Development of a Data Acquisition Software for the CULTASK Experiment

To cite this article: Soohyung Lee 2017 *J. Phys.: Conf. Ser.* **898** 032035

View the article online for updates and enhancements.

Related content
- Data acquisition: one step at a time
  Tony Taylor
- A MICROCOMPUTER BASED SYSTEM FOR DATA ACQUISITION AND INSTRUMENT CONTROL
  N. M. White and L. H. Wasserman
- Data acquisition software for the CMS strip tracker
  R Bainbridge, G Baulieu, S Bel et al.

Recent citations
- Velocity substructure from Gaia and direct searches for dark matter
  Ciaran A. J. O'Hare et al
- Refinement of the standard halo model for dark matter searches in light of the Gaia Sausage
  N. Wyn Evans et al
- Dark matter hurricane: Measuring the S1 stream with dark matter detectors
  Ciaran A. J. O'Hare et al
Development of a Data Acquisition Software for the CULTASK Experiment

Soohyung Lee
Research Fellow, Center for Axion and Precision Physics Research, Institute for Basic Science, Daejeon, Republic of Korea
E-mail: soohyunglee@ibs.re.kr

Abstract. Axion is a candidate of dark matter, and is a consequence of a solution to the strong CP problem. CULTASK (CAPP Ultra-Low Temperature Axion Search in Korea) is an axion search experiment which is being developed in Korea. As a part of the project, home-grown software, which governs the data acquisition and control systems, has been developed. The software governs the data acquisition as well as equipment control. In this proceeding, the development of the software is discussed.

The universe is believed to consist of roughly 68% of dark energy, 27% of dark matter, and 5% of ordinary matter [1]. Despite its dominance and persistent effort to find over many decades, the dark matter has not been discovered so far. One of the candidates of the dark matter is the axion, which is originally proposed to solve the “strong CP” problem in quantum chromodynamics (QCD) [2, 3, 4]. Currently, “invisible” axions are theoretically supported by two prominent models: KSVZ (Kim-Shifman-Vainshtein-Zakharov) [5, 6] and DFSZ (Dine-Fischler-Srednicki-Zhitnitsky) [7, 8]. The invisible axion is expected to have extremely small mass $\sim \mathcal{O}(\mu\text{eV}/c^2)$, and does not interact much with ordinary matter. However, the axion can be visible via its coupling to electromagnetic fields, in other words, the axion can be converted to photon in a strong magnetic field [9]. The axion-photon conversion is enhanced on a resonant mode of a microwave cavity, and its power picked up by a radio-frequency receiver is given by [10]

$$P_S = \left( g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a^2} \right) \left( \omega_c B_0^2 V C_{\text{mnl}} Q_L \frac{\beta}{1 + \beta} \right)$$

where $g_{a\gamma\gamma}$ is a model-dependent coupling constant, $\rho_a$ is the local dark matter density, $m_a$ is the axion mass, $B_0$ is the external magnetic field, $V$ is the volume of the cavity, $Q_L$ is the loaded quality factor of the cavity, $\omega_c$ and $C_{\text{mnl}}$ are the resonant angular frequency and the form factor of the cavity at a specific electromagnetic mode, respectively, and $\beta$ is the coupling parameter of the mode to the receiver. Though the axion power varies with different parameters in equation 1, it is roughly $\mathcal{O}(10^{-24})$ W for KSVZ model, which is challenging to pick up.

Since the resonant frequency of the cavity is determined by its geometric properties as well as material properties, a fixed resonant cavity can have a fixed resonant frequency for a specific electromagnetic mode. To search the axion in frequency domain, the resonant frequency has to be tuned with an appropriate tuning mechanism. Combining equation 1 with the radiometer...
Figure 1. Axion exclusion regions from experiments [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22] in the axion-photon coupling parameter \((g_{a\gamma\gamma})\) space as a function of axion mass \((m_a)\). Theoretical predictions from KSVZ and DFSZ models are also shown in blue lines.

