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# The new unified design of the ASEC data acquisition system based on the OPC XML-DA protocol

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## 1. Introduction

The ASEC (Aragats Space Environmental Center [1-3]) detector network currently consists of 6 detectors located in the two research stations on the slopes of Aragats Mountain. Additionally, possibility of the network extension to several near-equator countries is considered by the data acquisition system design.

The ASEC Particle detectors perform monitoring of various species of secondary cosmic rays with different energy thresholds. The detector setup measures a number of incident charged and neutral particles depending on their energy and coming direction along with atmospheric pressure and temperature. These measurements quantified as time series are the basic data for the physical inference on the Space Weather issues.

The research stations are located on the altitudes 2000 and 3200 meters above the sea level and connected with main lab in Yerevan by means of wide-range radio network. The OPC XML-DA (Open Process Control XML Data Access [4]) protocol is used to provide both the data dissemination and control capabilities for the distributed data acquisition system. The information from the detectors is used to issue time critical warning about space weather issues. Because of slow and not always stable connection between the stations, the centralized data processing not always possible. Therefore, the preliminary data processing is performed by the distributed network components operating on all research stations, independently. The main component of the data acquisition system is URCS (Unified Readout and Control Server). The URCS by means of the detector specific drivers reads out the time series from the underlying electronics and make preliminary analysis of the received data. Then, the data is made available for other system components by means of the OPC XML-DA protocol. Each detector channel is disseminated using separate item in the server data space. The predefined metadata properties are used to indicate the physical meaning of the channel. The URCS components may exchange information in order to correlate obtained data with the data collected by other components of detector network. Besides the data items the URCS server provides a set of control items providing possibility to control both detector electronics and URCS software behavior.

In addition to certain amount of URCS servers the distributed data acquisition system consists of the operator web frontends and data storage subsystem. The web frontend provides operators with possibility to monitor current data and adjust URCS configuration. The data storage servers are periodically inquiring the data from all detectors and storing it in the MySQL database as row numbers. The physical meaning of each column is obtained from metadata properties and stored in XML document of the special structure in the same database as well.

Further, the stored data is analyzed by the off-line software and made available to scientists by the means of DVIN (Data Visualization Interactive Network) interface [2, 3].

## 2. Galactic and Solar Cosmic Rays

Galactic Cosmic Rays (GCR, mostly protons and heavier nuclei), are accelerated in Galaxy in tremendous explosions of the supernovas and by other exotic stellar sources. After traveling tens of million years in the Intergalactic magnetic fields they arrive in solar system as highly isotropic and stable flux. In turn, our near star - sun is variable object, changing radiation and particle flux intensities many orders of magnitude during few minutes. Therefore, because of sun's closeness the effects of changing fluxes have major influence on earth, including climate, safety and other issues (see for example [5, 6]).

Before the cosmic ray flux can reach Earth surface and get registered by the detector the particles are exposed to the interactions with the magnetosphere and atmosphere. The ability of charged particles to penetrate into the magnetosphere from outside is limited by the Earth's magnetic field. The shielding effect of the magnetic field is usually described by the concept of cutoff rigidities since the magnetosphere imposes a lower limit on the energy of primary cosmic ray particles to enter the atmosphere. These cutoff rigidities are highly dependent from the geographic latitude and reaching their maximum at the near-zero latitudes. Near the poles the shielding effect is much lower. Then, the primary flux collides with atoms in the atmosphere and if energetic enough produce secondary elementary particles (electrons, muons, neutrons, etc.).

Among other geophysical parameters, influence of Sun on the Earth environments can be described as changing (modulation) of the stable galactic cosmic ray "background". The sun modulates GCR (Galactic Cosmic Rays) in several ways. The explosive flaring processes on the Sun result in ejection of huge amounts of solar plasma and in acceleration of the copious electrons and ions. These particles, along with neutrons, produced by protons and ions within the flare constitute, so called, SCR (Solar Cosmic Rays). The SCR reach the earth and, if energetic enough initiate secondary elementary particles in the terrestrial atmosphere. This effect is called GLE (Ground Level Enhancement). Other, non-direct solar modulation effects are also influence the intensity of the GCR. The solar wind "blows out" lowest energy GCR from the solar system, thus changing the GCR flux intensity inverse proportionally to the sun activity, well described by the 11 year cycle. Very fast solar wind from the coronal holes, huge magnetized plasma clouds and shocks initiated by CME (Coronal Mass Ejections) traveling in the interplanetary space with velocities up to 3 thousand of kilometer per second (so called interplanetary CME – iCME) disturb IMF (Interplanetary Magnetic Field). At arrival at Earth the magnetic field of the iCME plasma shock triggered overall depletion of the GCR, measured as decrease of the secondary cosmic detected by the networks of particle detectors covering the earth (so called Forbush decrease Fd). Charged particles hitting the shock are reflecting those forming the "depletion" region behind that. Due to abundance of low energy primary protons and nuclei which are normally deflected by the geomagnetic field at low latitudes anyway the Fd depletion is pronounced at high latitudes. Visa-verse geomagnetic storms appearing as sudden change of the earth magnetic field can enlarge count rate of the middle and low latitude particle detectors without any notable alteration of the high latitude detectors count rates. If the magnetic field of iCME is directed southwards it reduces the cutoff rigidity and GCRs typically effectively declined by the magnetosphere at middle and low latitudes now are penetrating the atmosphere and generated additional secondary particles. At high latitudes cutoff rigidity is very low and the count rates of particle detectors are determined mostly by the attenuation of the cascades in the atmosphere and decrease of the cutoff rigidity did not enlarge significantly number of secondary particles reaching detector.

Low energy cosmic rays (up to ~1 GeV/nucleon) are effectively registered by the particle spectrometers on board space stations (SOHO, ACE) and satellites (GOES, CORONAS). The latitudinal dependence of the earth magnetic field provides possibility to use dispersed network of the NM (Neutron Monitors) as a spectrometer registering GCR in the energy range from 0.5 to ~ 10 GeV [7]. The surface particle detectors measure the amount of the secondary particle incident on the usually not very large detector surface. These measurements quantified as time series are the basic data for the physical inference on the solar modulation effects. There is absolutely no possibility to distinguish SCR and GCR on the event-by-event basis. The solar modulation effects are detected as non-random changes of the time series. The SCR modulation is mostly affects the lower energy particles and, therefore, the registered effect is highly dependent from the detector location. At high latitudes the secondary particles produced by abundant low energy SCR modulation can reach 1000% and more. At low latitudes the enhancements due to SCR can be very small, usually a fraction of percent. The direct measurement of highest energy cosmic rays by space-born spectrometers or balloons is not feasible yet. Therefore, recently some large surface detectors intended to register GCR with energies higher that $10^5$ - $10^6$ GeV (PeV region) are used for detecting SCR [8, 9]. The experimental technique used for these detectors i.e. registration of the Extensive Air Showers (EAS) is very similar to the techniques used to detection SCR. The difference is that PeV particles generate millions and millions of secondary particles in the atmosphere large portion of which is reaching surface (in contrast only few particles generated by GeV SCR reach surface). To detect and measure energy and type of PeV particles hundred meters of particle detectors are used. Detectors are triggered by the special condition allowing rejection of the low energy particles.

Charged particles travel and reach the Earth by way of the “best magnetic connection paths”, which is not a straight line between their birthplace and the earth. The solar neutrons on the other hand, not influenced by solar and interplanetary magnetic fields, reach earth directly from their place of birth on the solar disc. This feature allows us to “map” the flare location and provide the “time stamp” of the neutron production making them excellent “probes” of solar accelerators. For this reason we need to detect the solar neutrons, distinguish them from other incoming particles, measure their energy, and determine their incoming direction. The first step to achieve these enhanced possibilities of neutron detection was to establish the network of SNT (Solar Neutron Telescopes), installed at seven locations on high mountains around the world, forming the second operating international world-wide particle detector network, the NM (Neutron Monitor) network being the first [10].

The large variety of solar modulation effects and the stringent limitations of space and surface based experimental techniques require new ideas for developing experimental techniques for measuring the changing fluxes of the elementary particles. Therefore, a new type of particle detectors with enhanced flexibility to precisely and simultaneously measure changing fluxes of different secondary particles with different energy thresholds will be a key to better understanding of the sun.

Hybrid particle detectors of ASEC (Aragats Space Environmental Center) measuring both charged and neutral components of secondary cosmic rays provide good coverage of different species of secondary cosmic rays with different energy threshold. A multivariate correlation analysis of the detected fluxes of charged and neutral particles is used for the research of the geo-effective events i.e. Ground Level Enhancements, Forbush decreases, Geomagnetic Storms and for the reconstructing of the energy spectra of SCR [2].

## 3. ASEC Detectors

The ASEC provides monitoring of different species of secondary cosmic rays and consists of six detectors located at two high altitude research stations on Mt. Aragats in Armenia. Geographic coordinates: 40°30'N, 44°10'E, geomagnetic cutoff rigidity: ~7.6 GV, altitude 2000m and 3200m. Both stations are connected with main lab in Yervevan. The specifications of the ASEC monitors are shown in Table 1. Additionally, the project of the new low-latitude world-wide particle detector network with participation of Costa-Rica, Croatia, Egypt, Bulgaria, Armenia and Indonesia was discussed at UN/NASA/ESA IHY workshop [1]. Establishing a new world-wide network of the ASEC detectors, at low to mid latitudes will give possibility to measure energy spectra of primary particles with energies up to 50 GeV, as well as, provide cost-effective possibilities for Space Weather research.

The two 18NM-64 neutron monitors [7] estimating number of incident neutrons are in operation at Nor-Amberd and Aragats research stations. They are called the NANM (Nor Amberd Neutron Monitor), and the Aragats Neutron Monitor (ArNM), respectively. The monitors are equipped with interface cards, providing time integration of counts from 1 sec up to 1 minute. Other ASEC detectors are based on the scintillation effect and layers filtering part of the particles spectrum. The scintillation is used in order to detect charged particles passing truth the detector. The sensor, called a scintillator, consists of a transparent plastic material that fluoresces when struck by ionizing radiation. A sensitive photomultiplier tube (PMT) measures the light from the scintillator. The PMT is attached to an electronic amplifier and other electronic equipment to count and possibly quantify the amplitude of the signals produced by the photomultiplier. The following subsections briefly review detectors operating at ASEC.

