

An Experimental Method for the Analysis of Attributes of Flint Artefacts Using Image Processing

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Abstract

The article describes an experiment that explored the applicability of image processing to lithic attribute analysis. Following this experiment, we developed an interface for the application of a computerised method of attribute analysis of lithic artefacts using image processing. The main purpose of the experiment was to examine the potential of image processing methods which would be used for the automation of attribute analysis of flint artefacts, using relatively non-expensive devices, increasing the accuracy of the process and reducing time consumption typical for the manual process. The developed interface is able to recognise the contours of an object, extract its sizes (length and width) as well as the shape of its edges, and store all information in a data-base (measurements and image of the object). Further developments will include classification of edge-shapes (according to a priori defined criteria) and number of arises on the dorsal side of the objects.

Key words: attribute analysis, flint artefacts, image processing, automatisisation, VTK, attributes extraction, data-base

1. Introduction

One of the tasks archaeologists are often involved in is the reconstruction of social and economical organisation of past cultures. These reconstructions rely heavily on the material culture retrieved through excavations. For prehistorians, such reconstructions sometimes depend on a scrupulous examination of the material culture, mostly flint artefacts. This data-base is manipulated by minute classification into various types, mostly using morphological and metrical characteristics of chosen items. This process of examination, known as “attribute analysis” (e.g. Clay 1976, Patterson 1983), involves the minute examination of lithic artefacts, including measurements of various sizes and ratios between them, as well as morphological observations of attributes, such as scar patterns, types of butts, modification patterns, etc. (see Inizan, et al. 1992). Thus, through these observations, the prehistorian hopes to reconstruct the mode of flint tool production, which will further be used for his/her reconstruction of models from the past societies:

“...Even the simplest techniques of any...society take the character of a system that can be analysed, in terms of a more general system. The techniques can be seen as a group of significant choices that each society has been forced to make, whether they are compatible, or incompatible with other choices...” (Lévi-Strauss 1976:11).

Techniques involve the manipulation of materials, sequences of action, tools and a particular knowledge (know-how, manual skills, procedures, etc). Different techniques form a system - each technique is a locus of multiple interactions and constant adjustment among its elements: without the action animating it and without the knowledge of its effects, the tool is nothing. Action itself is constantly adapted to transformations in material, to the characteristics of the tool, to the evolution of know-how; technical know-

edge takes into account the available tool, its effective action, the material worked upon, and so forth (Lemmonier 1986).

The basic notion is that technology embraces all aspects of the action performed upon the material as being “a social production” (Lemmonier 1990). Furthermore, technique is “a socialised action on matter...explained by three orders of facts: suites of gestures and operations (technical process), objects (means of action) and specific knowledge (*connaissance*)” (Schlanger 1994:145). Therefore, the archaeologist’s task is to describe in which way a given technology is a social production. The knapper is also limited by the knowledge (*savoir faire*) of knapping methods. The possibility that these constraints emerged not only from the nature of the environment, functional needs, and knowledge of the knapper, but also from the social system within which the technique was practised, cannot be excluded. This approach is inspired by a “conception of techniques as social products: the “objectification” of what are socially elaborate thoughts” (Lemmonier 1990).

The current approach to the analysis of lithic assemblages takes place by reconstructing “production systems” (Karlin and Julien 1994). The process of knapping involves an intellectual operation: abstraction, anticipation, working out a solution to the encountered problems, construction of models. Pelegrin (1991) distinguishes a scale of “conceptual knowledge” (*connaissance*) acquired through the memorisation of concepts (“the mental representations of forms that are considered ideal and also the materials involved”) and memorisation of modes of operation and procedural knowledge (*savoir faire*), that can either be ideational, arising from intelligence and memory, or physical movement, presupposing bodily skills. A distinction can be made between conceptual, abstract knowledge (*connaissances*), and practical or pro-

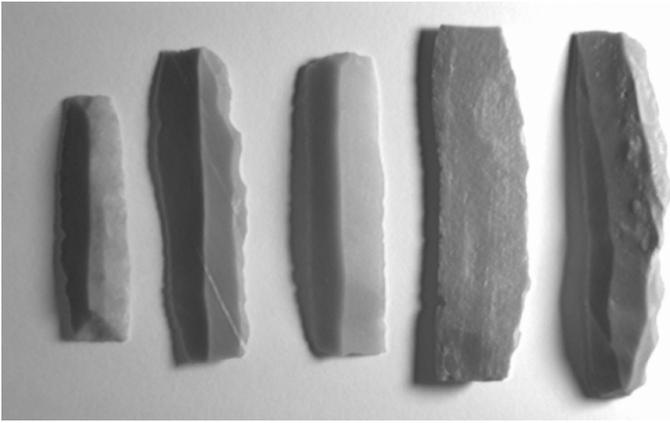


Figure 1: Image of sickle-blades used for the experiment, as acquired by the camera, before processing.

cedural know-how (*savoir-faire*). Both of these are present in an “elaborate flint knapping activity” (Pelegriin 1990).

