Low-cost Stereoscopic Solution for Operations in the Prospective Science Space Missions

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The stereo matching is the key stage in determine an object's metrical properties on a stereopair which is taken with the help of stereoscopic technical vision systems. One way to find the corresponding points on the digital images lies in carrying the visual stereoscopic measurements by means of the specific software and hardware systems. The large majority of such solutions in the market are focused on the professional users with the experience in the stereophotogrammetric measurements. The outstanding feature of those software systems is the usage of the expensive hardware (professional graphic cards and monitors) with the aim of providing the capability of carrying the visual stereoscopic measurements. These requirements are not always acceptable (first of all due to their high price and high barrier of entry for an user) in the scientific space research, especially in the performance of the tasks that are not connected with processing of the remote sensing data. At the same time recently in the market appeared the value for money hardware solutions for stereo visualization based on the page-flip method of views separation. The results of developing the software for carrying the visual stereoscopic measurements based on one of the most popular solutions in game industry NVIDIA 3D Vision Kit for the user segment graphic cards (graphic processor GeForce) are presented in the paper.

I. Introduction

At present the principle of 3D object's reconstruction and finding its location in the working space coordinates with the help of stereoscopic technical vision systems is widely used in solving a lot of problems of the scientific space research. The most significant of them are the robot's vision, mapping, construction of 3D object's models.

The key problem of this area is the problem of finding correspondence on the two images. And it is well known that despite a lot of repeated attempts to create the generic methods of finding corresponding points on a stereo pair this problem is not completely solved yet due to its intricacy and general complexity of image understanding[1]. For example the regions on the images with a small amount of intensity variation can over-complicate the automatic solving of the stereo matching problem. That is why the manual stereo measurements for measuring or correction the coordinates of corresponding points that are calculated by analytic algorithms are used in practice.

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II. Automation of Stereoscopic Measurements of Digital Images

One of the most used methods of visual stereoscopic measurements for producing the coordinates of the corresponding points in the coordinate system of images is the method of imaginary mark which was proposed by Stolz. The method is based on the fact that during a stereoscopic examination of photos and floating marks which are integrated with the views an operator will see an imaginary 3D model and one imaginary mark instead of two real marks. Moreover moving the real marks (or photos relative to marks) along the eye base will change the mark's location in depth. The real marks will be placed in the corresponding points when an operator will get an impression that an imaginary mark touches a stereo model's surface.

For the first time the method of imaginary mark was implemented by Pulfrich in the optical-mechanical instrument that was designed to measure the 2D coordinates of the corresponding points of stereo pair and was called stereo comparator. However with the appearance and further development of the technology of digital images the traditional stereo comparators were replaced by their hardware/software equivalents, the so called digital stereo comparators.

A. Features of the Digital Stereo Measurements Systems in the Market

Today almost all of the digital stereo comparators in the market are the parts of the expensive digital photogrammetric stations. The most popular of them are the module Stereo of the package Leica Photogrammetry Suite (developed by Leica Geosystems), ImageStation Stereo Display (developed by Intergraph), stereo comparator of the photogrammetric package Photomod (developed by Racurs). To a much lesser extent in the market are represented separate software and hardware suites.

A stereo model in these systems is created in one of the following ways:

1) Anaglyphic
2) Page-flip
3) Mirror

Some of the digital photogrammetric stations support also the polarization method of views separation.

The core feature of their realization is the usage of special hardware. In practice it almost always means availability for the end-user the specific monitors (the exception is only the anaglyphic method of views separation). And in case of supporting page-flip methods by a system the professional graphic card with the support of the technology of quad buffering API OpenGL or the specific controllers are needed as well. The first requirement is typical mainly for stereo comparators which are the parts of the digital photogrammetric stations[2-4], the second – for isolated software and hardware suites[5].

Such particularities are considerably reduced the application area of the existing software solutions in the research and educational purposes, primarily due to its high price. In case of using special controllers can also appear problems which are connected with supporting, obsolescence, standardization of the necessary hardware. A possibility of working in the anaglyphic mode does not solve the problem due to the fact that the stereo models which are created by this method have a number of disadvantages, the main of which is the easy fatiguability of an operator during stereo measurements.

B. The Visual Stereo Measurements based on the NVIDIA 3D Vision Kit

At the same time recently in the market appeared the value for money hardware solutions for stereo visualization based on the page-flip method of views separation. Thus, in the entertainment industry the technologies 3D Vision from NVIDIA and HD3D from AMD for the user segment graphics cards became wide spread. It should be noted that the cost of the monitor for the page-flip method an average of 6-13 times lower than that of the mirror or polarization monitors which are used in the digital stereo comparators introduced in the market (see table 1).