**Table 1. Characteristics of the ASEC monitors**

| Detector | Altitude, *m* | Surface, $m^2$ | Threshold(s), *MeV* | In operation since |
|---|---|---|---|---|
| NANM | 2000 | 18 | 100 | 1996 |
| ArNM | 3200 | 18 | 100 | 2000 |
| SNT channels and veto | 3200 | 4 (60*cm* thick)<br>4 (5*cm* thick) | 120, 200, 300, 500<br>7 | 1998 |
| 2 x NAMMM | 2000 | 4.86 + 4.86 | 7, 350[a] | 2002 |
| AMMM | 3200 | 45 | 5000 | 2002 |
| MAKET-ANI | 3200 | 6 | 7 | 1996 |

[a] **First value – energy threshold for the upper detector, second number – bottom detector.**

## A. Aragats Solar Neutron Telescope

The SNT (Aragats Solar Neutron Telescope) is a part of the world-wide network of Solar Neutron Telescopes. The Aragats SNT is formed from 4 separate identical modules, as shown in the Fig. 1. Each module consists of 60 cm thick scintillation block overviewed by photomultiplier. The detecting volume is formed from standard 50x50x5 $cm^3$ plastic scintillators stacked vertically on a 100x100x10 $cm^3$ horizontal scintillator slab. One meter above the thick lower scintillator slab is another scintillator slab 100 x 100 x 5 $cm^3$, with the goal to register charged particles. A scintillator light capture cone and PMT (Photo Multiplier Tube) are located on the bottom and top slabs separately to measure the number of events in each of them.

Incoming neutrons undergo nuclear reactions in the thick plastic target and produce protons and other charged particles. The intensity of the scintillation light induced by these charged particles has a dependence on the neutron energy and is measured by the PMT on the bottom scintillators. In the upper 5 cm thickness of the scintillator plastic, the neutrons do not effectively interact with the scintillator nuclei and, therefore, only registered by the bottom scintillators. In contrast charged particles are very effectively registered by both the upper thin 5 cm and the lower thick 60cm scintillators. Therefore, the absence of signal in the upper scintillators, coinciding with signal in the thick lower scintillators, points to neutral particle detection.

The signal amplitude of the photomultiplier output signals is discriminated according to 4 threshold values, corresponding to the threshold energies of 120, 200, 300, 500 MeV respectively. When coincidences of the top and bottom scintillators are registered, it is possible to roughly estimate the direction of the incoming charged particle.

## B. Nor-Amberd Multidirectional Muon Monitor

The NAMMM (Nor-Amberd Multidirectional Muon Monitor) consists of two layers of plastic scintillators above and below one of the three sections of the NANM (6 counters BP28) as shown in the Fig. 1. Each layer is composed of 6 scintillators having the area of 0.81 $m^2$. The distance between layers is approximately 1 m. The lead filter of the neutron monitor absorbs electrons and low energy muons. Muons with energy above 350 MeV can reach bottom scintillator. Therefore, the detector is able to count independently intensities of neutrons, high energy muons and other charged particles. Additionally, registration of coincidences between detector signals from the upper and lower layers allows separate measurements of muons arriving from different directions. Combinations when multiple detectors are triggered indicate EAS hitting the detector setup.

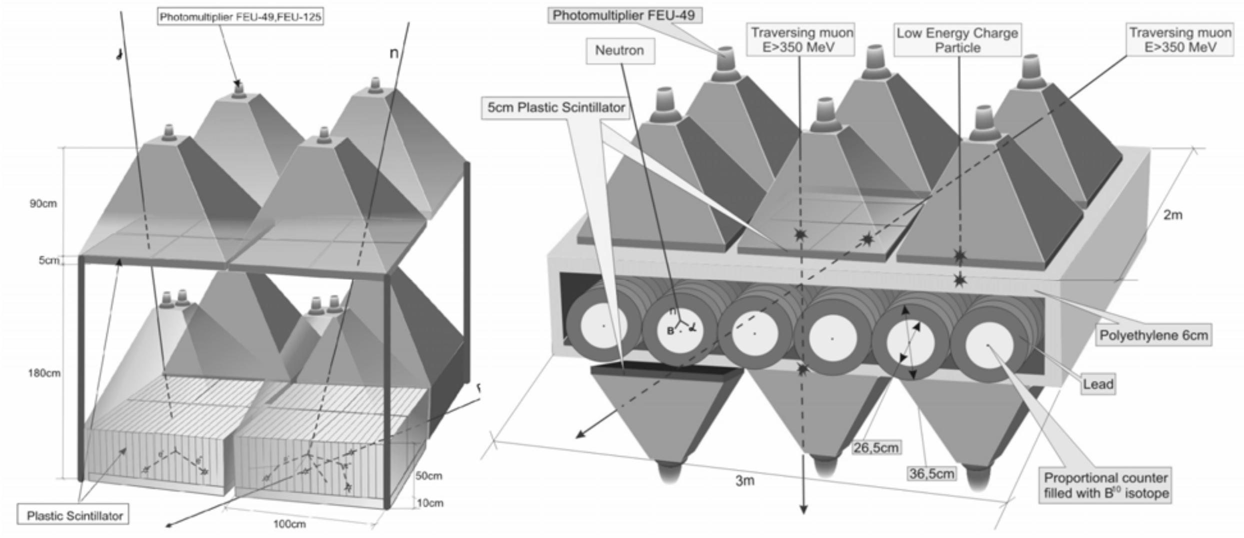


**Fig. 1. The figure represents Aragats Solar Neutron Telescope (left) and Nor-Amberd Multidirectional Muon Monitor (right).**

## C. Aragats Multidirectional Muon Monitor

The Aragats Multidirectional Muon Monitor (AMMM) consists of 15 $m^2$ scintillation detectors, located on top of the concrete stratum and 90 $m^2$ detectors of the same type 24 m below, as shown in the Fig. 2. The lower layer of the AMMM constitutes a very sensitive high energy muon monitor, robust to local atmospheric conditions because of the rather high energy threshold. The 6 m thick concrete blocks plus 7 m soil filter the electrons and the low-energy muons. Thus, only muons with energies above 5 GeV are registered by the bottom detectors.

Using the coincidence technique, it is possible to monitor changing count rates from numerous space directions. Detectors on the top are grouped in 3, while those in the underground hall are grouped in 8 to provide significant amount of coincidences. The geometry of the detector arrangement allows angle of incidence detection with angular accuracy of approximately 5º for the particles arriving from the range of directions from vertical to 60º declination.

## D. MAKET-ANI

The MAKET-ANI surface array consists of 92 detectors formed from 5 cm thick plastic scintillators to measure particle density of the registered EAS. Twenty four of them have 0.09 $m^2$ area and 68 have 1 $m^2$ area. The central part consists of 73 scintillation detectors and is arranged in a rectangle of 85 x 65 $m^2$. In order to estimate the zenith and azimuthal angles, 19 detectors from the 92 are equipped with timing readout to measure the EAS front appearance with an accuracy of approximately 5 nanoseconds. The photomultipliers (PM-49) are placed in light-tight iron boxes. Logarithmic Analog to Digital Converters (ADC) and Constant Fraction Discriminators (CFD) are placed just above the photomultiplier.

