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Visualizing and Processing Solar Images Efficiently

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Abstract— **STEREO** (Solar TErrestrial RElations Observatory) and SDO (Solar Dynamics Observatory) are satellites have been launched to observe the Sun. STEREO includes two spacecrafts circulating around the Sun to provide significant views from widely spaced locations. SDO tends to study the solar atmosphere on small scales and times and in many wavelengths. STEREO and SDO provide large volumes of data at rates of about one TB and one and a half TB per day respectively. Visualizing and processing these huge data volume efficiently at both high spatial and high time resolution is important to support scientific discovery, but needs increasingly efficient tools to browse, locate and manipulate specific data sets. In this paper, a tool for visualizing and analysing STEREO and SDO data is introduced. The aim of this work is to help scientists to discover new phenomena and link related data sets from various instruments that are often analysed in isolation. The proposed work offers a number of useful image processing tools associated with activities highly focused on solar images such as: tracking active region(s), anaglyphs, solar limb detection, and solar image enhancement.

Keywords— Solar Imaging Tool; Image Processing Tool; Super-Resolution Tool; 3D Viewing Application; Solar Images Browsing.

INTRODUCTION

STEREO's1 satellites were launched at the end of 2006, transmits approximately 1 TB of data per day. In 2010, SDO2 officially began its mission to provide data for study of the Sun and currently it is transmitting arround1.5 TB of science data per day. STEREO has four instrument packages employed on each of the two STEREO spacecraft: Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI); STEREO/WAVES (SWAVES); In-situ Measurements of Particles and CME Transients (IMPACT); and Plasma and Super-Thermal Ion Composition (PLASTIC). The proposed system downloads beacon JPEG images taken by SECCHI EUVI (Extreme Ultraviolet Imager). STEREO and SDO exhibit full disk images of the Sun at different cadence rates in several ultraviolet spectral bands with maximum resolutions of 8 megapixels (MPs) and 16 MPs respectively. This generates 2048×2048 and 4096×4096 pixels resolutions respectively. Browsing and analysing significant areas of interest for these data volumes on a remote server are not easy, simply because these processes overload the existing Internet and network infrastructure. From a scientist's viewpoint, the process of retrieving large data volume from even a few repositories, and dealing with immobile data sets poses the problems of searching, browsing and extracting interesting images while avoiding the search for a needle in a haystack problem explained in [1].

The main aim for presenting the proposed system is to help scientists to discover new phenomena and link related data sets from various instruments that are often analysed in isolation. To achieve this, the data of STEREO and SDO are integrated using a unique graphical user interface. The toolkit is designed to be updatable in response to feedback received from researchers and will be made available to the public.

RELATED WORKS

In this section, quite a lot of related web-browsing tools and applications associated with working on solar images gathered from SOHO, STEREO and SDO satellites are investigated.

An internet web-based application which was implemented and designed by [2] offers about near-realtime and archived information on active regions and solar activities as shown in Fig. 1. Another web browsing tool that browses of images for the most recent, solar images of each type in the Solar Data Analysis Center (SDAC) [3] archive is shown in Fig 2, where the time and date of each image is shown below the image description. It is serveing data from latest and current space-based solar-physics missions, funds and hosts much of the Solar-Soft library, and leads the Virtual Solar Observatory (VSO) effort.

[1] http://stereo.gsfc.nasa.gov
[2] http://sdo.gsfc.nasa.gov

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Fig. 1 NOAA active regions webpage that offers near-real-time and archived information on active regions and solar activity

