NITED STATES
ARTMENT OF
MMERCE
BLICATION

NBS TECHNICAL NOTE 712

Manual and Computerized Footprint Identification

U.S.
ARTMENT
OF
MMERCE
Nati
Bu
Stand

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation[2]—Nuclear Radiation[2]—Applied Radiation[2]—Quantum Electronics[3]—Electromagnetics[3]—Time and Frequency[3]—Laboratory Astrophysics[3]—Cryogenics[3].

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following divisions and offices:

Engineering Standards Services—Weights and Measures—Invention and Innovation—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering—Office of Fire Programs.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

UNITED STATES DEPARTMENT OF COMMERCE
Maurice H. Stans, Secretary
U.S. NATIONAL BUREAU OF STANDARDS • Lewis M. Branscomb, Director

NBS TECHNICAL NOTE 712

ISSUED FEBRUARY 1972

Nat. Bur. Stand. (U.S.), Tech. Note 712, 13 pages (Feb. 1972)
CODEN: NBTNAE

Manual and Computerized Footprint Identification

J. H. Wegstein

Center for Computer Sciences and Technology
National Bureau of Standards
Washington, D.C. 20234

NBS Technical Notes are designed to supplement the Bureau's regular publications program. They provide a means for making available scientific data that are of transient or limited interest. Technical Notes may be listed or referred to in the open literature.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.
(Order by SD Catalog No. C 13.46:712). Price 25 cents.

Manual and Computerized Footprint Identification

by J. H. Wegstein

Part 1 describes a manual footprint classification system that utilizes the ridge patterns adjacent to the toes on the sole of the right foot. This system is an extension of the FBI footprint classification system. Part 2 describes a method of coding minute details of these prints for storage in a computerized file. The computer can then search a similarly coded unknown print against this file and identify the most likely matching prints from the file.

Key words: Computerized-footprint-identification; footprint; pattern recognition.

Introduction

For personal identification, the use of fingerprints is the most common and most developed technique. However, other dermatoglyphic areas on palms, toes and soles of the feet can also serve to uniquely identify an individual.[1] This paper describes an identification system utilizing the sole print of the right foot. The area of the sole starting at the base of the toes and running for about 70 mm toward the heel is used. Prints may be obtained by inking and pressing the sole on a flat surface or by internal reflection photography utilizing a light source, prism, and camera.[2] The latter resulting high-contrast image resembles an inked print. This principle applies when one observes, through a glass of water, the prints of the fingers holding the glass. Figure 9 was made from an internal reflection photograph and shows the area of the sole that is used.

If a technician is given two dermatoglyphic prints of the same area, such as the soles of the feet, he can immediately tell by inspection of the prints whether they are from the same person. In making this identification, he utilizes minute details in the prints, particularly, ridge endings and bifurcations in the ridges that are hereafter referred to as minutiae.

When an unknown print is to be searched against a file of prints, making a positive identification is a minor problem compared to the task of finding the matching print in the file. To facilitate finding a print in a file, it is classified using the gross patterns that occur in the ridges. The resulting classification is then used to locate the print in the file. The classification of a search print should agree closely enough with the classification of a file print that only a few prints from the file need to be compared with the search print.

The remainder of this paper is divided into two parts. Part 1 describes a system for manually classifying, filing, and searching prints from the right foot. Part 2 describes a method of coding and storing right-footprint information in a computer memory so that a computer can identify an unknown footprint by comparing its code with other codes previously stored in its memory or mass store.

Part 1.

Manual Classification and Search

The manual classification system is a modification and extension of the Federal Bureau of Identification footprint classification system described in two issues of the FBI Law Enforcement Bulletin.[3,4] It is assumed that the reader who wishes to classify footprints will study these references. The precise definition of cores, deltas, and major pattern types requires further study of the basic FBI manual on fingerprints[5].

The complete classification for right-foot prints described here consists of three parts labeled PS, DST, and FIN. The classification for four typical prints appear as follows:

PS	DST	FIN
02	nu	-
La	m	22
Ww	mω	12
Wd	u	8

PS, short for Primary-Secondary, refers to the eight different patterns of ridges that occur on the ball of the foot immediately below the great toe. These are:

01 Ridges are plain arches that tend to flow from toe to heel.

02 Ridges are plain arches that tend to flow across the foot.

La Loops where staples point toward the toes.

Lb Loops whose staples point toward the great-toe side of the foot.

Ld Loops whose staples point toward the right and toward the heel of the foot.

Ww Whorls

Wd Double loops.

Wx Patterns that do not conform to any of the above types--called accidentals.

Schematic diagrams for these types of patterns are shown in Figures 1 and 2. These diagrams merely summarize the more elaborate FBI rules for primary-secondary pattern definition.

