VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
BRNO UNIVERSITY OF TECHNOLOGY

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ÚSTAV POČÍTAČOVÉ GRAFIKY A MULTIMÉDIÍ

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DEPARTMENT OF COMPUTER GRAPHICS AND MULTIMEDIA

RECOGNITION OF IMPORTANT FEATURES ON WEAPON SHELLS

DIPLOMOVÁ PRÁCE
MASTER'S THESIS

AUTOR PRÁCE — Bc. MATEJ JANÁČEK
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ROZPOZNÁVÁNÍ MARKANTNÍCH RYSŮ NA NÁBOJNICÍCH

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SUPERVISOR

BRNO 2010

Zadání práce

1. Nastudujte literaturu zabývající se rozpoznáváním markantních stop (rysů) na nábojnici zanechaných zbraní.
2. Navrhněte a implementujte metodu pro rozpoznávání těchto markantních rysů tak, aby bylo možné porovnat dva snímky nábojnic a rozhodnout, zda byly vystřeleny ze stejné zbraně.
3. Proveďte testování vytvorené aplikace na databázi nábojnic (nábojnice budou dány k dispozici).
4. Zhodnoťte a diskutujte dosažené výsledky.

Project tasks

1. Study the literature concerning the recognition of important features on used weapon shells.
2. Propose and implement a method for automatic recognition of these features, so that we can compare two cartridge images and decide whether they were fired from the same firearm or not.
3. Test the application on the cartridge database (cartridges will be provided).
4. Review and discuss the achieved results.

Abstrakt

Text se zabývá automatickým rozpoznáváním a porovnáváním markantních rysů na nábojnicích, tak aby se zlepšila efektivita podobných manuálních balistických systémů. Práce řeší problematiku programování aplikace pro automatické rozpoznávání a porovnávání markantních rysů na použitých nábojnicích.

Abstract

The text covers the automated recognition and comparison of features on used cartridge cases, in order to increase effectivity of similar manual ballistic systems. The work is addresing the issue of programming the application for automated recognition and comparison of features on used cartridge cases.

Klíčová slova

Rozpoznávání markantních rysů na nábojnicích, balistika, automatické porovnávání nábojů

Keywords

Recognition of features on weapon shells, recognition of features on cartridge cases, ballistic imaging, automated bullet comparison

Citace

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Recognition of Important Features on Weapon Shells

Prohlášení

Prohlašuji, že jsem tuto diplomovou práci vypracoval samostatne pod vedením pana Doc. Ing., Dipl.-Ing. Martina Drahanského, Ph.D. Další informace mi poskytnul pan Ing. Jozef Mlích.

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Matej Janáček
August 10, 2010

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Chapter 1

Introduction

In modern times, the significant part of criminal activities around the world includes usage of firearms and other projectile weapons. To effectively solve these crimes, police and other similar agencies are using a bullet or cartridge case comparison as a help in investigation, or as a direct evidence for fighting these crimes. These methods vary from a simple caliber measurement based on a physical properties of bullet or cartridge case, to comparison of features and marks left on used weapon shell.

As the computerization advanced throughout the time, the methods of comparison, storage or cataloging were naturally progressing. Nowadays, modern crime fighting agencies have usually access to some form of database containing various information on firearms used usually in crime activities. The data from these databases, especially the image data of used gun or cartridge cases, together with assisting software allow the investigators to notably speed up the process of culprit weapon identification.

This thesis focus on proposing a system for automatic processing of such image data, which would try to minimize the assistance from a human operator. Due to the usage of such system mostly in police criminal investigation, we would limit the manipulation with cartridges and bullets used in small firearms, such as revolvers, pistols and rifles, despite the fact that artillery cartridges posses many similar attributes.

Every used bullet or cartridge case is left with impressions and striations, which are characteristic for firearm being used. This system should be able to recognize these important features from their two-dimensional images, create their vector representation and compare them with data from another similarly processed image. The comparison should lead to results deciding, whether the two bullets or cartridge cases were fired from the same firearm. We would also discuss the possibilities of usage of similar systems, explore the existing alternatives to our system, and propose the way in which the research should continue in the nearest future.

This thesis relates to bachelor thesis Recognition of weapon shell types, which is focused on recognition of cartridge types and the best way of capturing the surface of cartridge cases.