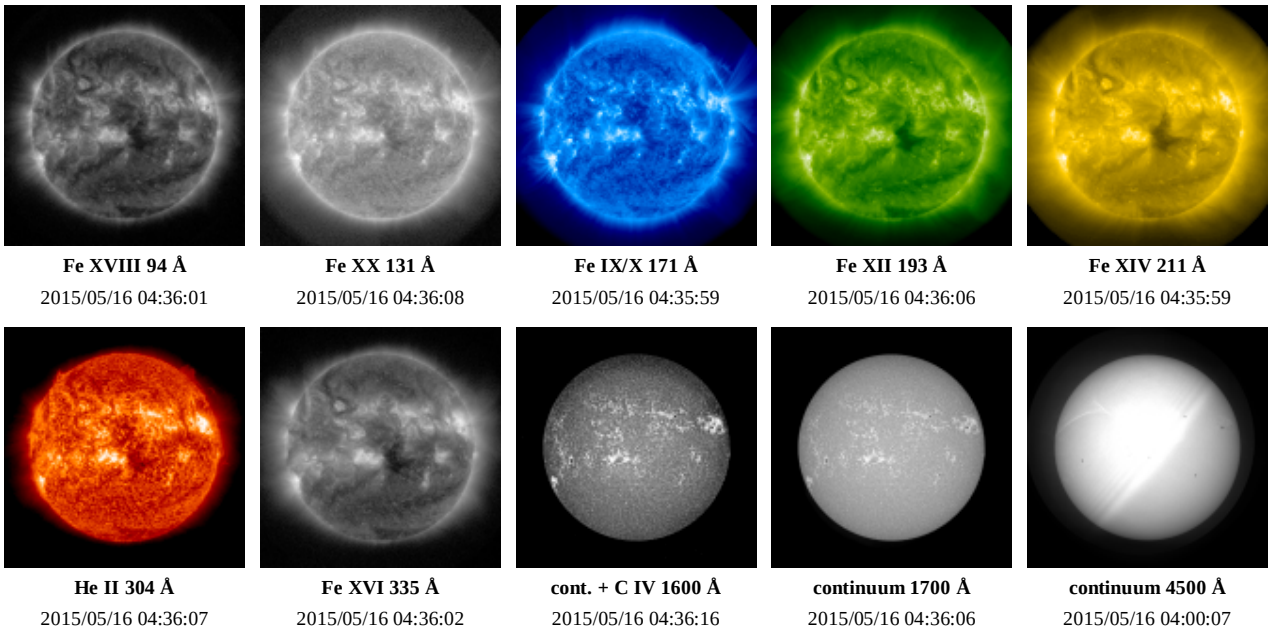

Fig. 2 Images for the most recent, solar image of each type in the SDAC archive.

A JPEG 2000-based visualization and discovery software for SOHO image data developed by Müller et al [1] is called JHelioviewer. A remote access as a client-server application for compressed images was provided. The compression was applied using the lossy compression mode of JPEG2000 by a compression technology system defined in IS 15444-1. The international standard for interactivity with JPEG2000 files called JPIP has developed by the Joint Technical Committee of Photographic Experts (JPEG). JHelioviewer uses JPIP and OpenGL. JPIP is useful to minimize data transfer by streaming image data in a region of interest and quality progressive way by exploiting the multi-resolution and spatially random access properties of JPEG2000, making a smart dissemination of the data for client-server communication. This was briefly illustrated by Taubmana, D. and R. Prandolinib [4]. OpenGL offers rapid hardware acceleration of image processing and rendering (see, http://www.opengl.org/about/overview). Java was used to implement JHelioviewer and supports users creating movies streaming between two dates/times, applying frame by frame basic image processing, overlaying unlimited number of images or movies under adjustable transparency levels, and locating solar events data. Integrating the JHelioviewer with the SDO repository was one of their future intentions.

ASAP the abbreviation of Automated Solar Activity Prediction system was designed by T. Colak and R. Qahwaji [5]. It is in use by both NASA and the European Space Agency (ESA) as reported in Scientific Computing [6]. ASAP identifies and classifies sun spots in near real-time resulting in predictions of the likelihood of solar flares. The active region (AR) candidates are detected from MDI magnetogram images and the sunspots candidates from MDI continuum images and then region growing and neural networks techniques applied to combine both candidates to determine precise boundaries of sunspot groups. The data of ASAP is gathered from the joint of NASA/ESA Solar and Heliospheric Observatory satellite (SOHO). The predictions accuracy is expected to be improved by using the data generated from SDO which shows the Sun's activities in more details than SOHO.

The Solar Weather Browser (SWB) is another software tool implemented by the SIDC (Solar Influences Data analysis Center) [7], for visualizing solar images in combination with any relevant information that can be overlaid on the images. The design of SWB includes: the SWB-server, SWB-user interface, SWB-download and user support website. The highly compressed formats of solar images and context data are available at server side that can be accessed by the client side on the user machine. Background images like EIT can be interactively combined with overlays (e.g. sunspot or filament locations) on the client side. This aspect can be useful for showing the results of automated solar image recognition/processing chains. It is also useful for distribution of solar image archives playing the role of the quick-look viewer. SWB is also provides data related to SOHO and STEREO. CMEs (Coronal Mass Ejections) detection method called CACTUS [8] (A software package for Computer Aided CME Tracking) is also associated with SWB. A screen shot of the SWB is shown in Fig. 3.

