CoLiTec Virtual Observatory Platform for the Cloud Computing Analysis of Light Curves for the Variable Stars

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***Abstract*—A growing of the cloud services and resources capabilities allow moving the desktop software/applications to the servers/clouds/clusters. In this paper we have presented a brief description and several aspects related to the cloud computing, Virtual Observatory (VO) and Software as a Service (SaaS) in astronomy, reviewed them, and provided some major approaches of their realization in scope of the Collection Light Technology (CoLiTec) project as the SaaS called "CoLiTec Virtual Observatory Platform". We have presented a realization of the developed mathematical and computational methods related to the light curve creation of variable stars incapsulated into the CoLiTecVS (CoLiTec Variable Stars) desktop software as a new Software as a Service approach with the graphical user interface (GUI) in the cloud with web access and visualization. All processing stages are performed on the backend and end user has access to the web interface only. The CoLiTec Virtual Observatory Platform was successfully tested on the astronomical data with a lot of investigated variable stars of the different observatories in Ukraine, Slovakia and Thailand using the different types of telescopes and observational conditions.**

Keywords—Software as a service; Cloud computing; Virtual Observatory; CoLiTec; database; light curve; photometry; variable star.

I. Introduction

Improving of the capabilities and possibilities of the cloud services, their computational and storage volumes lead us to use them as much as possible to simplify the support, centralizing of the architecture, availability, and stability of computational processing [1]. The cloud computing is an organization of the different computing services connected with each other to perform and realize the different applications to be accessed via the various ways like thin client, terminal, desktop, web online, mobile, etc. [2]. Such computing services have the common scalable storage and processing power, which is located at the separate server/cluster called "cloud" [3]. Almost all services in the cloud are designed to perform a wide range of actions – from the simple actions like storing, working with network and Internet to the complex actions like powerful processing and mathematical computation including the natural language processing and even the artificial intelligence (AI) [4].

There is a one direction in astronomy, which is required a powerful processing server, called the photometry [5] (light curve analysis of the variable stars [6]). The astronomical and scientific data grow very tremendously, so the volume of such data becomes the Big Data [7] and includes a lot of separate databases, big datasets, servers with the high-definition images/video, different astronomical catalogs [8] with variable stars and created light curves [9]. Such scientific data are collected during the long period of time and include a lot of metadata about the digital files, images, investigated variable stars and additional data that need to be processed and used in the different ways for the scientific purposes including even the Wavelet analysis [10].

Therefore, to perform the very complicated cloud computing analysis of light curves for the investigated variable stars the Collection Light Technology (CoLiTec) [11] project has migrated from the desktop application to a cloud and created the new SaaS for the performing a photometry of variable stars, creating the light curves, and analyzing them. The developed SaaS implements various mathematical methods for the image processing and filtering [5], object's astrometry [12], positional observations reduction [13], object's photometry (light curve creation) [9], object's recognition/detection [14, 15] and computational methods for the Big Data processing [7, 16].

In this paper we have presented a brief description and several aspects related to the cloud computing, Virtual Observatory and SaaS in astronomy, reviewed them, and provided some major approaches of their realization in scope of the CoLiTec project as the product called "CoLiTec Virtual Observatory Platform". Also, we have presented the realization of developed methods related to the light curve creation of variable stars and incapsulated into the CoLiTecVS (CoLiTec Variable Stars) software as a new SaaS approach with the graphical user interface (GUI) accessible via web interface in the cloud.

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II. Cloud Computing

According to the USA National Institute of Standards and Technology (NIST) [17] the cloud computing implements services using following standard models [18].

Infrastructure as a Service (IaaS): connected with the online services, which provide the different high-level Application Programming Interfaces (APIs) [19] that are used for the dereference to the appropriate low-level details of the underlying network infrastructure like data storing, location, partitioning, scaling, physical computing resources, security, backup, etc.

Platform as a Service (PaaS): implementation of the acquired applications, services, libraries, or tools created by the consumer into the cloud infrastructure but supported by the provider. The cloud infrastructure (operating systems, storage, servers, network) is not managed and controlled by the consumer but the last one can control and manage the deployed applications and the appropriate configuration settings for the hosting environment [20].