1.1 Project outline

This thesis is divided into logical chapters named accordingly. Chapter 1 describes short introduction into the topic and briefly familiarize the reader with the contents of the thesis. Chapter 2 reveals the history behind the developement of the firearms and ammunition, which is being examined in this thesis. Chapter 3 introduces the ballistics and modern forensic comparison methods. Chapter 4 reveals the concept of our solution for the cartridge markings comparison. Chapter 5 concerns the proposition and construction of data acquiring mechanism. Chapter 6 contains the description of the comparison algorithm created for this thesis. Chapter 7 describes the results of algorithm tests with the data acquired through the created mechanism. Final chapter 8 sumarizes the benefits of the thesis and proposes future work based on the information obtained from our results.

Chapter 2

Context for firearms and ammunition

From the early ages, humans were developing various weapons to help them in their activities, at first mostly hunting, later defense and warfare. Soon in addition to melee weapons, humans created so-called projectile weapons, which allowed them to attack their targets from the safe distance.

Projectile weapons are weapons capable of releasing some object, which is called projectile, with certain speed towards the designated target from a distance. As mentioned earlier, first of these projectile weapons were used in prehistoric times by hunters, and allowed them to hunt their food more easily. The weapons they used were crude spears, bows and arrows, and darts. During the times, humans were inventing new weapons and improving their old ones, so they would better suit their needs, and one of the most important step for projectile weapons, was the invention of gunpowder[1], or black powder, which allowed the creation of so-called firearms.

Figure 2.1: The "Glock-17" Self-loading Pistol [5].

[1]Gunpowder or also called black powder, is a mixture of saltpeter(KNO_3), carbon from charcoal(C), and sulfur(S) [25]. Upon ignition it produces heat and gases, which makes the bullet fly out of the weapon.

2.1 Firearms

Firearms are specific part of projectile weapons, where projectile is called bullet and is fired from weapon by a controlled explosion. First firearms were probably created in ancient China soon after the discovery of black powder, which was used as the explosive propellant [25]. In modern times the term firearm is often replaced with the term gun, which do not have the same meaning, but for our purposes we can consider them to be equal.

There are various definitions of gun, depending on nation, organization and branch of service. In modern speech however, gun is a projectile-firing weapon using a hollow, tubular barrel[2] with a closed end, the breech[3], as the means of directing the projectile (as well as other purposes, for example stabilizing the projectile's trajectory, aiming, as an expansion chamber for propellant, etc.), and firing in a generally flat trajectory [7].

caliber	inch	mm
22	0.2204	5.6
25	0.2500	6.35
32	0.3008	7.63
320	0.3200	8.13
38	0.3580	9.00
380	0.3800	9.65

Table 2.1: rifle gun barrel — bore size in inches and millimeters and caliber [2]

Guns are generally classified according to use, size, and tradition. This varies among the military services, as mentioned earlier. The basic distinction is between small arms and artillery. Any gun below a 20-millimeter bore size[4] (More popular alternative to bore size is caliber number, or cal. see table 2.1) is generally classified as a small arm. An alternative term gaining increasing currency is "light arms", to include individual and light support weapons [4].

Artillery and small arms ammunition bear many similar characteristics, but in this thesis we will focus mainly on the ammunition used in small arms, such as pistols, revolvers, rifles and shotguns, as those are the mostly used weapons in crimes for which the weapon shell comparison is needed and used.

2.2 Ammunition

Ammunition is a general term for projectiles used in all projectile weapons, such as arrows for bows, or even aircraft missiles and bombs. In this thesis, as we will deal mostly with modern small arms, the term ammunition will refer to all cartridges, shells or bullets for firearms.

Cartridge is term used for a small arms munition, and is made up of several following components. These are bullet, cartridge case, primer and propelling charge (see 2.2, there is one additional part highlighted — the rim, which is part of cartridge case used for loading) [4]. Before the existence of cartridges, bullets and propelling charges were used separately,

[2]Barrel or gun barrel is a tube through which a bullet travels when a gun is fired. [8]

[3]The end of a barrel into which a cartridge is inserted [22]

[4]A measure of the inside diameter of the barrel in inches (or in hundredths of an inch) or in millimetres [11]. The minimal bore in artillery is equal to 20 millimeter [2]

as in medieval cannons, where bullet was a sphere-shaped piece of iron and propelling charge was a gunpowder. Today all the small arms, use these parts combined in the cartridge case, which provides the container for bullet, propelling charge and primer.

