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Databased Classification System for Shoe Sole Patterns—Identification of Partial Footwear Impression Found at a Scene of Crime

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ABSTRACT: An image related databased classification system was developed for shoe sole pattern designs. Sole designs are stored with shoe information (brand name, size, style, material, etc.), pattern types and certain features existing on shoe soles or in footwear impressions, and they are used as searching criteria. There are two different classification code systems in the database. Preliminary classification is a very broad classification, and it is meant for shoe sole pattern designs and full shoe sole impressions. Feature classification is designed especially concerning partial footwear impressions, and its classification codes are based on defined basic shapes and certain principles, which facilitate also partial footwear impressions storing, shoe sole designs identifying for partial impressions and the elimination of interpretation error while classifying. User-friendly software makes the classification easy and searches rapid and effective.

KEYWORDS: criminalistics, crime scene footwear impressions, classification system, databased imaging

A criminal always leaves tracks at a scene of a crime. Very often those tracks are shoe impressions, which are potential physical evidence [*1*]. This evidence could be used to determine the style(s) of a shoe to give the investigator information about what to look for. This evidence may also assist the investigator in linking crime scenes [*2*].

Unfortunately, shoe impressions left at crime scenes are often only partial shoe impressions. Most of the shoe sole collection systems have been ideal for classifying and for searching full shoe impressions, and it is noticed that there are difficulties with partial shoe impressions, which are found at the majority of crime scenes [*3*]. To avoid these difficulties it is better to direct the attention to possible small differences, that is, certain features in the patterns existing on shoe soles. These differences are due to different pattern designs [*4,5*]. Recorded impressions could be filed by pattern designs and by features for future searching purposes.

A shoeprint collection could be developed by taking footwear impressions of known criminals and/or by visiting shoe stores. Since November of 1992 test impressions taken from suspects and crime scene impressions have been recorded including the cases that have been delivered to this laboratory for statements. In a case, in which there are shoe

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impressions taken from suspects, crime scene impressions and shoe designs with their brand names in the same database, it is possible to link crime scenes by a single search as well as to get a suggestion of a possible suspect, and to find a brand name of the shoe.

There are two different code systems in the database to classify the impressions. The preliminary classification is a very broad classification system, and its purpose is to distinguish shoe soles with one or two patterns from those with complicated patterns, and also shoe soles with continuous border from soles having any distinct border. This classification is intended for full shoe impressions.

The feature classification is a much more accurate system by which it is possible to define a pattern on edge, toe and back of heel areas, circles with their rings, a pattern or a shape inside any shape, a pattern surrounding certain features as a defined shape, motif, letter, number etc. This classification is useful, especially for the identification of partial shoe impressions found at scenes of crime, because the classified features could be observed even in very small impressions.

Experimental

In this text the classification codes are used to clarify the principles of the classification, although a user of the application does not need the codes.

Computer Hardware

The footwear and shoeprints are imaged by a high quality S-video camera and the video signal output is digitized by a frame-grabber. The frame-grabber, controlled by an effective microcomputer equipped with an extensive and fast mass storage, digitizes images to 320 $\times$ 256 pixels at 24 bit color resolution. The image data is automatically compressed using so-called lossless compression (JPEG algorithm), which allows a size of the image data of approximately 80 kB without any loss of quality.

Computer Software

The run-time database application controlling the frame-grabbing, scalable image and text data handling has been written in-house using Super Basic Language (SBL), the programming language of Superbase Developers Edition version 2.0.

The application contains three separate databased files: Shoe (parent), Manuf (child) and Codes (child). The parent file contains the searching criteria of the physical characteristics of the footwear (size, style, material, brand, etc.), classification code strings of the impression (Fig. 1), and an eventual data of the crime case. Rapid searching hits for the recorded crime scene impressions could be performed by a single command button. The user-friendly application also allows searching of certain features one by one existing in a crime scene impression. Furthermore, more complicated searches are possible to establish by selecting the fields, logical operators and typing criteria from a keyboard.