The equation [23], one can find a scan rate of an experiment as [24]

\[
\frac{df}{dt} = \frac{4}{3} \frac{1}{\eta \text{SNR}^2} \left( \frac{1}{k_B T_s} \right)^2 \frac{Q_a}{Q_L} P_S^2
\]

where \(\eta\) is a data acquisition efficiency, SNR is a signal-to-noise ratio, \(k_B\) is the Boltzmann constant, \(T_s\) is the system temperature, and \(Q_a\) is the axion quality factor (=10\(^6\)). As the scan rate is proportional to the data acquisition efficiency \(\eta\), a fast data taking is crucial to make the experiment sensitive to a wider mass range.

For decades, many experiments have tried to find the axion signal, but, no experimental evidence has been found yet. As shown in figure 1, though those experiments set the exclusion regions in the axion-photon coupling parameter space, there are still many unexplored regions.

The CULTASK (CAPP Ultra-Low Temperature Axion Search in Korea) experiment is a developing experiment to search for the axion dark matter using a resonant cavity and powerful magnets. The experiment will search for the axion in unexplored regions. To maximize the sensitivity and scan rate, we are visiting all the aspects of the experiment: strong magnetic field \((B_0)\), large bore size of the magnet to maximize the cavity volume \((V)\), high quality factor cavity \((Q_L)\), ultra-low system temperature \((T_s)\) with a dilution refrigerator and low noise amplifiers. Figure 2 briefly illustrates the experiment.
Figure 2. CULTASK experiment configuration. Various equipment are associated to operate the experiment, and a data acquisition software controls and monitors them.

CULDAQ (CULTASK Data AcQuisition software) is the software to control, monitor, and take data from equipment for the experiment. It is home-grown software utilizing various languages such as C++ for low-level interfaces to the equipment, Python for higher-level programming and run scripting, PHP and JavaScript for a monitoring user interface. The design of CULDAQ is shown in figure 3.

CULDAQ consists of several components: interface modules, equipment modules, run scripts, web components, and utility modules. Interface modules provide the interface to protocols supported by equipment. GPIB (General Purpose Interface Bus) is used by essential equipment such as a network analyzer, a spectrum analyzer, and a signal generator. RS232 protocol is used by a magnet controller and a temperature controller, and USB is used by a radio-frequency (RF) mechanical switches. AbstractGPIB, AbstractRS232, and AbstractUSB classes establish the connections to devices through those protocols, and provide functions to write commands and to read data.

Though the devices share protocols to communicate, each equipment has different command set to control. To support functions of various equipment, equipment modules dedicated to specific devices are necessary. For example, EquipmentNetworkAnalyzerN5232A class provides all the functions to control a specific model of a network analyzer. By calling member functions of those classes, users can control the devices in run scripts conveniently. Those equipment modules are combined to form a real run of the experiment.
Figure 3. Design of CULDAQ. It consists of several layers of interface, equipment, utility, run script, and web components. All the modules are written in object-oriented way, therefore, they can be easily combined in a flexible way.

Utility modules provide convenient and essential functions. Since some data from devices are serialized in binary formats, they have to be unpacked in a treatable form. Unpacker module unpacks those serialized data, so the software can utilize the data for the next run or an online monitoring. OutputServer module defines the data format of the experiment, and writes the data into a ROOT format. This ROOT data is the actual experiment data to be analyzed offline. To monitor the status of the experiment and the quality of data, online monitoring is necessary. Database module provides an interface to a database, so snapshot data for monitoring can be stored in database for the online monitoring. For the database, we employ MariaDB, and SQL (Structured Query Language) is all handled by Database module, therefore, users do not need to care about the SQL syntax.

Web components display the snapshot data for the online monitoring. Since we employ industrial standards for the web system, the monitoring system is platform-free. In addition, the monitoring system is deployed in a separate node, many connections to the monitoring system does not harm the data acquisition process. The web system also provides convenient features such as Logbook to make logs by experiment shifters and DataStore to navigate all the data taken from the experiment runs in an organized way.

