (DL) control system in a very efficient way to avoid time lags. OPDs are changed stepwise or continuously as “ramps”. In any case, it is a strong requirement that the system knows (and of course also defines) the actual OPD value for a given data frame. That means synchronization of the start of exposure with the controlled setting of the DL. This requires a fast and almost delay free communication (< 1 ms) between MIDI DL control system and ROE. Synchronization shall be possible within milli-seconds (throughput taken into account). In order to understand the previous requirements, one ought remember the typical time frame for a MIDI observation block, which is 100 ms only (this is the expected coherence time of the atmosphere at 10 μm on Paranal). In Fourier mode with 25 OPD changes within 100 ms time, time delays of the order of 1-2 ms may therefore reduce the power of the instrument considerably.

Fringes move due to atmospheric turbulences. A requirement to the instrument is to stabilize fringe motion (so called self fringe finding and tracking mode) at an open-loop rate of about 10 Hz (independent from external fringe tracking). This requires a fast communication between DWS, which runs the fringe finder program, and the MIDI DL-LCU running the OPD controller.

Visualizing MIDI data in real-time puts up requirements which are difficult to meet for all data taking modes. In particular the extremely high data rates of > 50 MB/s in test/burst mode keep the data receiver process (communication between ROE and DWS) almost 100 % busy. The requirements for the data pre-processing and visualizing capabilities are therefore reduced to manage the maximum average data rate of 2.3 MB/s continuously over minutes to hours. Since many uncertainties lie in the performance of not yet written software modules (e.g. how long does it take to find fringes) we still aim at handling up to 4 MB/s, the sustained data pipeline bandwidth.

3. MIDI SYSTEM ARCHITECTURE

The system architecture describes the major computing components of the MIDI control system. It includes the ROE which employs custom-made embedded software on a Texas Instruments digital signal processor. The data and command/status flow is shown in figure 2.

The main software and hardware components of the control system are:

1. the ROE[7] which operates the detector, receives and digitizes its data, transmits them to the DWS, and synchronizes the exposure start times with the MIDI OPD controller (controlled through the MIDI DL-LCU).
2. the DWS, which sets up the ROE, receives data coming from the ROE, stores data locally, transmits data to NRTS running on the pre-processing workstation (PP), and sends offset OPD values to the MIDI DL-LCU in self fringe tracking mode. The DWS runs the generic infrared software GEIRS, a program tuned to store up to 50 MB/s of data on local disks. Another operating mode includes the windowing of incoming data, a process which cuts useless information out of the data stream and sends the windowed data over to the PP for further processing in the NRTS environment.

   The DWS is a multi-processor (currently 2 CPUs running at 300 MHz) Sun Ultra 450 with 4 GB memory. The DWS is equipped with two high speed parallel interfaces (EDT PCD-60) and fast local disks connected to a single ultra-wide SCSI controller (40 MB/s).
3. the PP running NRTS, which is responsible for pre-processing incoming MIDI data, preparing data for the ESO online archive, assessing the quality of the data and visualizing them for verification of a proper functional instrument, and passing data to the IWS. The IWS runs the Solaris operating system.

   The PP is a multi-processor (currently 2 CPUs running at 300 MHz) Sun Ultra 450 with 2 GB memory. The PP is equipped with one high speed parallel interfaces (EDT PCD-60), fast local disks connected to a single ultra-wide SCSI controller (40 MB/s) and one ATM network interface. The science data flow (pipeline) towards the instrument workstation (IWS) will use this high speed network with a bandwidth of about 6 MB/s. The PP runs the Solaris operating system.