The manuf-file contains contact information of the footwear manufacturers/importers and the list of their brands.

Preliminary Classification Code System

The preliminary classification is intended for test impressions taken from suspects, shoe sole pattern designs and full shoe sole impressions of good quality found at crime scenes. Three codes with two digits in each one form the entire code. This code indicates only general patterns (the first four digits of the code string) and a continuous border on the shoe sole (the last two digits of the code string) and it is positioned in the SOLE PRIME-field and/or HEEL PRIME-field in the database.

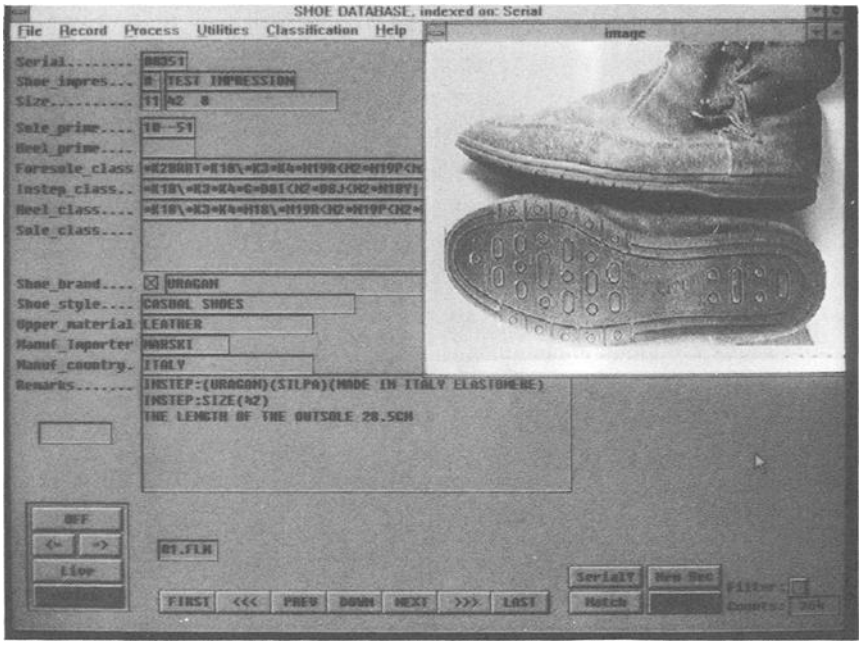

FIG. 1—*Shoe information in the record of the parent file.*

If the shoe has a separate heel, the classification code string for the heel is positioned in the HEEL_PRIME-field. If a sole pattern continues unbroken through the instep over the heel (the contact area of the instep is visible), the HEEL_PRIME-field remains empty. In this case the whole surface area of the shoe sole is considered including the heel, and the preliminary classification of this heel is part of the code string in the SOLE_PRIME-field.

Principles of the Preliminary Classification

Two digits form a code, and three codes form the entire code string. The first two codes are reserved for indication of the pattern types on shoe soles, and the third code is reserved for indication of the continuous border of shoe soles.

Main Groups of the Patterns

The codes are divided into eight main groups; mesh (first digit is zero, 0), stud (first digit is 1), wave (first digit is 2), zig-zag (first digit is 3), bar (first digit is 4), complicated (first digit is 5), crepe and plain (first digit is 6), and continuous border (first digit is 7).

Pattern Types in the Main Groups

The second digit of each code indicates the type of the main group pattern. For instance, in the mesh and stud groups the digit 0 (zero) as a second digit means that the mesh or stud has a circular shape, the digit 1 (one) that the mesh or stud is triangular etc. Concerning the wave or zig-zag, the second digit indicates the width of the line whether the line is broken or not, and whether the wave or zig-zag is low or high. In the bar pattern the second digit indicates the width of the line and whether the line is broken or not. In the continuous

border the second digit indicates the nature of the continuous border of the shoe sole, for instance the code 71 means, that there are triangular studs in an uninterrupted edge.