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CACTUS was designed to detect CMEs among image sequences from LASCO (Large Angle and Spectrometric Coronagraph) C1 and C2 corona-graphs. LASCO is one of a number of instruments aboard the SOHO satellite. A list of events similar to the classic catalogues is the output of this software. The detection is started by merging the C2 and C3 images, then clean, re-bin and reformat them with every step optimized for improving the CME contrast. After that, motion pattern extraction and pattern grouping in CMEs are applied. The performance was evaluated by comparing the output with the visually assembled CME catalogues. The success rate was about 75%. In addition, this technique revealed CMEs that were not listed in the catalogues.

The number of tools for browsing and accessing data available for STEREO and SDO is limited and each tool provides specific functionalities. For instance, the web browser for the official STEREO website [9] that provides Beacon JPEG images has since December 2006 served heliophysics JPEG image data in the five resolutions: 128×128, 256×256, 512×512, 1024×1024, and 2048×2048 pixels and SDO data in the four resolutions: 512×512, 1024×1024, 2048×2048 and 4096×4096 pixels. On the official sites; these data are used to create on screen animations with basic movie control functionality.

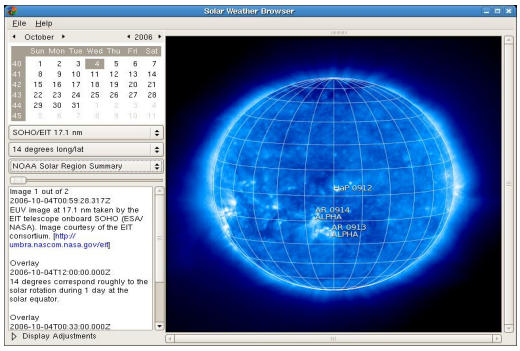

Fig. 3 Screen-shot of the SWB

Further restrictions on accessing STEREO and SDO images are the limited number of images per query. For instance, no more than 2000 images are allowed per telescope between two dates (time is not included which may not be convenient when the cadence rate is high) in the STEREO browser. The images of interest can be displayed with one of three options: List (just file names), images, or slideshow. On the SDO official site; no more than 400 images per query is allowed, generated as still images, movie, or archive (zipped file).

To address these problems, the STEREO and SDO Imaging toolkit (SSIK) for downloading beacon JPEG images provided by the STEREO and SDO missions has delveloped. SSIK makes it possible to minimize the volume of transmitted data while maximizing its usability. Accessing these huge data volumes efficiently at both high spatial and high time resolutions is important to support scientific discovery. SSIK allows users to browse large data volumes as still images and/or movies of multiple resolution image files. An archiving system is incorporated also to save the requested images, so next time they are needed there is no need to download them again (useful if no Internet connection is available). Users can display, manipulate, zoom, build super resolution images and construct anaglyphs (from un-calibrated STEREO pairs) automatically, without strict network bandwidth penalties.

REMOTE IMAGE ACCESS

Web-Request class is an abstract base class for the .NET Framework's request/response model for accessing data from the Internet. It makes a request to a Uniform Resource Identifier (URI) (see http://msdn.microsoft.com/en-us/library/system.net.webrequest.aspx). SSIK uses this class to request data from the official STEREO and SDO websites. For example, a request for images from STEREO or SDO is performed by sending a request to the URIs http://stereo-ssc.nascom.nasa.gov/cgi-bin/images and http://sdo.gsfc.nasa.gov/assets/img/browse, respectively.

The URI is structured as a string that is being built during the run time from a query string. The query string represents the resource on the Internet that is created from the parameters requested from users as shown in

Fig. 4. The file names of images for both STEREO and SDO missions are saved into a relational database. Two relational files are created to save the file names for each mission as shown in

Table 1. An index key is created also for each file in order to speed up the query process. The URI structures for STEREO and SDO are shown in

Table 2 and Table 3 respectively.