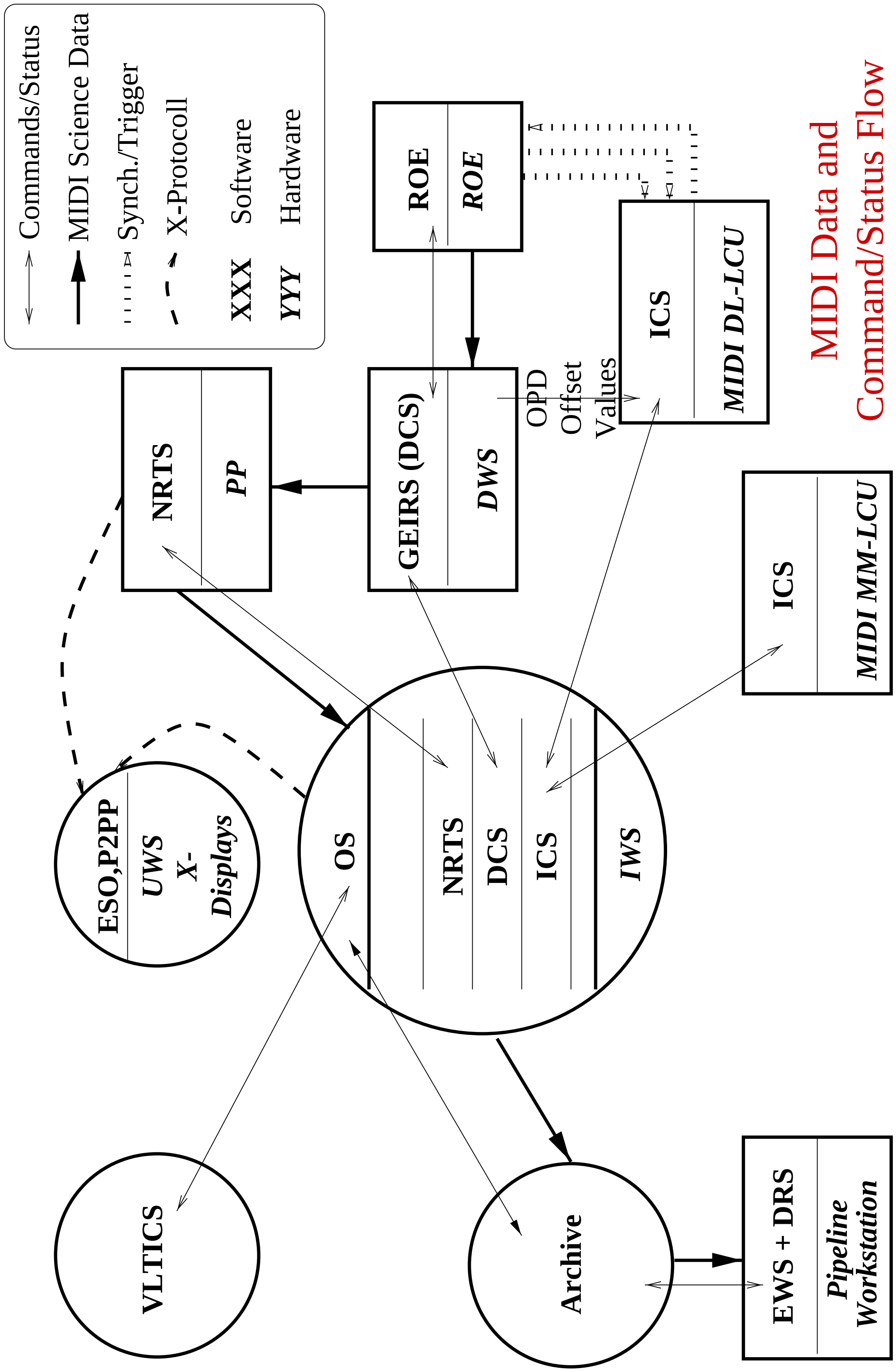

Figure 2. MIDI science data and command/status flow. Observation software (OS) coordinates all MIDI sub-systems. Telescope control is managed by the VLTI control system (VLTICS). Graphical user interfaces and ESO's *phase II preparation tool* P2PP (used to create and manage observation blocks) run on a dual monitor user workstation (UWS). The MIDI data pipeline (indicated by thick arrows) starts in ROE and ends in the online archive.

4. the IWS, which executes the MIDI instrument control software (ICS), detector control software (DCS), observation software (OS), including the coordination of all MIDI sub-systems, file serving for disk-less LCUs, server for graphical user interfaces (GUIs) etc. OS assembles the actual science data and their appropriate observational data/parameters for archiving and sends the final archivable data to the online archive.

   The IWS is an HP Visualize J5000 workstation (2 processors, 444 MHz, 2 GB RAM) equipped with an ATM interface.

5. the pipeline workstation, which executes the MIDI expert workbench system (EWS) and the *standard* MIDI data reduction software (DRS). EWS as well as DRS subscribe to the online archive to proceed with the evaluation of the science data. EWS will be an interactive IDL based system allowing data processing in a non-standard way, e.g. to establish algorithms that calculate fringe visibilities. In contrast, the DRS will use streamlined, tested algorithms. As algorithms become established, they will be ported to the NRTS and DRS environments. That means that after the commissioning phase of MIDI, EWS will be obsolete.