The classification system described here is intended to handle a larger file than the FBI system was designed to handle and differs from the FBI system as follows. The FBI classification includes only parts labeled PS and FIN for the right foot along with similar parts for the left foot. The system described here utilizes only the right footprint but includes an extra part called DST that makes use of the patterns in the remainder of the distal part of the sole. The ridge pattern on the interdigital pads below the toes may include no loops or it may include combinations of loops whose staples point up or down. A loop is considered to occur if at least one ridge recurves to form a staple. The various possible patterns are shown schematically in Figure 3 along with their DST designations. To elaborate on Figure 3, two or more downward pointing staples are designated M. Two or more upward pointing staples are designated ω. When upward and downward pointing staples both occur, it is immaterial whether they do or do not form a whorl.

The part of the classification called FIN is the distance in millimeters between a core and delta of the PS pattern (if a core occurs). The line along which FIN is measured is shown schematically as a fine straight line in Figures 1 and 2. Note that types 01 and 02 have no FIN number. In Ld, Ww, and Wd type prints where there are two deltas, the distance is measured from the upper delta to the core. The core point used is defined as the point on the innermost curving ridge where the curvature is greatest. In La type prints FIN is measured from the core to the delta on the great-toe side of the sole of the foot. In Wd type prints there are two cores and FIN is measured from the upper delta to the nearest core. Some additional examples of type Wd prints are shown in Figure 4 along with core-delta lines.

In the FBI system the FIN (or "final") part of the classification is obtained by counting the number of ridges that occur between the core and the delta. An FBI classification of a print is entirely topological in nature and is invariant to the size of the print. It does not change during the time an individual grows from a baby to a mature person. In contrast, the system described here is intended for use on prints from mature persons. The core-delta distance, in millimeters, is not expected to change significantly and, accordingly, it is used in lieu of the more difficult-to-obtain ridge count. The complete classification for the footprint shown in Figure 9 is: Ww nw 21.

Prints are filed in the PS sequence shown in Figures 1 and 2. Within each PS group the prints are filed in the DST sequence shown in Figure 3. And, finally, within each DST group the prints are filed in numerical order as indicated by FIN. Only those prints of good enough quality to be classified should be filed.

When an unidentified print is to be searched against the file, it is classified according to the above rules. It is then compared with prints having the same classification from the file. It must also be compared with neighboring prints from the file whose FIN values differ from that of the search print by as much as two or three millimeters plus or minus. If the search print is of such poor quality that there is an uncertainty in the value of PS or DST, then other prints from the file corresponding to possible PS and DST values of the search print must also be examined. In comparing prints a technician notes agreement in peculiarities of ridge patterns, but he makes final decisions based on exact correspondences of minutiae patterns. Creases, scars, and other marks that may be of a temporary nature are ignored.

Part 2

Codification and Computerized Search

Digitalized descriptive information suitable for use by a computer is obtained from specific areas adjacent to cores in the PS region of the footprint. Such an area might appear as shown in Figure 5. Ridges are observed in a clockwise direction from left to right and minutiae are given coded values, θ, as follows. Ridge-endings such as minutiae b, e, and g in Figure 5 have a value $\theta = 0$. Ridge-beginnings such as minutiae a and d have a value $\theta = 1$. Since a splitting of one ridge into two ridges such as minutia j might appear as a ridge-beginning if the print were less heavily inked, it too is given a value $\theta = 1$. Similarly, merges in ridges such as c are given the value $\theta = 0$ as though they were ridge endings. Breaks in ridges like f that are shorter than the distance between two ridges are ignored. Short ridges like i that are shorter than the distance between two ridges are also ignored. Incipient ridges like h are ignored. Ridges that "kiss" or touch briefly as at k are not coded.

Each minutia that is given a θ value is also given coordinate values x and y by superimposing a rectangular grid over the area as shown in Figure 6. The grid units are 0.5 mm and the grid covers an area of 15 mm x 10 mm. The grid is oriented so that the x axis passes through a delta and is tangent to the innermost recurving ridge of a core at the point x = 15. One convenient way to read minutiae data is to project the print with a ten power opaque projector. A suitably enlarged grid is then placed on the projected image. The positioning of the grid for each of the different PS pattern types is shown in Figure 7. Figure 8 shows the grid position to use on the illustrated variant of type La. To read minutiae data, one first locates each minutia as illustrated in Figure 5 then records the nearest x, y coordinates along with θ. The data corresponding to Figure 6 appears as follows:

x	y	θ
15	01	0
13	01	0
13	02	1
16	02	1
18	02	0
14	03	0
16	03	0
14	04	1
16	04	1

The number of minutiae per footprint that are recordable in this manner ranges from 5 to about 25. A set of data like this for each footprint along with its identification and classification (PS, DST, FIN) is read into a computerized file. The rather rare types 01 and 02 that have no core are not handled by this system.

When an unknown footprint is to be identified, its minutiae data are recorded as above and read into the computer. The computer compares this data from the unknown print with each set of data in its file and computes a score indicating how well the two prints match. The computer then prints the identification and classification of those file prints having the highest matching scores. A technician then compares the unknown print with each print from the file that the computer has indicated to be a possible match.

The algorithm used by the computer in comparing footprints is shown in flow diagram form in Figure 10. It is a slightly simplified version of the M19 matcher described in National Bureau of Standards Technical Note 538[6]. Here IMX is the number of minutiae in a print; Ident is the identification of the print including its classification; and array A contains the values x, y, and θ as shown at the bottom of Figure 10. Corresponding minutiae are used in making the identification, but they need not coincide. The tolerated amount of displacement is determined by the parameters LS and KR.