Software as a Service (SaaS): implementation of the different applications based on the various services as a combination for the cloud computing, which is everyday used by humans. The access for end user to such services is available via web browser or mobile client, and there are no dependencies on the underlying hardware, random access memory (RAM), operating system (OS) of the cloud infrastructure [21].

Mobile "backend" as a service (MBaaS): linking the web and mobile applications to the cloud storage and computing services using APIs to expose such applications by custom software development kits (SDKs), which support the push notifications, user management, and integration with the different social networks.

Serverless computing or Function-as-a-Service (FaaS): code execution with the managing start/stop virtual machines (VM) by the provider according to the requests, which are billed by a measured value of the resources required for the request, without involving the running code out of servers.

Also, for the correct cloud computing usage the following major cloud characteristics are described below.

- *On-demand self-service*: the computing capabilities like network storage and server time can be automatically provided without any human interaction.
- *Broad network access:* the network capabilities are available and can be accessed using the standard possibilities from the thin client like laptops, tablets, phones, etc.
- *Resource pooling:* the physical and virtual computing resources are pooled and can serve several consumers simultaneously using the multi-tenant model by dynamically assigning and reassigning to consumer demand.
- *Rapid elasticity:* the computing capabilities are elastically released and provisioned in automated mode for the rapidly scaling such capabilities for consumers with commiserating with demand at any time in any quantity without limitation.
- *Measured service:* the automatically controlling and optimizing the using of resources by leveraging a metering capability at the abstraction level for the appropriate type of service like bandwidth, processing, storage. Such resource usage for these types of services can be controlled, monitored, and reported by providing the transparency for consumer and provider.

Generally, the described above models and the appropriate major cloud characteristics are the basis for the almost all existed cloud architectures and systems in the world.

III. CoLiTec Virtual Observatory Platform

The Virtual Observatory (VO) in astronomy is a concept for storing the astronomical data in the digital archives and the providing an international access to them [22]. The International Virtual Observatory Alliance (IVOA) is an owner of the standards for VO, which developed the data processing methods and organized the cooperation in the astronomy communities [23].

The CoLiTecVS software for the automated reduction of photometric observations in CCD-frames [24] was selected as an example of the scientific desktop software in astronomy with the complex calculations and the integrated computational methods. The developers decided to migrate such CoLiTecVS software from desktop to the cloud using the SaaS model using their own server. The final product received the name “CoLiTec Virtual Observatory Platform” (CoLiTecVO).

CoLiTec Virtual Observatory Platform was designed according to best practices of the SaaS architecture model and modern information technologies. Also, it implement the IVOA recommendations for a storing of the photometric big data using crossreference approach. The last one provides the possibility to receive all required scientific data like CCD-images, photometric observations of the investigated variable stars and the appropriate light curves of them.

The brief scheme of the data flow through the CoLiTecVO is presented in the Figure 1.

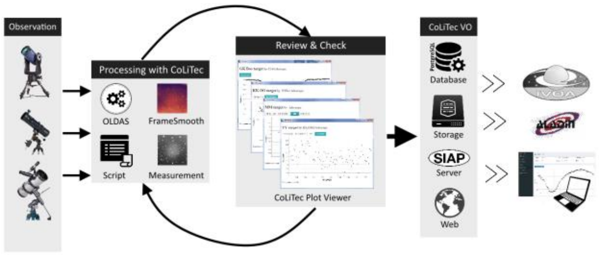


Fig. 1. Brief scheme of the data flow through the CoLiTec Virtual Observatory Platform.

Web interface of the CoLiTecVO (figure 2) allows end user to upload the raw CCD-frames with the investigated variable stars received right from the telescope. The backend services of SaaS architecture perform the following sequence in the image processing pipeline with incapsulated developed mathematical and computational methods: brightness equalization and cosmetics [5] → frames segmentation [25] → parameters estimation of the investigated variable stars [26] → frames identification with modern online catalogs [8] → astrometry of the investigated variable stars [27] → photometry of the investigated variable stars [9] → light curves creation → reports creation.