Thus, a detailed analysis of material culture remains, and in this case, flint artefacts can be used for reconstructing various aspects of past cultures and their socio-economic organisation. In recent years, several techniques were developed for accurate investigation methods of attribute analysis of artefacts. These methods also include a broader use of computers and their accessories (e.g. Barceló et al. 1999).

The main goal of the experiment described below was to explore the potential of image processing in the use of identifying various attributes of flint artefacts and their classification, in order to automatise, speed up the process of attribute analysis and improve its accuracy through the elimination of human subjectivity (as for measurements or classification of morphological attributes). Therefore, an interface was developed for these purposes. The main component of this interface is a camera attached to a computer. The camera captures the image (which is the artefact we want to analyse) and the interface reads the image and analyses it. The results are then stored into a data-base.

The case study chosen for the experiment was a collection of sickle-blades from Israel, belonging to the Chalcolithic period (approx. 4500-3500 BC). These items are well defined by morphological characteristics (see Gilead 1995). Their polythetic definition is:

1. Narrow, but relatively thick, elongated blade obtained from a prismatic or pyramidal blade core, mostly of banded flint (see below).
2. One steeply backed side edge. The cross-section is rectangular or triangular, with a perpendicular side formed by backing.
3. Mostly straight, but sometimes finely denticulated working edge.
4. Truncations on the proximal, on the distal or on both ends are common (figure 1).

Sickle-blades are among the tool-types recognised to respond (to a higher degree than other tool-types) to chronological/cultural variations in proto-historic and historic assemblages of southern Levant. Moreover, the recognition of some specialisation is reflected by the discoveries of workshops for producing sickle-blades at various sites (Gilead and Hermon in press). Therefore, the importance of a detailed attribute analysis of sickle-blades can re-

veal important socio-economic aspects of Chalcolithic cultures in the study area. Thus, the interface developed was designed to identify the sizes of sickle-blades (length and width, sensitive to cultural/chronological and regional changes), the pattern and number of scars on their dorsal face as well as the edge shapes.

2. Description of hardware and software

While developing the interface, it was necessary to maintain the following features: all the processes were to be automatized to the highest possible level, thus reducing human interference to the minimum (such as artefact positioning), the analysis process was to be substantially faster than the human analysis and the required equipment (both hardware and software) as simple and cheap as possible.

The equipment used was:

a. Cameras

Hyper Had Standard PAL black and white Sony camera (spt – m102ce)

Computer TV lens 1:1.4 , 3.5 – 8 1/3 inch CS

Auto luminosity electronic (ccd iris)

b. Acquisition board

Matrox Meteor II professional frame grabber (the acquisition board), with a resolution of up to 768x576 pixels with PAL video signals. This board is used to digitise the signal from the camera in order to obtain an image, i.e. a matrix of points each one with its own grey value. The use of the professional board allows maximum use of the PAL video signal resolution. A lower cost solution could use a commercial acquisition board (e.g. the one integrated in the Matrox Marvel); this would probably require reducing the resolution of the acquired images to reduce the jitter noise (e.g. using 384x288 images).

c. P.C. computer (basic requirements)

Intel PII 400 Mhz, with 128M RAM, and Microsoft NT OS.

d. Table with arms for lights

Standard stand for reproduction (Mini Repro/2 1192), with column height 70 cm and base board 40 x 50 cm. Micrometric elevation with screw locking. Universal attachment stud, ¼ inch. Complete with two light arms each equipped with one movable lamp holder.

The program used for developing the interface was VTK – Visualisation Tool Kit. One of its characteristics which should not be neglected is that it is a freeware program, available for any user, running both on Unix or PC systems. VTK is a true visual system; it supports a broad range of algorithms (scalars, vectors and tensors), texts as well as volumetric methods. The program supports several techniques for building 3D models (including mesh smoothing, polygon reduction, implicit modelling, contouring, cutting). The language is Tcl (Tool command language), in this case used for the experiment phase and the development of the graphic user interface, and C++ (to expand VTK with new objects) (for more information, see Schroeder et al. 1998).

