

## DEVELOPMENT AND APPLICATION OF DIGITAL IMAGE SURVEYOR DI-1000

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### ABSTRACT

Fully conscious of the tremendous importance of accurate measurement of all kind of outdoor objects for balanced civil engineering, prevention of natural disasters, environmental protection, etc., we have now developed a new sophisticated digital-image-surveying-system, which enabled us to measure and analyze not only on the site or field itself but also back in the office.

Our new "Digital Image Surveyor, DI-1000, is a software operative on Pen-Computer to create an accurate ortho-image. Its hardware system to work with is composed of a digital camera, Reflectorless Total Station (TOPCON GPT-1000 series) and a pen-based computer. It enabled us to photograph, measure, analyze and produce an accurate ortho-image on the very site.

DI-1000 can swiftly make ortho-image out of the oblique images of an object taken by a digital camera, make speedily an ortho-image out of them. It can also superimpose the three-dimensional data obtained by the Total Station onto the image data. This enables us to determine the object features, check and verify the measurement and add attribute information.

Besides, we have developed new Digital Plotter PI-2000 to acquire and process tremendous amount of three-dimensional data for image plotting. And with a newly developed hardware we have also developed a highly sophisticated software to realize an efficient stereo-matching, which utilizes the data obtained both by the measurement of this PI-2000 and that of DI-1000 and GPT.

To test the applicability of this system, we made experiments successfully on the road intersection and on the three-dimensional survey of a cliff side.

### 1 SYSTEM STRUCTURE

The figure 1 is the image-surveying system we have developed. It is consisted of data-acquiring part, analyzing part and result-outputting part.

The data-acquiring part obtains the data from digital camera and also obtains control points from the surveying instrument. And we use the "Digital Image Surveyor, DI-1000, the newly developed software, to process the data acquisition and analysis. It is connected with Reflectorless Total Station and by measuring on-line it can obtain the image data, measure them (orientation) and create various visual presentations at the site itself. The data, which were acquired at the site, are brought back to the office, and there they are edited, visualized and output for image file and printing. And for the three-dimensional measurement in the analyzing part, we use "Digital Plotter" PI-2000, which we have now developed.

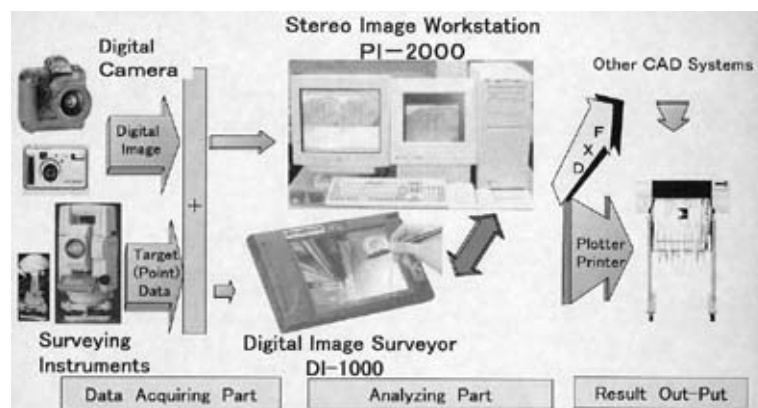


Figure 1. Image surveying system

## 1.1 Data Acquiring Part

**1.1.1 Digital Camera.** For the road intersection survey we used ordinary Ricoh digital camera RDC 5000 (2.3 million total pixels,  $1792 \times 1200$  array,  $4.2 \mu\text{m}/\text{pixel}$ , and its lens is  $38\text{mm} \sim 86\text{mm}$  i.e. 35mm equivalent, optical zoom). And for the cliff side survey we used Nikon D1, which is lens-interchangeable 35mm type digital camera (2.7 million total pixels,  $2000 \times 1312$  array,  $11.8 \mu\text{m}/\text{pixel}$ ).

Both recorded the image-data in small memory card, which can be easily processed by portable computer.

For camera calibration, we used "Self calibrating bundle adjustment software" which we had already developed (Cf.: Kochi, Otani, Nakamura and others 1996).