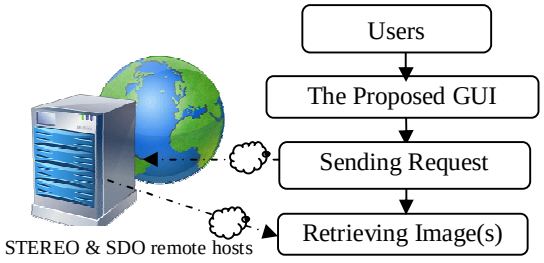

Fig. 4 The strucutre of the proposed imaging toolkit

TABLE 1
RELATIONAL DATA DEFINITION IS CREATED TO SAVE THE DATA FOR BOTH STEREO AND SDO

Field name	Data type	Description
Image Name	Text	Primary Key
Taken Date	Date/Time	Indexed key(yes for duplicate)

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TABLE 2
THE URI STRUCTURE FOR STEREO IMAGES

Field	Description	Example
Host	Remote host address	http://stereo.gsfc.nasa.gov/browse
Year	YYYY format	2007
Month	MM format	05
Day	DD format	01
Spacecraft	Spacecraft name	ahead
Instrument	Instrument type	euvi
Telescope	Telescope type	171
Resolution	Resolution in pixels	128
ImageName	JPEG image YYYYMMDD_HHMMSS_String_Telescope.jpg	20070501_235900_n4euA_171.jpg
URI	The URI composed from merging all above fields	http://stereo.gsfc.nasa.gov/browse//2007/05/01/ahead/euvi/171/128/20070501_235900_n4euA_171.jpg

TABLE 3
THE URI STRUCTURE FOR SDO IMAGES

Field	Description	Example
Host	Remote host address.	http://sdo.gsfc.nasa.gov/assets/img/browse
Year	YYYY format.	2010
Month	MM format.	06
Day	DD format.	01
ImageName	JPEG image file name in YYYYMMDD_HHMMSS_Resolution_Telescope.jpg format.	20100601_000136_512_0171.jpg
URI	The URI composed from merging all above fields	http://sdo.gsfc.nasa.gov/assets/img/browse/2010/06/01/20100601_000136_512_0171.jpg

SSIK STRUCTURE

A friendly GUI is created to provide image browsing capabilities. It provides access to local and remote images, creates animations for whole image(s) or regions of interest (sub-image(s)) and makes available several image processing methods including the Gaussian, extraction of colours, smoothing and median filters, thresholding, conversion to gray scale, resizing (Bicubic, Bilinear, Nearest Neighbour), cropping, sharpening, edge detection (Laplacian, Sobel and Difference), brightness adjustment, rotation, Fourier Transform (FFT) (backward and forward), thinning and erosion. All these image processing methods can be applied on the large image data sets related to STEREO and SDO. For example, the users are able to interactively browse a number N of images, a time seconds, minutes, hours, days and months after a predefined date/time. Ultraviolet images of the Sun that can be extracted from STEREO are shown in Fig. 5. SDO [9] provides the Atmospheric Imaging Assembly (AIA) that observes the solar corona in ten wavelengths and the Heliosesmic and Magnetic Imager (HMI) which measures the Sun's magnetic field, as shown in Fig. 6.

SSIK makes the local and remote image sets easily accessible via a .NET framework client application. In addition, all image processing methods are performed on the local machine (client side) to minimize hits on the server. SSIK is working by enavling the user(s) to select a set of images for visualisation and processing and then the system checks to see whether each image in the set already exists in the local machine. If an image doesn't exist locally, then a download will be started based on the URI returned by the SQL query. This process is important; it enhances the system efficiency by avoiding repeating processes on the same data set and the system is able to work on previously accessed data even if no Internet connection is available.

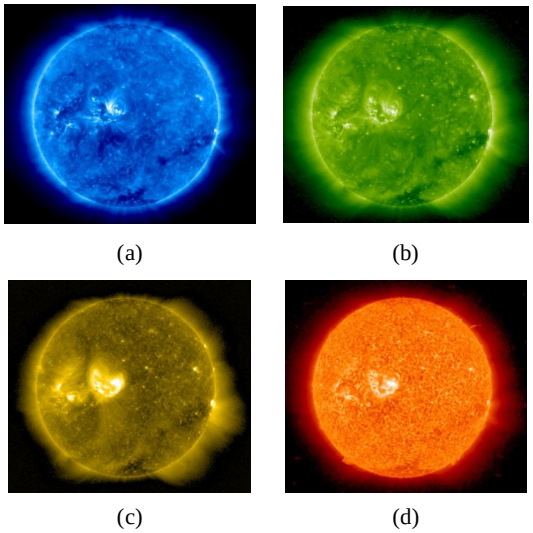

Fig. 5 STEREO EUVI images taken from STEREO-Ahead on 01/02/2007 (a) EUVI 171 at 00:15 UT(b) EUVI 195 at 00:15 UT (c) EUVI 284 at 00:51 UT (d) EUVI 304 at 00:52 UT

As shown in Fig. 7, SSIK enables local and remote access for solar images. For example, a pair of images taken from "Ahead" and "Behind" spacecrafts on 13-May-2007 at 00:13:00 was downloaded remotely and displayed on the local machine. Feature detection and matching method called STEREO-CPs (STEREO Corresponding Points) was applied to this pair of images. STEREO-CPs is an algorithm especially designed to generate CPs from uncalibrated pairs of STEREO images.