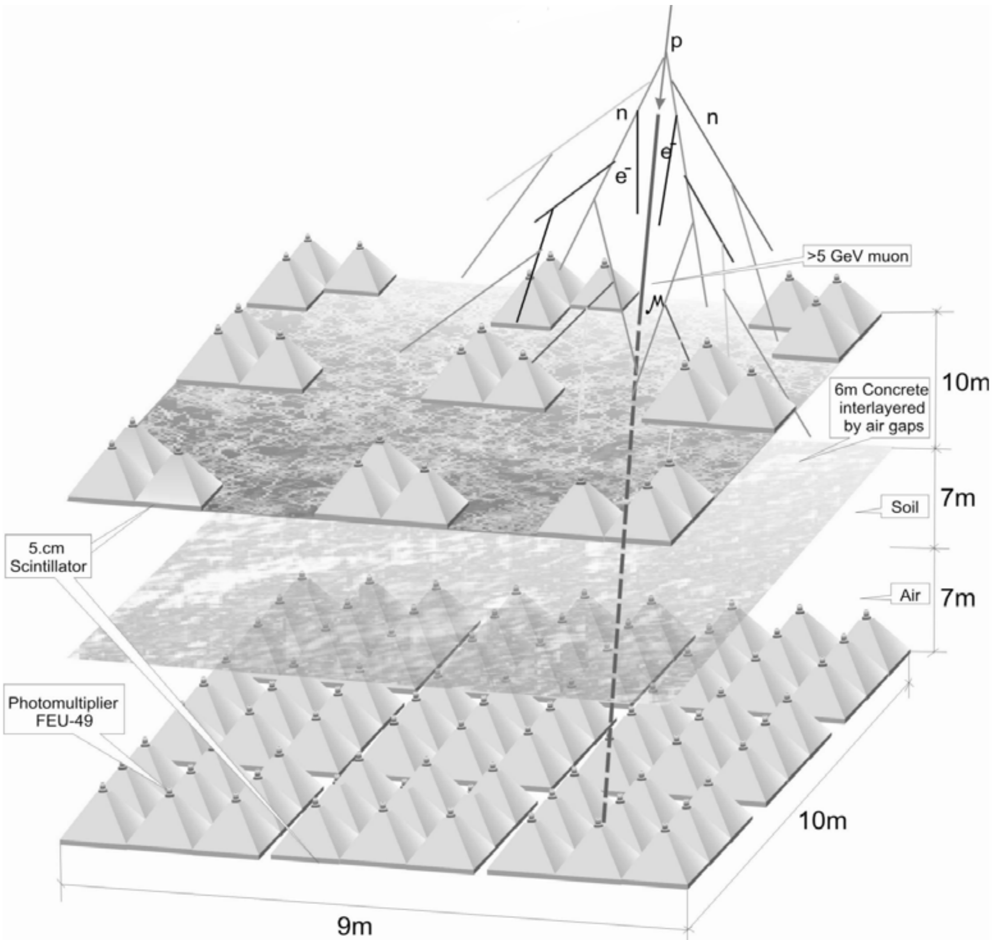

**Fig. 2. The figure represents Aragats Multidirectional Muon Monitor.**

## E. Frontend Electronics

All frontend equipment is developed by the electronics group of Cosmic Ray Division of Yerevan Physics Institute, according to modern very compact and high reliable technologies, oriented for easy maintenance and production. To minimize data transmission rate, the raw data is partially processed in microcontroller before sending it to the frontend computer. A newly designed readout is based on the concept of full software control of the detector parameters and maximum utilization of all detector data. Each photomultiplier has its own local programmable high voltage (HV) power supply and buffer preamplifier to condition the pulses in preparation for sending them via long coaxial cables without degrading the dynamic range and signal-to-noise ratio. Counting modules are located in the counter room. They have buffer preamplifiers and programmable threshold comparators (discriminators) at the inputs. The threshold of the counter module input comparators can be programmed by voltage and polarity in the range from -0.5V to 0.5V. Besides the comparators, the buffer preamplifier output signals can be transferred to other data processing devices such as ADC's, etc., to be installed later. All electronics modules are based on using modern 8-bit and 32-bit microcontrollers, for the detector control system (HV programming and measurement) and for the main data acquisition respectively. Currently the Atmel 8-bit and Fujitsu FR 32-bit controllers are used.

The main pressure sensor of the whole system is placed in a special pressure-tight box with possibility of periodic calibration using a standards Hg barometer. It consists of Motorola MPXA6115 Integrated Silicon Pressure Sensor and ATMEL 8-bit microcontroller and has frequency modulated output for direct coupling with counter modules and serial asynchronous interface to connect to the PC.

At the moment all detectors are equipped with a standard serial interface. However, this interface restricts the maximal number of devices connected to the single frontend host. The distance from the host system is limited as well. Therefore, the Lantronix XPort ethernet interface will be used in the next generation of data acquisition boards. Despite the fact, that all ASEC boards are currently missing embedded Ethernet interface, the UART-Ethernet converters produced by the 1st Mile Company are used as a temporary solution to provide Ethernet connectivity.

## 4. OPC XML-DA

The OPC XML-DA (OPC XML Data Access [4]) specification is a restatement of the industry accepted OPC DA [11] specification in terms of XML. It is based on the SOAP protocol and defines a Web Service interface facilitating the exchange of plant data in heterogeneous environments across the internet. According to the specification, the server data space is divided into the set of OPC Items which are addressed using "ItemPath" and "ItemName" identifiers. Each of the OPC Items stores the data variable along with standard and user-defined metadata information. By default the OPC XML-DA specification anticipates usage of variables and arrays of several basic data types (floating-point and integer numbers, enumerations, strings, time variables, etc…). However, the OPC Complex Data specification [12] gives an idea how complex data types can be constructed, described and served to the clients. As well the OPC Complex Data specification defines a way how the data should be served to the clients using several different data representations.

The Web Service provides interfaces for reading, writing current values and examining the metadata information. The variable value changes are reported to the clients using polled style subscription mechanism. The client initiates subscription to the group of OPC Items (OPC Group) and agrees to issue periodic refresh requests. The subscription behavior is controlled using several properties. The "EnableBuffering" demands buffering of the values-changes detected in between client polling requests. The "Deadband" specifies the percentage of a full engineering unit range of an item's value that must change prior to the value being of interest to the clients. The "Holdtime" and "Waittime" are used to reduce latency time of reporting a value change to the client and minimize the number of round trips between the client and server.

Despite the fact that the OPC XML-DA specification is designed mainly for control systems, the subscription mechanism used together with buffering makes the protocol usage in the data acquisition systems possible as well.

### A. Implementation

The data dissemination and control capabilities in the data acquisition systems are provided by means of the OPC XML-DA protocol. There still no open source solutions providing the server implementation of the OPC XML-DA. Therefore, the self-developed solution is used in order to provide both client and server capabilities [13-15].

The protocol is implemented as a double-layer library (see **Error! Reference source not found.**). The abstraction layer provides harboring of the operating system details. All memory management, thread synchronization, network communication and other OS specific operations are performed by means of the abstraction library. The hardware drivers intended to perform on the multiple platforms should rely on the library as well. Currently, it is implemented and thoroughly tested on the Linux and Windows environments. However, the Linux implementation is based on the POSIX specifications and, therefore, porting to other POSIX compliant systems is an easy task. Besides support of the general-purpose Windows OS the library is ported and tested on the Phar Lap real-time system.

The second layer is constructed on the top of the abstraction interlayer and provides a set of API interfaces for the data manipulations. The server API interface enables the management of the server configuration and run-time status. The backend API interface provides a way to configure data sources and submits new data. The conversion between different data representations and

coupling with the protocol related information is done using the frontend API interface.
The library is implemented in pure C utilizing object oriented approach by means of design similar to one described in [16]. This allows the library integration into the environments programmed by means of arbitrary language adopting concept of object files. The examples are C, C++, FORTRAN, Pascal and et cetera. The parts of the system written in other languages (Java is most used example) can be linked with the library using CORBA (Common Object Request Broker Architecture [17]).
On top of the library an OPC XML-DA server framework is constructed. The framework consists of the core data manager, the backend and frontend interfaces. The frontend interface accepts connections from the clients and prepares data in the user requested format in accordance with OPC XML-DA specification. The backend interface maintains plugins which are communicating with physical hardware and submitting data to the server.
The server is implemented using MVC (Model-View-Controller) style architecture. The frontend interface (view) is segregated from the data model by means of the core data manager. Such design allows using different frontend interfaces in conjunction with the same data handling core. At the moment, only the OPC XML-DA frontend is developed.

### B. LabVIEW Bindings

LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench [18]) is a platform and development environment for a visual control system programming from National Instruments. It is used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various flavors of UNIX, Linux, and Mac OS. Besides standard version, the real-time LabVIEW implementation operating on the industrial PXI platform is available [19].
The LabView based control and data acquisition is used to control part of the ASEC hardware. However, the current LabVIEW edition does not provide any means of OPC XML-DA protocol support. In order to allow integration of the LabVIEW components into the data acquisition system environment the OPC XML-DA bindings for LabVIEW are released. Both the Windows and Linux versions of LabVIEW are supported. In order to support LabVIEW Real-Time the framework is ported to the Phar Lap (Windows NT based real-time operating system).

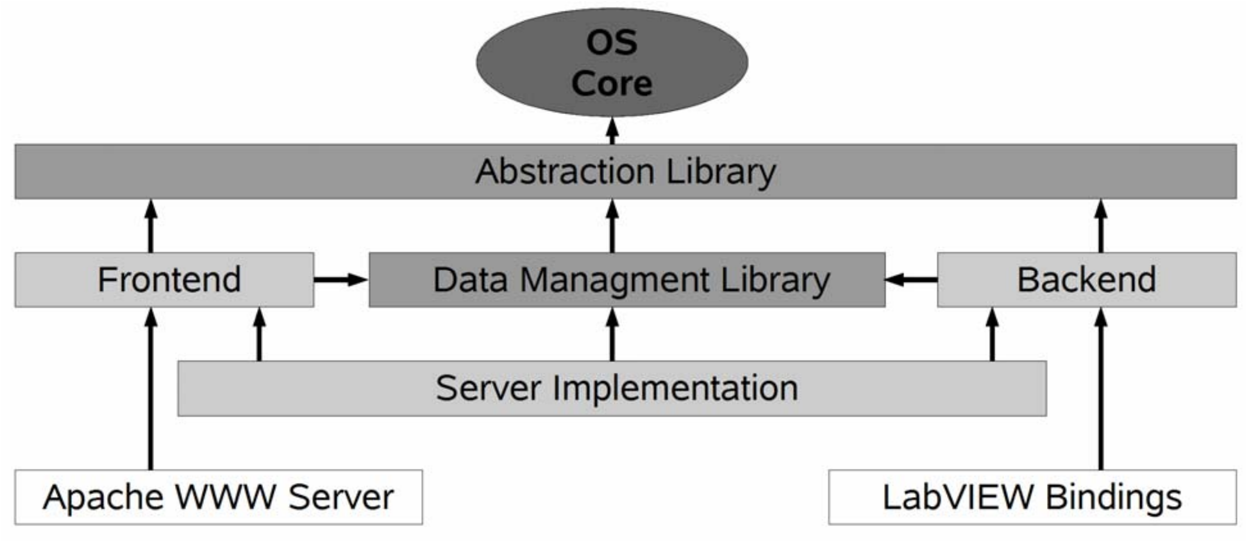


**Fig. 3. The figure represents multi-layer prototype server implementation. The Abstraction Library hides operating system details from the other system components. The Data Management Library provides a set of interfaces for the server data structure management. On the top of these libraries prototype server implementation is constructed. It consists of the Frontend and Backend parts and controller scheduling required operations in appropriate time. The Apache WWW server is used for the HTTP encapsulation. The LabVIEW bindings are enabling OPC XML-DA support in the LabVIEW based systems.**

## 5. ASEC Data Acquisition System

In the old data acquisition system each detector was frontended by the computer running Linux operating system with specialized readout software. Furthermore, certain detectors with possibilities of operator control were equipped with two frontend computers. First one was used for the data readout and second for the control by means of the LabVIEW software [18]. Such heterogeneous design caused not only requirement to maintain multiple unreliable computers but as well pose significant difficulties in the software management. The software components written for various detectors in different time utilized different interfaces and file formats. The comparable software components had to be synchronously developed for the systems controlling diverse detectors. Most of detector drivers were developed only for the specific Linux versions and there were problems with porting them on the new systems. The support of multiple interfaces and file formats considered by the various system components had brought complication to the development of analysis software. Moreover, the chaos with file formats had several times resulted in data misinterpretation and, therefore, had caused researchers to repeat considerable amount of the work.

