THE USGS INTEGRATED SOFTWARE FOR IMAGERS AND SPECTROMETERS (ISIS 3) INSTRUMENT SUPPORT, NEW CAPABILITIES, AND RELEASES. S.C. Sides[1], T.L. Becker[1], K.J. Becker[1], K.L. Edmundson[1], J.W. Backer[1], T.J. Wilson[1], L.A. Weller[1], I.R. Humphrey[1], K.L. Berry[1], M.R. Shepherd[1], M.A. Hahn[1], C.C. Rose[1], K. Rodriguez[1], A.C. Paquette[1], J.A. Mapel[1], J.R. Shinaman[1], J.O. Richie[1], [1]U. S. Geological Survey, Astrogeology Science Center, Flagstaff AZ (ssides@usgs.gov).

Introduction: The USGS Astrogeology Science Center (ASC) develops and maintains software to support the planetary science community. The cornerstone of this support is the Integrated Software for Imagers and Spectrometers (ISIS 3), a suite of applications for rigorous spatial treatment of planetary imaging data [1,2]. ISIS 3 is available for several Linux platforms and Mac OSX. Funding for infrastructural support is provided by an agreement with NASA but new instruments are added with funding from individual mission/instrument teams. ISIS 3 is publicly available and open-source but USGS works with missions needing specialized versions for their own needs.

The ASC has relied heavily on ISIS 3 in its support for missions and their instruments from the initial planning of a mission through archival. A key benefit of relying on ISIS3 is the sustained partnership with NASA can be expected to provide support for the instrument data for decades to come. Mission teams have used ISIS3 at various levels to facilitate planning, proof of concept prior to final instrument build, geometric calibration before launch, during cruise and science operations, landing site selection, data collection, radiometric calibration, SPICE maintenance, image control, mapping, and archival. There are currently 27 missions and 63 rigorous sensor models supported for solid target bodies throughout our solar system, with more being added every year. ISIS 3 supports instruments from missions as far back as Lunar Orbiter to as recent as OSIRIS-REx. Working closely with mission teams from the start of a mission has produced reliable software and processes that endure well past the end of a mission. The ability to provide sustained Planetary Spatial Data Infrastructure for georeference, geospatial, cartographic, geologic mapping and data fusion from orbit to lander data is central to planning ISIS3 development [3].

Recent Additions: ISIS 3 is regularly maintained with bug fixes and new features appearing in two or more public releases each year. Here we highlight some of the more significant additions and upgrade in the upcoming release.

*Digital Elevation Model*s: Specialized techniques for generating digital elevation models have been successfully derived for Mercury using MESSENGER MDIS images; Vesta using Dawn Framing Camera data; and 25143 Itakawa from Hayabusa AMICA data. These products were created using third party open source software libraries for pattern matching, such as OpenCV, that have been integrated into specialized ISIS applications [4].

Irregular Body Support: Recent NASA (New Horizons and OSIRIS-REx), European (Rosetta) and Japanese (Hayabusa and Hayabusa2) missions have been launched to study small irregular bodies in the asteroid and Kuiper belts. Conventional cartographic techniques for spheroidal bodies are not adequate for the mapping of irregular bodies. ISIS 3 was modified to utilize the Navigation and Ancillary Information Facility's (NAIF) digital shape kernel (DSK) toolkit to provide support for orthorectified cartographic mapping of asteroids and other bodies of this type.

Software Issue Tracking System: ISIS users (internal and community), developers, and mission/instrument teams track the status of questions, issue reports and feature requests through a publicly available ticketing system available at: https://isis.astrogeology.usgs.gov/fixit/projects/isis. New user accounts can be requested athttps://astrocloud.wr.usgs.gov/index.php?view=edituser&act=request. The system allows two-way communications for reporting bugs, requesting new features, installation questions, and email distribution lists for general announcements such as new public releases. There are currently 1256 total general issues with 409 of those open.