3. Description of the experiment

3.1. Extraction of the information from the object

One of the tasks explored was how to determine the best mode of extraction of the contour of the analysed objects. It was noticed that an important influential factor is the position (location) of the light source, which can be used to good effect in order to enhance the morphology of the objects. If the light source comes from the top, it does not allow to distinguish the number of surfaces (scars of previous removals on the dorsal face of the objects). It was decided that the image was to be taken with the light source from the top, in order to enable us to find the contour of a single object, due to the contrast between the background and the object itself. In this way, we also reduced the problem of shade and we could focus on the area of interest (the object itself) - the histogram of the object pixels is not corrupted by other information arising from the background. A simple sheet of glass supported by a black box was used as a table. The black box was placed underneath the glass sheet in order to avoid shading problems and was thus used to obtain a dark background and simplify the thresholding process. In order to avoid reflection from the camera itself the camera was covered by a dark shield.

In order to determine the surfaces of the object, at least two images had to be taken, each lighted from an opposite angle, so all information regarding the morphology of the object could be obtained. The light angle i.e. the angle between the camera axis and the direction of the source of light (sharp angle) should range between 45-90° - according to the best image obtained on the screen (the best image being the one where the surfaces are most visible, one side is almost completely dark, the other with emphasised surfaces). The luminosity should be constant as should the distance of the light source to the object (20 cm). While taking a sequence of images (up to 40 sec at two frames per second), we moved the light from one side to the other, in an arch above the object, in order to find the best angle for the camera.

3.2. Ambient luminosity

The problem of the ambient source of light (surrounding light) is that it must be diffused, in order not to create an unwanted shadow, particularly when we try to extract the contour of the object. In addition, if the ambient luminosity is too strong, it is of no use to change the angles of the light sources, since there will be no strong changes in the enlightenment of the object's surfaces. Therefore, we had to either create a constant shadow, or work in a dark environment, with a low ambient luminosity. Thus, the chosen light source was a normal 60 W light-bulb with a diffused light.

3.3. Process of image acquisition

In order to fit the object into the frame the distance from the ccd to the board was 16 cm, that is with the above specified lens. The positioning of the object was with the longer side parallel to the angle of the picture, but precise definition of the object location was not required. Zooming apparently increases the accuracy of the image (higher precision is translated in terms of higher resolution - one pixel corresponds to a smaller surface on the piece; maximum zooming depends on the distortion of the edges, due to the camera lens). A possible solution to this problem would be

developing an algorithm of sub-pixel precision (measures), which would virtually increase the information per pixel.

In order to obtain a sufficient number of images of a single object, a sequence of 40 sec (2 frames/sec) were taken from various angles. This was performed in order to identify the morphology of the object - to observe how the angle of the light source affects the acquirement of the image (the lamination of surfaces). Finally, it was decided to use three frames: one with the light source from the top and two frames with the light source from opposite angles (the latter served for surface identification purposes).

It should be noted that several objects could be placed on the main board at any one time, and they could be chosen sequentially. The number of items on the board should be between 3 to 6 in each sequence.

3.4. Saving the images

The images were saved in a pgm format (format for grey images, which can be read by VTK, Paint Shop Pro - read/write). This format saves the image in a raw format (400kb), which is an appropriate format, for it does not lose any information about the image during the process of compression. Pgm format is also useful because it can be read by a number of different graphic programs. The information regarding morphological characteristics of the object is stored in a database (accessed by Office - Access program, or compatible).

3.5. Algorithm description

The main stages of the program are described in figure 2. Following is a description of the main stages of the program development:

Thresholding is a labelling operation on a grey scale image. It distinguishes pixels that have higher grey values from pixels with lower grey values. This method is used for automatic determination of the threshold value. Since the threshold separates the dark background from the bright object (or vice-versa), the separation could be done if the distribution of dark and bright pixels was known. The threshold value could then be determined as that separation value for which the fraction of dark pixels (binary labelled with 1) equals the fraction of bright pixels (binary labelled with 0). The difficulty is that the independent distribution of dark and bright pixels are often not known, since what is known is the image histogram, which tells how many pixels are associated with any grey value in the mixture distribution. In the event that the distribution of dark pixels and bright pixels are widely separated, the image histogram will be bimodal (corresponding to dark and bright pixels, respectively).