6. the MIDI DL sub-system (MIDI OPD controller), which is responsible for operating MIDI's internal DL control hardware (consisting of piezo driven mirrors). This system synchronizes its operations with many other VLTI sub-systems like the VLTI DL system, the fringe tracker, the telescope(s) chopping secondaries etc. Further synchronizations with the MIDI ROE are implemented to verify and check on the various MIDI OPD tables. These tables contain data describing the throw/position of the MIDI DL as a function of time.

   The MIDI DL-LCU is a 333 MHz PowerPC 604e based VME system running the real-time operating system Tornado.

7. the vacuum, temperature control, and motor subsystem (MM), the main task of which is to control and operate all motorized stages of MIDI, including opto-mechanical positions (filters, cameras, foci,. . .)

   The MIDI MM-LCU is a 333 MHz PowerPC 604e based VME system running the real-time operating system Tornado.

4. SELF FRINGE TRACKING

During a typical MIDI observation run, the MIDI delay line is used to scan and measure fringes (fringe contrast). After certain periods (e.g. 100 ms) atmospheric OPD drifts may require the MIDI OPD to be adjusted such that the white light fringe remains at its start position. In our ''baseline" atmosphere, we expect an OPD maximum drift of one radian within approx. 100 ms. To keep the fringe locked we will sample individual frames at 4 times this rate (40 Hz). Four of these frames (called ABCD) will be used to measure the OPD zero point and adjust the MIDI OPD controller to compensate. Calculations of the OPD shifts will be performed on the DWS. Fringe estimates will be made on the raw frames and transferred directly to the MIDI DL-LCU controlling the MIDI OPD. OPD offset values calculated on the DWS are sent over a serial RS-232 link to the MIDI DL-LCU. We expect to calculate zero OPD positions within 5–10 ms.

For spectrally dispersed modes, the coherence length of individual spectral channels is at least of the order of 30 λ, and rapid tracking of the OPD is not necessary. In these modes, slow fringe tracking corrections will be derived by NRTS and forwarded to the MIDI DL-LCU. Similarly updates to the main VLTI delay lines should only occur, when the OPD shift threatens to move out of the range of the MIDI DL. This should only happen on relatively long time scales (1 s). In these cases, the NRTS will forward OPD offsets to the VLTICS.

5. SIMULATING MIDI OBSERVATIONS

The software package Sim*VLTI* written in IDL is currently under development. A first release for Unix and MacOS has been made publicly available at http://www.mpia-hd.mpg.de/MIDI/SIMVLTI. Sim*VLTI* allows selection of the target to be simulated under observation. The instrument setup option allows to select the spectral filter width as well as the start and end of an observation in units of hours, counted from the meridian. The baseline setup option allows easy configuration of different telescope baselines. After having run a simulation, four plot options are available:

1. visibility vs. frequency, shows the target visibility plotted against the spatial frequencies that occur during your observation.
2. visibility vs. time, plots the resulting visibilities against time.
3. UV plane plot, shows an image of the UV plane of the input target and marks the tracks of the telescopes in there.
4. image display, shows the target object.

