# An Automatic Bullet Cartridge Identification System

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## Abstract

*In this paper we present a bullet cartridge head stamp identification system. The present work uses mainly generic structural and symbolic properties of a head-stamp and the generic parameters (bore, caliber etc.) of a bullet. The knowledge base contains very simple and general information based on forensic model. The method is very flexible, based on simple object registration and matching technique. A circular invariant class separator is developed which can be used in wide class of pattern classification problem. The system is working at Central Forensic Science Laboratory, Calcutta.*

*Key Words: Head stamp, data chunks and circular invariant search.*

## 1. Introduction

Pattern recognition and computer vision methodologies find many different application areas. One of the important areas is automatic inspection and identification of industrial objects. Here we address an interesting problem of automatic classification and identification of bullet cartridges from their head stamp codes. This classification and identification is one of the central areas of forensic investigation.

In the present work, different types of bullet cartridges constitute the object space. Cartridge heads are metallic objects circular in shape. On these circular heads some concentric circles and characteristic marks are impressed by the marker. This is technically known as the head stamp. The impressions are usually a set of numbers, alphabet, geometrical patterns and typical symbols. In the books on forensic ballistic science [1], the meanings of these marks are given in details. It is clear enough that once the head-stamps are read correctly, it is possible to extract the following information:

1. Country of origin,
2. Name of manufacturer,
3. Year of production,
4. Bore or caliber etc.

These information help the investigator to decipher the motive behind the crime.

The present work addresses a complete software package to do this job. The software has two principal modules. The first module is an image database. Different identifiable features of the head stamp are the fields of the database. Each row of the database also includes the code number of the bullet and its description available in the forensic archive. The second module is a combination of pre-processing, feature extraction and pattern matching algorithms. The image of the head stamp in 128 x 128 pixels and encoded in 256 gray levels, taken by a digital camera is the input to the algorithm. When a test cartridge is the subject of identification, the software extracts features out of it and goes through a search process to find the maximum match in the database. It selects a particular entry of the database as the matched pair to the cartridge under test, where the match score is maximum. The patterns are usually static. But their separation in the feature space is not always wide. Sometimes even nearly overlapping features appear. To solve this problem we have used a hierarchical search process which is based on an angle invariant search algorithm.

In section 2 a brief description of the problem and the rule base is provided. Descriptions of the different modules of the software are provided in section 3. Section 4 finds the system specification and result.

## 2. Mechanics of identification

The basic steps of identifying an unknown cartridge, firstly, is to identify the weapon with which it is associated by means of measuring its principal dimensions. In order to make this search more systematic, the cartridge world is divided into a number of groups based upon their shapes. Within each of these groups, the dimensions are tabulated in ascending order of the rim dimension. Thus, after determining the shape group, the rim of the case should be measured and the relevant table should be consulted at the measurement. For the infrequent event of two cases having the same rim diameter, the other tabulated dimension-length, body, neck and cartridge diameter should be compared with the specimen until a match is made. Within each group of rim diameters the cases are listed in ascending order of case length.

The next layer of searching deals with the query, “who made it and when?” Here the head stamp is the only guide and in some cases the head stamp gives even more information. In the present work only the recognition through head stamp is addressed. Typical head stamp consists of concentric circles of different diameters.

letters, numerals, symbols are arranged in some manner around the cartridge head. To reduce the search space, a series of “type patterns” are adopted as separate classes. Based on the positional occupancy of the objects, we divide the search space into twelve categories. Along the circumference of the circle four principal positions have been selected. These are 12 o’clock position, 3 o’clock position, 6 o’clock position and 9 o’clock position. The distribution of patterns is the source of group classification [1].

The classification rules can be described linguistically as follows:

Type-1: A stamp bearing two items of information, disposed $180^{0}$ from each other, at 12 o’clock and 6 o’clock position.

Type-2: Two items of information, $180^{0}$ apart, at 3 o’clock and 9 o’clock position.