Pattern Combinations

1. One Distinct Pattern Type—This pattern is assigned for the appropriate two-digit-classification-code (for example, 01—, which means, that there is only a triangular mesh on a shoe sole). In this case, it is easy to direct the search criterion to the preliminary classification-field.

2. Two Distinct Pattern Types—In the four-digit-classification-code the first two-digit-code is assigned according to the predominant pattern and the second two-digit-code indicates the second pattern. If there is not a *distinctly* predominant pattern existing, then the assigned code is the first broad preliminary classification in sequence from the list of Preliminary Classification Codes (for instance studs are listed numerically before waves).

3. More Than Two Distinct Pattern Types—The preliminary classification code does not tell more than two pattern types. If there are more than two distinct pattern types, the rules concerning the sequence are the same as at point 2 (The pattern codes, which are first in the list of Preliminary Classification Codes, are assigned). In a case when there are more than two main group patterns on a shoe sole code 50 (a complicated pattern type) is used. All patterns are however defined by the numerals and letters in the SOLE CLASS and HEEL CLASS-fields. (Feature Classification)

Feature Classification Code System

The feature classification code string is defined for all impressions. Shoe sole patterns are given classification codes according to what can be seen in imprints. Patterns, numerals, letters, motifs, brand names etc. appearing in the instep area of the outsole are classified also in a case they are not visible (in casts they might be). Numerals and letters form the code string. Numeral-letter(s) combinations and letters alone in that string indicate patterns, pattern shapes and certain features, which include the pattern design of a shoe sole. All test impressions and the scenes of crime impressions (partial and full shoe soles) are classified and recorded. These code strings are positioned in the fields of the FORESOLE_CLASS, INSTEP_CLASS, and HEEL_CLASS. The feature classification is designed to help in finding pattern designs and in linking crime scenes for partial shoe impressions. The application combines automatically the code strings in the fields mentioned above and, the whole code string is positioned in the SOLE_CLASS-field, where it is possible to make searches, if it is not known which part of the sole the crime scene impression is.

Principles of the Feature Classification

Concerning classifying shoe soles for the collection, it is considered that it should also be possible to search and find pattern designs for partial shoe impressions. Therefore, we have to evaluate, while classifying shoe soles, what conclusions we are usually able to make about a partial shoe impression. The shape of the impression probably shows which area of the sole is in question, and of course we recognize the larger area, such as a heel part etc. Furthermore we are able to utilize so called features, which include a sole pattern; for instance on many soles of sport shoes there exists a circle with one or more rings. The center of that circle might be solid or hollow. We are able to separate those different pattern designs of shoe soles by a different code, sequence of characteristics etc.

Pattern or Shape Inside Any Shape

We are able to determine that the numeral '9' means a hollow area (an engraving in the floor of the sole), the letter 'R' means a circular shape in general. Based on this determination, the code '9RR' (Fig. 2) indicates that a hollow, circular area is inside a circular stud and the code '8RR' (Fig. 3) indicates that a circular center separated from a pattern by a circular valley is solid (8 = solid, a raised section from the floor of the sole). Going further the code '9RT' (T = quadrangular) (Fig. 4) indicates that a hollow circular area is inside a quadrangular shaped stud.

According to the principles of the classification it is possible to determine a pattern or shape inside any shape. The code '8YR<Z-' (Fig. 5) means that there are ridges forming a zig-zag pattern inside a circle, which is surrounded by vertical bars (8 = ridge, Y = zig-zag, R = circular shape, < = surrounded, Z = bar, - = vertical) and the code 'K18Z' (Fig. 6) means that there are ridges forming a bar pattern in an uninterrupted border (K1 = uninterrupted border, 8 = ridge, Z = bar).

A bar pattern may also be described by the numeral '9' (9 = hollow/valley/ an engraving in the floor of the sole) for instance by the code 'K19Z', because ridges cannot appear without valleys. For the standardization of the classification it is better to keep ridges as a primary consideration.