Therefore, a new ADAS (ASEC Data Acquisition System) system is designed. It is based on the universal and well defined interfaces developed in order to uniformly control all parts of the ASEC experiment. The Fig. 4 is representing the overall system design. The following subsections are briefly reviewing the main component of the system.

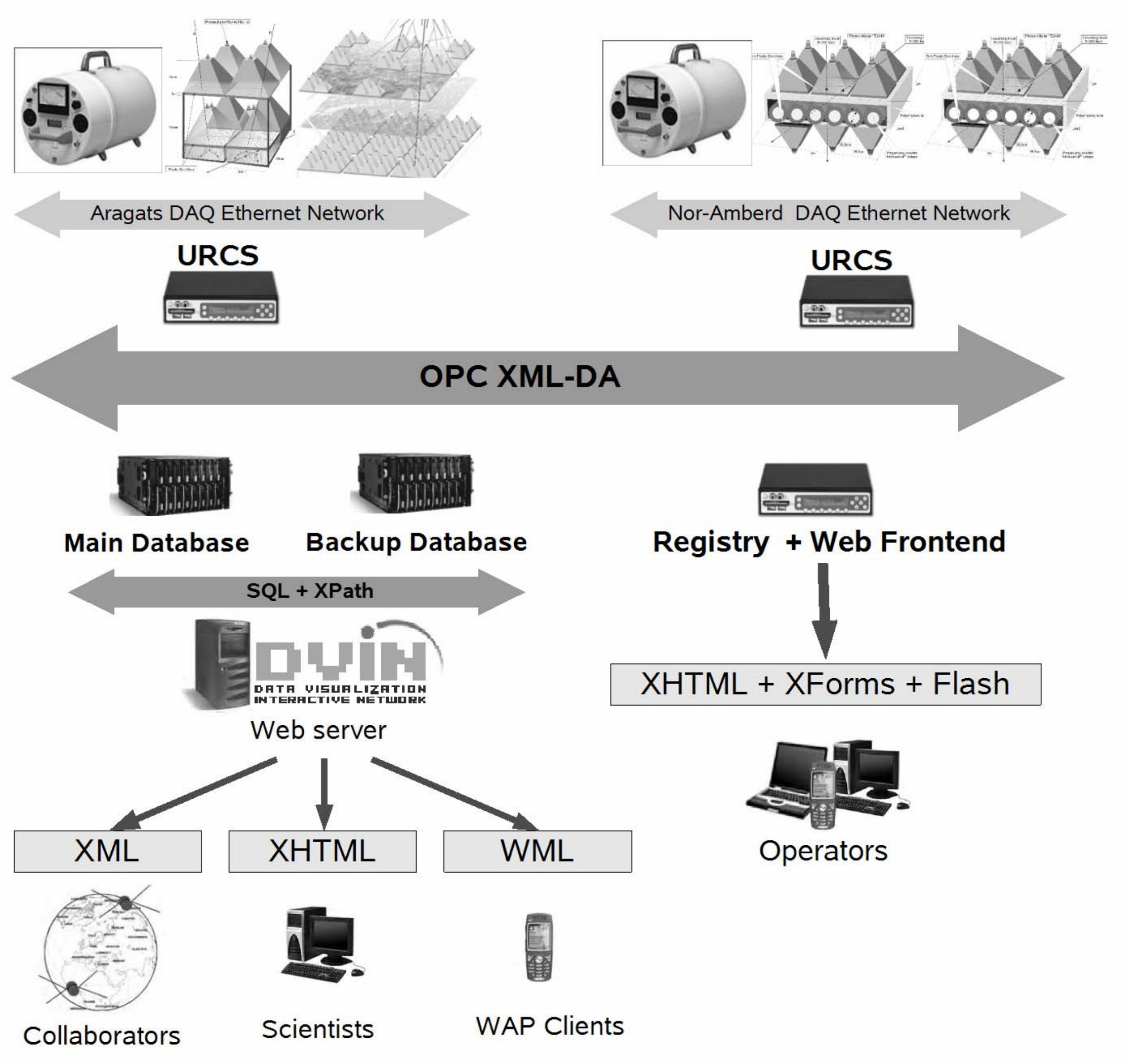


**Fig. 4. The figure represents layout of the new ASEC data acquisition system.**

### A. Embedded Software

The microcode running inside of all data acquisition boards is implemented using double buffer client-server architecture. The devices are initialized with predefined parameters and wait for control from the host system. The host system should specify desired detector configuration and issue initialization command. The data consistency is assured using CRC16 checksums carried along with commands. After the initialization request the detector starts operation in the standard mode. Double buffer architecture is used to relax timing demands. While the current data is prepared in the first buffer, the data of previous operation is available from the second one upon the driver request. After the data in the first buffer is ready, the buffers are switched. If the configuration adjustment is required the host system should alter the detector configuration and restart operation by means of initialization command.

In order to allow detector auto-detection the embedded software of all detectors supports the discovery query of a standard form. In the response to that query the information about detector type, embedded software version and hardcoded options is returned.

### B. Frontend Computers

All detectors are connected to the frontend computers over Ethernet interface by means of the UDP protocol using 1st Mile UART-Ethernet converters. Single frontend computer is dedicated for each research station in order to ensure reliability independently from the wireless connection faults. The same type of computers is used at all research stations. In that way the maintenance is greatly simplified. Currently, the Minibox M100 (VIA C3 533MHZ, 512 MB RAM) system based on the VIA Eden platform is used. The major advantage of this architecture is absence of mechanical parts. The system has passive (fan-less) cooling. Instead of a hard drive, the Compact Flash memory card is used. This is significantly improves system reliability. As an additional benefit comes the maintenance simplification. The data acquisition software can be performed just by replacing Compact Flash card and can be performed by the technical stuff. The Minibox M100 is equipped with small LCD display. It is used by the data acquisition software to represent current system status and notify operators about failures. The computers are equipped with Gentoo Linux based operating system. It is used in conjunction with the 2.6 family kernel optimized for the real-time applications [20].

### C. Unified Readout and Control Servers

The detectors are controlled by the URCS (Unified Readout and Control Server) which is operating on the described readout computers. Most of the URCS components are the same for all ASEC detectors. The specific actions are performed with help of the dedicated drivers communicating with the underlying electronics using appropriate protocol. The URCS server is a primary system component, both the data readout and detector control are carried with its help. The URCS architecture is precisely described in the section 6.

The OPC XML-DA protocol is used by the URCS server to provide both the data dissemination and control capabilities for the remote data acquisition components. However, the developed OPC XML-DA implementation is a complicated piece of code and not thoroughly tested in real applications yet. In fact, besides the sample applications developed for the performance and stability evaluation, the ASEC data acquisition system is first real-world application of the designed system. Therefore, in order to preserve data acquisition system continuity the OPC XML-DA support is not embedded into the URCS server but a separate OPC XML-DA server is executed on the same computer. The URCS server uses CORBA interface to publish detector data and accept control commands from the operators. The described design assures what the entire system would not fail because of problems in the OPC XML-DA interface. If the problems arrive the OPC XML-DA server will be automatically restarted while the underlying electronics will be continuously controlled by the URCS server. All the data will be available again as soon as OPC XML-DA server is restarted.

Each detector is represented using dedicated branch within the OPC XML-DA server data space. The detector channels are rendered using separate OPC Items. The predefined metadata properties are used to indicate the physical meaning of each channel (see section 8 for details). These properties may include information on the registered particle types, accepted energy range, particles coming direction and et cetera. The URCS components may exchange information in order to correlate obtained data with the data collected by other components of detector network. However, this capability is not used by the current software yet. Besides the data items the URCS server provides a set of control items providing possibility to control both detector electronics and URCS software behavior.

## D. Registry

The other components of the distributed system should be able to find full list of operating URCS servers. The special registry is developed to handle this goal. The registry is running on the stand-alone server (optionally together with one of the URCS servers) and providing self-announcement interface by means of OPC XML-DA protocol. The "Registry" item is available within the OPC XML-DA server data space. The URCS servers periodically write the XML document of a defined structure into this item in order to announce themselves (the document structure is described in the section 8). The registry server analysis this document and creates appropriate OPC Item in the server data space within the "Registry" branch. If Item already exists the associated information is just updated. So, the "Registry" branch contains a full list of the running servers. The used names are descriptive enough to give an idea about URCS server location and assignment.

The remote applications wishing to get full list of the active URCS servers are browsing the "Registry" branch and querying certain items for information. The query brings information about the server URL, current status, short assignment description and last renewal time.

## E. Operator Frontend

The operator web frontend is another component of the distributed system and used by the operators to control operation of the URCS servers and the detectors behind the URCS servers. The web interface is implemented in PHP language and support connection with URCS server by means of the OPC XML-DA protocol. The operator is able to browse the published data and monitor a current status of the system. The Macromedia Flash based animation is used to provide visual representation of the time series by means of periodically updated data curve. The program written in ActionScript (and used to control animation) establishes the subscription with the considered OPC Item and periodically inquiries for the new data. This data along with older cached values is used to draw the time-value curve in real-time showing the time evolution for the specified data channel. The metadata properties may be used by the URCS server to specify special conditions demanding the operator's intervention (see section 8). If this happens the frontend will sound an alarm.