STEREO-CPs using SURF (Speeded Up Robust Features) [11] algorithm to generate initial CPs and the number of mismatches produced is reduced by applying the SIFT (Scale-Invariant Feature Transform) [12] method to the area surrounding every pair of initial points, then reducing them again by thresholding the median of the difference of coordinates criteria. The resulting CPs were used in

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the creation of an anaglyph image. Also multiple frames were used to create a 3D video files.

The diagram of the architecture of the SSIK client-server application is shown in **Error! Reference source not found.**. SSIK is organized to request images from two servers if no images exist in the local archive (visited images) repository. The extracted images can be processed locally using any of the general image processing operations mentioned previously.

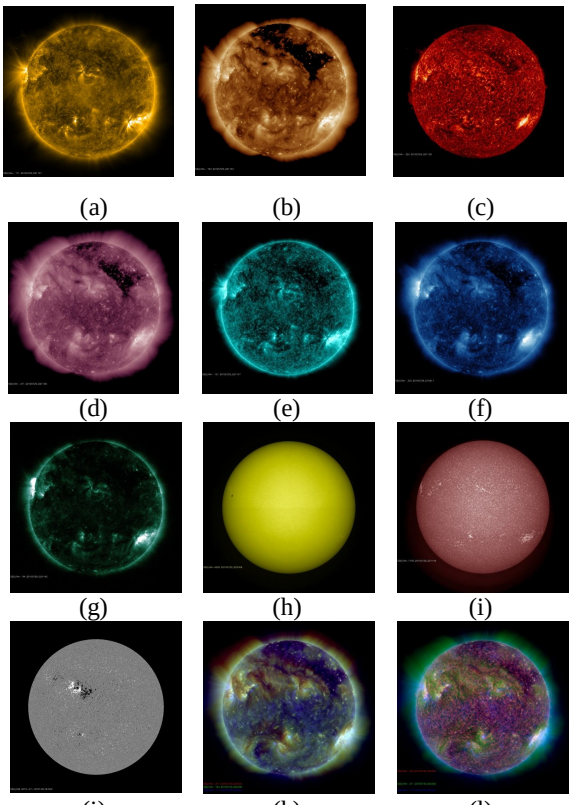


Fig. 6 SDO solar images taken on 29/07/2010 (a) AIA 171 (b) AIA 193 (c) AIA 304 (d) AIA 211 (e) AIA 131 (f) AIA 335 (g) AIA 094 (h) AIA 4500 (i) AIA 1700 (j) AIA HMI Magnetogram (k) AIA Composite of 211, 193, 171 wavelengths (l) AIA Composite of 304, 211, 171 wavelengths

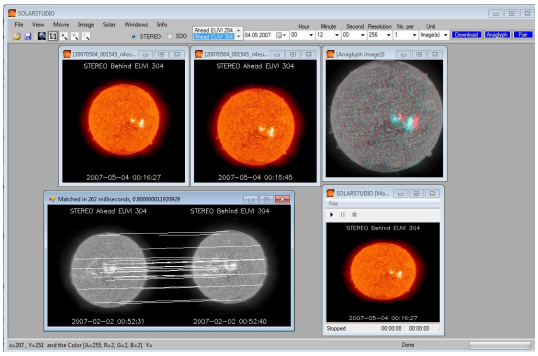


Fig. 7 Screenshot of the SSIK application. The above part of the application window is the database search interface. In this example a pair of images of EUVI 304 is used for feature detection and matching, and to create anaglyph and video files

Other several image processing methods specifically designed for images from STEREO and SDO are also incorporated including: segment active regions, adjust the solar disks in a pair of STEREO images to the same size, track object(s) (e.g AR) through sequences of images, combine images from multiple EU images, extract the solar limb from images in order to create an anaglyph images from pairs of STEREO images and create a super-resolution image from a sequence of lower resolution images.