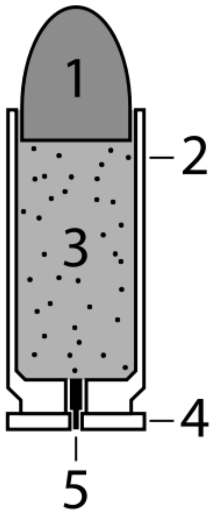

Figure 2.2: Diagram of cartridge [3]: 1. bullet, 2. cartridge case, 3. propellant, 4. rim, 5. primer

The bullet in general is cylindrical. The nose may be round, as in the caliber .50 bullet, or ogival as in all service rifles and machine gun bullets. The base may be square or boat-tailed [4].

There are various types of bullets, such as armor-piercing, incendiary or tracer bullets, which are used for different purpose and in different situations. Apart from general type, we also know various types of bullet shapes.

Figure 2.3: Rifling of a 105 mm Royal Ordnance L7 tank gun [9].

The propelling charge consists of a quantity of smokeless powder. The weight of the charge is not constant and it is adjusted for each powder lot to give the required velocity with pressure within the limits prescribed for the weapon in which it is fired [4].

In this thesis, we will concentrate mostly on the cartridge case, rim of the cartridge and the primer, which replaces the function of classic percussion cap, as they are the most important cartridge parts from the view of the ballistic imaging — the parts which are affected and distorted by the firing of a weapon.

Percussion cap as firing mechanism was a great step in advancement from its predecessors, the flintlock ignition system, because it does not use an exposed flash pan to begin the ignition process. Instead, it has a simple tube which leads straight into the gun barrel [6].

In modern firearms, when user pulls the trigger, the firing pin hits the primer on the back (rim) of the bullet, which then explodes, ignites the propellant and this starts the chemical reaction which creates the pressure on both the bullet and the bottom of the cartridge. The pressure then drives the bullet out of the gun barrel.

The inside of the barrel is usually lined with spiraling grooves (see 2.3), which spin the bullet to give it more stability. A longer barrel improves stability, since it spins the bullet for longer. Extending the barrel also increases the speed of the bullet, since the gas pressure accelerates the bullet for a longer period of time [20], thus giving it greater momentum.

