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The Puoko-nui CCD Time-Series Photometer

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Abstract. Puoko-nui (te reo Maori for 'big eye') is a precision time series photometer developed at Victoria University of Wellington, primarily for use with the 1m McLellan telescope at Mt John University Observatory (MJUO), at Lake Tekapo, New Zealand. GPS based timing provides excellent timing accuracy, and online reduction software processes frames as they are acquired. The user is presented with a simple user interface that includes instrument control and an up to date lightcurve and Fourier amplitude spectrum of the target star. Puoko-nui has been operating in its current form since early 2011, where it is primarily used to monitor pulsating white dwarf stars.

1. Introduction

The development of modern CCD cameras over the past 20 years provided a significant improvement in flexibility and sensitivity over the photomultiplier tubes that were the previous main-stay for photometric measurements. One downside of standard CCDs are that they can suffer from relatively long readout times, which can take several seconds if a low readout noise is desirable. This problem is solved by frame-transfer CCDs, which feature a dedicated readout region masked from incident light. Collected charge can be shifted from the active region to the readout region within a few microseconds, and then read out in parallel with the next exposure.

We have developed a flexible CCD photometer built around a Princeton Instruments 1k x 1k frame transfer CCD that is operated without a shutter. The frame transfers (and hence the exposure times) are initiated by a microcontroller based timer unit which receives accurate time information from a GPS receiver.

Commercially available CCD systems, such as those produced by Princeton Instruments, are offered as a complete system including proprietary software and 'black box' programming interfaces. The integration of such a system into a larger instrument is a non-trivial matter, particularly when it exposes problems in the underlying closed source software that must be worked around.

2. Hardware Overview

The original intention for Puoko-nui was to copy the design of the earlier Argos instrument developed at the University of Texas in Austin (Nather & Mukadam 2004). Various issues with hardware and software compatibility prevented this, and motivated a modified design which is significantly less reliant on the specific hardware and software of the data acquisition PC.

A particular example of this is the parallel port timer dongle used by Argos; this has been replaced with an external programmable hardware unit which operates independently of the host PC and communicates with the acquisition software via USB. The acquisition software was built using standard and cross-platform software libraries, allowing the data acquisition to be run on any computer supported by the proprietary camera drivers.

A block-level overview of the main instrument components and processes is illustrated in Figure 1, and the specifics are elaborated in the following sections.

2.1. Camera

Puoko-nui's 'eye' is a MicroMax 1024×1024 pixel back-illuminated frame-transfer CCD system produced by Princeton Instruments. The CCD is continuously exposed to light, taking advantage of the frame-transfer design to eliminate the need for a shutter. This allows for an essentially 100% exposure duty cycle, as the time to shift the image into the readout area of the CCD is negligible compared to a typical exposure.

The default (and fastest) readout rate of the CCD is 1MHz, which requires approximately 1.3 seconds to read and transfer an acquired frame to the computer via USB. A slower 100kHz readout rate reduces the noise associated with the readout electronics, but increases the readout time (and thus the minimum allowed exposure) by an order of magnitude. Faster rates can be achieved by reading only a sub-region of the CCD and/or aggregating pixels during readout (binning).

Our white dwarf observations use a broad blue band BG40 filter to reduce the sensitivity to red sky photons, and the CCD is thermoelectrically cooled to $-50°$C to reduce thermal noise. The camera settings are best matched to the seeing conditions at Mt John when operated with 2×2 pixel binning at the 100 kHz readout rate. In this mode, each aggregate pixel images a 0.66 square arcsecond region of the sky with the MJUO 1m telescope at f/8 and permits exposure times as short as 4 seconds.

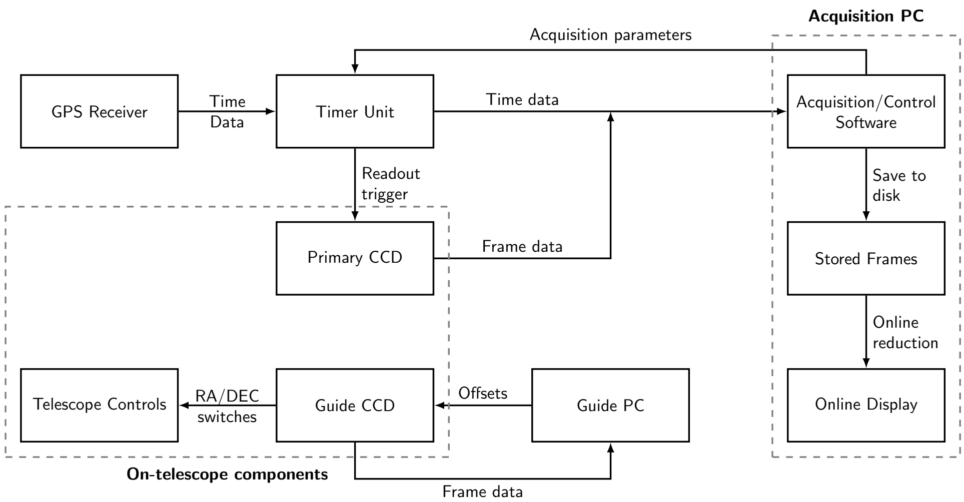

Figure 1. Block diagram illustrating the main components of Puoko-nui.

2.2. Timing

The heart (or perhaps brain, if we want to stretch the analogy) of the Puoko-nui instrument is a custom timer unit built around an Atmel AVR microcontroller. The unit has a USB connection to the data acquisition PC, a RS232 serial input and coaxial input for receiving timing information from an external GPS receiver, and a coaxial input and output for monitoring the camera and triggering frame readout.