At this stage of our research, the method implied for the development of the interface is manual thresholding: a window with a cursor scale, showing the grey scale is set; the operator changes the grey scale until the required image (the contours) is acquired, and the object is separated from the background (figure 3). However, the thresholding required is minimal, since the contour is found at a low level of thresholding in any case. A future development of the interface will include the implementation of automatic thresholding, using either the Otsu method (Otsu 1987), or the Kittler and Illingworth method (Kittler and Illingworth 1985, 1986).

Flow-chart of image processing and storing

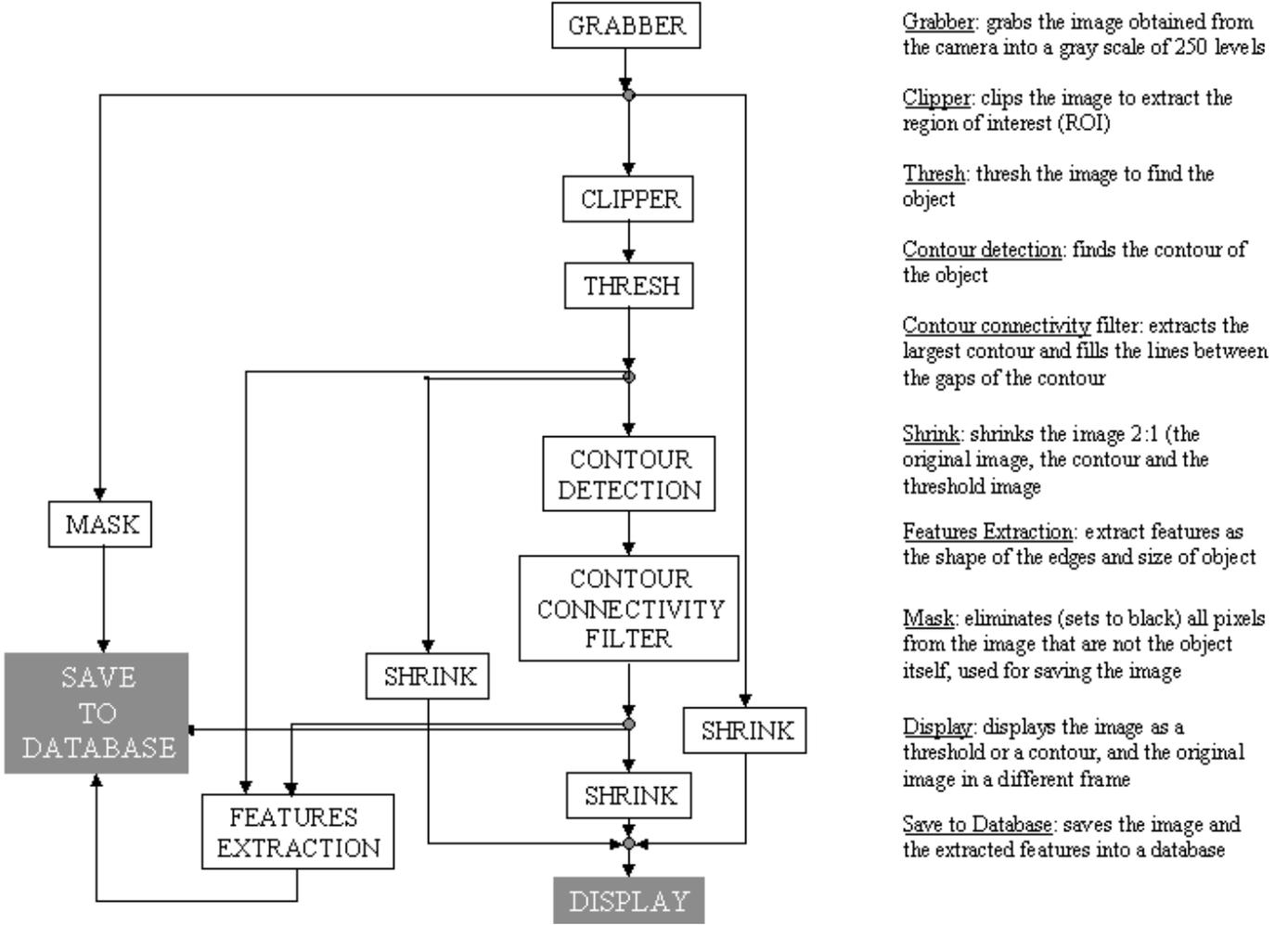


Figure 2: Flow Chart describing the main stages of the developed algorithm.