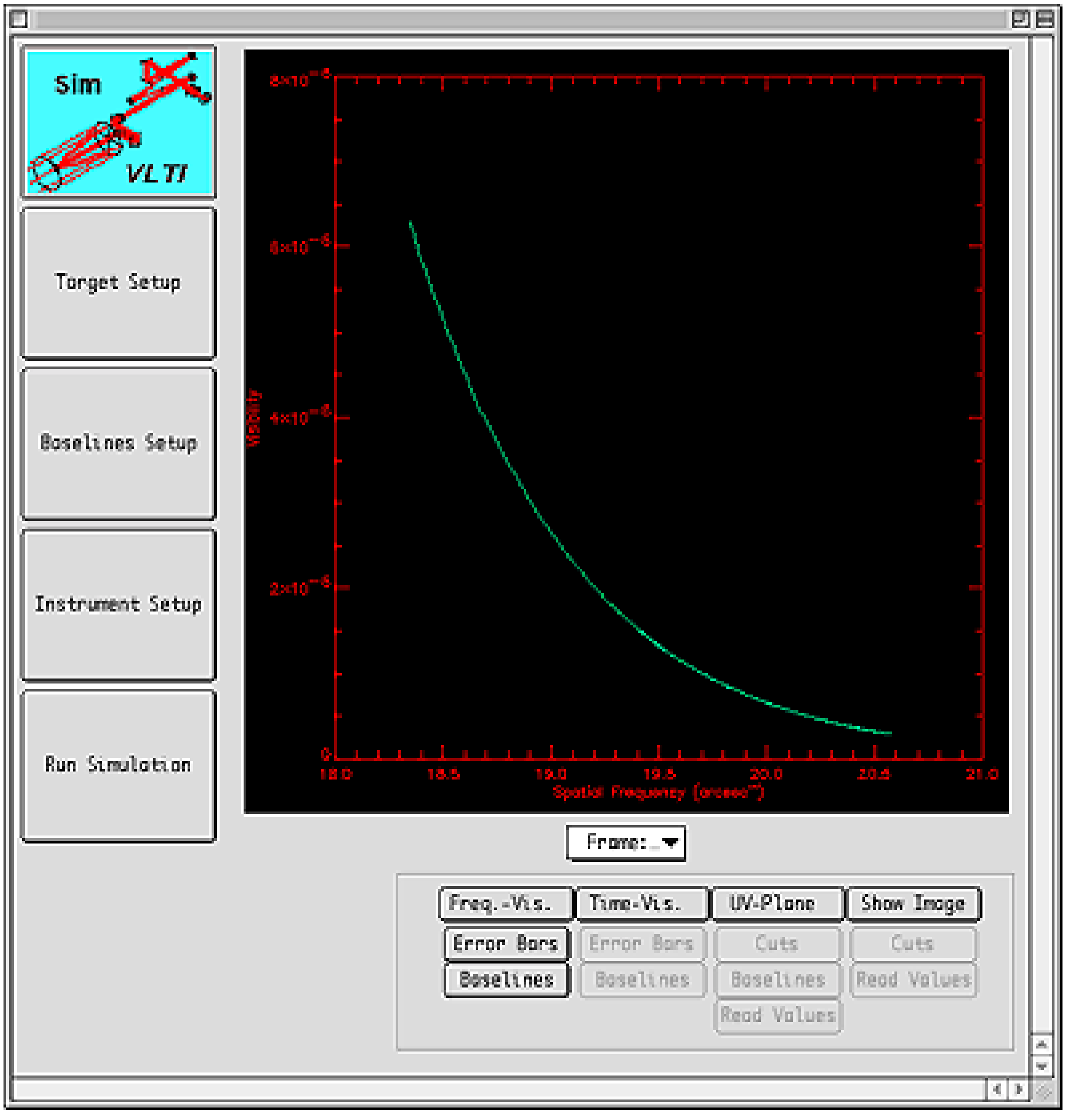

Figure 3. Graphical user interface of Sim*VLTI*

6. CONCLUSIONS

The MIDI control system will be able to fulfil most of the requirements raised. Some requirements like data taking in Fourier mode over half an hour are covered but with restricted quality of data monitoring.

Some important performance numbers of the instrument are difficult to predict at the current stage of development. What the final efficiency for the standard MIDI observing mode will be is still unknown, for example. Scanning over OPDs at 40 Hz while chopping at 5 Hz and tip-tilt stabilization on one side of the chop phase looks complicated at a first glance (i.e., one would expect large overheads) but may turn out to be realized in a very efficient way.

MIDI and its control system will neither be perfect nor optimal during instrument commissioning. One should therefore accept the somehow provisional nature of the control, pre-processing, and data reduction software. The hardware design is flexible enough to adapt easily to new generations of workstations, LCUs, network devices, etc.

An actual problem not yet solved to full satisfaction is the parallel processing and storing of data at high bandwidths. Very expensive hardware solutions exist, but one may ask whether they make sense as long as standard data reduction software or even standard pre-processing is not available. As soon as these standard software packages exist, one can measure their performances and then decide which hardware design is most suitable to run them.

7. ACRONYMS

ATM	Asynchronous Transfer Mode
DCS	Detector Control System
DL	Delay Line
DWS	Detector Workstation
ESO	European Southern Observatory
EWS	Expert Workbench System
GUI(s)	Graphical User Interface(s)
GEIRS	Generic Infrared Software
HP	Hewlett Packard
ICS	Instrument Control System
LAN(s)	Local Area Network(s)
LCU(s)	Local Control Unit(s)
MIDI	Mid-infrared Interferometric Instrument For The VLTI
MPIA	Max-Planck-Institut für Astronomie, Heidelberg
NRTS	Near Real-time System
OPD(s)	Optical Path Difference(s)
ROE	Readout Electronics
OS	Observation Software
SUN	Sun Microsystems
UWS	User Workstation
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VLTICS	Very Large Telescope Interferometer Control System
WS(s)	Workstation(s)

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