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

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***Abstract*—An extending of the available cloud services and the appropriate resources gives us a possibility to move as many calculations and computational processes from the desktop tools/applications as possible directly to the cloud, servers or even clusters. In this work we present an information about the cloud processing, Virtual Observatories and Software as a Service (SaaS) technological model in astronomy, analyzed them, prepared a few interesting approaches of its implementation in scope of the Collection Light Technology (CoLiTec) project as the final tool named as "CoLiTec Virtual Observatory Platform" (CoLiTecVO). An implementation of the realized computational algorithms for creation of brightness curves for the studied variable stars in the CoLiTecVS (CoLiTec Variable Stars) desktop software was inserted into the SaaS structure of the CoLiTecVO platform in the cloud using the web interface. The CoLiTecVO platform was successfully verified with the different types of astronomical information for a big number of the studied variable stars in the various observatories in Slovakia, Ukraine and even Thailand using several kinds and sizes of telescopes as well as the different conditions during the observations.**

Keywords—cloud processing, software as a service, Virtual Observatory, CoLiTec, photometry, light curve, magnitude, variable star

I. Introduction

The growing capacity and potential of cloud services [1] and increasing computing and storage capacity have led to the use of cloud services wherever possible to simplify support, centralize architecture and increase the availability and stability of computing processes [2]. These computing processes share the same shared storage and computational power on independent clusters/servers named as "clouds" [3].

Nowadays, cloud services, micro-services, backend modules, components perform a lot of different tasks including the natural language processing and even the artificial intelligence (AI) [4].

For example, in the astronomical direction we have the photometry tasks [5] (analysis of the light curves of the studied variable stars [6]) that require a mighty server for cloud processing.

A very quick progress in information technologies as well as the telescope creation technologies create a big number of scientific Big Data [7] as well as high dimensional information and appropriate computational algorithms and mathematical methods [8, 9] including even the Wavelet analysis [10]. So, to make a very complex cloud calculations or processing for analysis of the light curves for the studied variable stars the Collection Light Technology (CoLiTec) [11] project moved the calculation process from the desktop tool to a cloud application with the client-server architecture to perform a photometry of the studied variable stars, create the appropriate light curves, and analyze them for each studied variable star.

The implemented Software as a Service (SaaS) technological model includes the different computational algorithms for the image cosmetic filtering [5], astrometry of the studied astronomical object [12], reduction of the positional astronomical observations [13], creation of the light curve (photometry) of the studied variable star, detection/recognition of the studied astronomical object [14, 15] and calculation algorithms for the Big Data mining and processing [16].

In this work we presented a short information about the cloud processing, Virtual Observatories and SaaS technological model in astronomy, analyzed them, prepared a few interesting approaches of its implementation in scope of the CoLiTec project as the final tool named as "CoLiTec Virtual Observatory Platform" (CoLiTecVO). An implementation of the realized computational algorithms for creation of brightness curves for the studied variable stars in the CoLiTecVS (CoLiTec Variable Stars) desktop software was inserted into the SaaS structure of the CoLiTecVO platform in the cloud using the web interface.

II. Cloud Computing

Based on the USA National Institute of Standards and Technology (NIST) [17] the cloud computing can develop services or micro-services based on the implementation according to the next technological models [18]:

- Infrastructure as a Service (IaaS) using the high-level Application Programming Interfaces (APIs) [19];

- Platform as a Service (PaaS) [20];
- Software as a Service (SaaS) [21];
- Mobile "backend" as a service (MBaaS);
- Serverless computing or Function-as-a-Service (FaaS).

Commonly, the mentioned above technological models and corresponding major technological characteristics (like, on-demand self-services, broad access to the networks, resource pooling, rapid elasticity, measured services) for the cloud computing approach create a strong basis for all existent architectures, structures, and systems for the cloud computing.

III. CoLiTecVO

The Virtual Observatory (VO) concept has become very important development direction in astronomy as an approach for storing the various kinds of scientific data in a digital archive and providing world-wide access [22].

The International Virtual Observatory Alliance (IVOA) implemented standards for different Virtual Observatories (VOs), defined algorithms for the astronomical data processing and organized the necessary cooperation between different scientific organizations [23].

The CoLiTec Variable Stars (CoLiTecVS) software for the automated photometric reduction of the Solar System objects' observations in a series of images [24] was taken as an example of the astronomical software implemented as the desktop application.

The CoLiTecVS software (desktop version) includes a huge set of the developed by researchers of the CoLiTec project [11] complicated scientific astronomical algorithms and mathematical methods that perform a very complicated computations related to the photometry reduction of the Solar System objects' observations in a series of CCD-images.