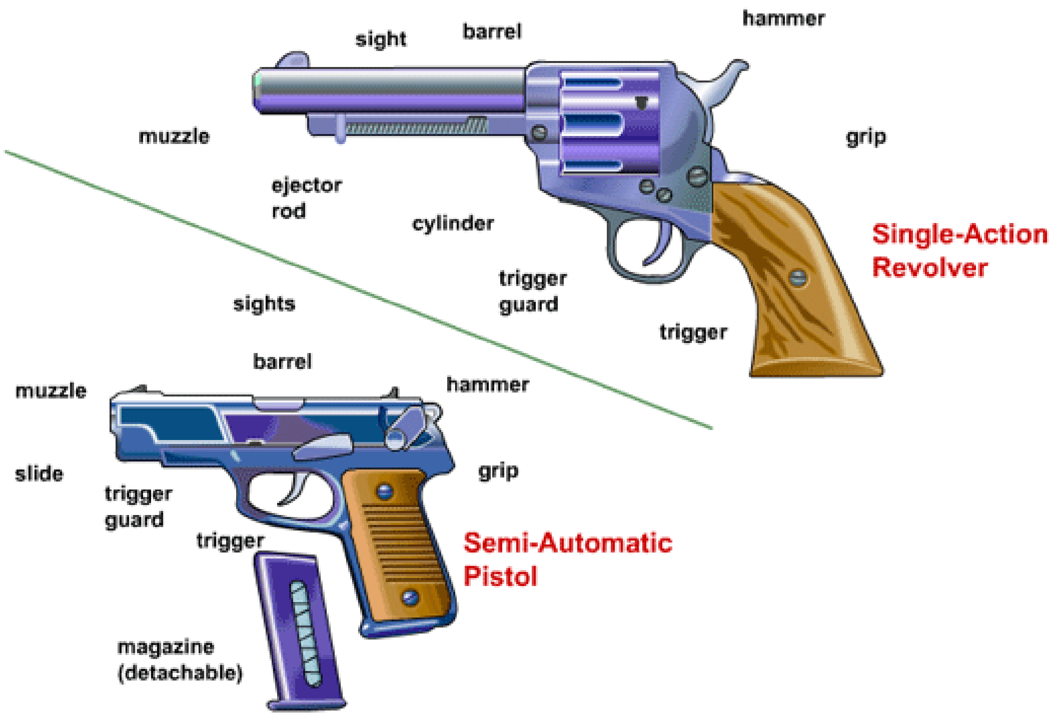

Figure 2.4: Parts of a revolver and a semi-automatic pistol [10].

The inside of a barrel and especially spiraling grooves are one of the main contributors to the creation of impressions and striations left on the cartridge case and bullet.

Note that after the separation of a bullet from the rest of the cartridge, the gun may or may not eject the empty cartridge case. This is the main difference in comparison with the revolvers, which keep the empty cartridge case inside the cylinder, and the pistols which eject the cartridge case out of the gun (see 2.4). The cartridge case ejected will also have marks, which are caused by the firing pin, the breech face as the cartridge is repelled back in the breech[5]by the force of rifling[6]. The feeding, extraction and ejection mechanisms of the firearm will also leave characteristic marks. [19]

In early Colt revolvers, the firing pin was a shooter had to pull the hammer back before each shot and then pull the trigger to release the hammer. In modern revolvers, simply pulling the trigger will force the hammer backward and then release it [20].

The impact of a trigger upon the on the rim of the cartridge (and the firing pin) is responsible for the main mark left on the surface of the cartridge case — the hole on the rim with the shape of the trigger. This mark is much more visible than the impressions and striations on the side of the cartridge and therefore provide valuable information for the cartridge examiner.

[5]The end of a barrel into which a cartridge is inserted [22]

[6]Rifling is the process of making spiral grooves in the barrel of a gun or firearm, which imparts a spin to a projectile around its long axis. This spin serves to gyroscopically stabilize the projectile, improving its aerodynamic stability and accuracy [9]

Chapter 3

Firearms identification and the use of ballistic evidence

3.1 Data collection for ballistic imaging

Very important part for all of the two-dimensional comparison methods in ballistic imaging is creating the digital representation of bullets and cartridge cases in the most proficient way. As the accuracy is very important in every comparison system, the image data has to be stored with the highest quality possible. This goal is often limited by the need to minimalize the cost of the whole system though.
There are many different approaches and methods for this problem:

- **Destructive methods**
  On of the oldest methods. Before taking a photography of cartridge case, it is cut and narrowed with proper tools (pliers, hammer, etc.). The original form of cartridge case is destroyed during the process, hence the name "destructive" [1].

- **Cartridge case impression**
  This method uses the impression of cartridge case made in the proper material (there are two main methods for creating such impression. First is galvano-plastic process, for creating the copy of the case relief, and the second is simple rolling of the cartridge case over sensitive material), but even the best materials for taking a case impression don't provide as good result as the other methods [1].

- **Cartridge case scanning**
  During the scanning of a cartridge case, a three-dimensional representation of the case is created, usually by a laser beam or with some sort of contact . This method provides the highest quality possible and is used in many modern systems (for example IBIS BulletTRAX-3D, see 3.3). The downside of such systems is their cost in comparison to classical two-dimensional methods [1].

- **Cartridge rotation**
  The case of the cartridge is rotating with constant rotation speed and fixed camera is taking pictures or video of the case. The quality depends on the speed of the rotation and number of pictures taken in one rotation. [23].

For our purpose of creating a digital representation of cartridge cases, we will use the last method mentioned, the cartridge rotation, and we will duplicate the mechanism created in the bachelor thesis "Recognition of weapon shell types" [23].