This work was performed at the NBS Center for Computer Sciences and Technology and was encouraged by the Center's Director, Dr. Ruth M. Davis. The author is also indebted to Mr. John Rafferty of NBS and to Mr. Alan Meyrowitz of the Special Action Office for Drug Abuse Prevention for testing this footprint identification system. He also appreciates the advice received on footprint identification problems from Mr. H. Caton of the Federal Bureau of Identification.

References

1. Cummins, H. and Midlo, C., Fingerprints, Palms and Soles, Dover Publications, Inc., New York 1961.

2. Harrick, N. J., Internal Reflection Spectroscopy, Interscience Publishers, New York, 1967, pp. 3-6.

3. "Classification of Footprints, Part I", FBI Law Enforcement Bulletin 40, 9 (September 1971), pp. 18-22.

4. "Classification of Footprints, Part II", FBI Law Enforcement Bulletin 40, 10 (October 1971), pp. 23-27.

5. The Federal Bureau of Investigation, The Science of Fingerprints, U.S. Government Printing Office, Washington, D.C. 1963.

6. Wegstein, J. H., Automated Fingerprint Identification, National Bureau of Standards Technical Note 538, U.S. Government Printing Office, Washington, D.C., 1970.

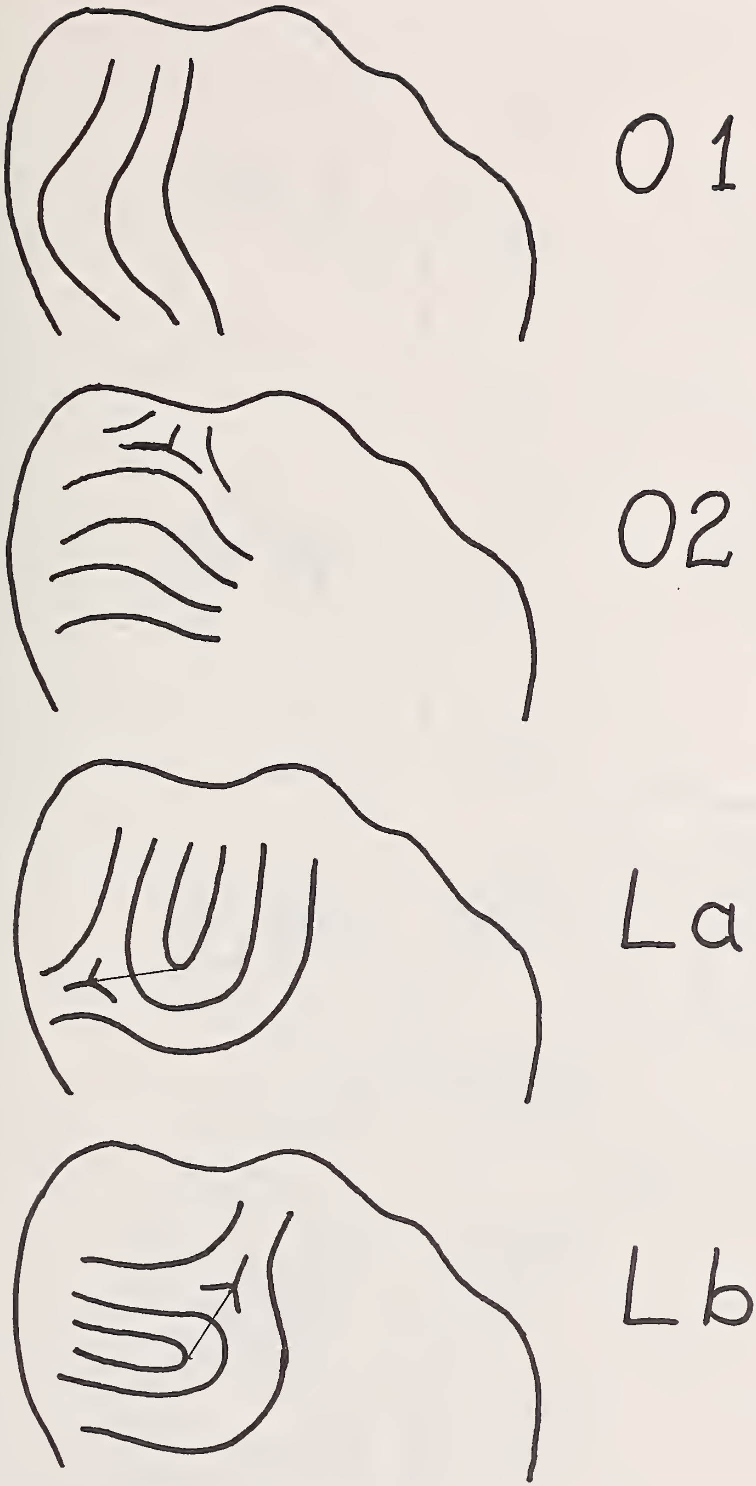

Figure 1. PS Pattern Designations

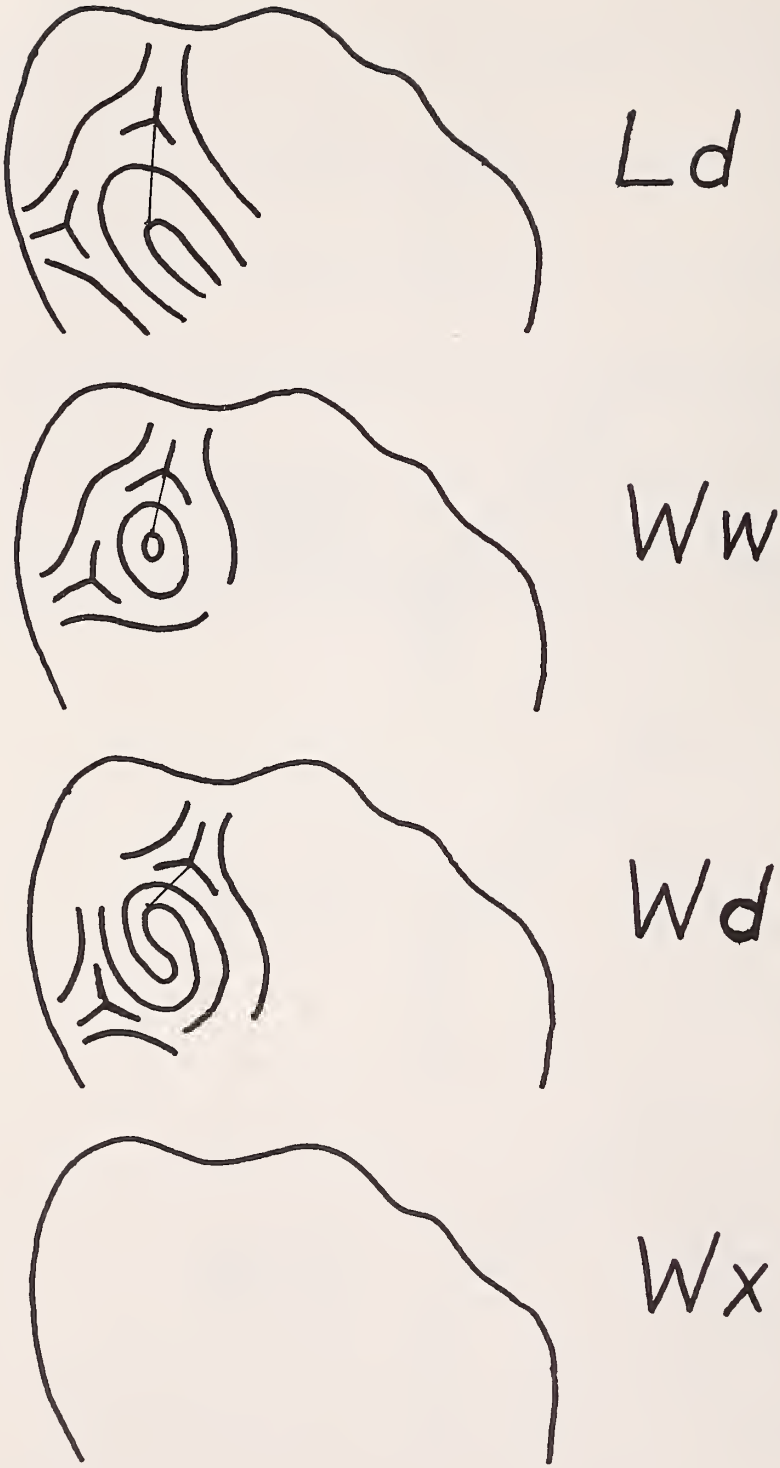

Figure 2. PS Pattern Designations (Continued)