Contouring is a method of constructing boundaries between regions of similarly coloured areas. Contouring begins with selecting a scalar value (or contour value), which corresponds to the generated contours values. To generate the contours, some form of interpolation must be used, usually a linear interpolation along the edges. Once the points on the cell edges are generated they can be connected into contours. The method implied for contouring was the implementation of a 2D algorithm of *marching squares* (Schroeder et al. 1998:159). The basic assumption applied by this method is that a contour can only pass through a cell in a finite number of ways.

The method of extracting the sizes of the object (length and width), are based on the following formulae, which define the second-order spatial moments of the region (the shape of the object):

Second-order row moment:

$$M_{rr} = \frac{1}{A} \sum_{(r,c) \in R} (r - \bar{r})^2$$

Second-order mixed moment:

$$M_{rc} = \frac{1}{A} \sum_{(r,c) \in R} (r - \bar{r})(c - \bar{c})$$

Second-order column moment:

$$M_{cc} = \frac{1}{A} \sum_{(r,c) \in R} (c - \bar{c})^2$$

where r is the row; c is the column, R is the contour and A is the number of points in the contour.

In order to obtain the lengths of the major and minor axis and their orientation from the second-order moments, four cases are considered:

$$1. \begin{cases} M_{rc} = 0 \\ M_{rr} > M_{cc} \end{cases}$$

The major axis is oriented at an angle of -90° counter-clockwise from the column axis and has a length of $4M_{rr}^{1/2}$. The minor axis is oriented at an angle of 0° counter-clockwise from the column axis and has a length of $4M_{cc}^{1/2}$.

$$2. \begin{cases} M_{rc} = 0 \\ M_{rr} < M_{cc} \end{cases}$$



Figure 3: Image of the interface, showing the processing of the thresholding function.

The major axis is oriented at an angle of 0° counter-clockwise from the column axis and has a length of $4M_{cc}^{1/2}$. The minor axis is oriented at an angle of -90° counter-clockwise from the column axis and has a length of $4M_{rr}^{1/2}$.

$$3. \begin{cases} M_{rc} \neq 0 \\ M_{rr} \leq M_{cc} \end{cases}$$

The major axis is oriented at an angle (between the orientation of the object related to the camera) of:

$$\alpha = \tan^{-1} \left[-2M_{rc} / \left(M_{rr} - M_{cc} + \sqrt{(M_{rr} - M_{cc})^2 + 4M_{rc}^2} \right) \right]$$

counter-clockwise with respect to the column axis and has a length of

$$\sqrt{8 \left(M_{rr} + M_{cc} + \sqrt{(M_{rr} - M_{cc})^2 + 4M_{rc}^2} \right)}$$

The minor axis is oriented at an angle of 90° counter-clockwise from the major axis and has a length of:

$$\sqrt{8 \left(M_{rr} + M_{cc} - \sqrt{(M_{rr} - M_{cc})^2 + 4M_{rc}^2} \right)}$$

$$4. \begin{cases} M_{rc} \neq 0 \\ M_{rr} > M_{cc} \end{cases}$$

The major axis is oriented at an angle of:

$$\alpha = \tan^{-1} \left[\left(\sqrt{M_{cc} + M_{rr} + \sqrt{(M_{cc} - M_{rr})^2 + 4M_{rc}^2}} \right) / 2M_{rc} \right]$$

counter-clockwise with respect to the column axis and has a length of

$$\sqrt{8 \left(M_{rr} + M_{cc} + \sqrt{(M_{rr} - M_{cc})^2 + 4M_{rc}^2} \right)}$$

The minor axis is oriented at an angle of 90° counter-clockwise from the major axis and has a length of

$$\sqrt{8 \left(M_{rr} + M_{cc} - \sqrt{(M_{rr} - M_{cc})^2 + 4M_{rc}^2} \right)}$$

4. Results

The results of the experiment are shown in the development of an interface (figure 4) that enables us to extract features such as contour and size of the object, as well as store data in a database, together with the image of the object itself. The entire process is almost fully automatized, in the sense that the person's task is only to place the object on the table, threshold the image and press the required buttons on the interface. It should be stressed that there is no special requirement for a specific position of the items to be analysed (the only requirement is that they are in the camera frame). The entire process does not take more than a few seconds, thus drastically increasing the acquisition process of attribute analysis. Moreover, the data is acquired by means of measurements taken by the developed program, and thus has an increased accuracy, and at the same time it is stored in a database available for general use. Thus, the operator's tasks are to place the objects to be analysed on the board, choose the object by framing it in the rectangle (in the camera view window), set the thresholding on the processed image window to the required size (until the contour is clear) and click on the appropriate buttons in order to obtain the required information. The measurements given on the processed image are translated into the metric system (millimetres)