3.2 Basic markings on used cartridge cases

When a firearm is loaded and fired the mechanisms and part in the firearm which come into contact with the cartridge case or bullet cause impressions and striations that can be characteristic for the firearm being used. The cartridge case ejected will also have marks, which are caused by the firing pin, the breech face as the cartridge is repelled back in the breech by the force of rifling. The feeding, extraction and ejection mechanisms of the firearm will also leave characteristic marks [19]. There are though, some similarities, through which we can categorize these markings and choose the best way to approach them for comparison in our solution.

Figure 3.1: Used cartridge case rims [23].

The most important markings for forensic laboratories, are those left on the cartridge cases, as the bullet is usually deformed by the impact during the shooting. We can divide the markings on the cartridge case into two groups, as mentioned earlier. The marking on the rim of the case, left by the firing pin and the breech face, and the impressions and striations left on the side of the cartridge case, usually by the rifling of the gun or by ejection system.

The rim of the cartridge case can carry additional information, such as the cartridge type number.

3.3 Current ballistic imaging technology

Forensic comparison microscopes

Comparison microscope are ideal for side-by-side comparison, when examiner is able to see two samples with great magnification. In case of ballistic evidence, the examiner is able to compare markings on cartridge cases, those from the crime scene with those made during the test shooting.

DRUGFIRE

DRUGFIRE is a database-driven multimedia system designed to significantly increase the effectiveness of forensic laboratories in maintaining and searching Open Case Fired Ammunition Files. DRUGFIRE seamlessly integrates forensic database information, video, audio, digital images, and telecommunications technologies to simulate the functionality of forensic equipment.

National Integrated Ballistic Information Network (NIBIN)

National Integrated Ballistic Information Network (NIBIN) was formed in 1997 in United States of America by the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF). NIBIN is currently a large system connecting various law enforcement agencies, which contribute to a database of images of bullet and cartridge case evidence recovered from (or test-fired from weapons linked to) crime scenes. NIBIN program doesn't hold any non-crime evidence, as this is prohibited in the United States by it's legislative. The program equips agencies with ballistic imaging equipment called Integrated Ballistic Identification System (IBIS) [18].

IBIS

The two-dimensional version of IBIS platform, formed by combining BULLETPROOF with a BRASSCATCHER apparatus for imaging cartridge casings [18], acquires gray-scale photographs of bullet or cartridge case evidence, scoring and ranking pairs of exhibits by deriving a mathematical signature from images. IBIS platform is able of partial automatic bullet markings comparison.

Figure 3.2: IBIS ballistic system [19].

IBIS BulletTRAX-3D

In January 2007, Forensic Technology WAI, Inc. (FTI), the developer of two-dimensional IBIS platform, repositioned its line of products to emphasize its existing BulletTRAX-3D platform. The product now referred as IBIS BulletTRAX-3D, is a possible enhancement to the current IBIS system and it is based on three-dimensional topographic measurement instead of classic two-dimensional photography [18].

LUCIA B-SCAN

Czech made ballistic system was designed for automated scanning and digitalization of cartridge cases and their comparison. Digital image data can be stored in a database and used for comparison in the future [1].

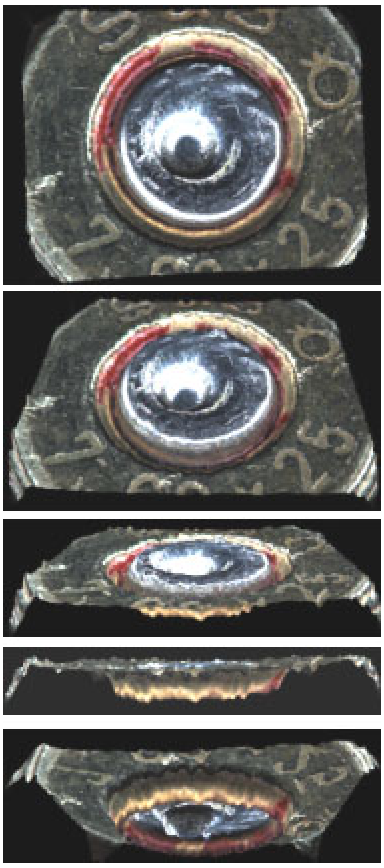

Figure 3.3: 3-D representation of cartridge case rim created by LUCIA BullScan system [1].

