Real-time multimessenger observation system for the search of optical counterparts of the high energy events

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Abstract The system for prompt search and follow-up study of transient astrophysical objects in optical and high-energy gamma ranges is under developing now. The search for the bursts of cosmic rays and cosmic gamma radiation will carry out at the complex of facilities of the Baksan Neutrino Observatory. The search and follow-up study for optical flashes accompanying high energy events will carry out at the complex of astronomical telescopes of the Terskol Peak Observatory. The universal control program of the astronomical telescopes has been developed. The program allows searching for transient phenomena in the optical range using external alerts (from BNO facilities, the GCN network, etc.).

Keywords: transient phenomena, multi-messenger observation, real-time systems

1. Introduction

Of late years the multi-messenger approach is widely applied for the study of astrophysical objects and transient phenomena. The fact of the matter is that the high-energy sky has revealed a large number of powerful astrophysical objects capable to emit radiation across the entire electromagnetic spectrum. Now it is obvious that the joint study of the different "cosmic messengers" (cosmic rays, neutrinos, photons, and gravitational waves) is necessary for the complete understanding of the most energetic phenomena in the Universe.

At present the quick search for astrophysical objects which produce both, bursts of high energy cosmic radiation and optical flashes, is carried out in the near real-time mode with the system for collecting and analyzing data from the facilities of the Baksan Neutrino Observatory (BNO) of INR RAS and a complex of astronomical telescopes at the Terskol Peak Observatory (Terskol branch of INASAN). Unique complex of BNO facilities is intended for study of cosmic rays and cosmic gamma radiation in wide range of primary energies. The complex consists of Baksan Underground Scintillation Telescope (BUST) [1, 2] and two EAS arrays: "Carpet-2" [3] and "Andyrchy" [4]. The BNO facilities work in continuous mode of operation and they are recording of cosmic rays from upper hemisphere (so called "all sky all time" mode). These apparatus allow searching for bursts of cosmic gamma radiation in wide range of primary gamma-rays energy: from 1 TeV (at the BUST) up to 80 TeV (at the EAS arrays "Carpet-2" and "Andyrchy") [5, 6]. The search for the bursts of cosmic radiation (EAS

clusters) is carried out in the near real-time mode using data of the BUST and “Carpet-2” facilities. Then the coordinate position of the burst is used for the search of possible optical counterpart. Integrated server for the data concentration is placed at the BNO. There are two communications paths. First one joins the local networks of BNO and Terskol Peak Observatory by means of radiochannel with Cisco Aironet 1410 units (Figure 1). Second one use Internet. Search for transient phenomena in the optical range is carried out using alerts from BNO facilities. For this purpose the universal control program for the astronomical telescopes has been developed.

Fig1. *Scheme of networking. The local networks of BNO and Terskol Peak Observatory are joined by means of radiochannel implemented on three Cisco Aironet 1410 modules. One module operates at Cheget peak in the access point mode. Two others modules operate in bridge mode at the «Andyrchy» EAS array and at the Terskol peak.*

2. Search for cosmic radiation bursts

Raw experimental data of the BNO facilities are accumulated in the internal memory of on-line computers of each facility during fixed time interval (15 minutes for the BUST and 20 minutes for the “Carpet-2” EAS array) and then are copied to hard disk of the file server. After this the data are analyzed at two dedicated workstations. For each of registered events the EAS arrival direction is reconstructed. A search for bursts in the sky is in fact a search for spatiotemporal clusters of events. In the past this method was applied at the BNO facilities for the searching of gamma-ray bursts [5, 6].

Since the time intervals were taken to be fairly short, the search for spatial clusters of events is performed in the horizontal coordinate system. For each event i with an absolute time t_i and arrival angles $(\theta, \varphi)_i$, we searched for a cluster of such events $i, i + 1, \ldots, i + N - 1$ that the shower arrival directions differed by less than α_r from the weighted mean direction. The maximum time difference in the cluster should not exceed 10 s. Thus, each cluster is characterized by the multiplicity N, duration Δt, absolute time T, and arrival direction (θ, φ). At the moment the size of the angular cell, α_r, was chosen in such a way that the cell contains about 96% of the events from point-like source. On the assumption of Rayleigh distribution α_r is 3º for the BUST and 5.58º for the EAS array “Carpet-2”. It should be noted that such selection conditions gives us too large number of clusters (about several thousand per day)

with the purpose to use they as alerts. Therefore in this experiment the clusters are discriminated on duration against their multiplicity. And in the issue only 0.15% of clusters are used as alerts. In the first place this discrimination allows separating clusters with large multiplicity, i.e. bursts with large energy fluxes. The clusters of short duration with small multiplicity are used as alerts, too. The discrimination used allows us to save a part of events for the search for hypothetical evaporating primordial black holes [7, 8]. In what follows at the EAS array "Carpet-2" the method of separation of showers produced by primary photons will be used [9].

3. Remote control of the astronomical telescopes complex

The work with experimental data is carried out using dedicated server which is placed at the laboratory building of BNO. Access to the experimental data of BNO facilities is realized by means of two communications paths. First one is the internetworking of the local networks of BNO and Terskol Peak Observatory. The radiochannel on base of three Cisco Aironet 1410 units is used (***Fig2***). One module operates at Cheget peak in the access point mode. Two others modules operate in bridge mode at the "Andyrchy" EAS array and at the Terskol peak. The module operated at the "Andyrchy" EAS array is connected with BNO laboratory building by optical cable.