Software releases: From January 1, 2016 through December 9, 2016, a total of 1588 unique clients (users) downloaded ISIS. During that same time period, 183,132 updates to the ISIS data and software were processed. The next release of ISIS (version 3.5.0) is due in late January 2017. . This release will contain significant updates to all of the features reported above. The release will also contain updates to most of the third-party libraries ISIS 3 uses, including Qt 5.6, Qwt 6.1, Open CV 3.1, Protobuf 9, GEOS 3.5 and Cholmod 3. The supported platforms will be RHEL 7, Fedora 21, Ubuntu 14.04, Debian 8, and Mac OS 10.11. Due to the magnitude of these changes, it is suggested ISIS 3.5.0 be well-tested before using it in a production environment.

Ongoing Work: Multiple topics of research and development for ISIS 3 are underway. A select few are highlighted below.

Photogrammetry User Interface: We are developing an "Integrated Photogrammetric Control Environment" (IPCE) that merges all aspects of the photogrammetric control process into a single user interface [5]. By simplifying data management, implementing rigorous algorithms, providing statistical and graphical data analysis tools, and automating processes and analysis, we improve efficiency and cost-effectiveness and, in turn, the quality of mapping products.

Photogrammetric Control: The least-squares bundle adjustment software, critical to the photogrammetric control process, generates improved image position and pointing parameters and the triangulated coordinates of tie and ground points [6]. We are continually refining the ISIS bundle adjustment program, *jigsaw* [7], to address the many challenges of extraterrestrial photogrammetry. Current areas of investigation include 1) the use of piecewise polynomials to more accurately represent the position and pointing of time-dependent sensors; 2) solutions for target body parameters (e.g., pole position, spin offset/rate, and radii); 3) solutions that include multiple sensors and/or multiple sensor types; and 4) the incorporation of sensor parameters (e.g. focal length and lens distortions) into the solution (i.e., self-calibration [8]).

Image Matching: Establishing the correspondence between measurements of surface features that appear in overlapping images is essential for photogrammetric control. Manual measurement is impractical, particularly for large numbers of images. We are implementing advanced techniques to automate the image matching process and related photogrammetric functions based on open source software (e.g. Python, OpenCV) and the ISIS API.

Community Sensor Model: To better support software interoperability between different photogrammetric applications (including ISIS), the ASC team is researching the use of the Community Sensor Model for the sensor model infrastructure. The results may provide a well-defined application programming interface (API) and code-base for sensor models to be utilized by ISIS as well as other photogrammetric applications [9].

Quality assurance of ISIS: Providing stable software suitable to the varied requirements of science, production, and mission teams requires adherence to internal standards. The process for incorporating new features and fixing bugs with ISIS 3 has been refined over the past few years, but continues to undergo regular review. Our current process consists of the following steps 1) all issues or requests are documented in the tracking system; 2) the impact of each issue is assessed by expert users and developers with issues concerning accuracy and difficult work-arounds receiving the highest priority; 3) a rough estimate of the level of effort is assigned 4) changes are made in an isolated environment where the solution can be tested; 5) backward compatibility is addressed and documented; 6) standard parameter names are used; 7) unit tests and regression tests are written for all modified code; 8) any new or modified code has complete test coverage; 9) code review are completed; 10) documentation is reviewed; 11) the author of the ticket has approved the solution; and 12) all changes are checked into the source code repository.

Although work on ISIS continues year-round, there are two to three dedicated efforts scheduled to resolve tickets. For each of these efforts, 1) expert users and scientists identify a set of high priority and high impact issues while also taking into account the expertise of the developers on the team; 2) test plans are created to ensure each issue is correctly addressed; 3) an Agile SCRUM style team is assigned to address the issues in a six week dedicated effort consisting of three two week sprints; 4) test plans are converted to unit tests or regression tests where appropriate. All standard processes from above are followed.

Future: The ASC is committed to keeping ISIS and its capabilities current with modern computer science and engineering to support new missions and sensors collecting an increasing quantity and diversity of data [10, 11, 12, 13,14] while maintaining a stable product.

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