The unit is designed to respond with minimal latency to signals from the GPS receiver and camera. Specifically, it implements three main subsystems:

1. Count time pulses from the GPS receiver, where the leading edge of each pulse is aligned to the start of a new second. Every Nth pulse (for an N second exposure) triggers a readout pulse to be sent to the camera.

2. Extract time information from a serial data stream provided by the GPS receiver. Timestamps corresponding to frame readout triggers are forwarded to the data acquisition PC, along with updates of the GPS time every second.

3. Monitor the current status (idle, initializing, reading out, exposing) of the camera via its configurable logic output. This information is forwarded to the data acquisition PC, and used to avoid a bug in the camera firmware that is triggered when commands are sent to the camera whilst it is reading out a frame.

The timer firmware implements support for the serial data output of two GPS receivers: a Magellan unit which has fixed installations at both MJUO and VUW, and a portable Trimble Thunderbolt unit. The system is designed to be easily extended to support additional receivers should the need arise.

The standard timer firmware has a timing resolution of 1 second by counting pulses from the GPS receiver. A modified version of the firmware provides a "high-speed" mode with a timing resolution of 10 ms by using an internal oscillator disciplined to maintain long term stability by the 1 Hz GPS signal.

2.3. Auto-guiding

Autoguiding functionality is inherited from the earlier VUW 3-channel photometer (Sullivan 2000), and operates as a standalone subsystem. A SBIG ST-402ME CCD is mounted in an offset guiding position with a 2D slide mechanism, which allows a bright star outside the main field of view to be imaged independently of the main detector. It communicates with a dedicated guide PC running the proprietary SBIG acquisition/autoguiding software in a Microsoft Windows environment.

3. Software Overview

The instrument control software is designed to run in either a GNU/Linux or a Microsoft Windows environment. It currently runs on a compact "net-top" PC running Ubuntu 12.04. The software provides facilities for setting metadata that is recorded in each frame (target name, observers, etc) and configuring run parameters such as exposure time and CCD temperature. The software configures the camera and timer with these parameters at the start of an exposure sequence, and then enters a passive receiver role where it combines the frame data with timestamps and saves the resulting file as a compressed FITS image.

In addition, we have created a software package, `tsreduce`, for online reduction and analysis of Puoko-nui data. Aperture photometry is performed on selected stars in each frame to produce a running lightcurve and Fourier amplitude spectrum of the target star that is updated in real time. `tsreduce` is also used for offline analysis of data, and includes routines for determine optimum aperture sizes, BJD timestamp corrections, and Fourier analysis techniques for identifying the multiple pulsation modes that are visible in pulsating white dwarf stars.

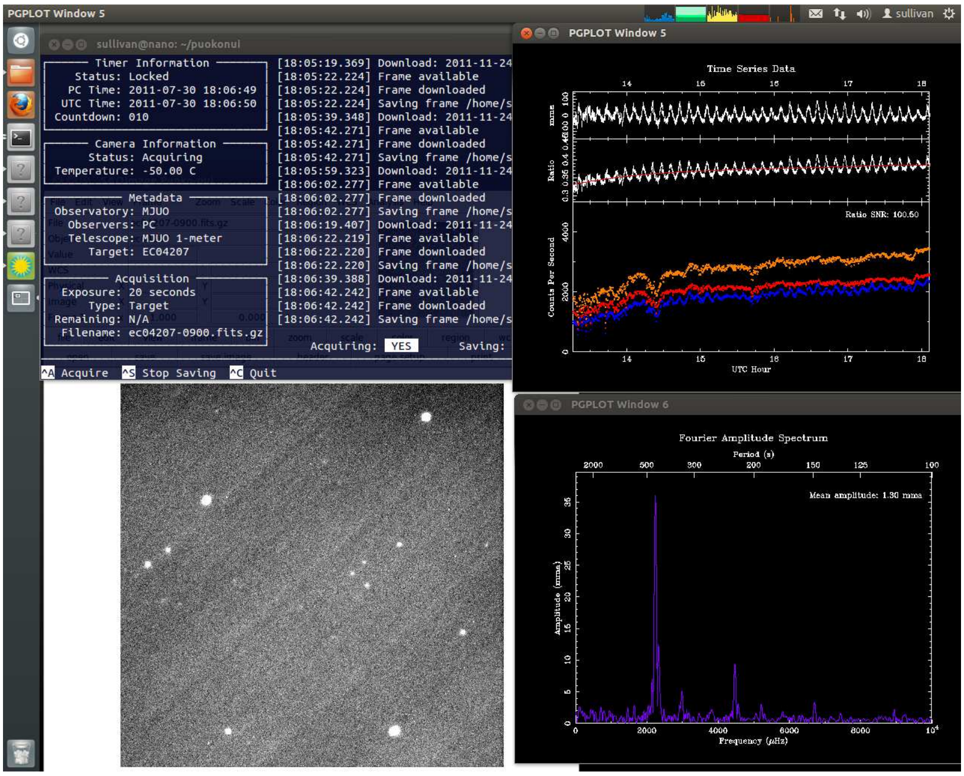

Figure 2. The Puoko-nui instrument control and online reduction software as visible during an observing session.

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References

Nather, R. E., & Mukadam, A. S. 2004, ApJ, 605, 846
Sullivan, D. J. 2000, Baltic Astronomy, 9, 425