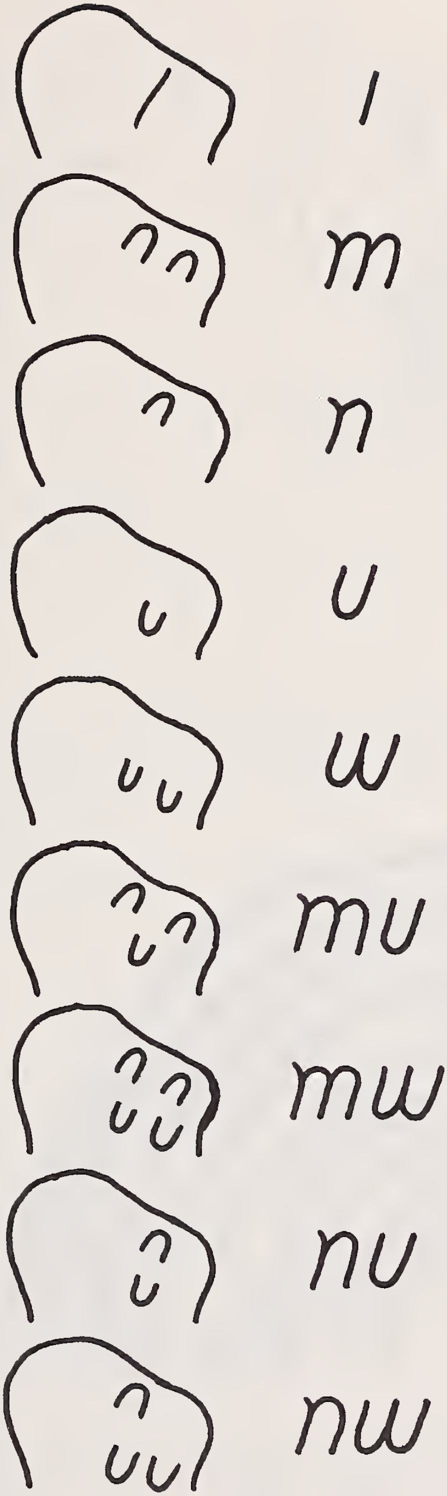

Figure 3. DIST Pattern Designations

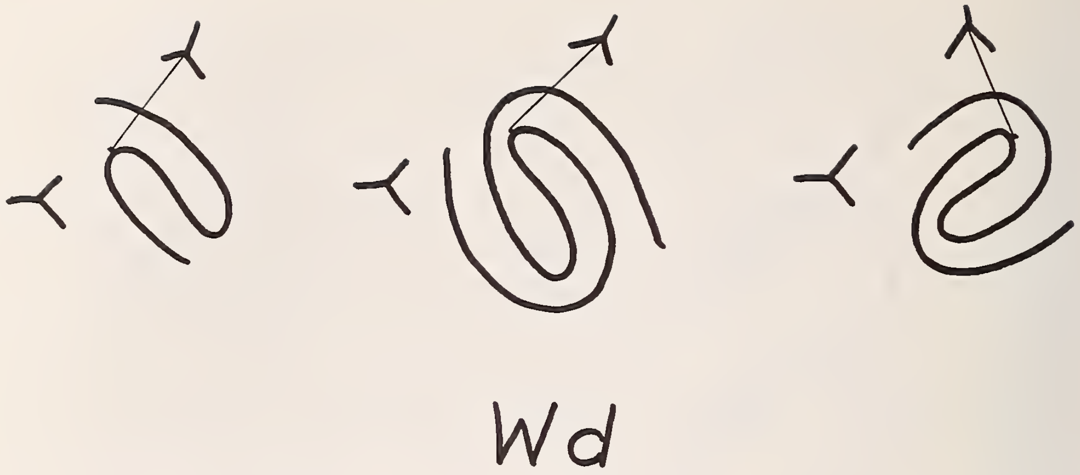

Figure 4. Core-Delta Lines on WD Prints

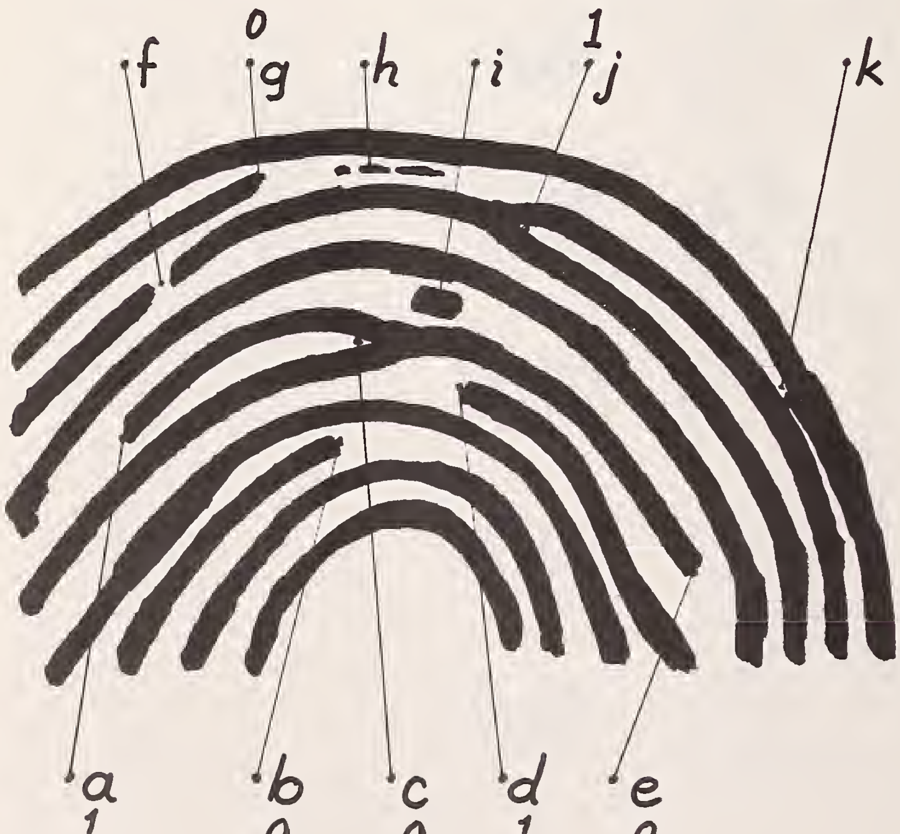

Figure 5. Minutiae Identifications

Figure 6. Grid for Reading Minutiae Data

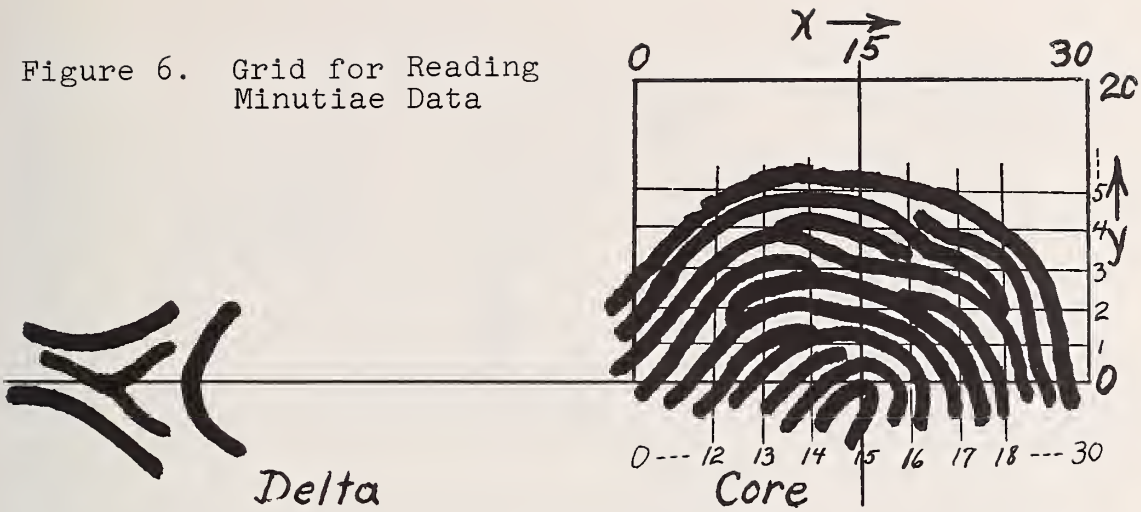

Figure 7. Placement of Grid on Various Types of Prints

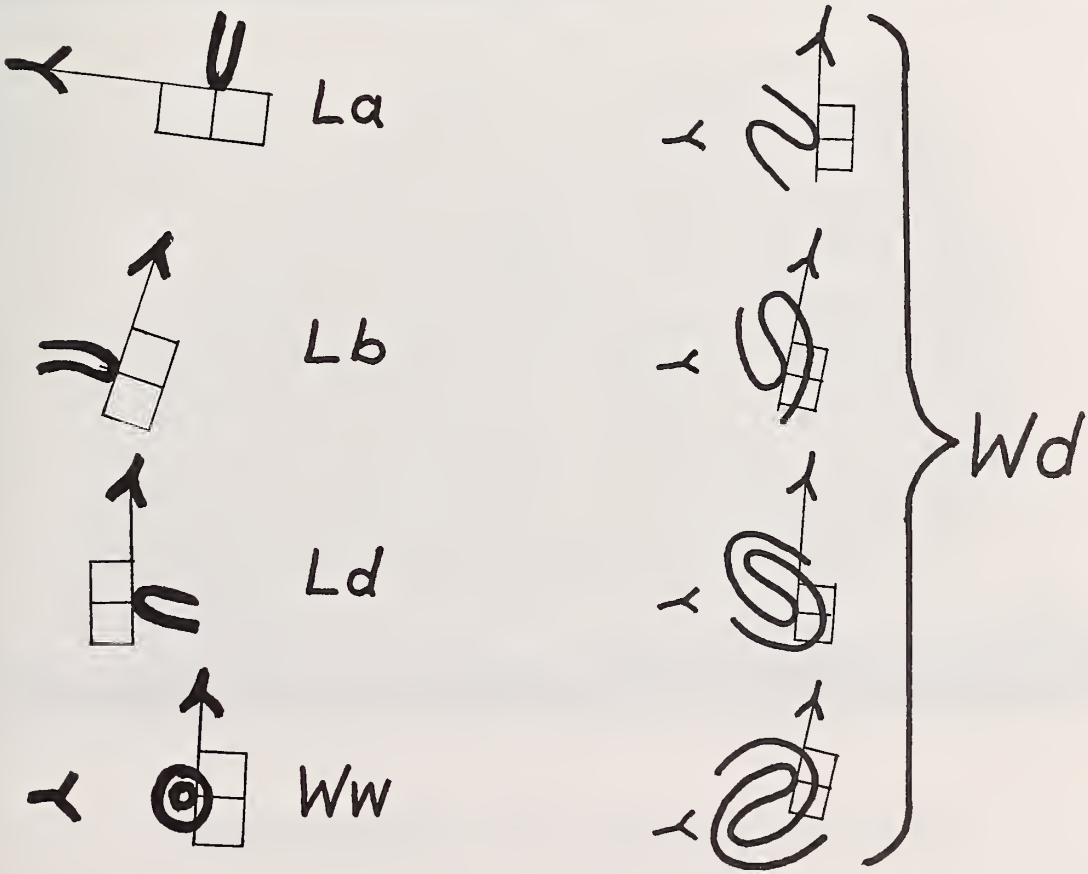

Figure 8. Grid Placement on Variant La Print

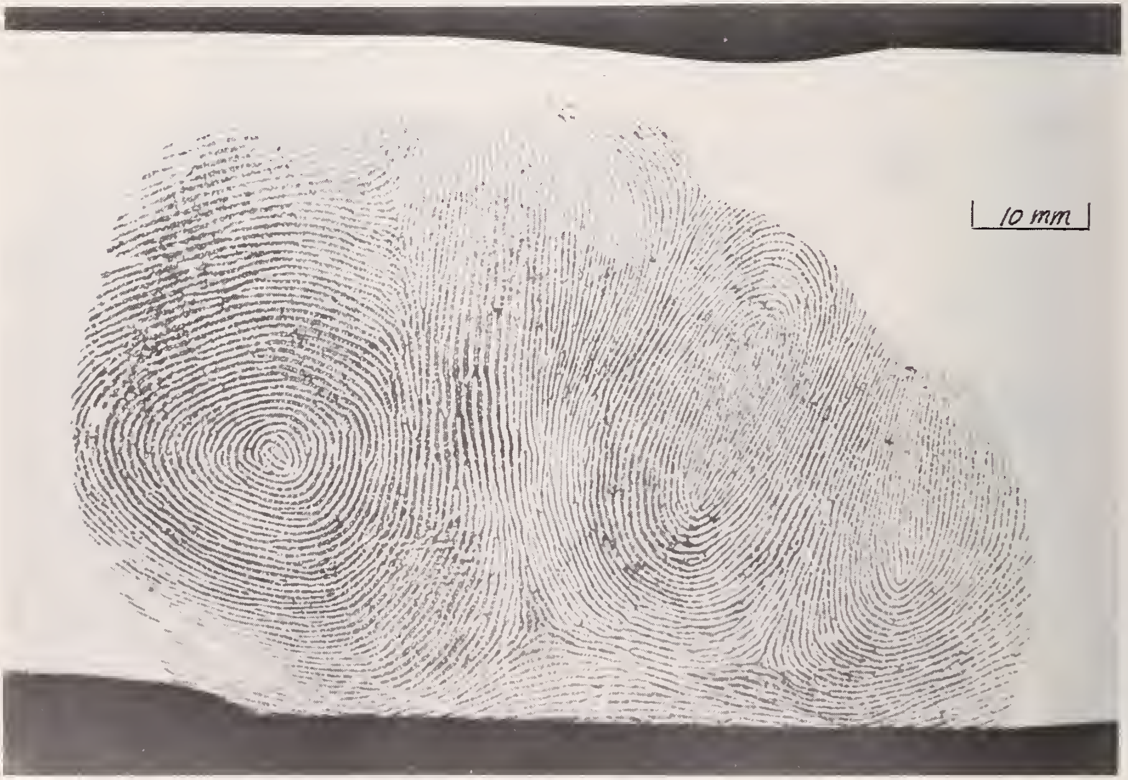

Figure 9. Footprint with Classification:
Ww nw 21

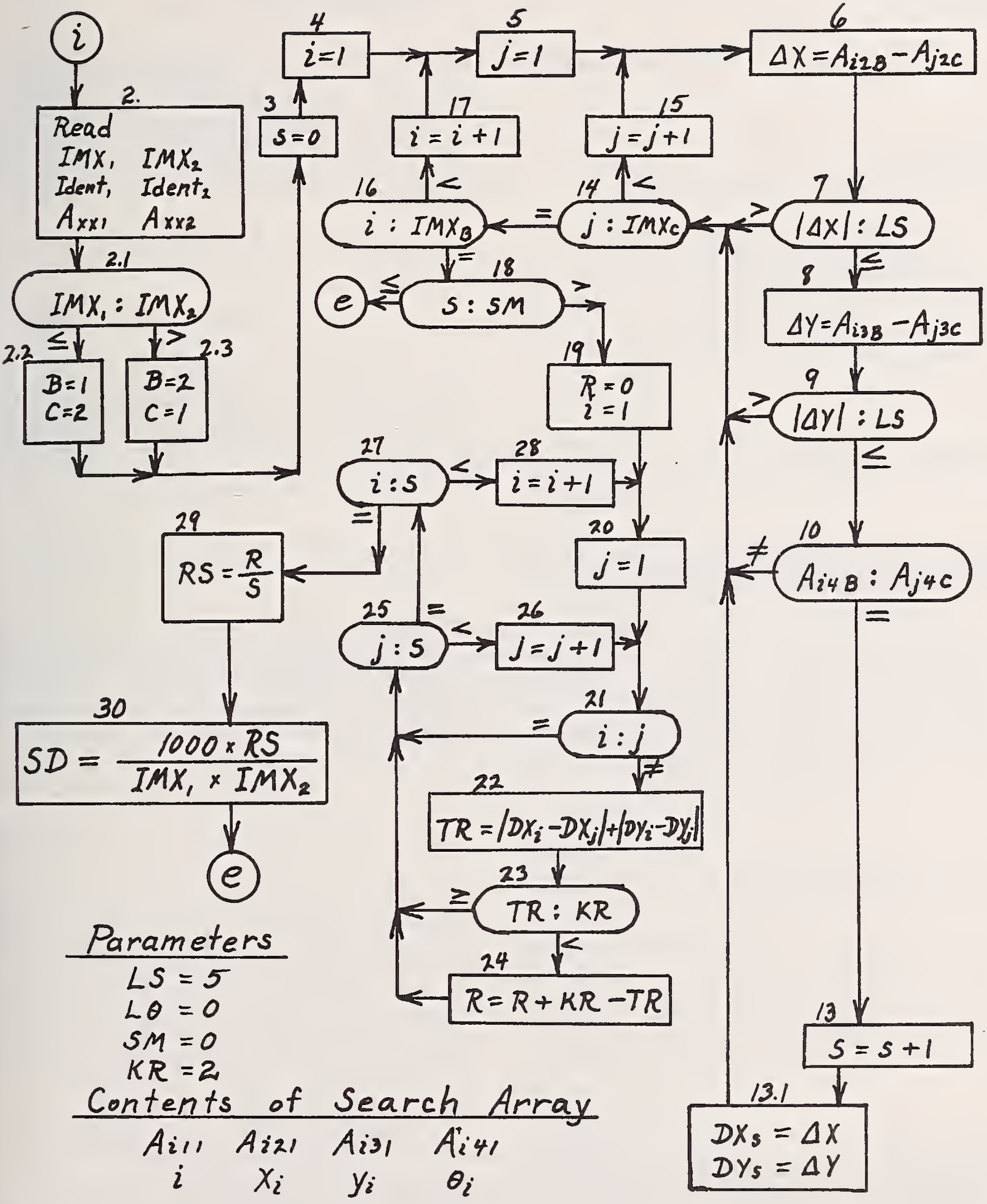

Figure 10. Footprint Matching Algorithm

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972--481-330/165

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS-TN-712	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Manual and Computerized Footprint Identification			5. Publication Date January 1972
			6. Performing Organization Code
7. AUTHOR(S) J. H. Wegstein			8. Performing Organization
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 600 4114
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address Same			13. Type of Report & Period Covered Final