The difference between the technologies from NVIDIA and AMD lies in ambition of AMD to market HD3D as an open platform that supports a lot of different standards. In contradistinction to NVIDIA’s concept that is based on the particular certified hardware. Such reference allows to ensure the acceptable, proved by chip producers, quality of stereo visualization which is known to be one of the main factors affecting the accuracy of manual stereo measurements as well as the level of operator’s eyestrain. Furthermore it is easy to make a stereo system based on the NVIDIA’s technology works right. The only requirement is to buy the “3D Vision Ready” equipment.

So it becomes apparent that the formation of stereo model by means of NVIDIA 3D Vision Kit for the user segment graphics card will allow to significantly reduce the price of a software and hardware system with stereo comparator’s traditional functions without compromising the accuracy of stereo measurements. And not least that there is a full product support of the solution from the manufacturer.

Table 1. The average price of the monitors used in the digital stereo comparators in the market.

Monitor's Series	Stereo Visualization Technology	Diagonal Size (Resolution)	Digital Photogrammetric Station	Average Price, $
Planar SD 3D	Mirror	22" (1920 x 1080) 26" (1920 x 1200)	LPS Stereo; ImageStation Stereo Display (Intergraph); Photomod	2 495
True3Di SDM		19" (1280 x 1024)	LPS Stereo	4 143
StereoPixel LcReflex-20		20" (1400 x 1050)	Photomod	2 726
RealD Monitor ZScreen (for CRT monitors only)	Polarization	19" 20" 21"	LPS Stereo	2 500 (as of 2009)
Nvidia 3D Vision Ready	Page-flip	from 22" (1680 x 1050)	LPS Stereo; ImageStation Stereo Display (Intergraph); Photomod	400

III. The Digital Stereo Comparator based on the NVIDIA 3D Vision Kit

The problems described above as well as our experience in using the different stereo visualization methods for the representation of the scientific information of the space projects[6] are led to the development by the authors the software which is allowed to measure the coordinates of the corresponding points in image's coordinate system by means of visual stereoscopic measurements.

The developed software can be classified as a human-machine system for image analysis. In this case the controlled object is the procedure of stereopairs measurement. The input data - stereopairs and output - the coordinates of the corresponding points in image's coordinate system which are calculated with the subpixel accuracy.

A. The Functional Scheme of the Digital Stereo Comparator

The functional structure of the digital stereo comparator can be presented as the complex of the following subsystems (see fig. 1):

1) Stereopair views pre-processing subsystem
2) Input control and error handling subsystem
3) Stereopair visualization subsystem
4) Stereopair measurement subsystem

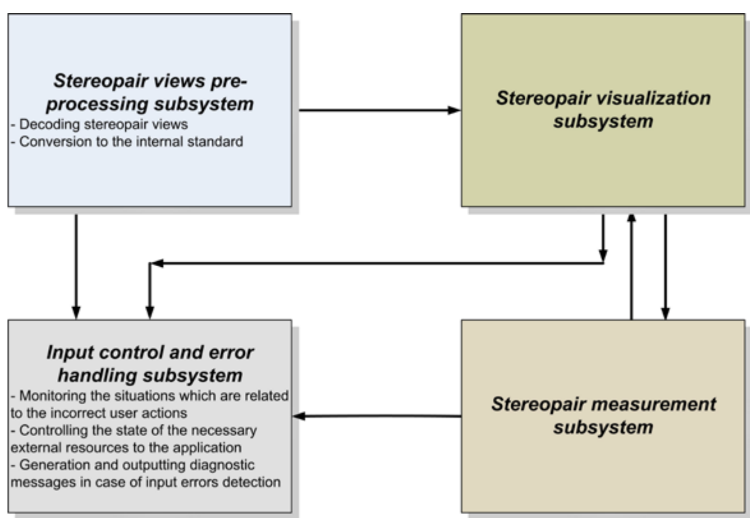


Figure 1 The functional scheme of the digital stereo comparator

The main task of the stereopair views pre-processing subsystem is decoding and conversion to the internal standard images of the stereopair. In the current version of the digital stereo comparator is supported bmp, jpg and png file formats. Before starting the input stereopairs are automatically converted to 24 bit format. And in case when the image's pixel size is not equal to the display's pixel size (or undefined) scaling is applied to the stereopair views, which affects the actual physical size of the screen image.

The input control and error handling subsystem is monitoring the situations which are related to the incorrect user actions (for example, attempt to use images of the different sizes as an input stereopair), controlling the state of the necessary external resources to the application. In case of input errors detection or unavailability the needed external resources the subsystem generates and outputs relevant diagnostic messages.

The stereopair visualization and measurement subsystems are mutually complementary and solve the main list of tasks facing the digital stereo comparator.

B. The Stereopair Visualization Subsystem

The main goal of the stereopair visualization subsystem is providing a capability to measure and view the digital photos by an operator in two operating modes:

1) 2D
2) Stereoscopic

Figure 2 The 2D mode

The cursor is used as floating mark regardless of the measuring method. It is formed like an image on the view's surface.