And for RDC5000 we used 38mm and for D1, 18mm and 28mm.

**1.1.2 Surveying Instrument.** The image analysis requires at least 6 control points. To acquire the data we can use Total Station or GPS. Particularly Reflectorless Total Station has the advantageous capability of measuring the object without actually touching it and capability of supplementing necessary data afterwards.

In our system we connected Topcon Reflectorless Total Station (GPT-1002/1004) and DI-1000 to make it possible to measure and supplement on-line.

We can use GPT series in prism mode as well as in non-prism (reflectorless) mode. In non-prism-mode we can measure up to 100m with accuracy of  $\pm 1\text{cm}$ .

## 1.2 Analyzing Part

**1.2.1 Digital Image Surveyor DI-1000.** DI-1000, the software we have recently developed, has the function of not only acquiring data in the field but also of producing three-dimensional image presentations out of three-dimensional data. When we use this function in the field to acquire and analyze data, we must first install DI-1000 in Pen-Computer.

Here DI-1000 thus installed is lined with GPT. After the image is obtained by digital camera, GPT measures the strategically aimed control points and on the display of the Pen-Computer we touch with a pencil-like pointed thing the same corresponding points so that the orientation may be processed. The procedure is very simple. Here we use DLT (Direct Linear Transformation process), because it is not necessary to fix the exterior orientation parameters. This facilitates the accurate analysis of the oblique image.

We use TIN (Triangulated Irregular Network) to interpolate the surface of three-dimensional data so that the image of digital camera can be transformed to ortho-image. Here it is also possible to automatically compose different ortho-mosaic images. (See: Figure 2 for DI-1000 process diagram)

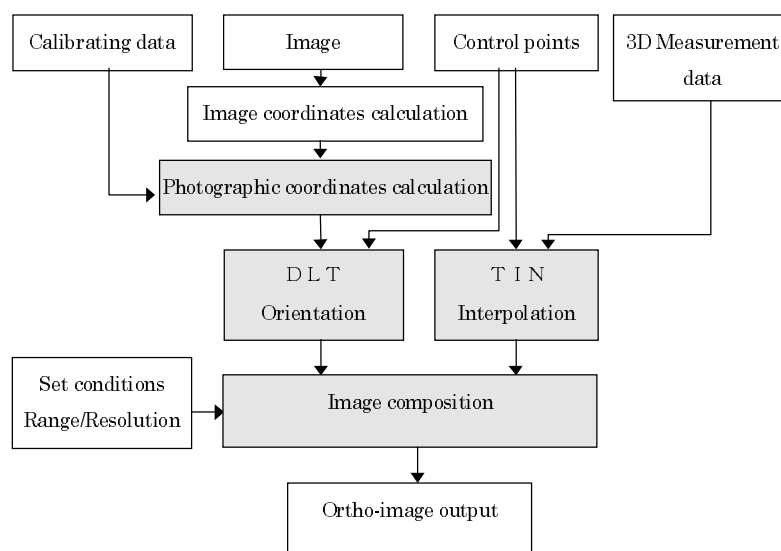


Figure 2. DI-1000 Process diagram

And by using TIN we can produce various image presentations such as birds-eye-view, wire-frame, rendering, contour line and cross-section.

If the three-dimensional features of an object can not be fully presented by the data obtained through a surveying instrument, we make stereo-photographing, and measure three-dimensional measurement (PI-2000), and then input the obtained data into DI-1000 to produce more accurate result.

In addition to DLT, DI-1000 has the function of relative orientation. By determining relative orientation of more than 6 control points, it can check and judge whether the obtained data can be processed through stereo-analysis or not at the site. So, if the judgement is negative, we can immediately take photos again to avoid miscarriage and assure the accurate and highly reliable result.

Furthermore, DI-1000 can be lined up with FC-10A (Topcon software, Digital Plain Table) on a Pen-Computer. This enables us to add already at the site the visual image elements to two-dimensional topographical data.

And DI-1000, which thus has absorbed the data, can work off-line.

