DATA ACQUISITION FOR THE DOT

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Summary. This memo to the DTBC[1] details plans for the DOT data acquisition system. The approach is to obtain speckle bursts with high frame-rate CCD cameras simultaneously at four wavelengths, and to write these via stacked hard disks to cassette tape for subsequent off-line processing.

Contents

[1] DOT Technische Begeleidingscommissie (steering committee); chair Achterberg, members Pel, Verkerk, Hammerschlag, Rutten

1 Summary of the DOT initial science program

The DOT initial science program is funded by:

- Sterrekundig Instituut Utrecht;
- Faculteit Natuur- en Sterrenkunde Universiteit Utrecht;
- Gebiedsbestuur Exacte Wetenschappen NWO;
- Nederlandse Onderzoeksschool voor Astronomie;
- European Commission TMR Network programme.

It covers the period Sep 1998 — Sep 2001 and should serve to establish and carry out a DOT science program defined in various grant applications[2] which consists of (quote):

> (i) – installation of three-channel proxy-magnetometry filter imaging (G band, Ca II K and tunable Hα);
> (ii) – observations with the above, especially in concert with SOHO, TRACE, and/or other Canary Island telescopes;
> (iii) – software development of phase-diverse speckle restoration.
>
> Other DOT plans (fiber reformatter, Stokes magnetometer, near-real-time phase-diverse speckle processor, larger aperture, adaptive optics experiments) are deferred to a second tranche subject to review, or to separate project proposals.

At present, the optical concepts for simultaneous imaging at the three proxy magnetometry wavelengths at the nominal resolution set by the DOT aperture have been formulated by Hammerschlag and have been tested at the DOT itself. Detailed design of the three-channel optics is underway; construction is to be completed this autumn (Hammerschlag, Bettonvil, IGF). This memo specifies the corresponding data acquisition system that must be realized simultaneously. As decided at the DTBC meeting in december, Rutten is its “trekker” in order to free Hammerschlag for timely DOT completion, in particular of the secondary optics.

2 Speckle reconstruction

2.1 Speckle tests at the DOT

A key element of the proposed DOT data acquisition system is that it will be geared towards high-volume software image reconstruction. A first test of the speckle masking technique (Weigelt 1977, von der Lühe 1993) at the DOT by P. Sütterlin, a recent addition to the DOT team (three-year postdoc on the EC–TMR grant) and a speckle expert, is highly promising. His very first DOT specke reconstruction may be inspected at `http://www.astro.uu.nl/~rutten/dot`, together with the best frame

[2] The most detailed one being the application to NOVA titled “Instrumentation for the Dutch Open Telescope” by Rutten & Hammerschlag, June 1998.

and the average of the burst (sixty 1 ms exposures at 1 s cadence) that went into the reconstruction. The seeing was fair but not excellent; the high quality of the speckle reconstruction demonstrates that using this technique, the DOT may approach diffraction-limited imaging at times when this is not at all provided by the ambient seeing — meaning much of the time instead of only far too seldom. The test proves the point made in the various DOT proposals that off-line image reconstruction will greatly improve the effective frequency and duration at which the DOT can perform high-resolution proxy magnetometry, and therefore the hit rate of overlap with space campaigns.

Further processing of a 15-minute sequence of such speckle bursts by Sütterlin (using the extensive cluster of 500 MHz Compaq Alpha workstations at Oslo during the ESMN[3] school) has resulted in the first speckle-restored granulation movie from the DOT. It indeed confirms the large promise of speckle reconstruction for dynamical feature evolution studies, but it also demonstrates the restrictive limitations of the simple video camera and analog link to the SVST building used at present. The large noise level and its time variability limit the quality of the restoration to below what may and should be reached.

2.2 Speckle versus phase diversity

The approach chosen for the DOT consists of off-line speckle processing. Various reasons contribute to selecting this technique over phase-diverse speckle restoration (combining multiple-image registration, one in focus and one deliberately out of focus, with speckle bursts of only a few frame pairs). The choice for straightforward speckle reconstruction without phase-diverse registration was made on the following grounds:

- hardware simplicity: no camera duplication or field halving as required for phase-diverse data taking;
- software robustness: speckle reconstruction of solar scenes has evolved over the past two decades into a mature technique. In addition, there are indications that speckle restoration breaks down only at appreciably worse seeing than phase-diverse restoration does;
- processing speed: the subsequent processing is the major bottleneck for large volume data analysis (see below). Speckle processing is less complex and less computationally demanding than phase-diverse restoration;
- processing versatility: by recording all frames of all speckle bursts, faster "quick and nasty" processing strategies are also possible and may be run in parallel or as quick-look utility (for example off-line frame selection, frame-to-frame rubber-sheet correction, deconvolution to best-frame power spectrum; these techniques are being explored with L. Strous at Lockheed-Martin);
- signal to noise: recording complete speckle bursts at all wavelenghts maintains the option to restore narrow-band frames, in particular Hα bursts that are too

[3]European Solar Magnetometry Network, see `http://www.astro.uu.nl/~rutten/tmr`

noisy for direct speckle reconstruction, through deconvolution with the point-spread function determined from a nearby wider-band continuum speckle burst with better photon statistics. Burst summing then produces larger signal to noise ratio (Keller & von der Lühe 1992).