			14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Part 1 describes a manual footprint classification system that utilizes the ridge patterns adjacent to the toes on the sole of the right foot. This system is an extension of the FBI footprint classification system. Part 2 describes a method of coding minute details of these prints for storage in a computerized file. The computer can then search a similarly coded unknown print against this file and identify the most likely matching prints from the file.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Computerized-footprint-identification, footprint, pattern recognition.

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[XXX] UNLIMITED.	UNCLASSIFIED	13
[ ] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $.25

USCOMM-DC 66244-P

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, chemistry, and engineering. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts.

Published in three sections, available separately:

- **Physics and Chemistry**

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, $9.50; $2.25 additional for foreign mailing.

- **Mathematical Sciences**

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemisty, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, $5.00; $1.25 additional for foreign mailing.

- **Engineering and Instrumentation**

Reporting results of interest chiefly to the engineer and the applied scientist. This section includes many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It will also cover some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Annual subscription: Domestic, $5.00; $1.25 additional for foreign mailing.

TECHNICAL NEWS BULLETIN

The best single source of information concerning the Bureau's research, developmental, cooperative, and publication activities, this monthly publication is designed for the industry-oriented individual whose daily work involves intimate contact with science and technology—*for engineers, chemists, physicists, research managers, product-development managers, and company executives.* Annual subscription: Domestic, $3.00; $1.00 additional for foreign mailing.

NONPERIODICALS

Applied Mathematics Series. Mathematical tables, manuals, and studies.

Building Science Series. Research results, test methods, and performance criteria of building materials, components, systems, and structures.

Handbooks. Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications. Proceedings of NBS conferences, bibliographies, annual reports, wall charts, pamphlets, etc.

Monographs. Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

National Standard Reference Data Series. NSRDS provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated.

Product Standards. Provide requirements for sizes, types, quality, and methods for testing various industrial products. These standards are developed cooperatively with interested Government and industry groups and provide the basis for common understanding of product characteristics for both buyers and sellers. Their use is voluntary.

Technical Notes. This series consists of communications and reports (covering both other agency and NBS-sponsored work) of limited or transitory interest.

Federal Information Processing Standards Publications. This series is the official publication within the Federal Government for information on standards adopted and promulgated under the Public Law 89–306, and Bureau of the Budget Circular A–86 entitled, Standardization of Data Elements and Codes in Data Systems.

Consumer Information Series. Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

NBS Special Publication 305, Supplement 1, Publications of the NBS, 1968-1969. When ordering, include Catalog No. C13.10:305. Price $4.50; $1.25 additional for foreign mailing.

Order NBS publications from: Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE

U.S.MAIL