As well the web frontend is used to control the URCS configuration, including configurations of the underlying electronic devices. Individual OPC Items are controlling the configuration of correspondent detectors. Additional item controls the URCS software behavior. Each configuration is described by the XML file with detector-specific structure. The structure is not hard-coded in the software and described by means of the XSD Schema descriptions. This description is used to present appropriate XForm entries to operators providing ability to adjust certain options. On the basis of the submitted data new XML file with configuration is generated and submitted to the appropriate URCS driver which can use that at its discretion. The Chiba software is used to generate XForm and configuration documents basing on the XSD Schema

[21]. Chiba is implemented in Java and designed to run in a Servlet 2.3 webcontainer [22]. The webcontainer is provided by means of the Apache Tomcat server.
Several hardware components within the data acquisition system still controlled by the LabVIEW based programs. These components are integrated in the new environment as well. The integration is achieved by means of the OPC XML-DA bindings for LabVIEW and, therefore, the operators are able to use standard web frontend for the control.

### F. Error Handling and Notifications

Besides sophisticated web based interface, simple Linux command-line control application is available. It implements basic functionalities, including URCS restart, certain driver restart, and configuration renewal. The current status, current value and the last error message may be reviewed using this client as well. That brings possibility to implement simple automated control scripts periodically executed in order to control system status and perform recovery operations if necessary. In the case if automatic recovery is not possible the notification is delivered to operators by means of e-mail.
In order to automatically detect hardware failures and Space Weather severe conditions the acceptable value ranges are specified for the data channels. If certain data value is dropped outside of these ranges indicating either the hardware failure or the Space Weather sudden disturbances the notification message is delivered to operators. The [2] demonstrated strong relation between inter-detector correlations and CME driven Space Weather conditions. Therefore, the correlations between time series obtained from the different detectors are calculated and in the case if those surpass the defined threshold the notification is sent to the operators as well.
As it was described before, the slow long distance wireless links are used to connect the research stations with main lab. Due to weather conditions, sometimes the link is completely down. The URCS servers are developed in the way allowing fully autonomous operations. If connection is not available for a long period of time, the data is stored in local files on the flash card and delivered to the storage server by means of FTP protocol as soon as the connection is restored.

### G. Data Storage

The data is stored by means of two powerful servers working in parallel at the main lab. The dual-core AMD Athlon X2 4800+ systems equipped with 2GB of operating memory and two Serial-ATA 400GB hard drives organized in mirroring raid are used. These servers are periodically inquiring the data from all detectors and storing it in the MySQL database as row numbers. The physical meaning of each database column is obtained from metadata properties and stored in the XML document of a special structure (see section 7) within the same database.
Further, the stored data is analyzed by the off-line software and made available to scientists by the means of DVIN (Data Visualization Interactive Network) web interface [2, 23].

## 6. Unified Readout and Control Server

The URCS (Unified Readout and Control Server) is main system component and used to control detectors. The data readout is performed by means of URCS server as well. The data is disseminated to the clients using OPC XML-DA protocol. For each detector the separate branch is registered within the OPC XML-DA data space. As well in this branch several control items are registered. Using these items the operators are able to adjust detector (and driver) configuration, send a few supported commands and retrieve error reports. The same control items are registered in the stand-alone branch associated with URCS server and used to perform general server operations.

## A. Layered Architecture

The several levels of abstraction are forming the core of a URCS server layout. The abstraction library lies in the deepest level, providing ability to run data acquisition software under the multiple operational systems (this library is a part of the OPC XML-DA library, see section 4.A). Currently, the Windows NT family and Linux systems are fully supported in both 32 and 64 bit environments. However support for any POSIX complaint system can be easily added.

The connections and writers are forming next abstraction layer. The connection abstraction interface provides uniform way of accessing underlying data acquisition boards and makes easy supporting new protocols without any changes in data acquisition code. The current version of the software supports devices connected through UART, USB and Ethernet interfaces. The writer abstraction layer provides ability to save data in the different formats. The multiple ways of bringing data to the client applications is another possibility brought by the writer abstraction layer utilization. This possibility is used to distribute the data using the OPC XML-DA protocol. The data is submitted to the OPC XML-DA server by means of the CORBA protocol. The ORBit CORBA implementation is used for that purpose [24]. However, for the data safety in addition to the dissemination by means of OPC XML-DA protocol, the data is stored locally in files. The file format used to store files consists of two parts: an ASCII data compatible with legacy software developed for the old data acquisition system and XML data containing metadata description of the ASCII data. More detailed review of the data format is available in the section 7.

The Device is a top most system component. It is used to get the data from the connected hardware, perform required preprocessing and pass it away. Each of the devices is associated with single Connection used to communicate with underlying data acquisition board and multiple Writers disseminating the data.

The multiple described devices are supported within single URCS server. The list of devices along with their settings is provided by the system integrator by means of the XML configuration file. The Fig. 5 illustrates described abstraction layers.

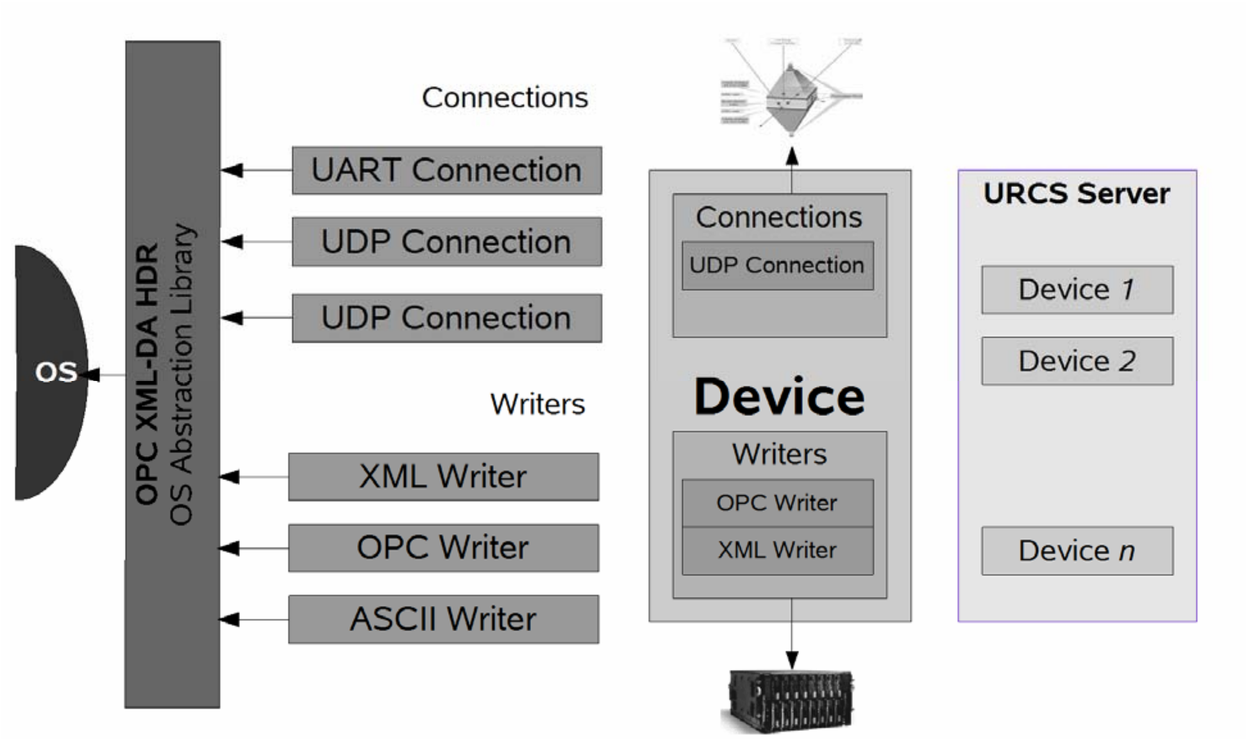


**Fig. 5. The figure illustrates URCS server abstraction layers.**

### B. Threading Model

The URCS server is developed using multiple readout threads and single processing. For the each device the dedicated thread with highest system priority is executed. This thread controls the underlying data acquisition board sustaining strict timing demands. As well the thread is polling the board for the data and storing that in the intermediate ring buffer. The single buffer is used for all devices. The pointer to the device which is obtained the information is stored along with the data.

The processing and dissemination is performed by a single thread running with lower priority. However, this priority is still higher than a priority assigned to the OPC XML-DA server. The thread processes the ring buffer record by record and for each record executes processing routine of appropriate Device. As well it passes the data to the appropriate Writers upon the request from Device processing routine. In order to prevent overall server hang-ups due to the Writer delays (for example, if the OPC XML-DA server is crashed and temporary inaccessible) the timeout restricts maximal amount of time used to the data storage and dissemination. If the processing is not finished in the assigned time slice, the record is postponed and processing of the next record from the buffer is started.

### C. Detector Network

As it already has been stated the URCS server communicates with underlying data acquisition boards using Ethernet interface by mean of UDP protocol. The detectors Ethernet segment is isolated from the outer world in order to avoid the spying and data corruption. Only a frontend computer running the URCS server is connected to the segment.

In order to obtain the network address the connected devices are issuing discover request by means of the DHCP protocol. The frontend computer accepts the request and assigns an IP address from a dedicated pool.

Usually, all operating detectors are listed along with their IP addresses in the URCS configuration file. However, it is possible to specify the IP range and default configuration in order to enable the device autodetection. In this case the URCS server will probe all IP's in the range using discovery command (see section 5.A). The found detectors will be initialized using specified default configuration.

### D. Configuration

The behavior of device is controlled by means of XML configuration. Initially this configuration is read from the URCS configuration file. After that, it is mapped to the correspondent OPC Item and operators are able to adjust configuration by writing new value into this item. Upon the configuration adjustment, the configuration file is updated. So, the current configuration would not be lost after a server restart.

The configuration structure is completely device specific. The DOM in-memory representation of the appropriate configuration is passed to the device driver. It is up to the driver to process configuration and extract required information. A portion of the configuration is controlling the driver behavior. Normally, this part includes connection properties (type, address, timeouts), list of writers to use for the data storage along with their properties, properties of the data preprocessing algorithms, et cetera. Another part controls the detector hardware behavior and passed by the driver to the detector's embedded software. The configuration is described by XML Schema Description which is available to the clients by means of the OPC XML-DA server as well. Both current configuration and this schema description are used by Chiba to generate XForms entries providing control interface.