Type-3: Three items, disposed $120^{0}$ apart.

Type-4: Four items, disposed $90^{0}$ apart.

Type-5: One item, placed at the 12 o’clock position.

Type-6: Five patterns, equispaced $72^{0}$ apart.

Type-7: Four patterns at $90^{0}$ apart, divided by radial lines.

Type-8: Two items, as Type-1, divided by radial lines at 3 and 9 o’clock.

Type-9: Cases on which the information (usually address) is written continuously around the head stamp.

Type-10: Cases in which the mark is impressed (or raised) in the center of the head-stamp.

Type-11: Three items of information, $90^{0}$ apart at 12,3 and 9 o’clock position.

Type-12: One item of information, at the 6 o’clock position.

The head stamp of type groups are shown in Fig.1, Fig.2 shows the flow diagram of the hierarchical search process.

## 3. Brief description

### 3.1. Pattern registration and Normalization

In the present problem the object is circular in shape and the patterns are arranged in circular orientation. In a circular arrangement infinite invariant orientation is possible and without proper registration, matching will not give the correct result. We have utilized a fully automated non-rigid image registration method that maximizes a local pixel-based similarity metric, the correlation ratio. Overlapping image blocks are defined using a square (128 x 128) grid pattern. The transformation vector required to achieve local registration is found by rotating the test pattern so as to maximize the local similarity measure. The resulting sparsely sampled angular vector field is interpolated to obtain a locally smooth transformation between the test and stored images. We use a coarse – to – fine approach to capture local deformation associated with large scale low-resolution structures and fine details. The rotation is

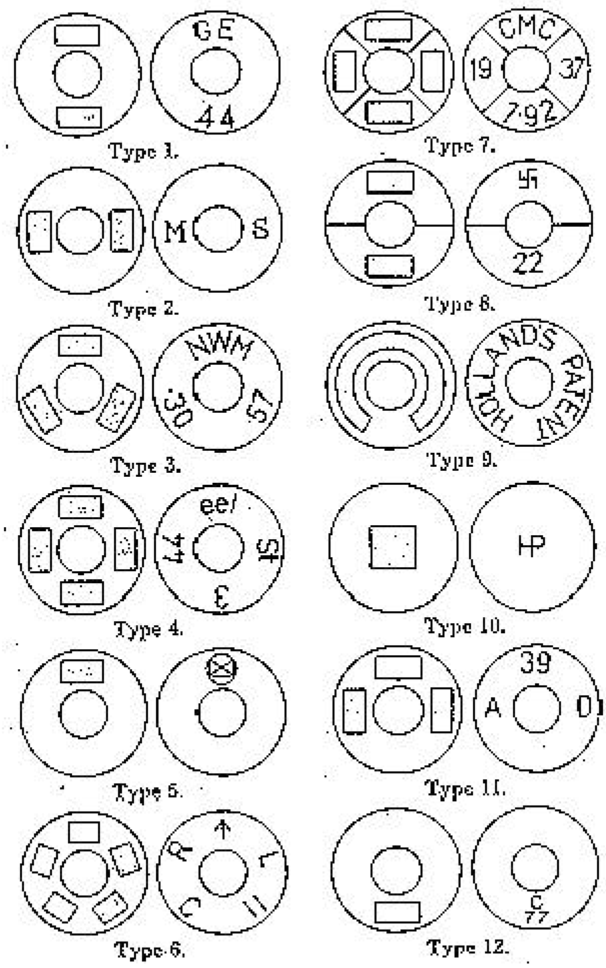


**Fig 1.** Head stamp type groups

done with respect to the center of the test pattern obtained through Hough transform. Another point to note here is that, in our final level of searching we have used correlation matching of the test and stored patterns. For this both the patterns are normalized to (128 x 128) pixels.