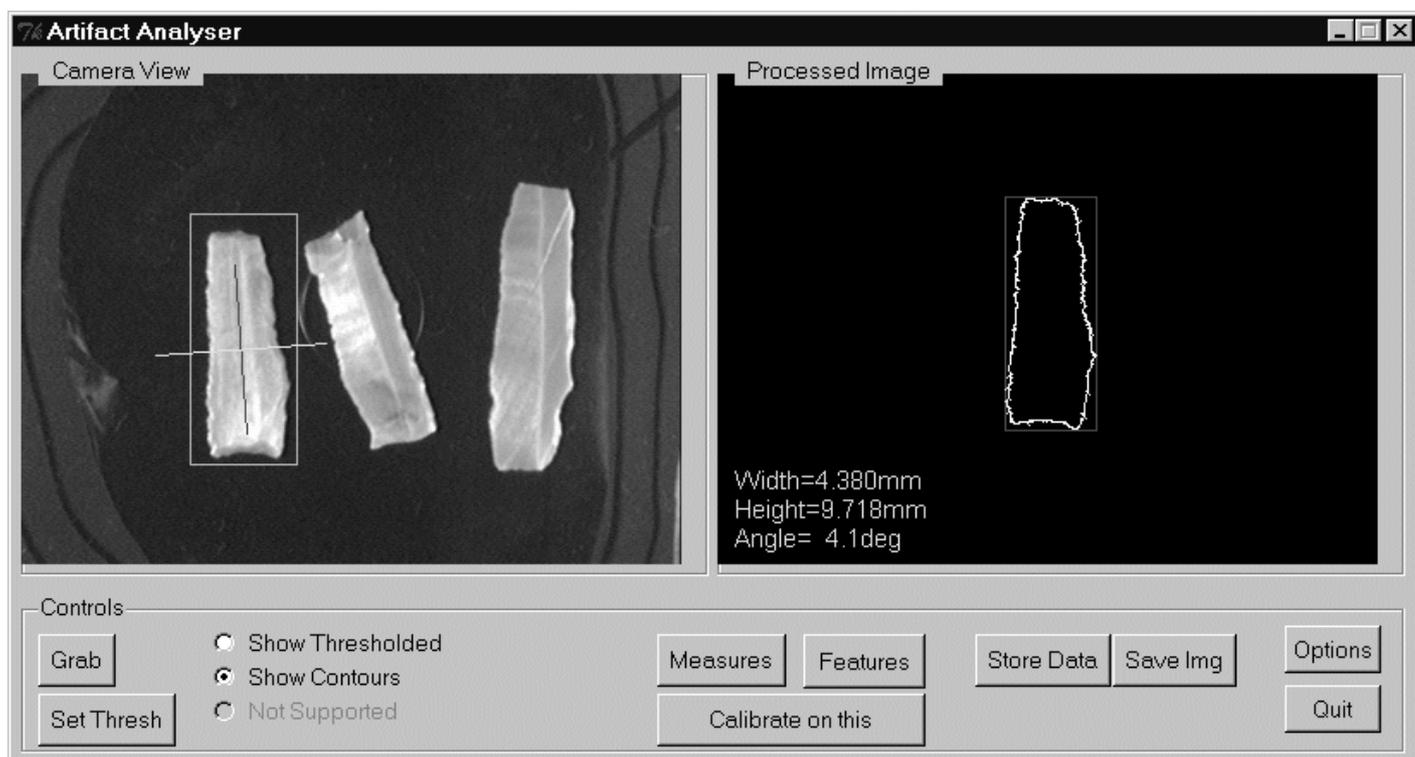


Figure 4: Image of the developed interface.

and stored in a database, which can be reached through any standard database program.

Further developments of the program will be total automatization of thresholding, recognition of edge shapes and a more vigorous relation with the database. Even though it seems that the results obtained so far are modest from an archaeological point of view, the importance of this experiment lies in its nature itself, i.e. in the exploration of the application of image analysis to the technological interpretation of flint artefacts, or, in a wider view, to any object. The algorithm developed can be used for any object, no matter its nature, and can be adjusted for the needs of any final user. Thus, following this experiment, the potential and limitations of using image processing and analysis in the field of archaeological artefacts is better understood. Further developments will hopefully improve and expand the performance of the interface, making it more applicable from an archaeological scientific point of view.

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