So, in this case, the researchers of the CoLiTec project as well as the appropriate scientific software engineers made a decision to perform the migration of the CoLiTecVS software from desktop application/tool to the cloud application. The new product received the title "CoLiTec Virtual Observatory Platform" (CoLiTecVO). This new product implements the better approaches of the Software as a Service technological model and the appropriate best technological technologies.

A high-level interpretation of the processing pipeline implemented in the CoLiTec Virtual Observatory Platform is presented in Figure 1.

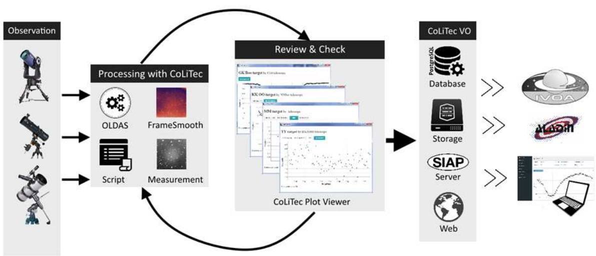

Fig. 1. High-level interpretation of the processing pipeline implemented in the CoLiTec Virtual Observatory Platform.

The client user interface of the CoLiTec Virtual Observatory Platform (Figure 2) allows uploading the input astronomical images with the studied variable star. From the backend side, the CoLiTecVO platform has an implementation the processing computational pipeline, which includes the following incapsulated computational algorithms and mathematical methods, like brightness alignment [5] → image segmentation [25] → estimation of parameters related to a studied variable star [26] → identification of images using the online international astronomical catalogs [8] → astrometry of a studied variable star [27] → photometry of a studied variable star [9] → creation of the light curves for a studied variable star → creation of the output reports in the international formats.

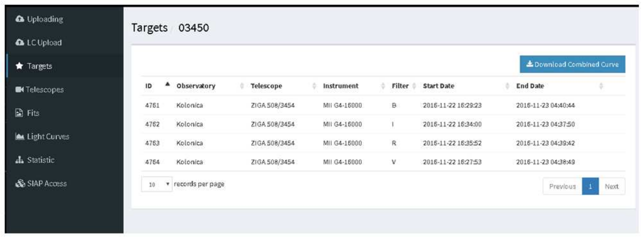

Fig. 2. "Targets" screen with a data of the created ligth curves in the CoLiTecVO.

The final destination of the cloud computing analysis of the big photometric astronomical data by the CoLiTec Virtual Observatory Platform is a presentation of the light curves of the specified variable stars as graphical plots with a deviation of the magnitude measurements in the client web interface (see Figure 3).

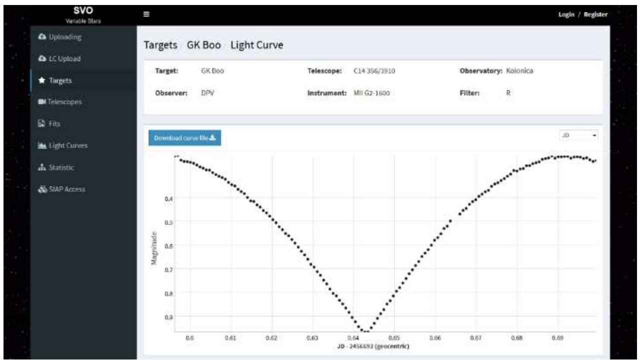

Fig. 3. "Light Curves" screen with a data of the specified targets in the CoLiTecVO.

Each target or the investigated variable star includes a huge number of photometric measurements made by the different telescopes and observational systems and sent directly to the CoLiTecVO platform software. Such a huge number of photometric measurements of the investigated variable stars are appeared from the different outputs, like from the backend services and computational modules related to the photometric reduction processing, from the different open-access archives [28], for the cloud storages, and from the different online international astronomical astrometric and photometric catalogs.

An extended data, like the root mean square (RMS) error of the magnitude measurements, brightness of the selected studied variable star, the Julian date and time of an observation of the studied variable star is available in the "Light Curve Data" screen (see Figure 4).

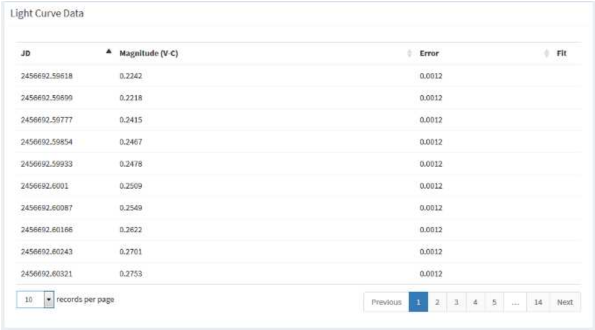

Fig. 4. "Light Curve Data" screen with an information about each measurement made for the specified studied variable stars in the CoLiTecVO.