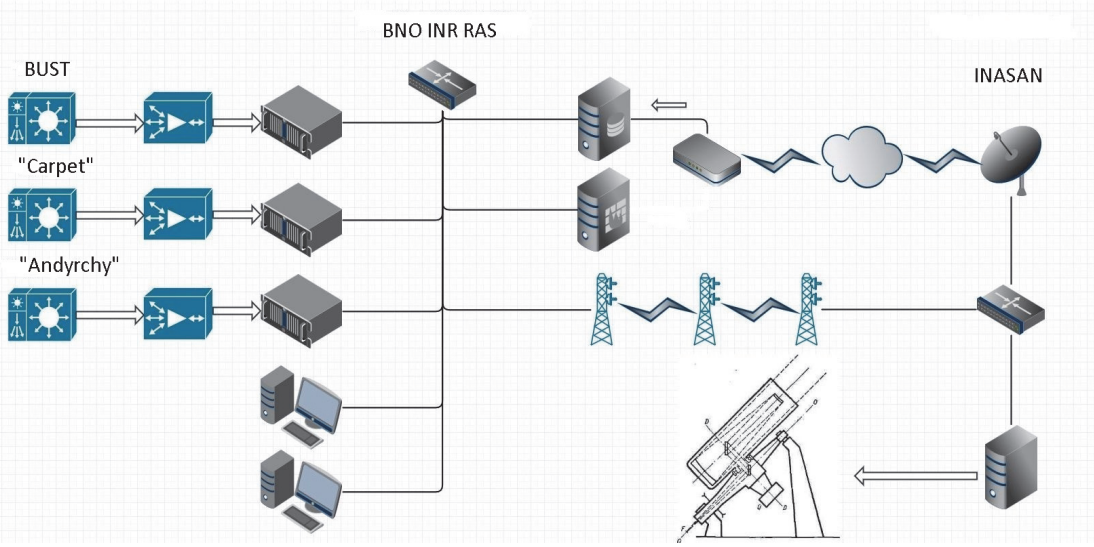

Fig2. *Block diagram of the system for the search of optical counterparts of the high energy events.*

Second one is routing through the Internet with a fixed IP address. Both communications paths allow us to connect with dedicated server via HTTP and FTP, and over the local network using the SMB protocol. The communications paths and the dedicated server are protected from the extraneous access.

The program for control of the complex of astronomical telescopes is designed to work with astronomical instruments (support-rotating device, CCD camera, wheel of light filters, dome) during observation sessions. This program uses the ASCOM standard (Astronomy Common Object Model) what allows to communicate with any equipment using this standard. Advantage of the ASCOM standard is the possibility to operate with different instrument

models, irrespective of their manufacturer. And the program for control of the complex of astronomical telescopes interplays with any software driver of astronomical instruments (***Fig3***).

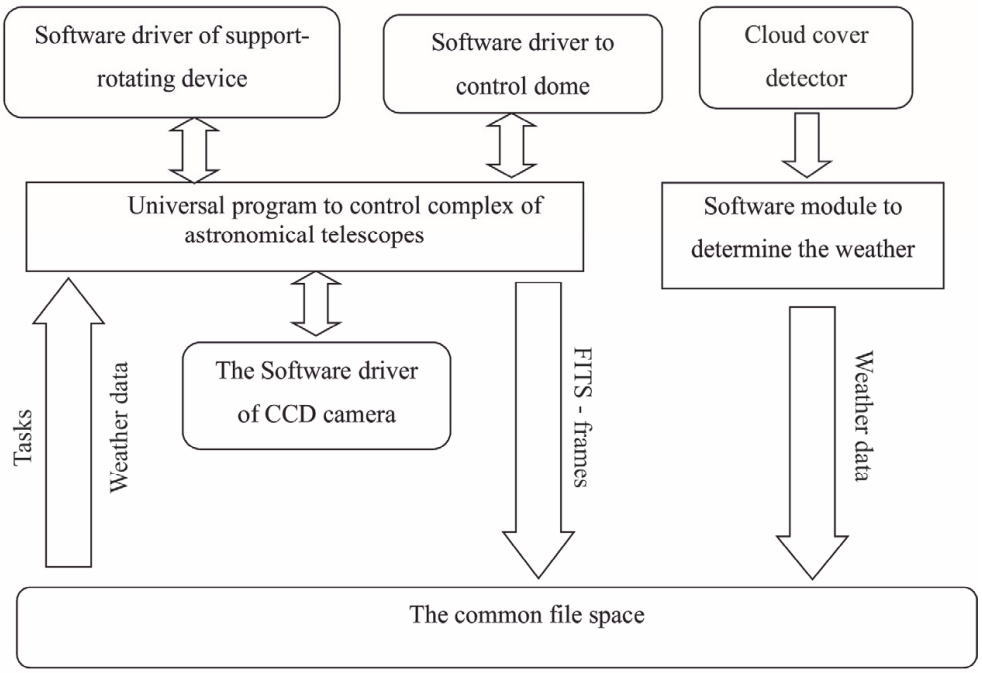

Fig3. *Scheme of intercommunications between devices drivers and universal control program of the astronomical telescopes complex*

The program has a mode of operation "robotic telescope". Weather permitting at the onset of navigational twilight the software drivers of dome, rotary support and CCD camera will be turn on. The schedule of observation session will be loaded from web-server in automatic mode. If during observation session alerts with greater priority (from BNO facilities or GCN) appear then program flow is interrupted and subsequent observations are conducted using pointing from these alerts.

The test observation sessions revealed that the observation process is under way in automatic mode without failures. But due to wide field of view of BNO facilities the wide-field optical telescopes are needed for such kind of investigations.

4. Conclusion

Prompt search for optical counterparts of high energy events, revealed by EAS arrays and neutrino telescopes, is very important for the study of cosmic transient phenomena. To date such search is carried out at the complexes of facilities of the Baksan Neutrino Observatory and astronomical telescopes at the Terskol Peak Observatory in the near real time mode.

At the moment a real time system is under development. New system will allows making essential progress in the study of transient astrophysical objects.

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