The Converse All-Star is probably the most popular athletic shoe in the world [*4*]. In its molds there are small variations, for instance inside the horizontal strip in the heel there might be either horizontal (the bars are in the opposite direction to the strip) or diagonal bars. It is also possible to distinguish these features by classification. We are able to indicate that there are horizontal or diagonal bars inside the strip (Fig. 7 and 8). Strips in the Converse design shoes position between the heel and instep, and therefore they are not very exposed heavy wear. If 'bars inside the strip' is used as a searching criterion you will probably find several different shoe designs corresponding with the criterion. Two searching criteria naturally decrease the number of different designs matched. For instance, the features 'bars inside the strip' and 'a hollow quadrangular inside a quadrangular mesh' positioned in the heel area as searching criteria will in all probability correspond just with the Converse design shoe. Furthermore, the definition of the bar direction distinguishes variables of the Converse design.

It is also possible to tell whether there are numerals, letters and motifs inside any shape (Fig. 9).

Shape Inside a Mesh Pattern

A hollow quadrangle that is inside a quadrangular mesh could be described by the code '9TTTO' (9 = hollow, T = quadrangular area, O = mesh $\underline{=>}$TO = quadrangular mesh (Fig. 10). According to the classification principles the code '8TTO' means that there is a solid quadrangle inside a quadrangular mesh (Fig. 11).

Shape Surrounded by a Pattern

By the feature classification system it is also possible to indicate if there is a certain pattern around a defined shape. For instance the code '8JR<TO' indicates that a quadrangular mesh is surrounding a circular shape which includes numerals (8 = ridges, J = numerals, R = circular shape, T = quadrangular shape, O = mesh, TO = quadrangular mesh) (Fig. 12).

Concerning partial shoe impressions it is important to distinguish a shape/pattern inside another shape from a shape surrounded by a pattern (Figs. 13 and 14).

FIG. 2—*A hollow circular area inside a circular shape.*

FIG. 3—*A solid circular area inside a circular shape.*

FIG. 4—*A hollow circular area inside a quadrangle.*

FIG. 5—*Zig-zags inside a circular shape, which is surrounded by vertical bars.*

FIG. 6—*Bars in an uninterrupted border.*

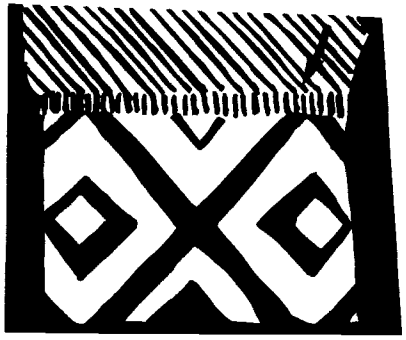

FIG. 7—*Horizontal (the opposite direction of the strip) bars inside the strip.*

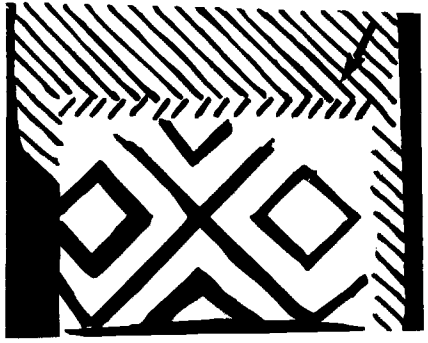

FIG. 8—*Diagonal bars inside the strip.*

FIG. 9—*Numerals inside a circular shape.*

FIG. 10—*A hollow quadrangle inside a quadrangular mesh.*

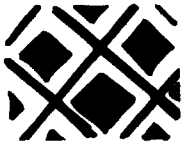

FIG. 11—*A solid quadrangle inside a quadrangular mesh.*

FIG. 12—*A quadrangular mesh surrounding a circular shape, which includes numerals.*