The CoLiTecVO uses the following Amazon services in the serverless architecture for a structured astronomical data mining solution (see Figure 5):

- Amazon S3 service, which is used for storing the original astronomical input dataset.
- AWS Lambda for starting of a state machine, using the original astronomical data as its input.
- AWS Step Functions are used for managing the preparing process of the input dataset for the parallel processing of them. It will automatically manage the queue of processing items when the input dataset is very big. AWS Step Functions provides the visibility of process, reporting errors, and decouples the compute-intensive scraping operation for each processing item.
- DynamoDB database, which is used for storing the appropriate hashes with mapping of files.

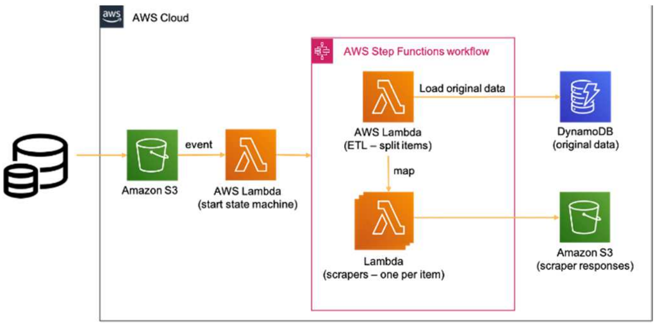

Fig. 5. Amazon services in the serverless architecture for a structured astronomical data mining solution.

Another benefit of the CoLiTec Virtual Observatory Platform with implementation of the Software as a Service is an implementation of the IVOA contracts and rules for connection to the open-access APIs for the various international astronomical astrometric and photometric databases (Simbad [29], Aladin Sky Atlas [30]) and services/tools (AAVSO [31], VizieR [32]).