### 1.2.2 Stereo Image WorkStation PI-2000.

Most importantly, this time we have developed PI-2000, which is a PC-based digital plotter. This is the device, which is used to make three-dimensional measurement out of stereo images. It is used when we want to obtain manual measurement of irregular complex surfaces which requires cubic display, or when we want to process automatically a large amount of three-dimensional data, which requires speedy processing.

PI-2000 has LSI for high-speed image processing for handling a large amount of data ( $\sim 1\text{GB}$ ) and has large dual liquid-crystal-display monitors for cubical display ( $1024 \times 768\text{dot}$ ). It also packed the image-control-board into the display unit to make the system smaller and lighter (See: Figure 1 center). Its software is based on Windows. (See: Figure 3 for the block diagram of electric system).

PI-2000 can handle the data of DI-1000, while the three-dimensional data obtained by PI-2000 can be fed back to and reprocessed by DI-1000 to produce various image presentations.

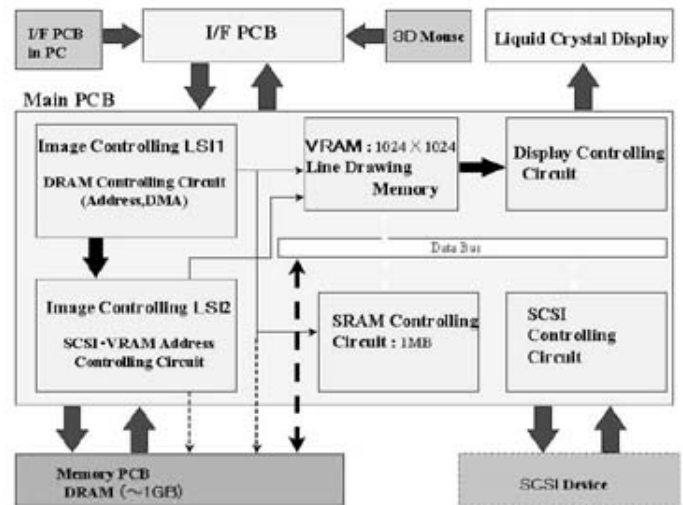


Figure 3. Block diagram of electric system

We have also developed a program of new automatic DTM (Stereo-matching). First we make TIN, using the points measured by a surveying instrument and using the points on outline or irregular land surface obtained manually by PI-2000. And then with this TIN data as initial value, we make stereo-matching. By combining this method with coarse-to-fine-image-correlation we made it possible to obtain more accurate and speedy three-dimensional measurement.

As to the manual measuring, we have developed a new program of semi-automatic-image-correlation, which operates simultaneously and correspondingly on both stereo-monitor and on PC display. With this new system, even the person, who finds difficult to use stereo-monitor, can work with ease.

Besides, as another useful and important function of digital plotter PI-2000, it made much easier to check the correctness of measurement by superimposing stereo-contour-line on stereo-monitor itself.

### 1.3 Measuring Flow

The figure 4 demonstrates the flow of measuring.

First on the site of measuring, we set at least 6 targets on the object, if possible. If, however, it is impossible we select at least 6 specific points on the surface.

Next we take picture of the object by digital camera. If the stereo-analysis is necessary, we take more than two pictures from different positions in such a way that a certain portion of a picture overlaps with the other.

Then we take memory card out of the digital camera and put it into the Pen-Computer.

DI-1000, which now has camera data, displays its image and we measure at least 6 points with GPT. For this measurement we first confirm the predetermined points on the computer display and aim GPT at the points and touch each of the points on the display. Then the GPT in this linkage actually measures the object.

After GPT measurement we make TIN by DI-1000, which provides us the frame on which to create various images we want.

If we find the data are still insufficient, we can make supplement measurement by simply commanding GPT the measurement of the point we indicate. By multiplying such points we can make more accurate, detailed and realistic measurement.

Having finished these works, we can bring back the data to the office, where we produce and edit the images, and store them up in file or print them out.