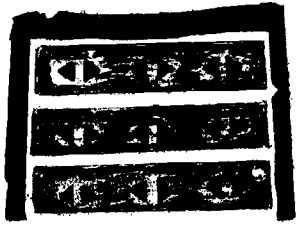

FIG. 13—*Triangular studs inside a bar pattern.*

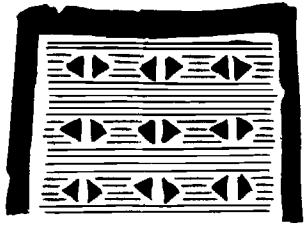

FIG. 14—*Triangular studs surrounded by a bar pattern.*

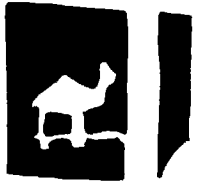

FIG. 15—*The motif is engraved in the border of the sole.*

FIG. 16—*Unusual shaped studs are on the edge of the sole.*

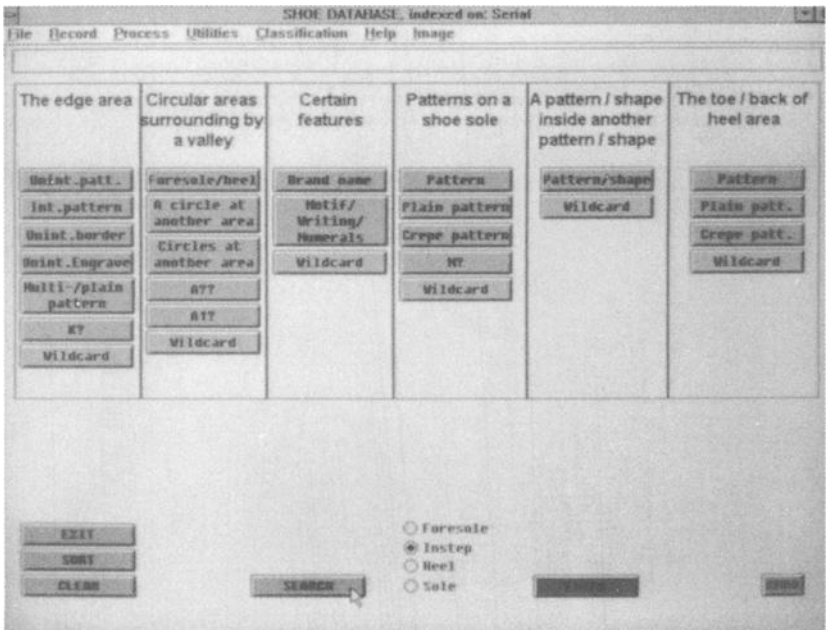

FIG. 17—*The main level of the feature classification.*

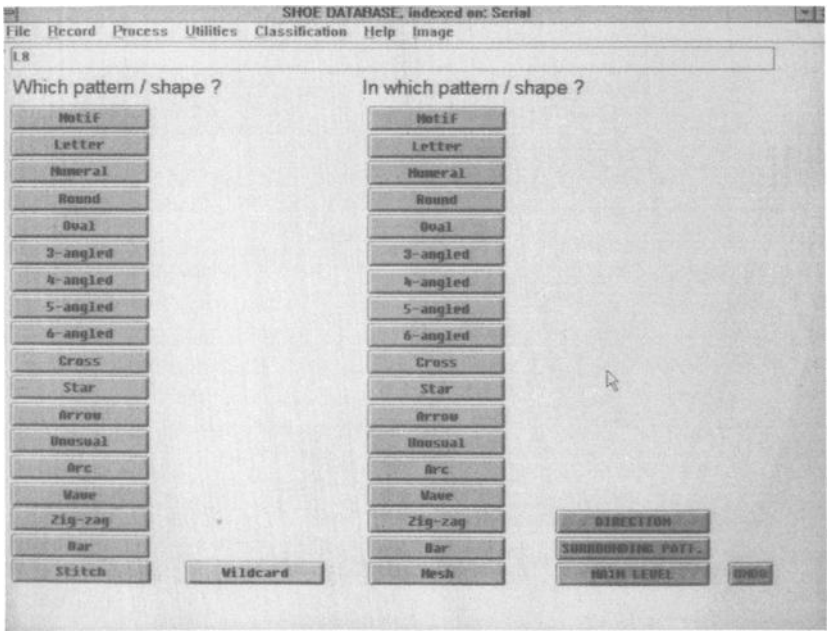

FIG. 18—*The choosing level of a pattern or shape.*

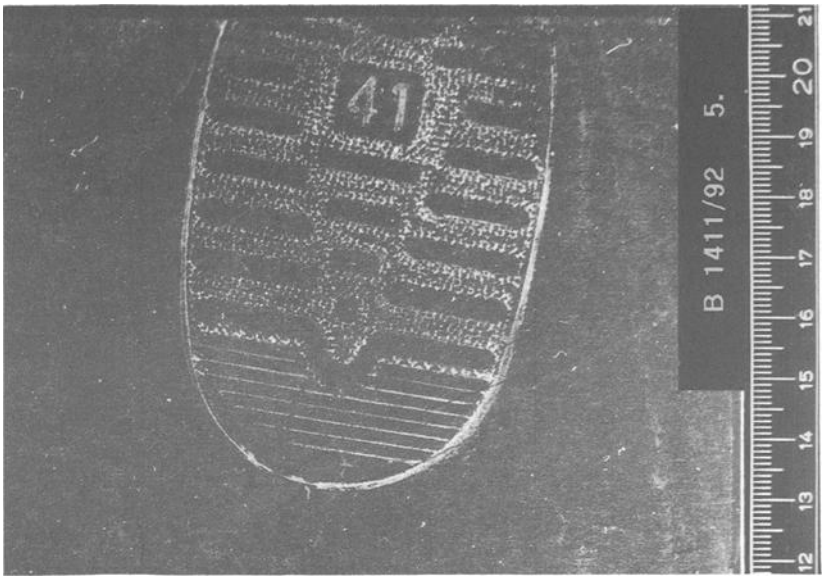

FIG. 19—*The crime scene impression used as a searching criterion.*

Uninterrupted Edge

The code 'K1' denotes an uninterrupted border. If there is a certain pattern or shape in that border, the letter 'K1' will be defined. For instance 'K19H' (Fig. 15) means that a motif shaped depression appears in an uninterrupted border and 'K18Z' (Fig. 6) that a bar pattern appears in an uninterrupted border.

Interrupted Edge

The code 'K2' indicates that on a shoe sole, there is a certain interrupted pattern along the perimeter of the foresole, instep or heel (Fig. 16; 'K28W', unusual shaped studs are on the edge of the sole).

Code String for Feature Classification

It is advantageous to form all kinds of codes if the code indicating a certain feature is formed by individual characteristics (numerals and letters). The entire code string is formed by several short codes. And one code is formed with one letter or numeral-letter combination. Because the classification codes are constituted piece by piece, new outsole designs do not cause problems.

Order of the Codes

The order of codes is instructed by the application and the user has to follow the suggested order of the codes (Especially, when the user wants to utilize the automatic comparison of the respective code fields for recorded crime scene impressions) (Fig. 17). At first a border or an edge area of a sole is classified. The second task is to classify certain circles including an inside pattern, number of ring(s) and a possible surrounding pattern. After that come brand name, motifs, writing and numerals. Then the application requests answers what kind

of patterns there are existing on a sole. The application continues with queries concerning a pattern or shape inside another shape (Fig. 18). And the last code(s) in the classification code string indicates a pattern, shape or feature on the toe area or back-of-heel area.