### 3.2. Pre-processing

The true tone image of the cartridge, taken in controlled illumination, has distinct object and background regions and almost no noise. Isolated noise points, however, are removed by filtering. After the noise removal Hough transform is used to detect the center, radii and numbers of concentric circles in the image. To reduce the processing time we have utilized some a-priori information to select the accumulator cell in the Hough transform. Once the number of concentric circles,

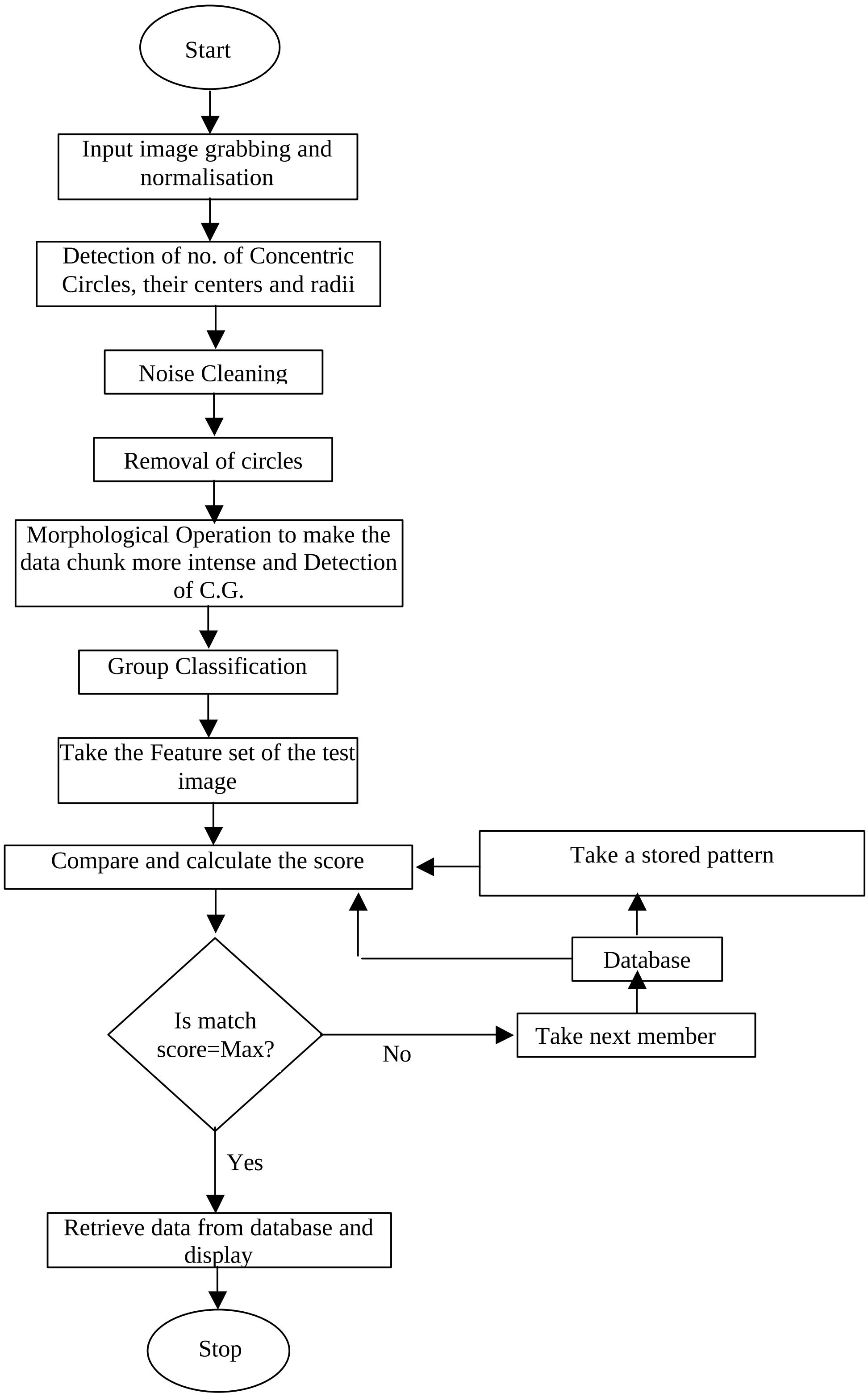


**Fig 2**. Flow chart of the complete recognition algorithm**.**

coordinates of their center and their radii are known, they are recorded and removed from the image. These are the features used for first level of searching.