A few examples of such a contract for the IVOA and AAVSO (extended format) services with the astrometric and photometric information is presented as an astronomical report format in Figure 6. The additional screen with the collected information of the telescopes parameters as well as data about the studied variable stars in the CoLiTecVO is presented in Figure 7. Such data can be used for a future data mining [33] and recognition [34] tasks.

```
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. 6. Examples of contracts for the IVOA and AAVSO (extended format) services with the astrometric and photometric information as an astronomical report format.

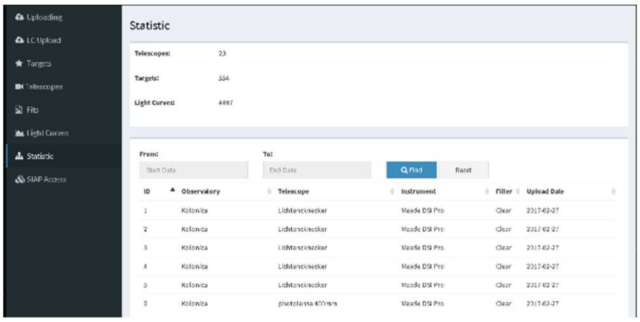

Fig. 7. "Statistics" screen with a data of the telescopes parameters as well as variable stars studied in the CoLiTecVO.

IV. Conclusion

The CoLiTec Virtual Observatory (CoLiTecVO) Platform with implementation of the Software as a Service (SaaS) approach was prepared by the developers, scientist and researchers from the Collection Light Technology (CoLiTec) project. The main goal of the CoLiTecVO platform is to perform the image processing and photometry of the investigated variable stars during the cloud computing. After receiving the appropriate photometry information about the investigated variable stars, the CoLiTecVO platform allows performing the deep analysis of the created light curves for all these investigated variable stars.

The CoLiTecVO platform in scope of the CoLiTec project was successfully verified with the different types of astronomical data including a lot of investigated variable stars. All such astronomical information was received from the different observatories in Slovakia, Ukraine and Thailand produced by the various kinds of telescopes: observing station Mayaki of "Astronomical Observatory" in the Research Institute of I. I. Mechnikov of the Odessa National University [35, 36], Vihorlat Observatory in Humenne [37], National Astronomical Research Institute of Thailand [38].

As a summary, more than one million astronomical CCD-frames were computed in cloud using the CoLiTecVO platform. All mathematical algorithms and models [39] were analyzed as well as statistical imitation modeling [40] was performed. Such frames were also received from the various historical archives, big data servers and originally formed directly from the observational instruments during the near real-time processing. The final number of the created light curves is 4 887 for 554 investigated variable stars.

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REFERENCES

[1] D. Bruneo, S. Distefano, F. Longo, A. Puliafito, and M. Scarpa, "Workload-Based Software Rejuvenation in Cloud Systems", IEEE Transactions on Computers, 62 (6), pp. 1072–1085, 2013.

[2] S. A. Miraftabzadeh, P. Rad, and M. Jamshidi, "Efficient distributed algorithm for scheduling workload-aware jobs on multi-clouds", Proc. 11th System of Systems Engineering Conference (SoSE), pp. 1-8, 2016.

[3] V. Akhmetov, et al., "Cloud computing analysis of Indian ASAT test on March 27, 2019", Proc. 2019 IEEE International Scientific-Practical Conference: Problems of Infocommunications Science and Technology, PIC S and T 2019, pp. 315–318, 2019.

[4] C. J. Fluke, and C. Jacobs, "Surveying the reach and maturity of machine learning and artificial intelligence in astronomy", Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, vol. 10, issue 2, e1349, 2020.

[5] Š. Parimucha, et al., "CoLiTecVS – A new tool for an automated reduction of photometric observations", Contributions of the Astronomical Observatory Skalnate Pleso, vol. 49, issue 2, pp. 151-153, 2019.

[6] K. Kuijken, et al., "The fourth data release of the Kilo-Degree Survey: ugri imaging and nine-band optical-IR photometry over 1000 square degrees", A & A, vol. 625, A2, 2019.

[7] C. Yang, Q. Huang, Z. Li, K. Liu, and F. Hu, "Big Data and cloud computing: innovation opportunities and challenges", International Journal of Digital Earth, vol. 10 (1), pp. 13–53, 2017.

[8] S. Khlamov, et al., "Development of computational method for matched filtration with analytic profile of the blurred digital image", Eastern-European Journal of Enterprise Technologies, vol. 5, issue 4-119, pp. 24-32, 2022.

[9] V. Savanevych, et al., "CoLiTecVS software for the automated reduction of photometric observations in CCD-frames", Astronomy and Computing, vol. 40 (100605), 15 p., 2022.

[10] V. Baranova, et al., "Wavelet Coherence as a Tool for Studying of Economic Dynamics in Infocommunication Systems", Proceedings of the IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology, pp. 336-340, 2019.

[11] S. Khlamov, and V. Savanevych, "Big astronomical datasets and discovery of new celestial bodies in the Solar System in automated mode by the CoLiTec software", Knowledge Discovery in Big Data from Astronomy and Earth Observation, pp. 331–345, 2020.

[12] V. Akhmetov, S. Khlamov, V. Khramtsov, and A. Dmytrenko, "Astrometric reduction of the wide-field images", Advances in Intelligent Systems and Computing, vol. 1080, pp. 896–909, 2020.

[13] L. Mykhailova, et al., "Method of maximum likelihood estimation of compact group objects location on CCD-frame", Eastern-European Journal of Enterprise Technologies, vol. 5, issue 4, pp. 16-22, 2014.