The experiment is run according to a run script which defines the sequences of operation. By combining all the modules described above, users are able to form any job from a simple test of a device to a complete experiment run. For a general run of the experiment, a run script defines the procedure of runs, for example; the script reads and writes the cavity performance (quality factor ($Q_L$), coupling parameter ($\beta$), and so on) by using network analyzer; it reads and records system temperatures ($T_s$) and a magnetic field ($B_0$); it controls the antenna of the cavity to achieve a desired coupling parameter ($\beta$); it takes power spectrum ($P_S$) data from spectrum analyzer; it rotates the tuning rod to change the resonant frequency ($\omega_0$); it repeats the whole procedure. The script takes an input parameters in JSON (JavaScript Object Notation) format. In the JSON file, all the initial parameters such as a resonant frequency of the cavity, definitions of windows in network and spectrum analyzers, data sampling rate, and so on. Therefore, once
the run script is established, users do not need to modify the script, but change the parameter values in the input file. The JSON input file can be generated on the web system, so the software can be controlled over web interface as well.

As shown in equation 2, the data acquisition efficiency (\( \eta \)) is crucial to maximize the performance of the experiment. The overhead from the software turns out to be negligible, however, the performances of equipment is the limiting factor of the efficiency since our data acquisition strongly relies on those devices. For example, it takes about 140 seconds to measure 10,000 power spectra averaged with a spectrum analyzer. The resolution bandwidth (\( \Delta f \)) is 270 Hz for this particular test, therefore, the integration time is \( t = N/\Delta f \simeq 37 \) seconds. During the data taking, the software only consumes about 50 ms, therefore, the performance of the spectrum analyzer is the dominant source of the dead time. It opens an opportunity to employ a fast digitizer, and it requires that the software includes FFT (fast Fourier transform), however, we are focusing to run the experiment with a commercial spectrum analyzer for the moment.

The essential parts of the software are all developed, and the overall robustness is proven. Features for convenience mostly in the web component are under development. We expect that the experiment will start to operate in a few months, and the software will serve for the success of the experiment.

Acknowledgments
This work was supported by IBS-R017-D1-2017-a00 of the Republic of Korea.

References
[1] Ade P A R et al. (Planck Collaboration) 2014 Astron. Astrophys. 571, A1
[2] Peccei R D and Quinn H R 1977 Phys. Rev. Lett. 38, 1440
[3] Weinberg S 1978 Phys. Rev. Lett. 40, 223
[4] Wilczek F 1978 Phys. Rev. Lett. 40, 279
[5] Kim J E 1979 Phys. Rev. Lett. 43, 103
[6] Shifman M A, Vainshtein A I, and Zakharov V I 1980 Nucl. Phys. B 166, 493
[7] Dine M, Fischler W, Srednicki M 1981 Phys. Lett. B 104, 199
[8] Zhitnitsky A 1980 Sov. J. Nucl. Phys. 31, 260
[9] Sikivie P 1983 Phys. Rev. Lett. 51, 1415
[10] Brubaker B et al. 2017 First results from a microwave cavity axion search at 24 \( \mu \)eV, Preprint astro-ph/1610.02580
[11] Kolb E W and Turner M S 1990 The Early Universe (Reading: Addison-Wesley)
[12] Burrows A, Ressl M T, and Turner M S 1990 Phys. Rev. D 42, 3297
[13] Engel J, Seckel D, and Hayes A C 1990 Phys. Rev. Lett. 65, 960
[14] Raffelt G and Dearborn D 1987 Phys. Rev. D 36, 2211
[15] Inoue Y et al. 2002 Phys. Lett. B 536, 18
[16] Steffen J H and Upadhye A 2009 Mod. Phys. Lett. A 24, 2053
[17] Cebrian S et al. 1999 Astropart. Phys. 10, 397
[18] Arik M et al. (CAST Collaboration) 2015 Phys. Rev. D 92, 021101(R)
[19] Asztalos S et al. (ADMX Collaboration) 2001 Phys. Rev. D 64, 092003
[20] Asztalos S J et al. (ADMX Collaboration) 2010 Phys. Rev. Lett. 104, 041301
[21] Wiensh W U et al. 1989 Phys. Rev. D 40, 3153
[22] Hagmann C et al. 1990 Phys. Rev. D 42, 1297
[23] Dicke R H 1946 Rev. Sci. Instr. 17, 268
[24] Kenany S A et al. 2016 Design and Operational Experience of a Microwave Cavity Axion Detector for the \( 20 – 100 \) \( \mu \)eV Range, Preprint physics/1611.07123