### 3.3.Clusterization of patterns and angle invariant search algorithm

The objective of the second layer of searching is to identify the correct class (among the twelve classes) to which the test pattern belongs. In all the twelve broad classes data chunks occupy characteristic positions. In this layer we have searched for the group identity of a test head stamp depending on the positional occupancy of the data chunks. Mathematical morphological techniques have the capabilities of detecting spatial pattern and analyzing them [2], [3]. In the development of the present algorithm we have exploited this inherent capability of morphological operators. After removal of the circles we have used a conditional closing operator to make the residual pattern thick. The reason behind this is two-fold, first, it fills up any discontinuity, if arises and second in thick patterns the intra cluster distance is small and the inter cluster distance is large. This gives clearer distinction to the data chunks. After this we have used a search algorithm to find out the group to which the test bullet belongs. In this layer our aim is focused to find out:
1. How many data chunks are there?
2.Out of the four principal locations (12 o'clock, 3 o'clock, 6 o'clock and 9 o' clock), where the data chunks are concentrated.

The algorithm is divided into the following steps:

Step-1: The algorithm starts raster scanning and when comes across the first object (defined by pixels of value 1), starts finding out its boundary using 8-connectivity. This process continues till all the characters are segmented.

Step-2: In this step it calculates the center of gravity of each segmented pattern and with respect to a horizontal line passing through the calculated center of the circle it calculates the angular position of the center of gravity.

Step-3: The angular position of the C.G.s of all the segmented patterns are used to find the inter-pattern angular distance.

Step-4: First it assumed that the pattern is of type 5 i.e. only one integrated data chunk is available at 12 o'clock / 6 o' clock position. Then all the segmented patterns are the parts of a single data chunk. The C.G of the data chunk should be either at $90^{0}$ or at $270^{0}$ angular position. If the search shows that the angular position is far away of this then the assumption is wrong. Assuming then the head stamp belongs to type 1 or type 2 i.e two data chunks are there and oriented either around ($90^{0}$,$270^{0}$) or ($0^{0}$, $180^{0}$) angular coordinate pairs. Then all the segmented patterns are divided in two groups and two segmented patterns, whose angular distance is maximum and next to maximum, are concatenated to form one data chunk. The remaining segmented patterns make the second data chunk. These procedures continue iteratively until all the twelve cases are checked.

The pseudo-code of the algorithm is described below:

```
/* Segmentation of the image into separate data chunk */
no_chunk=0 ;  init_char = 'A'(ascii) ;   /* initialization*/
do while ( All the object pixels are not filled up )
{
        hit any pixel of a pattern using raster scan;
        do while  ( All the 8-connected pixels of the pattern
                                                  are not filled up )
        {
              pixel_code = init_char ;
        }
        no_chunk = no_chunk + 1;
        init_char = next ascii code ;
}
/*Calculate the centre of gravity of the segmented
pattern*/
for ( i =0  to  i = no_chunk ; i=i+1 )
{
        X_i = Óx_i   P  ;
        Y_i = Óy_i   P  ;
        /* P is the number of pixels in the data chunk */
        è_i = tan^-1 y/x;
        /*è is the angular position of the C.G of the data
       chunk with respect to the horizontal reference line */
}
/* Relative angular distance of the data chunks */
for ( i=0 to   i = no_chunk  ; i = i +1)
{
        j = i+1;
        è_ij = è_i - è_j;
}
Arrange the result in descending order ;
/* Group Classification */
n= 1 /* Assume the cartridge belongs to type-5 (n=1) or
type-12 (n=1).Where the data chunks are positioned at 12
o'clock or 6 o'clock position*/
sub-1:
for ( k = 1 to  k = n ; n=n+1 )
{
       determine k distinct data chunks according to the
       descending order of relative  angular separation ;
       è_cg ( k ) = tan^-1 Y_k / X_k   ;
       if  è_cg ( k ) = 90^0;
           Type = 5 ;
       else if  è_cg ( k ) = 270^0;
           Type = 12;
       else
           n =n+1;
          go sub 1;
          continue the loop until all the groups are
          checked ;
  }
```