Case Example

The police of a location in southwestern Finland requested a statement from the Crime Laboratory in a burglary case. Ecco design shoes and the recorded crime scene impressions were received for comparison. The conclusion of the comparison was negative because of air bubbles existing in different places in the outsole of the Ecco shoes and the crime scene impressions (Fig. 19). It was noticed that there was also another shoe design (triangular studs in a continuous border and bars in a foresole Fig. 20) among the recorded crime scene impressions. The coded crime scene impression (Fig. 19) was used as a searching criterion and the comparison was performed. The result of the search was four Ecco design shoes, of which the two pairs had the same size number as the crime scene impression. Another pair of these same sized Ecco design shoes had been received for the statement from a location in southeastern Finland, and the owner of the shoes was suspected of committing a burglary. Besides Ecco design, another same kind shoe design was discovered both in the southwestern location and southeastern location (Fig. 20). There had been a time period of two days between the burglaries which were linked. Hints were sent to both police units.

Discussion

The classification is based on the recognition of features on shoe soles. The definitions of the shapes and patterns have been simplified to reduce the possibility of confusing and the effect of different human interpretations. For instance, a shape having four angles is

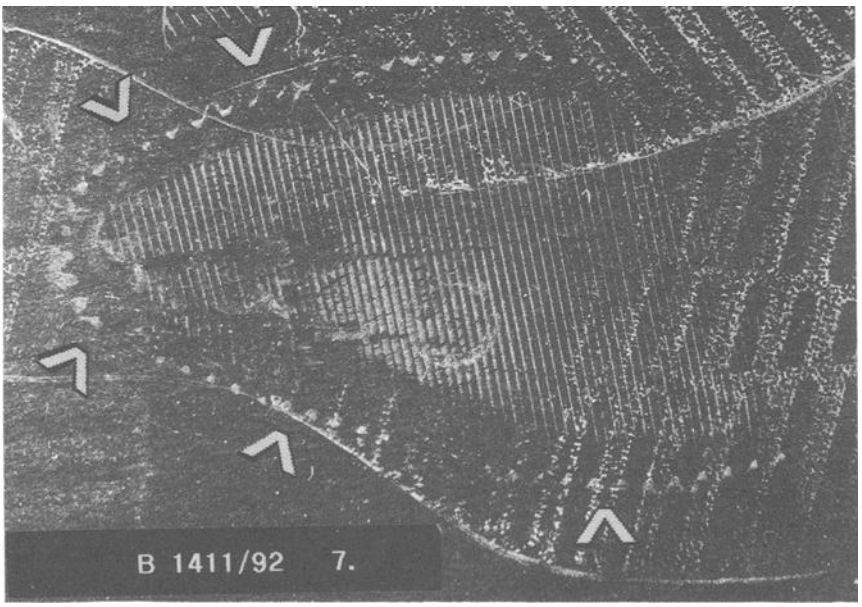

FIG. 20—*Another shoe design found at crime scenes.*

assigned a quadrangle, therefore there exists no diamond shape at all in the classification codes. Another example is a bar pattern in which the width to length ratio must be smaller or equal than 1:5 and furthermore the opposite sides are approximately parallel.

The quite complicated classification coding of the sole patterns was made more user-friendly and a kind of 'interactive' by developing separate input and search interfaces. An operator may build classification code strings piece by piece by selecting an option button for queries appearing in logical order. This allows effective inputs and searches without necessity to care about codes.

The application allows the following definitions of the features existing on shoe soles:

- Location of a pattern (foresole, instep, heel, edge, toe area or back-of-heel area).
- Character (a solid or hollow in a outsole) and shape of the pattern or feature.
- Pattern/shape inside any shape.
- Shape surrounded by any pattern.
- Direction of an arrow, a bar, wave, arc or zig-zag pattern.

Until now the system has been tested in laboratory conditions. It has recently been set up in a local police unit for pilot phase testing. According to the experiences collected, the feature classification seems to be flexible because it permits a feature to be constituted of the defined basic shape(s) and the certain definition(s). The user must only follow the simple principles and order of the coding while classifying. The classification could also be used both at a very accurate level (as it ought to be for the reference collection in a network in a police unit) and a lower level (as the local collection of crime scene impressions and of shoes of suspects). Because the coding is started from the center of the feature going outwards, it is easy to make an agreement at the local level which is sufficient accuracy.

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