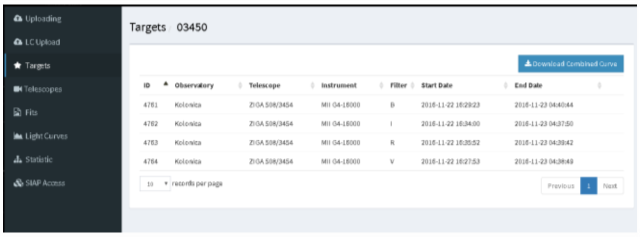


Fig. 2. "Target" page with the information about the ligth curves in the CoLiTec Virtual Observatory Platform.

As an end point of the cloud computing analysis of CoLiTecVO is a representation of the light curve as a plot with the variations of brightness measurements on the web interface (see Figure 3).

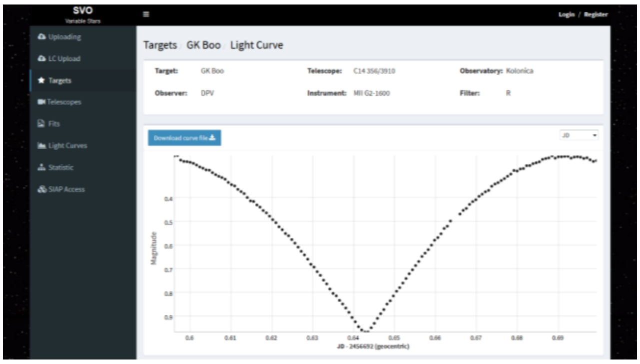
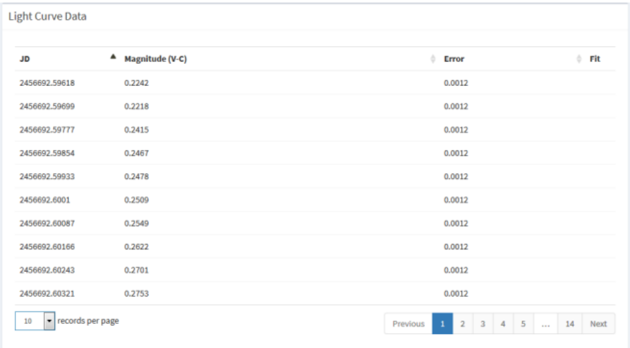


Fig. 3. "Light Curve" page with the information about the selected target in the CoLiTec Virtual Observatory Platform.

Such plot is based on the photometric measurements of the investigated variable star received from the several sources: right after processing on a backend, from cloud storage, or from the different online catalogs and archives [28]. The detailed information (magnitude, root mean square (RMS) error of the brightness measurement and its Julian date of creation) for the appropriate light curve of the selected investigated target (variable star) is available for displaying by clicking on a point in the plot with light curve (see Figure 4).


Light Curve Data

JD	Magnitude (V-C)	Error	Fit
2456692.59618	0.2242	0.0012	
2456692.59699	0.2218	0.0012	
2456692.59777	0.2415	0.0012	
2456692.59854	0.2467	0.0012	
2456692.59933	0.2478	0.0012	
2456692.6001	0.2509	0.0012	
2456692.60087	0.2549	0.0012	
2456692.60166	0.2622	0.0012	
2456692.60243	0.2701	0.0012	
2456692.60321	0.2753	0.0012	

10 records per page   Previous 1 2 3 4 5 ... 14 Next

Fig. 4. "Light Curve Data" page with the list of measurements and information for the selected investigated variable stars in the CoLiTec Virtual Observatory Platform.