[14] V. Savanevych, S. Khlamov, V. Vlasenko, et al., "Formation of a typical form of an object image in a series of digital frames", Eastern-European Journal of Enterprise Technologies, vol. 6, issue 2-120, pp. 51-59, 2022.

[15] N. Yeromina, et al., "Method of reference image selection to provide high-speed aircraft navigation under conditions of rapid change of flight trajectory", International Journal of Advanced Technology and Engineering Exploration, vol. 8, issue 85, pp. 1621–1638, 2021.

[16] I. Perova, Y. Brazhnykova, N. Miroshnychenko and Y. Bodyanskiy, "Information Technology for Medical Data Stream Mining", Proc. of the 15th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering-TCSET, pp. 93–97, 2020.

[17] A. N. Link, "Technology transfer at the US National Institute of Standards and Technology", Science and Public Policy, vol. 46, issue 6, pp. 906-912, 2019.

[18] B. Rochwerger, D. Breitgand, E. Levy, et al., "The Reservoir model and architecture for open federated cloud computing". IBM Journal of Research and Development, vol. 53, issue 4, pp. 1–11, 2009.

[19] F. Chen, L. Zhang, and X. Lian, "A systematic gray literature review: The technologies and concerns of microservice application programming interfaces", Software: Practice and Experience, vol. 51, issue 7, pp. 1483-1508, 2021.

[20] M. Boniface, et al., "Platform-as-a-Service Architecture for Real-Time Quality of Service Management in Clouds", Proc. IEEE 5th International Conference on Internet and Web Applications and Services (ICIW), pp. 155–160, 2010.

[21] E. Loukis, M. Janssen, and I. Mintchev, "Determinants of software-as-a-service benefits and impact on firm performance", Decision Support Systems, vol. 117, pp. 38-47, 2019.

[22] I. B. Vavilova, Y. S. Yatskiv, L. K. Pakuliak, et al., "UkrVO astroinformatics software and web-services", Proc. of the International Astronomical Union, vol. 12, issue S325, pp. 361-366, 2016.

[23] M. G. Allen, et al., "The International Virtual Observatory Alliance in 2019", Astronomical Data Analysis Software and Systems XXIX, vol. 527, pp. 795, 2020.

[24] G. K. Adam, et al., "Embedded microcontroller with a CCD camera as a digital lighting control system", Electronics, vol. 8, issue 1, p. 33, 2019.

[25] V. Akhmetov, et al., "New approach for pixelization of big astronomical data for machine vision purpose", IEEE International Symposium on Industrial Electronics, pp. 1706–1710, 2019.

[26] V. Savanevych, S. Khlamov, O. Briukhovetskyi, T. Trunova and I. Tabakova, "Mathematical methods for an accurate navigation of the robotic telescopes", Mathematics, vol. 11, issue 10, 2246, 2023.

[27] V. Savanevych, et al., "Selection of the reference stars for astrometric reduction of CCD-frames", Advances in Intelligent Systems and Computing, vol. 1080, pp. 881–895, 2020.

[28] I. B. Vavilova, et al., "Surveys, catalogues, databases, and archives of astronomical data", Knowledge Discovery in Big Data from Astronomy and Earth Observation, pp. 57-102, 2020.

[29] A. Oberto, et al., "Categorisations of Object Types in SIMBAD", Astronomical Data Analysis Software and Systems XXVII, vol. 522, p. 105, 2020.

[30] S. A. A. Albakri, M. N. A. Hussien, and H. Herdan, "Measurement of the distance to the central stars of Nebulae by using Expansion methods with Alladin Sky Atlas", IOP Conference Series: Materials Science and Engineering, vol. 757, issue 1, IOP Publishing, 2020.

[31] N. N. Samus, et al., "General catalogue of variable stars: Version GCVS 5.1", Astronomy Reports, vol. 61, issue 1, pp. 80-88, 2017.

[32] K. C. Chambers, "VizieR Online Data Catalog: The Pan-STARRS release 1 (PS1) Survey-DR1 (Chambers+, 2016)", VizieR Online Data Catalog, II-349, 2017.

[33] S. Khlamov, et al., "Data Mining of the Astronomical Images by the CoLiTec Software", CEUR Workshop Proceedings, vol. 3171, pp. 1043-1055, 2022.

[34] S. Khlamov, et al., "Recognition of the astronomical images using the Sobel filter", International Conference on Systems, Signals, and Image Processing, IWSSIP 2022, 4 p., 2022.

[35] V. Troianskyi, et al., "First reported observation of asteroids 2017 AB8, 2017 QX33, and 2017 RV12", Contributions of the Astronomical Observatory Skalnaté Pleso., vol. 53, issue 2, pp. 5–15, 2023.

[36] V. Troianskyi, P. Kankiewicz and D. Oszkiewicz, "Dynamical evolution of basaltic asteroids outside the Vesta family in the inner main belt", Astronomy and Astrophysics, vol. 672, A97, 2023.

[37] I. Kudzej, et al., "CoLiTecVS – A new tool for the automated reduction of photometric observations", Astronomische Nachrichten, vol. 340, issue 1-3, pp. 68-70, 2019.

[38] Y. Mingmuang, et al., "The mass distribution and the rotation curve of the Milky Way Galaxy using NARIT 4.5 m small radio telescope and the 2.3 m Onsala radio telescope", Journal of Physics: Conference Series, vol. 1380, issue 1, IOP Publishing, 2019.

[39] I. Grebennik, et al., "Distribution of Permutations with Different Cyclic Structure in Mathematical Models of Transportation Problems", Proceedings of the IEEE 12th International Conference on Advanced Computer Information Technologies, pp. 18–21, 2022.

[40] V. Shvedun, et al., "Statistical modeling for determination of perspective number of advertising legislation violations", Actual Problems of Economics, vol. 184 (10), pp. 389–396, 2016.