In the 2D mode two images, left and right views of a stereopair, are shown to a screen (see fig. 2). Originally an image's pixel on a display corresponds to a pixel of an initial digital image that lets to put a floating mark to the image's point within the accuracy of 1 pixel by means of mouse. From the technical point of view the visualization in 2D mode is performed by means of the graphical API Microsoft Windows Presentation Foundation for the platform .Net Framework 4.0.

A stereo model which is formed from the stereopair views and their floating marks is shown to a screen in the stereoscopic mode. Currently the 3 methods of stereo model viewing are implemented in the system:

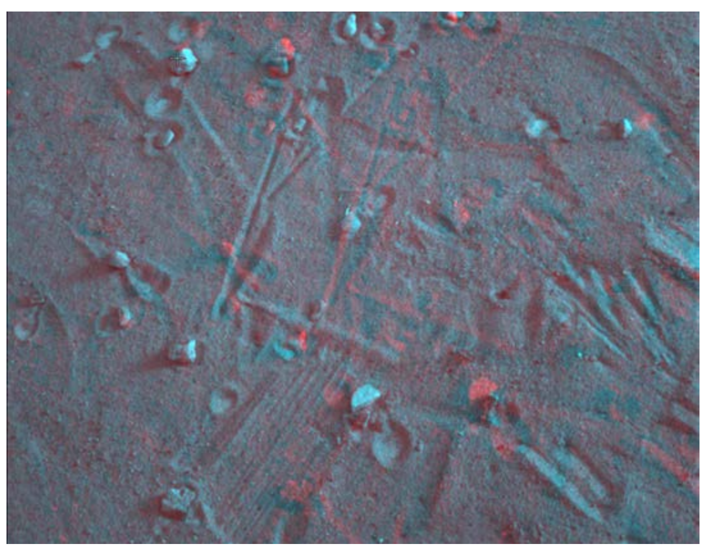


Figure 3 The stereo model (the stereoscopic mode)

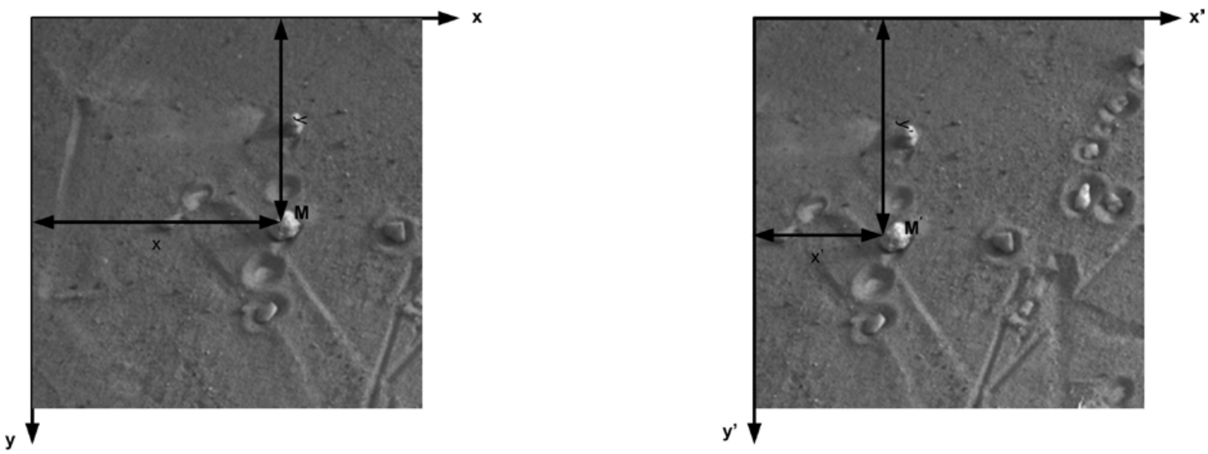
1) Anaglyphic (the Dubois algorithm) (see fig. 3)
2) Autostereoscopic for the parallax barrier display Sharp LL-151-3D
3) Page-flip based on the NVIDIA 3D Vision Kit for the user segment graphic card

For all three variants of views separation the output of a stereo model is implemented on the basis of the component Direct3D API DirectX 9.0, for the page-flip method of stereo visualization the stereo driver NVIDIA was also used. The output of a stereo image only in full screen mode by means of Direct3D is caused by the NVIDIA solution requirements. It should be noted that the software's rework will not required if the NVIDIA's professional graphic card with the 3D Vision driver will be used by the end-user.