Chapter 4

Proposed system concept

Our system should be composed of two separate steps:

- A mechanism for acquiring a data representing the case of a cartridge
- A software able to provide a comparison of markings upon individual cartridges

With the help of the mechanism which we will create, we should be able to get the visual representation of both rim of the cartridge and case of the cartridge. The proposition of this mechanism is described in chapter 5 and examples of proposed mechanisms are described in section 5.1.

The second part of the solution, which is the software for comparison, should be able to localize, extract and compare important fetures (or markings) from the two-dimensional data representation of a cartridge acquired by our mechanism and compare them with data from another image.

The software should process the data in any way suitable to achieve the best possible comparison results and should return by some means, the value of numeric correspondence between images. Based on the comparison results, we should be able to propose the decision whether the cartridges were or were not fired from the same firearm, which is the most important goal in the area of ballistic comparison.

Based on the algorithm performance on test data, we will decide the thresholds and settings for consequent sub-algorithms used in our program to achieve the best positive search and to look for possible upgrades or changes to our alogrithm and the whole solution proposed by this thesis.

Figure 4.1: Historically first digital image of cartridge case in the Czech Republic [1].

4.1 Input data

As a direct input to our comparison algorithm, we will use multiple images or videos. Many of the sub-algorithms used in the main program are working only with the grayscale data input, therefore the first step should be check if the input images are not gray-scaled and if needed, then we will automatically convert them to gray-scale format.

Each input will consist of the couple of data as mentioned before. The pictures of the cartridge rim and the circumference of the cartridge case, acquired through our rotation mechanism (see appendix B — after the testing phase done with the first mechanism, another one was constructed used, which doesn't include rotating parts — see 5.2). The rim will be used to get the information of the impression of the trigger and any other markings such as scratches left there during the process of loading or ejecting.

The image representation of the circumference of the cartridge case can be used as a secondary source of information for the comparison, if we could extract and process all the most visible scratches, impressions or striations left there during the processes of loading, firing and ejecting of the cartridge.

4.2 Image preprocessing

With our method of data acquisition (see 5.2), the images of cartridge cases and cartridge rims will need some sort of preprocessing to eliminate the problem that may occur during this acquisition, to unite the data which can be acquired through different means, and to improve the resulting accuracy of the comparison. The problems which may occur are the different lightning conditions during the picture taking, different position of the cartridge, either in horizontal and vertical dimension, or the actual distance of camera and cartridge, wich may affect the comparison as well. Also the shift of the cartridge may be different every time and our algorithm should be capable of eliminating this problem. The distance of the camera taking images or recording a video and the cartridge itself should be constant in order to ease further processing and to allow us to compute the exact dimensions of the cartridge, such as it's height and shape and diameter of the base (rim). This values can be used for basic comparison.

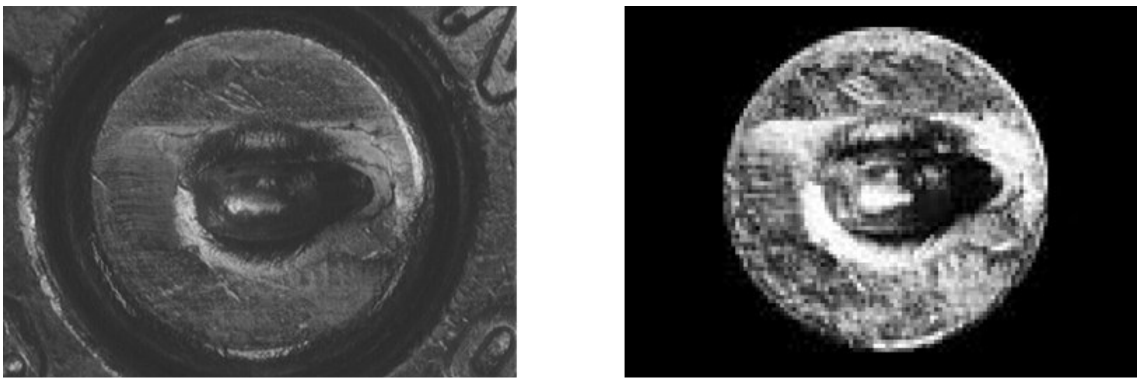

Figure 4.2: Detail of firing pin marking, original and preprocessed image.