Besides, the device specific configurations the configuration controlling the global URCS behavior is available. This configuration is mapped to the OPC Item and may be adjusted by the operators as well.

### E. Commands

The URCS server and affiliated Devices are able to accept commands. The “Command” item is registered for each device in the OPC server data space. The client by writing an XML document into this item may request the driver to perform certain actions. As well the “Command” item is registered in the URCS-wide branch within the OPC server data space. The execution of the server-wide operations may be requested by writing the inquiry into this item.

Currently, only two commands are supported by the URCS server. The server accepts commands demanding the server restart and the reload of the configuration file. As well it is possible to restart only a certain driver by writing command in the “Command” item associated with that driver.

The structure of the “Restart” and “Configuration Reload” commands are described in the section 8. Other device specific commands are not standardized by the URCS server design. In this case an XML query is passed to the Device driver and it is up to the driver implementation to handle the request in the proper way.

### F. Error Logging

Under Linux the information about problems during server operation is reported using standard syslog facility. The Linux syslog implementation is a very powerful tool and able to store the logged information in local files, in the temporary memory buffer and on the remote server by means of different protocols. As well the information may be sent to the operators by mail depending on its criticality. Under Windows the error messages are stored in the local file.

Besides the log files, the URCS server provides information about last occurred error by means of OPC XML-DA protocol. The errors related to each of the operating Devices is reported separately using “Error” item registered in the correspondent branch with the OPC server data space.

### G. Self-Announcement

The URCS server announces itself to the other components of the distributed data acquisition system by means of the OPC XML-DA based registry server. The address of the registry server is obtained from the configuration file. The URCS server periodically writes the information about its current status and address into the “Registry” item available within the registry server’s data space.

## 7. Data Representation

The embedded software controlling the ASEC detectors classifies the incident particles by several properties. The number of events in each class is summed over considered amount of time and transferred to the URCS server upon the request. Therefore, the ASEC data is represented as a sequence of vectors identified by the readout time and duration of the integration interval (time series). The vector components are representing a number of events registered in each class. The information from the environmental sensors (pressure, temperature, etc…) are obtained at the end of integration time slice and stored in the additional vector components.

The data storage subsystem of the old ASEC data acquisition system has been based on the unstructured ASCII files. The rows were representing vectors and the columns were representing vector components. As it was stated before a lack of structure caused misinterpretations in the data meaning and introduced a lot of obstacles in the data analysis automation. Even more problems of such kind are expected after the international network will be set. Therefore, the new XML based data format was developed.

### A. Basic Data Format

The XML is excellently fit system demands on meta-information describing meaning of the enclosed data. However, the completely new approach will obsolete all existing data analysis software. Further, providing full range of meta-data with each element of the time series will drastically increase size of the stored data. This will result in the increased requirements to the network and computational resources and, as a consequence, in a higher installation costs. Finally, the comparison of the XML based query languages and SQL has shown a tenfold advantage of the SQL approach [13]. Therefore, to compensate the described drawbacks the interim solution is introduced. In the way similar to the ancient data acquisition system the data is represented as vectors within the ASCII strings. These ASCII strings are enclosed in the XML structure providing basic information about the enclosed data and referencing an external document with thorough detector description.

The data depicted in the Fig. 6 illustrates the representation of a single vector by means of the new format. The “installation” attribute references external entity with the detector description. However, the detector structure may be changed several times during detector operation. Therefore, the specific layout used to obtain the vector should be referenced as well. The “layout” attribute is used for that purpose. The “Time” and “Duration” elements indicate the end and duration of the integration time slice. The timestamp and duration are represented following the encoding rules defined by the ISO-8601specification [25]. Special conditions encountered during data acquisition are described using “Quality” element. Usually, this element indicates hardware failures resulting in partly or completely inaccurate data. The “Value” element holds a data vector in the ASCII representation.

```
<Data installation=”NAMMM” layout=”layoutid”>
    <Time>2006-02-25T16:50:00.0000000+04:00</Time>
    <Duration>P30.0000000</Duration>
    <Quality>Good</Quality>
    <Value>1846 2760 1956 1848 1763 … </Value>
</Data>
```

**Fig. 6. A sample data vector represented using new XML based format is shown on the figure.**

In that way, the ASCII strings can be easily extracted from the data and used by the legacy applications. The newly developed applications are considering the XML description in order to extract appropriate data from the ASCII strings.

So, the detector data consists of the data vectors of the aforesaid type and the detector description. This description is not transported with the data but available upon the request from the URCS server by means of the OPC XML-DA protocol. Therefore, the network utilization of new data acquisition system does not exceed that of the old one. However, the data and description can be reconciled in a single document destined for the data exchange with the collaborating groups of scientists (see example in the Fig. 7).

Three main components may be segregated in the detector description: the global detector description, the description of the detector components and description of the logical data layout (scientific meaning of each vector component). First two components are preliminary filled by the operators and data layout is automatically generated by the URCS software.

### B. Detector Description

The information included in general detector description is presented in Table 2. The description of the NAMMM monitor is provided as an example in the Fig. 7.

```
<Installation id=”NAMMM”>
    <Title>Nor-Amberd Multidirectional Muon Monitor</Title>
    <Type>Multidirectional Muon Monitor</Title>
    <Collaboration>
        <Title>Aragats Space Environmental Center</Title>
        <URL>http://crdlx5.yerphi.am/DVIN/</URL>
        <Email>asec@crdlx5.yerphi.am</Email>
    </Collaboration>
    <Maintainer>
        <Title>Cosmic Ray Division of Yerevan Physics Institute</Title>
        <URL>http://crdlx5.yerphi.am/</URL>
        <Email>crd@crdlx5.yerphi.am</Email>
        <PostalAddress>…</PostalAddress>
        <Phone>…</Phone>
        <FAX>…</FAX>
    </Maintainer>
    <Location>
        <Country>Armenia</Country>
        <Region>Aragatsotn</Region>
        <Coordinates>
                <Latitude>40.5</Latitude>
                <Longitude>44.167</Longitude>
                <Altitude>2000</Altitude>
        </Coordinates>
    </Location>
    <CutoffRigidity>7.6</CutoffRigidity>

    <Geometry id=”geometryid”>
        XML description of the detector components, see below. The multiple geometries may
         be used during the experiment operation and, therefore, described here. The
         “geometryid” is used to reference correspondent geometry from other parts of the
        detector description. The “CurrentGeometry” element  is used to reference currently
        used detector geometry.
    </Geometry>
    <Layout id=”layoutid”>
        XML description of the logical data layout, see below. The data layout may be altered
        during the experiment operation. The “layoutid” is used to reference correspondent
        data layout from other parts of the detector description. The “CurrentLayout” element
        is used to reference currently used layout.
    </Layout>
    <CurrentGeometry>geometryid</CurrentGeometry>
    <CurrentLayout>layoutid</CurrentLayout>

    <Data installation=”NAMMM” layout=”layoutid”>
        The optional data vectors embedded into the descriptions, for format see Fig. 6
    </Data>
    <Data installation=”NAMMM” layout=”layoutid”>
        The optional data vectors embedded into the descriptions, for format see Fig. 6
     </Data>
</Installation>
```

**Fig. 7. The figure contains an example of the detector description. The information corresponds to Nor-Amberd Multidirectional Muon Monitor.**

**Table 2. The standard fields of the detector description.**

| Element | Description |
|---|---|
| Title | Detector name |
| Type | Type of the detector |
| Collaboration | Information (Web Server, E-Mail) about network the detector is participates in, if any |
| Maintainer | Information (Web Server, E-Mail, Postal Address, Phone, FAX) about organization maintaining the detector |
| Location | The detector location (country, region and geographical coordinates in WGS84 system) |
| Cutoff Rigidity | The cutoff rigidity at the detector location |
| Geometry<br>Layout<br>CurrentGeometry<br>CurrentLayout | Geometry contains description of the hardware component parts; Layout contains description of the data arrangement within the vector. The configuration may be changed during the detector operation. Therefore, several geometries and layouts may be described. CurrentGeometry and CurrentLayout elements are referencing present-day descriptions. |
| Data | By means of Data elements the detector description can be reconciled with one or more data vectors. |

## C. Detector Geometry

The detector geometry describes the detector component parts and their mutual disposition. This information is used to help hardware engineers in finding damaged components, to help physicists in finding a direction the particles are coming from and to provide the basic detector description for the third parties overlooking the data.

```
<Geometry id="geometryid">
   <Coordinate>
      <Slope>0</Slope>
      <Angle>25.4</Angle>
   </Coordinate>
   <Layer id=”1” Z=”1”>
      <Description>The upper layer of the NAMMM</Description>
      <Sensor id=”1” X=”0” Y=”0” Width=”0.9” Length=”0.9” type=”scintillator”/>
      <Sensor id=”2” X=”0.9” Y=”0” Width=”0.9” Length=”0.9” type=”scintillator”/>
      …
   </Layer>
   <Layer id=”2” Z=”0”>
      <Description>The bottom layer of the NAMMM</Description>
      …
      <Sensor id=”5” X=”0.9” Y=”0.9” Width=”0.9” Length=”0.9” type=”scintillator”/>
      <Sensor id=”6” X=”1.8” Y=”0.9” Width=”0.9” Length=”0.9” type=”scintillator”/>
   </Layer>
   <Layer id=”3” Z=”0.5”>
      <Description>Filtering layer. The electrons and muons with energy below 350MeV are
      filtered by this layer.</Description>
   </Layer>
</Geometry>
```

**Fig. 8. This figure contains an example of the detector geometry description. The parts of a description of the Nor-Amberd Multidirectional Muon Monitor detector are taken as a source.**

The “Coordinate” branch defines a coordinate system by means of two angles. “Slope” is a slope of the XY-plane and “Angle” is an angle between northern direction and Y-axis. The point specified in the “Location” branch of the general detector description is used as an origin of coordinates. Then, the detector placement is described in this coordinate system.