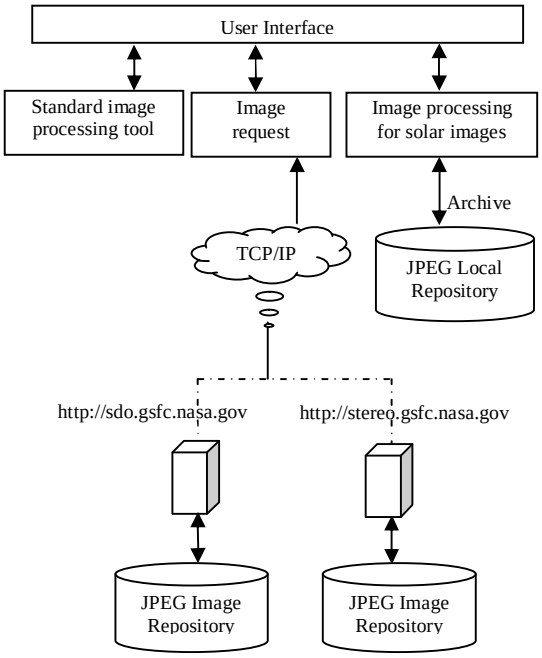
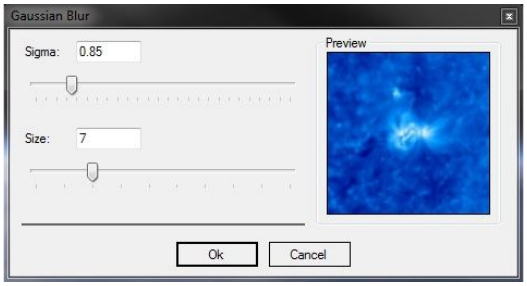


Fig. 8 The SSIK architecture which consists of four components: database interface, STEREO and SDO repositories, the standard image processing operations and specialised image processing operations for solar images.



- Fig. 9 A preview sample effect of a Gaussian filter before applying it to the original image

SSIK FEATURES

SSIK is designed to allow solar physicists to quickly browse through large volumes of images from both STEREO and SDO missions. It provides several standard image processing tools specifically focused on the solar applications. The resulting images can be saved in BMP, PNG, TIFF, or JPEG formats. The

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tools currently provided in the SSIK are described in subsections A and(*B*).

A. Standard Image Processing Tools

Several image processing tools to manipulate and analyze images are integrated and the parameters required by the tools are assigned through friendly user interfaces; e.g. using slide bars and/or list boxes, etc. and show the effect on a preview image before applying it on the original image as shown in

The image processing features and tools that included in the SSIK application are:

- Colour operations such as: gray scale, invert, channel extraction and brightness adjustment
- Resize and rotate can be performed using either nearest neighbour, bilinear or bicubic interpolation

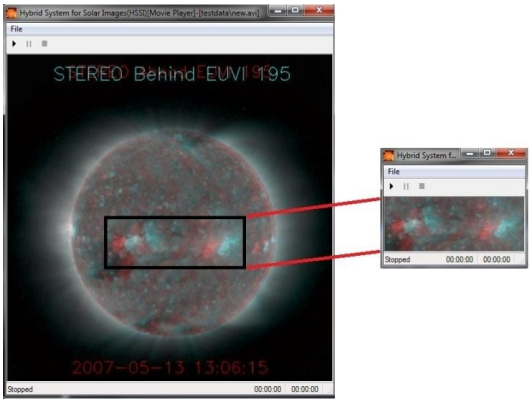


Fig. 10 3D video (from whole images or user defined sub-images) generated automatically without prior information from STEREO pairs of images taken on 13/05/2007 between 12:41:15 UT and 13:06:15 UT