One more advantage of the CoLiTecVO SaaS platform is a support of the IVOA contracts for the Application Programming Interface (API) connection to the different international photometric databases (Simbad [29], Aladin Sky Atlas [30]) and services (American Association of Variable Star Observers (AAVSO) [31], VizieR [32]). Some of such described above contracts are presented in the Figure 5.


```
JulianDate      Mag     ErrMag  PathFit
2457875.3735995 0.18300 0.00483 STEP-Img_20170501-001FV60.fit
2457875.3744097 0.15920 0.00482 STEP-Img_20170501-002FV60.fit
2457875.3751968 0.13480 0.00403 STEP-Img_20170501-003FV60.fit

#TYPE=Extended
#OBSCODE=AAVSOCode
#SOFTWARE=CoLiTecVS
#DELIM=,
#DATE=JD
#OBSTYPE=CCD
#NAME,DATE,MAG,MAGERR,FILTER,TRANS,MTYPE,CNAME,CMAG,KNAME,KMAG,AIRMASS,GROUP,CHART,NOTES
DQ Her,2457875.3735995,2457875.3735995,0.183,0.0048,FV,NO,DIF,ENSEMBLE,na,CmpMain,14.437,
DQ Her,2457875.3744097,2457875.3744097,0.159,0.0048,FV,NO,DIF,ENSEMBLE,na,CmpMain,14.432,
DQ Her,2457875.3751968,2457875.3751968,0.135,0.0040,FV,NO,DIF,ENSEMBLE,na,CmpMain,14.430,

<Note>
    <Observer>Observer</Observer>
    <Telescope>Telescope</Telescope>
    <Instrument>CCD</Instrument>
    <Filter>FV</Filter>
    <Exposure>60.00</Exposure>
    <Target>DQ Her</Target>
    <Position>18:07:30.25;+45:51:32.7</Position>
    <MainComp>18:07:25.44;+45:54:06.1</MainComp>
    <ReferenceMagnitude>0.000</ReferenceMagnitude>
    <MagnitudeSystem>V-C</MagnitudeSystem>
    <MagnitudeSystemAAVSO>DIF</MagnitudeSystemAAVSO>
    <TimeSystem>JD geocentric</TimeSystem>
    <Reduction>true</Reduction>
    <Source>No Comment</Source>
    <Comment>No Comment</Comment>
</Note>
```


Fig. 5. Examples of contracts (from up to bottom): light curve contract of the investigated star, report contract in the AAVSO extended format, note contract with the detailed information about the light curve.

The additional web page for the collected processing statistic is also available on GUI of CoLiTecVO SaaS platform (see Figure 6). Such page contains the information about all targets (variable stars), observatories, telescopes, filters used during an observation and storing the photometric data. Such information is used for the further data mining process [33].

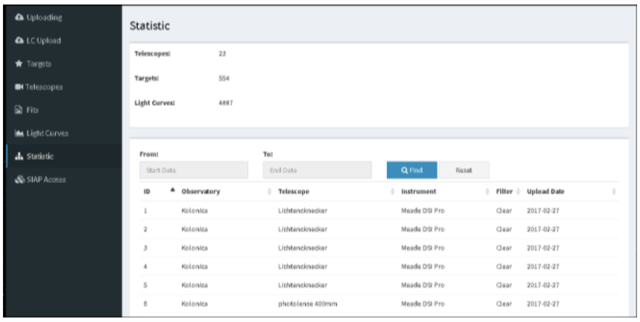


Fig. 6. "Statistic" page with the information about the telescopes, targets (investigated variable stars), ligth curves in the CoLiTec Virtual Observatory Platform.

IV. Conclusion

The CoLiTec Virtual Observatory Platform (CoLiTecVO) as a realization of Software as a Service (SaaS) was developed for the cloud computing analysis of light curves for the variable stars in scope of the CoLiTec project. CoLiTecVO platform was successfully tested on the astronomical data with a lot of investigated variable stars of the different observatories in Ukraine, Slovakia and Thailand using the different types of telescopes and observational conditions: observing station Mayaki of "Astronomical Observatory" in the Research Institute of I. I. Mechnikov of the Odessa National University [34], Vihorlat Observatory in Humenne [35], National Astronomical Research Institute of Thailand [36]. Totally, up to 1 million astronomical CCD-images were processed using CoLiTecVO software. Such images were from the different archives, big data storages and originally formed right from the telescopes during online processing. The total number of the created light curves is 4887 for 554 investigated variable stars.

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