– expertise: with P. Sütterlin the DOT team now has in-house speckle expertise.

A disadvantage of speckle reconstruction is that it corrects primarily time-varying wavefront aberrations, whereas phase-diverse restoration corrects more of the permanent low-order Zernike terms of the telescope aberrations. Since the DOT optics is simple and high-quality, the absence of this correction is not a large drawback. The major speckle disadvantage is that it needs intermediate storage of many more frames (factor 10–20).

2.3 Speckle versus adaptive optics

Adaptive optics (AO) is actively pursued at three major solar telescopes, namely the NSO Dunn Solar Telescope at Sacramento Peak, the German Vacuum Tower Telescope in Tenerife and the Swedish Vacuum Solar Telescope on La Palma. The US and Swedish colleagues have recently managed to close the loop. Demonstration results including on/off movies are web-posted at

– SVST: http://www.astro.su.se/groups/solar/matsdir/AO/

– NSO-DST: http://www.sunspot.noao.edu/AOWEB/

and illustrate the AO potential for real-time image improvement.

These AO programs are not yet mature but it is clear that successful regular application is on the near horizon. In the US, it is leading to renewed pressure for a large optical solar telescope, listed as major priority for US optical solar physics in the coming decade (recent Parker report). Adaptive optics is a sine-qua-non requirement for large telescopes because the atmospheric seeing at even the best sites will almost never reach the diffraction limit of apertures that exceed the current telescope generation (SVST and DOT: 45–47 cm; German VTT and NSO/SP DST 70–75 cm) except in the infrared. Speckle reconstruction becomes less viable because the speckle amplitudes diminish with increasing aperture. Thus, 1–4 meter-class solar telescopes aiming at high angular resolution in the visible must have AO systems.

A disadvantage of adaptive wavefront restoration is that only a single isoplanatic patch is corrected, limiting the high-resolution data acquisition to only a small field (of order 5×5 arcsec^2 in the visible), much smaller than a solar active region (granules measure about one arcsec in diameter, large sunspots over a hundred arcsec). Future AO-corrected large-aperture data gathering will therefore concentrate on spectrometry and spectrographic Stokes polarimetry of the smallest solar fine structures.

The DOT will not be equipped with adaptive optics, a spectrometer or a Stokes polarimeter during the initial-science phase. Since speckle reconstruction works well at the DOT aperture and since the seeing at La Palma is frequently good enough to permit speckle reconstruction with 3–4 times resolution enhancement, there is a viable and scientifically worthwhile niche for the DOT to perform imaging at the three proxy-magnetometry wavelengths — strictly simultaneously, of fields substantially larger than an isoplanatic patch, at the angular resolution required to locate and track magnetic bright points, and sufficiently frequent to regularly overlap with space campaigns diagnosing the overlying higher atmosphere.

3 DOT data acquisition

3.1 Hardware

In keeping with the DOT science proposals underlying the three-year initial funding, we will concentrate on the three-band proxy magnetometry imaging program while improving off-line reconstruction software. The data acquisition hardware therefore needs to encompass high frame rate cameras taking speckle bursts simultaneously at the multiple wavelengths, writing on storage media for subsequent off-line processing:

- CCD cameras (minimum 4). Digital, 10 bits, fast (order of ten frames per second), preferably high quantum efficiency, also at Ca II K ($\lambda = 393.3$ nm). The fourth camera will register the broad-band continuum near Hα, needed for parallel wide-band/narrow-band restoration and also to provide granulation without magnetic bright points to be combined with the G-band images. Fast-rate cameras seem to exist up to 1300×1000 px^2 at present, not larger. The corresponding field size is about 90×120 arcsec^2, smaller than the field provided by the 4.2 Mpx Megaplus cameras used at the SVST when not adaptively corrected, but it yet covers hundreds of isoplanatic patches and it is scientifically worthwhile. The size is also about the maximum that can be accommodated at reasonable cadence by the storage pipeline defined below. Machine-vision cameras with chips of this size are available at prices that fit just within the DOT budget, but it isn't yet clear how well they actually perform[4]. This is a matter of concern requiring testing one or more prototypes.
- Links to SVST (minimum 4). Digital, 10 bits. The distance is 120 m; copper may do but fiber seems preferable.
- Frame grabbers (probably 4; the term applies also to digital input). Capable of putting 30 Mb/s per camera into the computer memory.
- Data-acquisition computers (probably 4), most likely a Windows-NT PC per camera. Robust, at least 512$^+$ Mb of RAM;

[4]The present DOT camera is a small-field progressive-scan Hitachi video camera with an analog link to the SVST building, an analog frame grabber and 8-bit digitization. The quality does not meet the speckle reconstruction requirements. The initial reconstruction tests with bursts registered with this camera demonstrate that speckle is the way to go, but have also shown that the dynamic range is too small to cover active regions including dark umbrae and that the noise variations (probably set by the temperature sensitivity of the link) are too large to permit photometric calibration.

