BART: real time follow-up of GRBs since 2001

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Abstract. BART is a 25 cm aperture, intelligent robotic CCD telescope, devoted for observation of prompt gamma ray burst emission and early afterglow. It's operating since early 2001. Till now, it responded to many GCN GRB alerts.

BART SYSTEMS

The system does not involve only telescope, but forms all-robotic observatory with automatic roof opening, weather sensors, and telescope, running in a software system, with observation scheduling, automatic image analysis and of course robust Virtual Observatory compatible image archiving.

BART was built primarily to perform observations of GRB positions reported by GCN, to search for optical transients. As the time pass, we have been using the spare time (no GRB to follow) of the telescope in different ways, trying various scheduling scenarios.

BART OPTICAL SETUP

Over years, BART hardware have been developing considerably.

We started with a 25 cm Meade LX200 mount, equipped with a CCD camera. The most important instrument was, however, wide-field camera, for it's importance as an INTEGRAL OMC test device and field of view compatible with GRB error boxes available at that time.

While the narrow field telescope was prone to frequent problems with focusing and collimation, the wide field camera is a source of reliable and stable data over years.

Later we added another wide-field camera to get color information and after several problems with LX200, we have got Losmandy Titan mount with Gemini control system, recently we have replaced old parallel port CCD cameras with new USB devices, to get better cooling performance and fast readout.

Most of the observations in the BART archive was therefore carried with one or two wide-field CCD cameras. The limiting magnitude of this system is typically 15, and can provide reasonable monitoring of objects up to 12 magnitude.

The 25 cm narrow-field telescope, for it's low reliability mostly unused for some time, has received considerable attention lately (digital focuser, new CCD camera, filter wheel) and is supposed to provide reliable results by the end of this year. With current setup, the 3σ limit of 19.0 was reached on a 60 s unfiltered exposure.

RTS2 - OBSERVATION SYSTEM OF BART

Observations on BART are conducted using RTS2[1] software. BART served as reference platform for RTS2, enabling it to grow from a small subset of functions into a full-featured package, which is capable of controlling complicated observatory setups.

RTS2 evolved from RTS1, which was written in Python language. RTS2 was originally written in C, but as time progress, was completely rewritten in C++. We developed RTS2 to work in two basic layers - abstract, network-based, which handles communication between various RTS2 components, and device-driver layer, which translates network commands to physical hardware.

RTS2 is by our knowledge only currently available system, which is able to control telescope setups with multiple detectors, control full observatory (including dome, weather station etc..), runs on Linux operating system and which source code is available under GNU General Public License (GPL).

RTS2 is designed for automatic observations, so it doesn't have graphical user interface (GUI) for planning and manual observing. As communication protocol is well defined, a graphical user interface (most probably Qt-based) will be available when we will be happy with automatic observations performed.

FOUR YEARS OF OBSERVATION - RESULTS

We started regular observation runs with BART in May 2001. Unfortunately, this time coincided with end of service of CGRO and "dark years" of very few available real-time alerts. Anyhow, we observed locations of many GCN alerts. Table 1 summarizes both realtime and offline bursts followed by BART.

SYSTEM STABILITY

After extensive bug-fixing, we enjoyed quite stable operation of the software. Thanks to the ssh remote shell access, we have full control over whole software environment, including operating systems. That's critical for RTS2 deployment on remote sites.

TABLE 1. BART GRB OT search observations

GRB	GRB Δ time	GCN Δ time	comments
020124	11h 30m	10h 20m *	R>14 mag
020305	10h 30m	30m	R>14
020317	58m	90s	R>13.5
020331	5h 30m	5h 20m *	R>12.5, bad weather
030824	1h 50m	30m	R>14.3
031111A	1h 10m	30s	overexposed due to moon, GCN 2456
031111B	10m	30s	R>14.5, I>14.2
040403	-93m	-	preburst limit
040606	5.5h	*	I>12 (weather)
050505	9.5m	29s	V>11.5 (poor conditions)
050509A	79s	62s	V>14.9
050520	15m	14m	limit V>14 mag, GCN 3431
050525	10m	16s	**V∼15±1, GCN 3481**
050824	10m	31s	V>12: too low

* Daytime burst

OBSERVATION NOTIFICATION

As RTS2 runs mostly in fully automatic mode, it poses mailing capacity. It can send emails to observers when target observations starts, ends, when all images from observation are processed, and at the end of night with list of all observations of given target. Mailing can be widely customized.

TARGET HIERARCHY

In order to solve complex observation tasks, which RTS2 perform, we designed target hierarchy.

Beside Target, we use Observation class for summing together information about one run of target observation - e.g. one target can have more observations, but one observation is only for one target.

ARCHIVE AND VIRTUAL OBSERVATORY

RTS2 uses relational database to store all target information (priority, exposures, observing conditions), observation metadata(observation start, end and list of images taken) and image properties (WCS, exposure).

We have developed code, which provides Virtual Observatory[2] access to images produced by RTS2. We plan to provide public access to images through Virtual Observatory in near future.

IMAGE ANALYSIS AND IMAGE PROCESSING

We have spent a lot of time developing an astrometry package[3]. This way we can set-up mapping between image (x,y) and sky (α,δ) coordinates (WCS) with plate solution precision typically better than 1/10 of a pixel. This approach further simplifies automatic photometry, object detection and other possible tasks needed in real-time pipeline.

All images obtained and stored in database have proper WCS keywords in their FITS header, are roughly photometrically calibrated (in terms of a limiting magnitude against catalog) and in some cases the relative photometry is performed. Automated transient detection is being actively tested and expected to be routinely used soon.

RTS2 is designed to cooperate with the astrometry package, calls and maintains the pipeline and depending on result, it stores the image in the archive.

LONG-TERM OPERATION OF A ROBOTIC TELESCOPE

From experiences we gained with robotic follow-ups of GRBs, it's clear to us that building and operating robotic observatory for long period of time isn't as easy as one might think.

It's relatively easy to build and run one purpose instrument setup for few nights, with observer at disposal to solve either technical or software problems which arises during run.

To be able to reproduce results through years, while still preserving ability to react to GCN notice in fastest time possible, and continuously improving and patching control system, so it's able to fulfill tasks it wasn't originally designed to do, is at least a magnitude harder.

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