### 3.4. Matching

After the group or type classification, the final identification of the head stamp is done. At this stage the search space is already reduced. The search process is confined to a particular class. The test head stamp is allowed to go for correlation matching with all the members of that particular class. The correlation metric is defined as [4]

R = fg - f g - f g (1)

Here ‘f ’ and ‘g’ are the binary images of the test and stored head stamp respectively. The primes are their reverse images. Within a class, R is maximum when the test head stamp has got maximum match with a corresponding stored head stamp. At the end of this stage, the full classification and identification is obtained. Then, from the corresponding entry of the database, the description of the head stamp is displayed on the screen.

## 4. Experimental results and discussion

The automatic bullet cartridge identification system consists of a controlled illumination line scanner attached to a PC. The head stamp to be inspected is placed over the scanner. Before capturing the images head stamp may be viewed on the monitor for proper placement. Captured images are fed to the computer for subsequent processing. The program is encoded in visual $C^{++}$ language and the database is developed on Microsoft Access. The system is tested on two thousand head stamps. In addition to this, testing is done also with synthetic images (generated by introducing synthetic noise in the image of good head stamps) to study the performance of the system for all possible situations. Noisy images are shown in Fig.3. Quantitative results are given below in tabular form. The result shows that, with increasing noise, the separation of the target image with the next nearest member is decreasing. However, the separation always remains above a threshold value. This secures the low false detection probability. In the field trial it has now been found that the system performs quite satisfactorily in most of the cases. The system is fully functional at Central Forensic Science Laboratory, Calcutta.

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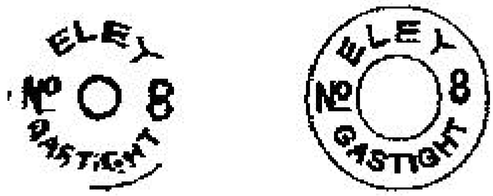


**Figure 3.1.**

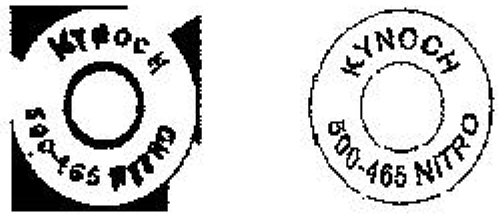


**Figure 3.2.**


**Figure 3.3.**

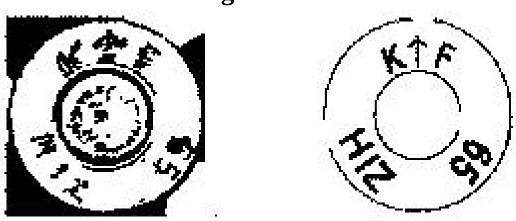

**Figure 3.4.**

**Fig. 3** Head stamps with added noise. The left column shows the images of noisy head stamps. The right column shows retrieved images from the database after recognition.

**Table 1**.

| Figure No. | Amount of noise added (in %) | fg - f g - f g | Mismatch with next nearest group member (in %) |
|---|---|---|---|
| 2.1. | 5 | 389 | 30% |
| 2.2. | 10 | 361 | 26% |
| 2.3. | 15 | 456 | 21% |
| 2.4. | 20 | 201 | 18% |

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