Most of ASEC detectors have layered architecture. Several layers of the scintillation sensors are segregated by the transition layers filtering part of the particles spectra. Therefore, the sensors are described layer by layer. For each layer the unique ID number, vertical alignment, short assignment description and list of sensors are defined. For each sensor the following information is defined: ID number unique within the layer, the coordinates, dimensions, type and short HTML description. The Fig. 8 contains parts of the Nor-Amberd Multidirectional Muon Monitor description as an example.

Each system component part is uniquely identified by the layer ID and sensor ID. This two ID numbers are used to reference component parts from the logical data layout in order to describe which detector component is used to obtain information contained in the certain data channel.

## D. Data Layout

The most important part of the detector description is an explanation of the component layout within the data vector. This data layout description indicates the physical meaning and acceptable value range for each vector component. The XML description providing the layout explanation consists of an element list. Each element provides information about a single data component and specifies its location within the data vector (see Fig. 9).

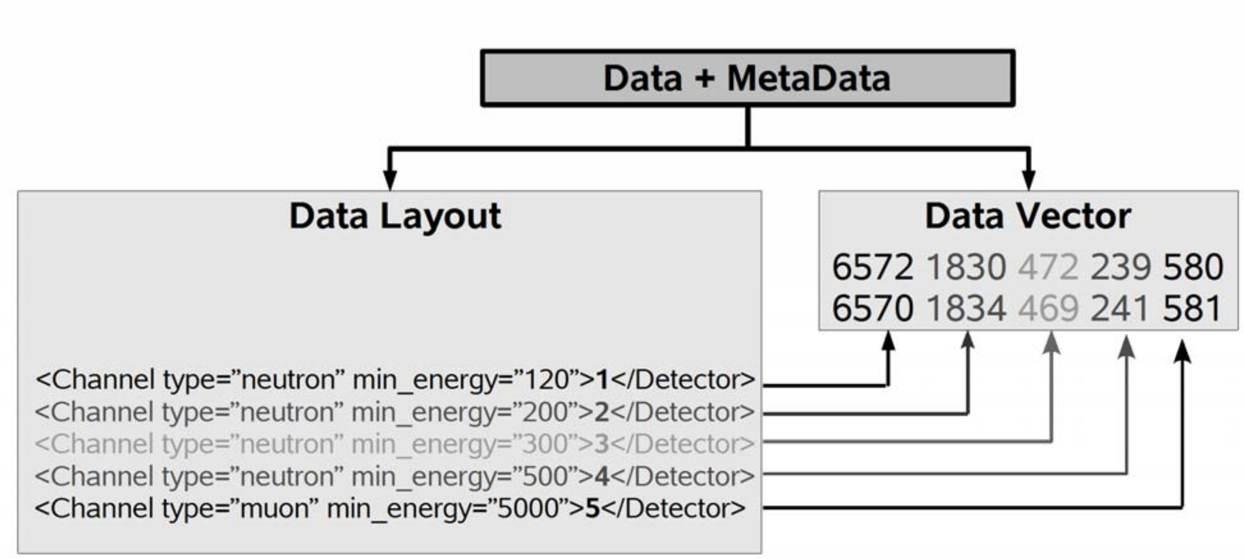


**Fig. 9. The figure illustrates how the data layout description is used to provide information on the physical meaning of the data components.**

Utilizing the proposed approach the application may execute XPath query on the layout description and select the nodes of interest. For, example the query “*//Layout/Channel[@type = ’moun’]*” will extract all elements providing the information on the muon flux intensity. Then, the application finds positions in the data vector containing the interesting data and extract it. Thus, the data acquisition system can automatically find the required information and in the case if the some channels are added to the detector, removed from the detector or rearranged the software will automatically handle new data layout without code adjustment.

Currently, there are defined three types of channel description elements: “Channel”, “Variance” and “Correlation”. The “Channel” describes a value representing measurements of a certain sensor. As it was described in introduction, the ASEC detectors are measuring the number of incident particles registered during certain amount of time. At the moment the minute intervals are used. However, the embedded software is able to operate with intervals having precision up to the hundreds of milliseconds. This information is not stored, but used to calculate variances of the stored minute data and correlations between the data channels. The “Variance” and “Correlation” elements are used to describe values containing these variance and correlation information, accordingly.

The following attributes are used to describe the value meaning and acceptable range:
*id*: Unique ID number, used to reference value.
*detector, layer*: The attributes contains detector and layer ID numbers indicating the detector part used to obtain value. The attributes are not included for the data obtained by means of several parts, like a coincidences (count rate of particle flux registered by the sensors in the upper and lower layers simultaneously).
*type*: The “type” is an enumeration describing the physical meaning of the value. Currently defined types are listed in the Table 3.
*units*: The attribute specifies engineering units in which the value is represented.
*low*, *high*: These attributes are pointing the minimal and maximal values likely to be obtained in normal operation. If the values are exceeding these limits the alert is sent to the operator.
*energy_min*, *energy_max*: For the sensors counting a number of incident particles, these attributes are specifying minimal and maximal energy thresholds. Only the particles with energy within the specified thresholds are counted. If only “energy_min” attribute is specified, then the data value represents a number of incident particles with energy above the specified threshold. The energy is specified in megaelectron-volts.
*direction*: In order to estimate the intensity of the particle flux coming from the certain direction, the ASEC electronics separately counting number of particles simultaneously registered by the several layers of the scintillation sensors. The “direction” attribute is used to describe such type of the coincidence data.
To indicate the direction the ID numbers of the sensors which are registered the particles are presented top-down. The numbers are divided by the ‘-‘ sign. For example, “*1-5*” means what the counted particles are passed truth the first detector in the upper layer and fifth detector in the lower one.
*description*: This attribute contains a short description of a free form.

For the “Variance” and “Correlation” elements only ID number and information about the primary data channels (for which the dispersion and correlation are calculated) is included. For the “Variance” element it is the “targetid” attribute and for the “Correlation” the “targetid1” and “targetid2” attributes are used. The Fig. 10 illustrates the data layout description.

**Table 3. Basic types of the ASEC sensors**

| Type | Description |
|---|---|
| temperature | Temperature sensor |
| pressure | Pressure sensor |
| humidity | Humidity sensor |
| magnx, magny, magnz | Sensor measuring components of the geomagnetic field vector |
| intensity_charged | Sensor measuring intensity of the incident charged particle flux |
| intensity_muon | Sensor measuring intensity of the incident muon flux |
| intensity_neutron | Sensor measuring intensity of the incident neutron flux |

```
<Layout id=”layoutid” geometry=”geometryid”>
    <Channel id=”1”  type=”intensity_charged” layer=”1” detector=”1”>1</Channel>
    <Channel id=”2”  type=”intensity_charged” layer=”1” detector=”2”>2</Channel>
    <Channel id=”3”  type=”intensity_muon” direction=”1-3”
                            energy_min=”350”>3</Channel>
    <Channel id=”4”  type=”intensity_muon” layer=”2” detector=”2”
                            energy_min=”5000”>2</Channel>
    <Variance id=”5” targetid=”1” >4</Dispersion>
    <Correlation id=”6” targetid1=”1” targetid2=”2” >5</Correlation>
</Layout>
```

**Fig. 10. The figure illustrates the data layout description.**

## 8. OPC XML-DA Interface

Within the data acquisition system the data dissemination and control are achieved by means of the OPC XML-DA protocol. The OPC XML-DA interface is available for all URCS and registry servers. Each detector frontended by the URCS server is represented in the OPC XML-DA data space by a separate branch (see Fig. 11). A set of standard items as well as the detector dependent data items are provided within this branch. The following standard items are mandatory registered within the detector branch: “Description”, “Configuration”, “Command”, “Error” and “Data”.

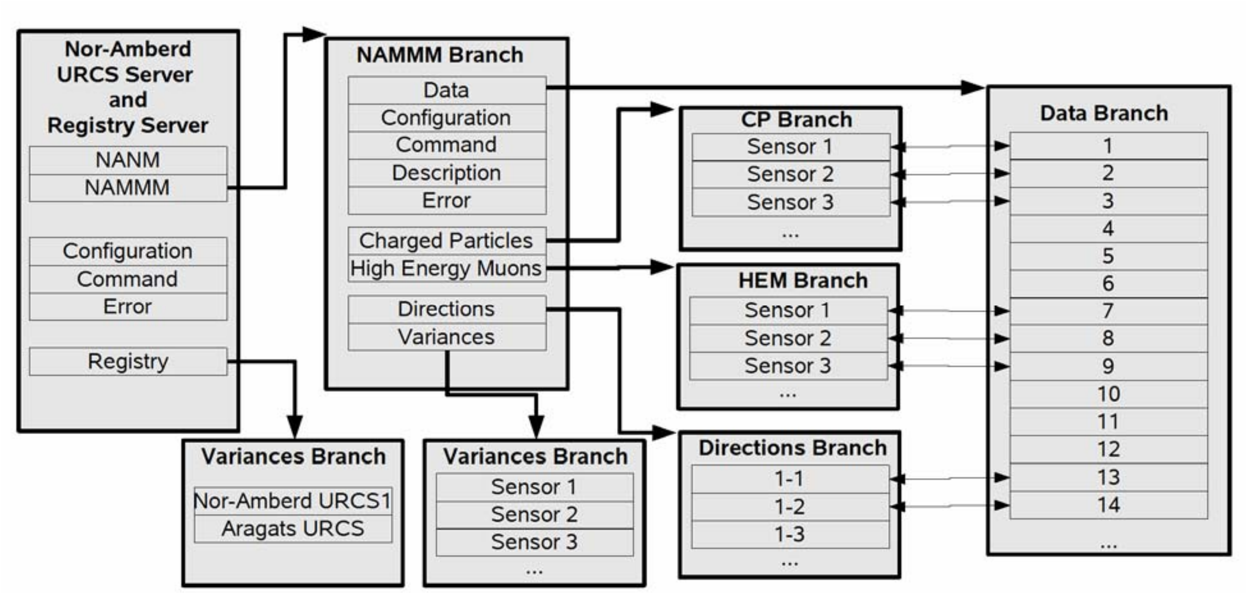


**Fig. 11. The figure illustrates the OPC XML-DA server data space. Most of the data represents real layout of the Nor-Amberd URCS server and Nor-Amberd Multidirectional Muon Monitor. The “Registry” branch represents the data space of the Registry server operating in the main lab in Yerevan.**

The “Description” is a read-only item and provides the detector description introduced in the section 7. Besides obtaining current detector layout, the client application may subscribe to this item in order to be notified about the detector layout changes. The “Configuration” item provides a way for handling detector configuration. The current configuration can be obtained using the read request. The certain operators (the authentication is currently performed basing on the IP addresses) are permitted to write a new configuration into the item. As well the client application may subscribe to the item in order to get notified about configuration changes. The “Command” item is used by the client applications to issue commands. Currently, the only supported command is “Restart” demanding the driver restart (other operating drivers are not affected). The command syntax is presented in the Fig. 12. However, the arbitrary drivers may support other commands. In this case it is up to the driver implementation to define the syntax of these commands. The client application should be able to get a full list of the supported commands along with their descriptions by means of reading the “CommandInfo” item. The “Error” is a read-only item and provides information about last occurred error concerning the detector operation. Finally, the “Data” branch exposes the data items providing information from the detector sensors. The items are named basing on their positions in the data vector considered by the current detector layout (see section 7 and Fig. 11).