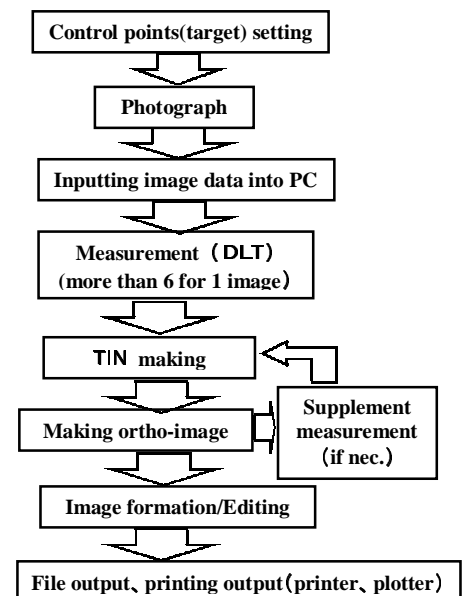


Figure 4. Flow of measuring

For off-line work, the image and measurement data, which are obtained at the site, are brought back to the office. There the data undergo whole process of measurement, image production and editing.

If the speedy Tele-communication of large amount of data is possible, the measurement data obtained at the site can be sent to the distant analyzing center.

## 2 MAKING LAYOUT PLAN OF A ROAD INTERSECTION

For road planning or reparation, it is often necessary to accurately find the various features of the road such as manhole, road signs, stop-line, crossing lines etc. So, we tested our device to make an accurate layout plan of the road intersection with our DI-1000, GPT and FC-10A.

We connected DI-1000 and GPT on-line. Then we measured and made orientation and supplement measurement to produce an ortho-image. After that we applied our software DI-1000 and FC-10A (Topcon Digital Plain Table software), which are both installed in the same Pen-Computer, on the obtained ortho-image to produce the finale layout plan of the road intersection.

For photographing we used RDC5000 (Ricoh CCD Camera) of 2.3 million pixels. We got on the stepladder of 2.5m and took picture of the area of about 40m × 15m. We took two pictures with slightly different perspective (See: Figure 5 right below). And on GPT-1002 we determined 6 main targets which are different for two photos and 30 supplemental targets altogether, which makes 42 targets in total.

The figure 5 above shows what came out of superimposing the ortho-image, which had been obtained from two pictures with DI-1000, on the image, which had been produced out of the ortho-image by FC-10A. The figure 5 below is its flat layout plan.

Since the object of survey is a two-dimensional road intersection we did not use stereo-photography. The accuracy of the image depends on the degree of image-resolution and the accuracy of GPT measurement. It is  $\pm 5\text{cm}$ . For the map of scale 1/500 this would be sufficient for practical purposes.