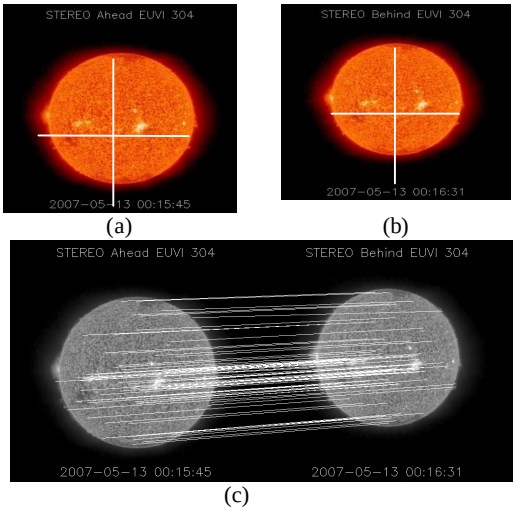
- Feature detectors including Harris and Fast corner detectors
- Animation creates a movie loop from displayed images which can be played in SSIK and exported as an AVI file
- Crop can be performed for an unlimited number of frames to extract regions specified by a window defined in the first frame
- Binarization to produce a black and white image based on a threshold value
- Mathematical morphology operations in 8-bits mode including erosion, number of objects, dilation and thinning
- Convolution filters including Gaussian smoothing and edge sharpening
- Median and adaptive smoothing filters
- Feature detectors and matching such as Harris with correlation, SIFT and SURF
- Edge detectors including Canny, Sobel and difference methods
- Fourier forward and backward transformations

B. Solar Image Processing Tool

The other metods that are specifically designed for solar images and included in SSIK are:

- Super-Resolution (SR) [12][15][16] generates a high resolution image from a set of 4 low resolution images with best performance achieved at a high cadence rate of about 2.5 minutes per image
- Anaglyphs are generated from uncalibrated pairs of images using predefined scale factors or the feature based detector with output used for still image(s) or video files.Translate the centres of the solar disks in a pair of images to the same position as shown in Fig. **11**
- Track object(s) through a stream of images
- Segment active region for EUVI images
- Merging unlimited number of EUVI or AIA images building 24 bit colours in the combined image file as shown in Fig. **12.** This is useful to accentuate features and simultaneously compare between multiple wavelengths.
- Movie creation for Active regions from a stream of images

- Resize the solar disks in a pair of images to the same scale
- STEREO-CPs method to detect and match features between a pair of images (see Fig. **11**.c)
- Translate the centres of the solar disks in a pair of images to the same position as shown in Fig. **11**
- Track object(s) through a stream of images
- Segment active region for EUVI images
- Merging unlimited number of EUVI or AIA images building 24 bit colours in the combined image file as shown in Fig. **12.** This is useful to accentuate features and simultaneously compare between multiple wavelengths.
- Movie creation for Active regions from a stream of images



(a) (b)

(c)

Fig. 11 Resizing solar disk using CPs obtained using the STEREO_CPs method. The images of size 512×512 pixels are

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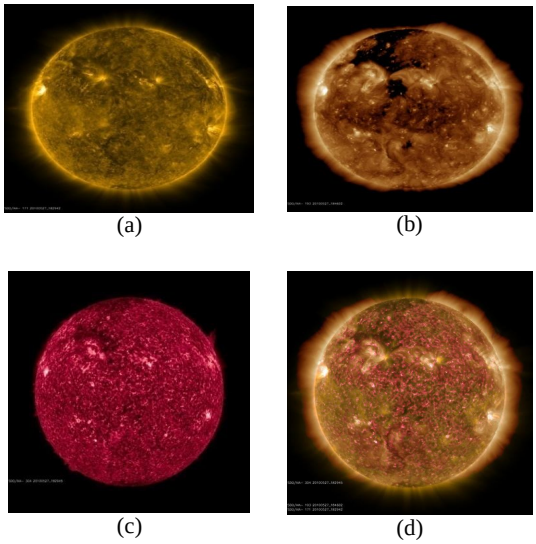
taken from STEREO spacecrafts on 13/05/2007. For comparison, the vertical and horizontal lines show the height and width of the solar disk measured in pixels. (a) Ahead EUVI 304, solar disk of size 317×317 pixels (b) Behind EUVI, solar disk of size 290×290 pixels (c) Feature detection and matching generated from STEREO_CPs



(a) (b) (c) (d)

Fig. 12 Merging colour channels from a sequence of AIA images. The images were taken by the SDO spacecraft on 27/05/2010. (a) AIA 171 (b) AIA 193 (c) AIA 304 (d) Combined image.

C. NEAR REAL-TIME BASED SYSTEM

To look for the latest STEREO and SDO images can be a time consuming task, often worsened by slow internet access. SSIK is designed as a near real-time resource for the latest STEREO-SECCHI EUVI and SDO beacon images without having to be concerned with the formats and locations of images. The local database updates automatically following a user request. The system will check the last date/time covered and compare this with the current time; the updating process finds all the images that fall between them.

This service is useful, because it provides an up to-date stream of images. SSIK can provide the infrastructure for other systems such as those concerned with predictions from solar images by providing EUVI and AIA beacon images. The associated functions are designed to be ready to be used by such systems to be able to create anaglyphs when ever the two STEREO spacecrafts are closed to each one.