Besides the data items published within the “Data” branch, the OPC server may expose available data by means of the structured branches with descriptive names. In this case the data items available within these branches are linked together with certain items within the “Data” branch. That is the data space is organized in such a way that multiple OPC Items are providing access to the same data. The data is not copied, but several OPC Items are referencing the same data structure in the memory space in this case.

The Nor-Amberd Multidirectional Muon Monitor data layout is presented in the Fig. 11 as an example. All data are available within the “Data” branch by means of the numbered data items. The appropriate numbers may be obtained from the detector description as described in the section 7.D. Additionally, the “Charged Paticles”, “High Energy Muons”, “Directions” and “Variances” branches are providing the same data in a structured way. The “Charged Paticles” contain values from the sensors which are located in the upper layer of the NAMMM detector and counting incidents of all charged particles. In turn the “High Energy Muons” branch contains information from the bottom sensors which are counting only muons with energies above 350MeV. The “Directions” branch is used to provide information about muon fluxes from different directions. And the “Variances” branch contains various statistical data.

**XML Schema Definition**

```
<xs:complexType name=”DeviceCommandType”/>
<xs:element
            name=”DeviceCommand” type=”DeviceCommandType”
             abstract=”true”/>
<xs:element
            name=”DeviceRestart” type=”DeviceCommandType”
            substitutionGroup=”DeviceCommand”/>
```

**Example**

```
<DeviceRestart/>
```

**Fig. 12. The figure illustrates a sample and an XML schema definition of the device restart command.**

### A. URCS Server

Besides the detector-specific branches available within the data space of the OPC XML-DA server frontending an URCS server, a set of items controlling global behavior of the URCS server are provided as well. The following items are mandatory: “Configuration”, “Command” and “Error”. The “Command” item is used to accept commands affecting inter-server operation. Currently the restart and configuration renewal commands are supported. The restart command has the same syntax with its driver-specific analogue, but completely restarts whole URCS server including all drivers. The syntax of the configuration renewal command is described in the Fig. 13. Upon receipt of that command the server reloads configuration file and notifies all operating drivers about configuration modification. The “Error” item is used by the clients to obtain information about last occurred error concerning the inter-server behavior.

```
<xs:complexType name=”URCSCommandType”/>
<xs:element name=”URCSCommand” type=”URCSCommandType” abstract=”true”/>
<xs:element
        name=”URCSRestart” type=”URCSCommandType”
        substitutionGroup=”URCSCommand”/>
<xs:element
        name=”URCSReloadConfiguration” type=”URCSCommandType”
        substitutionGroup=”URCSCommand”/>
```

**Example**

```
<URCSReloadConfiguration/>
```

**Fig. 13. The figure illustrates a sample and an XML schema definition of the reload configuration command.**

## B. Registry Server

The registry server exposes in the OPC XML-DA data space a single branch named “Registry”. The URCS servers are writing in this item the self-announcement notifications. The XML Schema presented in the Fig. 14 defines a structure of such notification. Inside the “Registry” branch the items correspondent to the registered servers are available. Clients by means of the reading data from these items obtain information about the certain URCS server. The information includes the URL at which the server is available and last re-announcement time along with a short server description.

**XML Schema Definition**

```
<xs:element name="URCSAnnounce">
  <xs:complexType>
    <xs:sequence>
      <xs:element minOccurs=”1” maxOccurs=”1” name=”Name” type=”xs:string”/>
      <xs:element minOccurs=”1” maxOccurs=”1” name=”Status” type=”xs:string”/>
      <xs:element minOccurs=”1” maxOccurs=”1” name=”URL” type=”xs:anyURI” />
      <xs:element minOccurs=”0” maxOccurs=”1”
              name=”Description” type=”xs:string”/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

**Example**

```
<URCSAnnounce>
  <Name>Nor-Amberd URCS Server</Name>
  <Status>Running</Status>
  <URL>http://192.168.0.16/URCS.opc</URL>
  <Description> Short server assignment description</Description>
</URCSAnnounce>
```

**Fig. 14. The schema represented on the figure defines a structure of self-announcement request accepted by the registry from the URCS servers. The sample of such query is demonstrated at the bottom of the figure.**

### C. ASEC-Specific Metadata Properties

To simplify the automatic processing by the OPC XML-DA client part of the complete detector description is provided for the OPC XML-DA clients by means of the ASEC-specific meta-data properties. The list of theses properties is presented in the Table 4 along with short descriptions.

**Table 4. The ASEC-specific metadata properties**

| Property | Description |
|---|---|
| scanRate | A standard property defined in the OPC XML-DA specification specifying the fastest rate at which the server could obtain the data from the underlying data source. For the ASEC detectors, this property represents the duration of counting interval in milliseconds. |
| engineeringUnits | A standard property defined in the OPC XML-DA specification specifying the units of measurement. |
| lowEU, highEU | The property defined by the OPC XML-DA specification for analog data in order to specify lowest and highest values likely to be obtained in normal operation. By the ASEC servers this properties are used to indicate acceptable count rates. If the data is out of specified range, the monitoring software should issue notification for the operator. |
| description | A short description of the data channel. The property is defined by the OPC XML-DA specification as well. |
| asec_sensor_type | Enumeration indicating the basic physical meaning of the data. The acceptable values are presented in the PPTable 3. |
| asec_sensor_id | The property specifies ID number of the enclosed data (position in the data vector). For the items registered in the structured branches, this property may be used to find the associated OPC Item within the “Data” branch. |
| asec_target_id | This property is used in conjunction with statistical data items providing variance and correlation information on the certain data channel. It references a primary data channel used for variance and correlation calculation. A single ID number pointing the primary data is used for variance items and array of the two ID numbers for the items providing correlation information. |
| asec_energy_min, asec_energy_max | For the sensors counting a number of incident particles, these two attributes are specifying minimal and maximal energy thresholds. Only the particles with energy within the specified thresholds are counted in order to obtain value disseminated by the OPC Item. The energy is specified in megaelectron-volts. |
| asec_direction | This property provides information on the direction of the counted particles. The ID numbers of the sensors which are registered coincidence are presented top-down divided by the ‘-‘ sign. For example, “*1-5*” means what the counted particles are passed truth the first detector in the upper layer and fifth detector in the lower one. |

## 9. Conclusion

In this chapter a new data acquisition system of the ASEC detector network is described. The system is based upon the uniform components utilizing the high level standards. The standard Ethernet interface is used to connect the detector electronics to the frontend computers. A single

frontend computer handles all detectors within the research station. The single-type Minibox M100 computers are used everywhere. These computers are based on the VIA Eden architecture and do not include any unreliable mechanicals parts. The processor with low power consumption allows to use the passive cooling. Instead of the hard drives the Compact Flash is used.
The software controlling detectors is based on the layered architecture running multiple drivers. Therefore, the detectors of all types are controlled within a single application running multiple drivers. The OS abstraction library allows software execution within any supported platform and simplifies implementation of the new ones. New XML based self-describing format eliminates problems with data misinterpretations and allows the processing automation. Furthermore, the self-describing format facilitates the data exchange between related experiments. The XML description is designed in a way that the data is not drastically enlarged size and still can be stored within a fast SQL database.
The OPC XML-DA protocol is used to provide both the data dissemination and detector control capabilities. The protocol is based on a standard HTTP transport and an XML data representation and, therefore, allows constructing highly heterogeneous systems distributed over the world. Also the protocol is supported by the quantity of commercial control solutions, including LabVIEW by means of bindings described in the previous chapter. Thus, the components of the data acquisition system controlled by the LabVIEW applications are uniformly embedded in the data acquisition environment as well.
The data control and monitoring capabilities are provided by means of the sophisticated web frontend. The web frontend obtains the data and status information from the frontend servers by means of the OPC XML-DA protocol and makes it available to the operators running a standard web browser. The Macromedia Flash animations are used for the data visualization, and the Chiba XForm generator is used to provide sophisticated control interfaces. Such design eliminates the complex requirements for operator workplace and opens a way for the detector monitoring practically from the anywhere. Even the GPRS or WiFi enabled PDA and Smartphone devices can be used for the control purposes.
Besides the sophisticate control frontend, a set of the automatic scripts is periodically executed in order to monitor the detectors status and current sensor values. The information obtained from the different detectors is correlated and under certain conditions a notification message is sent to the operators.
The data is stored by means of two interchangeable servers working in parallel at the main lab. These servers are periodically inquiring the data from all detectors and storing it in the MySQL database. Further, the stored data is analyzed by the off-line software and made available to scientists by the means of DVIN (Data Visualization Interactive Network) web interface.

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