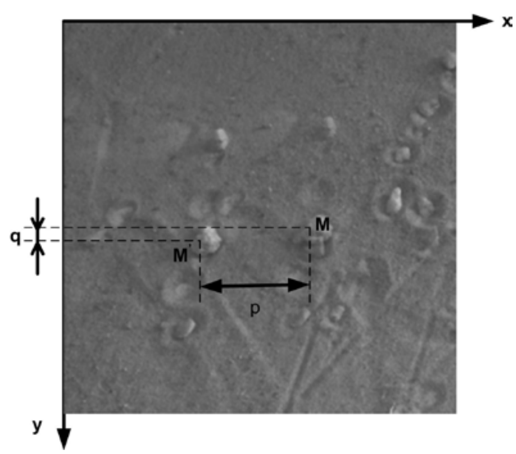
C. The Stereopair Measurement Subsystem

The task of the stereopair measurement subsystem is in providing the user with the necessary tools for carrying the visual stereoscopic measurements of a stereopair. As a tool in the system are used two floating marks, each of which can be put on any point of an appropriate view.

The coordinates and parallaxes of the points are measured in pixels which are represented the smallest unit of measurements, with the origin of coordinates in a top-left corner of an image. This fact is illustrated by the fig. 4. On the fig. 4a is shown left and right views of the stereopair, the corresponding points M and M' are marked on them. After combining the views in the one coordinate plane (fig. 4b) it can be seen that the coordinates of the points differ by the values of the absolute and vertical parallax, p and q respectively.



a)



b)

Figure 4 The principle of stereo measurements

The sighting of a floating mark on an image's point can be done in one of the following ways:
1) By moving a mark itself
2) By view's parallel translation

The photos and floating marks can be moved only discretely by proper hotkeys. The minimal step of moving a mark is one pixel.

An operator measures the pixel coordinates of the corresponding points by the method of imaginary mark according to the following algorithm:

1) By means of one of the methods described above a mark is sighted with the measuring point on a left or right view, on the other photo the image's point is selected by an operator in an arbitrary manner. In general the selected points will not be corresponding
2) An operator sights the floating mark with the desired point of the visible model in the stereoscopic mode by independent moving the floating marks or parallel translation of the views themselves

With the aim of getting subpixel accuracy in the mode with movable marks there is an opportunity to increase the stereopair views. In this case the pixel coordinates of the points on the enlarged image can be measured within the accuracy of 1/n of the original image's pixel, where n is the enlargement scale of the original image. In the second mode the stereopair view can move relative to fixed floating mark with step which is lesser than the pixel size, moreover in general X shift and Y shift can be set different.

For changing the pixel size or shifting of an image interpolation is used. At the moment the system supports the nearest neighbour, bilinear, bicubic interpolation algorithms that are implemented by means of OpenCV 2.3.

D. The Digital Stereo Comparator in Scientific Space Research

The developed digital stereo comparator in the scientific space research can be used for solving those problems wherein there is a necessity to measure and (or) improve the coordinates of the corresponding points of a stereopair, for example, for planets mapping, creating the three-dimensional models of spacecrafts from a sequence of images etc.

The peculiarity of this complex compared with the stereo comparators which are included in the digital photogrammetric stations is the orientation on the users with no experience in carrying the visual stereoscopic measurements. Its main application area primarily is the laboratory experiment, not a digital photogrammetric processing of remotely sensed data. However as standalone product it can be used for this too. That fact significantly affected not only the approaches of the architecture and user interface design of the digital stereo comparator but also the choice of the necessary hardware. Thus while choosing the hardware it was taken into consideration not only the fact of its compliance with standards and modern technologies but also its accessibility to a researcher. The accessibility in this case means the complex of such criteria like the hardware's cost, relative flexibility in application, as well as full technical support from the manufacturer.

In future this software can be included into a human-machine system of the supporting and maintenance of the scientific space research as subsystem.

IV. Conclusion

The complex of such criteria like the cost of the using hardware, relative flexibility in application, the availability of full technical support from manufacturer as well as orientation of the software on the researcher's needs significantly affect the efficiency of working on the scientific space projects and as consequence its results. The developed software with stereo comparator’s traditional functions as distinct from the existing solutions in the market allows to reduce not only the product's exploitation cost through using the cheaper hardware but also to lower the barriers to entry through its orientation on an user with no experience in carrying the stereophotogrammetric measurements. The modular principle of the system's organization will allow in future to add new functions without reworking of the existing software.

Appendix A
Glossary

Absolute parallax	The difference of the x-coordinates of the corresponding points that are measured on the stereopair.
Stereo matching	The problem of finding the corresponding points on the images of scene which are taken from the different angles.
Stereo model	The 3D image of the object that is seen to an observer while viewing the pair of overlapping photos which are taken from the different points in space (stereopair).
Stereoscopic technical vision system	The installation with the two image formation sensors. The sensors are mounted so that the subject can be observed from the two different points in space[7].
Vertical parallax	The difference of the y-coordinates of the corresponding points that are measured on the stereopair

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