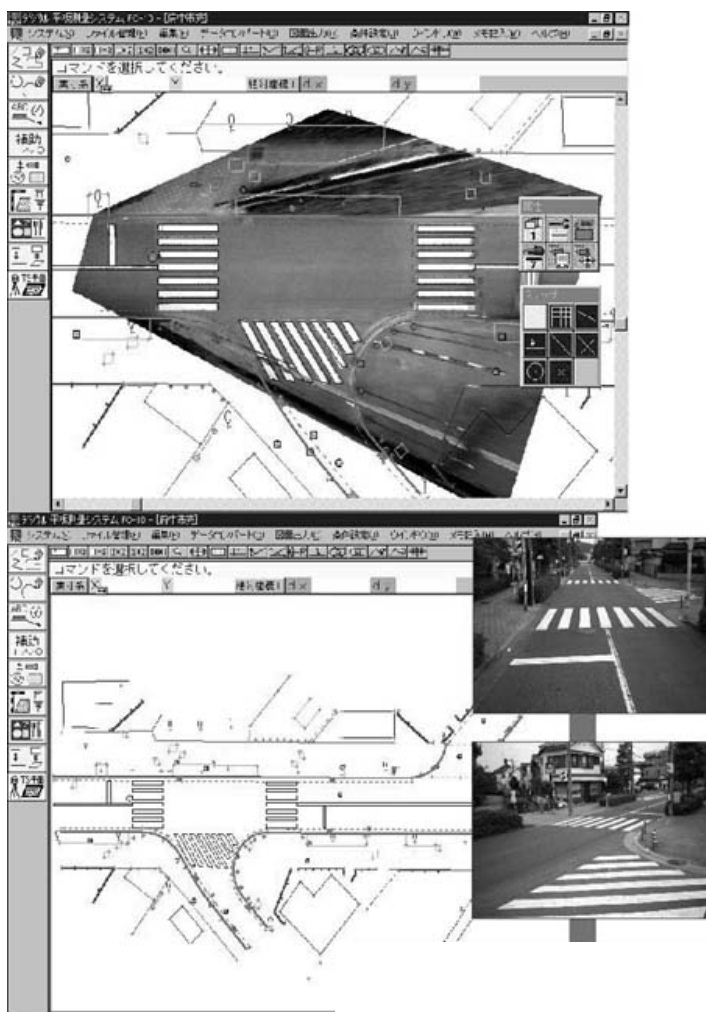


Figure 5. Making layout plan superimposing Ortho-image

## 3 THREE DIMENSIONAL MEASUREMENT

To grasp and find the way to tackle with the dangerous spot of land, for example, we must first find out its three-dimensional features by gathering the basic data necessary for analyzing the situation.

However, where the land is steep it is difficult to grasp the actual facts. Besides, up to now, even if the immediate action was necessary, we could not but spend a lot of time (more than a week) to gather necessary basic data and facts.

Or again, when the object is irregular and complex, we need to have multiple three-dimensional data in order to make an accurate ortho-image. If we use GPT it is not difficult to obtain the measurement points, but unfortunately it takes time to get measurement of each point. Besides, some inaccuracy could creep in, as it is actually impossible to make physical access to the points. To overcome such inconveniences, we have now developed a software to easily obtain an accurate ortho-image. Using the several measurement points obtained from GPT as initial values, we can automatically measure from the stereo images it produces.

In order, therefore, to investigate the problems and to test the accuracy of stereo-matching with GPT (TIN), we made a simulation experiment of measuring three-dimensional object.

In this experiment we chose a cliff side and placed 24 targets against the wall and we measured them with GPT and DI-1000, which are linked together for the on-line measurement and relative orientation. For stereo-photographing we used Nikon digital camera D1 set at 8m from the object. And the data was brought back to the office and processed through stereo-matching measurement of PI-2000 and the three-dimensional data was again fed back to DI-1000 to produce the final image.

Figure 6 shows the contour lines obtained from GPT and DI-1000 on 9 target points.

Figure 7 shows the contour lines obtained on 18 target points.

Figure 8 shows the contour lines obtained from PI-2000 on 170 target points with automatic DTM measurement.

Figure 9 shows the ortho-image obtained from GPT and DI-1000.

Figure 10 shows the ortho-image obtained from PI-2000 with automatic DTM measurement.

Figure 11~14 show the finally obtained ortho-image, cross-section (Figure 11.A~B), TIN image, and contour lines.

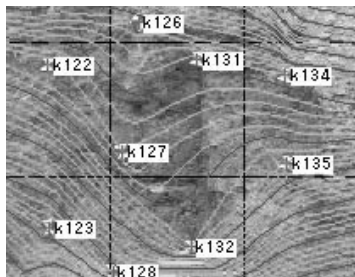


Figure 6. 9 Target points

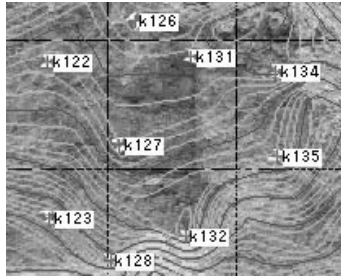


Figure 7. 18 Target points

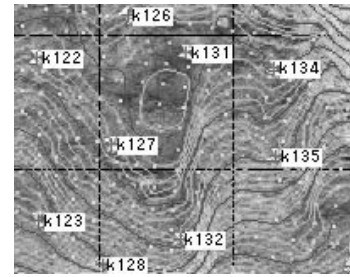


Figure 8. 170 Target points

So, the more the points, the more accurate will be the three-dimensional measurement.

As it is clear, if you compare the result of figure 9 and figure 10, you will find that the figure 9 evidently lacks the aimed points. So, the targets are a bit distorted and location is displaced (Look at the square matrix and the location of target).