– RAID disk system, 20 Mb/s input, 250 Gb net storage. This multi-disk (16 disks 18 Gb each) serves to transfer the speckle bursts from the camera computers as an intermediate step in off-line storage. The transfer limits the sustained frame rate to about one four-camera burst per minute. This is a good sampling rate for many solar problems.
– DLT robot system for archiving. DLT cassettes have larger capacity (about 50 Gb) and are more reliable than other media (Exabyte, DAT). The writing speed is 5–10 Mb/s depending on the compression factor. Archiving a RAID-filling run of 250 Gb will take about a night and five cassettes.

This pipeline system delivers 250 Gb of data per storage-filling observing run, covering say 200 4-camera bursts taken at 1 minute cadence during 3.3 hours. This duration fits the solar physics desires and also fits the usual duration of good-seeing periods at La Palma. The archiving will typically be done overnight. These numbers concern a full-field full-capacity full-speed run. Depending on the science requirements, the pipeline size may be redistributed over a smaller field, shorter/longer duration, less/more Hα coverage, shorter/longer sampling intervals.

3.2 Off-line processing

The speckle processing methodology is mature and the software is ready for use. However, this processing represents the pipeline bottleneck. Presently, a single burst reconstruction producing one sharp image takes 2.5 hrs on a fast PC, 1 hr on a 500 MHz Compaq Alpha. In addition, the process presently requires knowledgeable interaction in the re-alignment of all the separately restored isoplanatic patches. Thus, using the present software and the present facilities at Utrecht limits the processing capability to just a few observing runs per year.

This bottleneck is the reason why "software development" was added to the DOT science proposals. Speckle processing of solar scenes has been amply demonstrated by different groups over the past decade, but it hasn't been turned into production-line machinery anywhere. The aim is to advance significantly towards that goal during the coming years. Various steps to be taken are:

– Hardware speedup. A default step: computer speeds double about every two years. Even without a specific effort on our side, the processing turnaround will improve considerably;
– Software speedup. The current codes rely much on IDL imaging routines that should become much faster when recoded in C;
– Distributed processing. Seeing restoration can be split between computers by simply assigning different bursts to different computers. Recoding into C also removes the bottleneck posed by the scarcity of IDL licenses.
– Parallel processing. The observed fields are split into isoplanatic patches at the outset and re-concatenated at the end. This makes speckle reconstruction an excellent candidate for parallel processing.

By the end of the DOT initial science period, an appreciable speed increase should already be realized, and sufficient experience should be in hand to define processing at a much faster turnaround than possible at present. One anticipated action is to formulate a parallel-processing proposal. The long term goal is to achieve overnight processing of the daily harvest, doing away with the need for burst-to-tape transfers.

4 Realization

4.1 Budget

The cost of the hardware configuration above is estimated to be:

− 4 digital 1.3 Mpx cameras + links + grabber interfaces	140 kf
− 4 data-acquisition PC's	60 kf
− RAID disk storage system	55 kf
− DLT cassette storage robot system	25 kf
− off-line processing	pm
	total 280 kf

The total cost for cameras, links and image grabber interfaces is an estimate based on an initial market search (May – June, van Haren). Limiting the search to machine vision cameras (primarily because these fit in the budget whereas scientific cameras such as Megapluses are far beyond it) implies that it is hard to obtain or believe the actual camera specifications; the procurement procedure should therefore include testing a single prototype before ordering the other three. The total cost fits within the DOT budget for instrumentation (Table 2 of the NOVA proposal of June 8 1998, which is in principle covered by the three-year initial-science funding), but only with an appreciable reduction of the amount budgetted for secondary optics. Hammerschlag believes this to be a viable option on the basis of his multi-wavelength optics design, which uses pairs of stock lenses to correct aberrations rather than the expensive custom-made lenses targeted before.

4.2 Timeline and task list

The key initial step is to select a camera (plus link and interface) and experiment with that while the three-channel optics is completed. The rest of the pipeline system can be acquired during the coming autumn or winter.

Financially, this means that the part of the DOT budget allocated to instrumentation will largely be spent within a year from now. This spending profile is not a surprise since obviously, the DOT needs its instrumentation now in order to get science results written up if not published by the third year, and has indeed been discussed with the various funding agencies in terms of pre-financing.

In summary, the to-do list re DOT data-acquisition consists of the following actions:

- design and construct secondary optics (Hammerschlag, Bettonvil, IGF);
- select, purchase and test one camera with link and grabber (IGF, Sütterlin, Bettonvil);
- define and construct a software camera user interface (IGF, Sütterlin, Rutten, Bettonvil, van der Zalm);
- streamline speckle processing (Sütterlin, Krijger?, student?);
- negotiate spending profile with funding agencies (Rutten, Achterberg);
- purchase and install complete four-wavelength system (IGF, DOT team);

References

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