COMPARISON WITH PREVIOUS WORKS

A comparison involved SolarMonitor, SDAC archive, ASAP, JHelioviewer, SWB, CACTus, STEREO-GSFC (Goddard Space Flight Centre), SDO-GSFC and the proposed imaging toolkit was conducted and shown in Table 4. The comparison was based on three criteria: the covered mission(s) which includes SOHO, STEREO and SDO; the information required to perform the image processing (e.g. calibrated or un-calibrated data); and the functionalities that are offered by each application. The comparisons reveal that SSIK is the only tool works with both missions of STEREO and SDO and also on local images, provides standard image processing tools, and offers more highly focused functions on uncalibrated solar images such as AR detection, super resolution technology and 3D viewing.

TABLE 4
A COMPARISON OF SOLAR IMAGING TOOLS BASED ON MISSIONS COVERED, INFORMATION NEEDED AND THE FUNCTIONS OFFERED

No	Software	Missions Covered	Information Needed	Functions
1.	SolarMonitor.org [2]	Global H-alpha Network, Solar and Heliospheric Observatory (SOHO), GONG+	Includes information on active regions and solar activity.	Client browsing
2.	SDAC archive [3]	SDO, AIA*, and other resources	Webpages will continue to be updated to facilitate automated retrieval of content	Client browsing
3.	ASAP [5]	SOHO	Sunspot group catalogue, Solar flare catalogues, SOHO/MDI Continuum and Magnetogram images	AR detection Sun spot detection McIntosh classification CME prediction
4.	SWB [7]	SOHO STEREO	Sunspot group catalogue, NOAA Active Regions, CACTus CME, SOHO/MDI Continuum and Magnetogram images, SOHO EIT images, STEREO-A and STEREO-B views with respect to the view of SOHO	Client browsing Information overlaying CME detection
5.	CACTus [8]	SOHO	LASCO images	CME detection
6.	JHelioviewer [1]	SOHO	Sunspot group catalogue, NOAA Active Regions,	Client browsing, Movie creation streaming between two dates/times, Applying frame-by-

			LASCO catalogue, SOHO EIT images, CACTus CME	frame basic image processing, Overlaying unlimited number of images or movies under adjustable transparency levels, and Locating solar events data.
7.	STEREO GSFC [13]	STEREO	SECCHI instruments: an extreme ultraviolet imager, two white-light coronagraphs and a heliospheric imager	Internet server browsing, Movie creation streaming for a day or between two dates/times.
8.	SDO GSFC [14]	SDO	Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI) images	Internet server browsing, Movie creation streaming for a day or between two dates/times.
9.	The proposed Imaging Toolkit	STEREO SDO	STEREO- SECCHI EUVI, AIA images, HMI images	AR detection, Client browsing, Movie creation streaming between two dates/times, Applying frame-by-frame image processing, Merging various AIA images, Segment ARs within movie, Feature detection and matching, Tracking solar events, Anaglyphs, Super resolution, Adjusting the size of solar disk for a pair of STEREO A and B images to the same scale and offset
*AIA stands for Atmospheric Imaging Assembly				

CONCLUSION

To the best of our knowledge, SSIK is the first software that: firstly, locates STEREO and SDO repositories from a single interface and also local images. Secondly, offers image processing tools specifically designed for solar images such as: Active region segmentation in multiple EUs through single or streams of images, solar event tracking (e.g. Active region), merging of several AIA beacon images to accentuate features and simultaneously compare between multiple wavelengths, super resolution from sets of consecutive frames available at high cadence rates, feature detection and matching between pairs of un-calibrated images, and creating single or streams of Anaglyph images from pairs of images taken from STEREO Ahead and Behind spacecrafts.

SSIK offers a research infrastructure for solar scientist researchers who are interested in studying the solar atmosphere at different scales, times and wavelengths, and for those who are working on un-calibrated solar images. Some methods highly focused on solar images are provided, base on standard image processing tools. The future work will be mainly aim to add further methods focused on solar images within the SSIK application such as: accessing some of calibration data in order to generate 3D images (obj or vrml files) and view them locally; access solar events catalogues and associate them with the existing methods for the case of solar weather prediction; and make this application available to the public in order to create anaglyphs for still image(s) or video files during any coming meeting of the STEREO spacecraft in the future.

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