Our entire stereo-matching operation used 4335 target points and finished within 2 minutes.

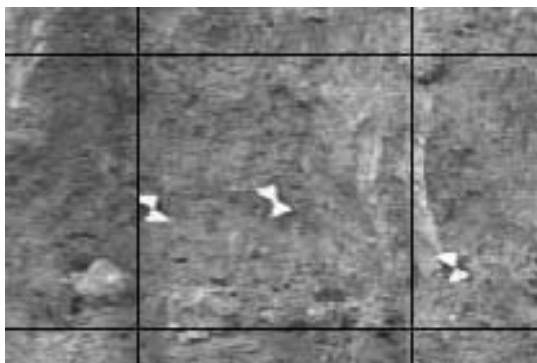


Figure 9. Ortho-image: GPT and DI-1000

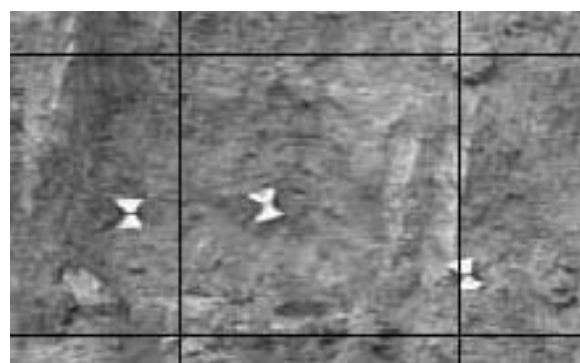


Figure 10. Ortho-image :PI-2000(DTM measurement)

From the above experiment, it is obvious that the stereo-matching, which uses GPT data as its initial values, is much more speedy, reliable and accurate than coarse-to-fine-image-correlation.

And the depth and horizontal accuracy became 1~2cm (rms). As to the accuracy, non-prism TS is  $\pm 1$  cm. The image resolvability is 5mm for horizontal and 13mm for depth dimension. The contour lines (Figure 6~8,14) were drawn for each altitude difference of 2cm, which is good. The final target accuracy of our experiment this time was within 5cm. So, the result was satisfactory.

The time spent on the experiment site was about 1 hour. And the time spent for processing from data reading to the final ortho-image production was also about 1 hour. However, the ortho-image production itself was only a few seconds. Thus, our system will be able to tackle urgent needs.

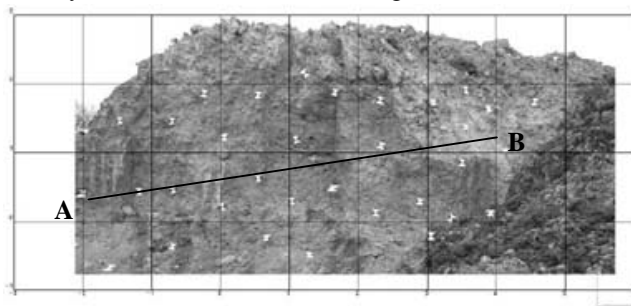


Figure 11. Ortho-image

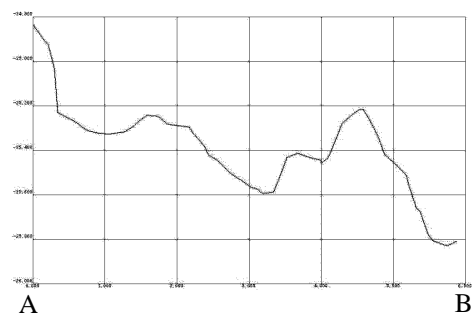


Figure 12. Cross-section (A-B)

#### 4 CONCLUSION

We have succeeded this time to produce DI-1000, which can create ortho-image from the measurement on the site and PI-2000, which can create stereo-image. And in order to assess their capacity and applicability we made experiment on a road intersection and a cliff side.

The result was quite rewarding. We could obtain a satisfactory ortho-image through the measurement and supplement measurement operation of DI-1000. And by making stereo-matching with the points, which DI-1000 and GPT had measured and PI-2000 had manually measured, as the initial values, we succeeded to measure a complex and irregular object with high speed and accuracy.

Thus, we were able to produce reliable ortho-images and various other image presentations so useful for diverse purposes.

We are highly convinced of having able to prove the great utility of our newly developed system.

Our objective now is to prove its capability by multiplying its practical applications.

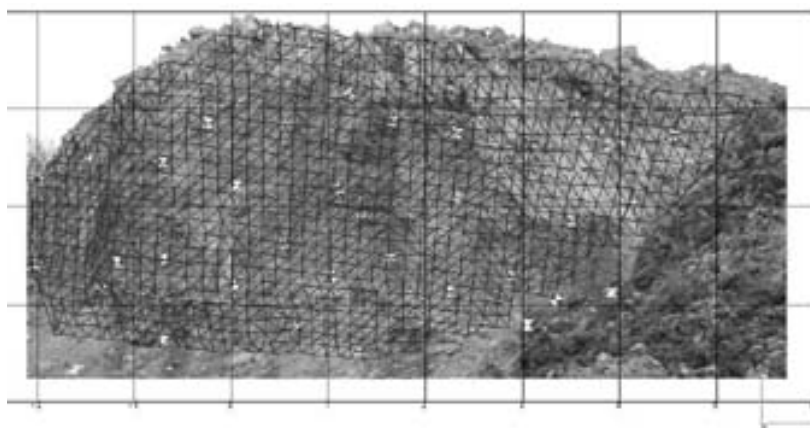


Figure 13. TIN image

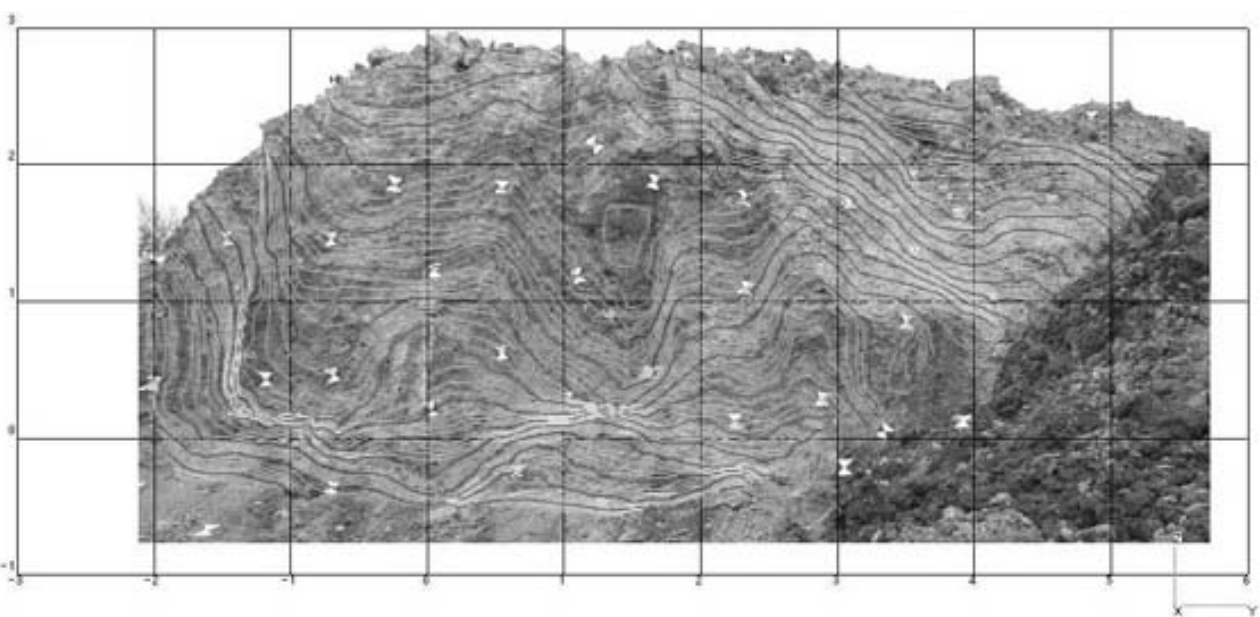


Figure 14. Contour lines

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