We could filter non-important parts of images we are going to use, such as the outside ring area in the image of a cartridge rim, or parts of the image where the cartridge case is not present. This would lower the requirements for the further algorithms and speed up the whole comparison process (see 4.2). The construction of our mechanism will provide high contrast images of a cartridge rim (see 5.2). The images will display the parts of a cartridge on theoretically completely white background. However there may be irregularities and visual artefacts, such as the shadows created by the light sources or the bends of the paper, but these should be easily eliminated.

Gray-scale conversion

For easier processing and also due to many intensity based sub-algorithms, we are going to use gray-scale version of our input images (see figure 4.3). Gray-scale image is an image where each of it's pixels holds only the information about it's intensity, which is represented by a corresponding shade of gray, varying from black at the weakest intensity to white at the strongest [21].

Figure 4.3: Image of a cartridge rim converted to its gray-scale version.

In gray-scale format we can represent all pixels of the image by a simple gray-value function g(x,y), where x and y are pixel position values and the value returned by the function g(x,y) will be the colour intensity for this position.

Sharpening

Another step in the preparation for the final comparison should be some kind of sharpening algorithm (see figure 4.4), which has the objective of making the edges steeper [26] and would result in much brighter and sharper details of the whole surface of cartridge. This would allow the following sub-algorithms such as edge detection and feature extraction to get better results from the processed image.

The sharpened output image f is obtained from the input image g as

$$f_{x,y} = g_{x,y} - CS_{x,y}, \tag{4.1}$$

where C is a positive coefficient which gives the strength of sharpening and $S_{x,y}$ is a measure of the image function sheerness, calculated using a gradient operator [26].

Histogram equalization

Another global sub-algorithm, which can further improve the accuracy of our algorithm is the histogram equalization (see figure 4.5).

Figure 4.4: Gray-scale image of a cartridge rim and the same image after sharpening operation.

Histogram[1] equalization is a gray-scale transformation for contrast enhancement. The aim is to create an image with equally distributed brightness levels over the whole brightness scale. Histogram equalization enhances contrast for brightness values close to histogram maxima, and decreases contrast near minima [26]. This can be very helpfull when approaching input images with lowered contrast — unequal distribution of intensities over the whole image. However histogram equalization can also produce undesired effects on the processed images, therefore it should be applied only when it will improve the final comparison results.

Figure 4.5: Gray-scale image of a cartridge rim before and after the histogram equalization.

Edge detection

One of the goals for our comparison algorithm is also the computation of the exact dimensions of a cartridge. This values would allow us to find out the type of the cartridge and so perform a basic comparison of a two cartridges. However for this task we would have to exactly locate the cartridge in the input images. More precisely we would have to locate where in the image is located cartridge and where not.

[1] A **histogram** is basically a graphical representation of the tonal distribution in the digital image — a graph which shows the size of the area of the image that is captured for each tonal variation that is available [27].

One of the possible approaches is to use some kind of edge detector, which would allow us to locate and extract the edges from the rest of the image. Edge detectors are a collection of very important local image pre-processing methods used to locate changes in the intensity values of an image. Edges are pixels of an image, where values of brightness (intensity) change abruptly [26]. To be more precise, an edge is a property attached to an individual pixel and it is calculated from the image behavior in a neighborhood of that pixel. It is a vector variable with two components: magnitude and direction. The edge magnitude is the magnitude of the gradient, and the edge direction ϕ is rotated with respect to the gradient direction ψ by $-90°$. The gradient direction gives the direction of maximum growth of the function, e.g., from black $f(i,j) = 0$ to white $f(i,j) = 255$ [26].

These edges are often used in image analysis for finding region boundaries. So the use of edge detector on our input data will not only return the approximate boundaries of processed cartridge, but also it will reduce the data representing our input image without elimination of most of the important information, which is the image data holding. Assuming the contrast background, the actual outer edges of the cartridge should be easily detected by the edge detector of our choice. Once we have the location of the edges we can calculate the digital distance of pixels on the edges and with this value obtain the actual real dimensions of a cartridge.

Another usage of an edge detector in our project would be the recognition of letters located on the rim of a cartridge. Each cartridge has a letters or numbers impressed in its rim, holding a certain information about it. The impressions represents also a sudden changes in the intensity values of pixels of an image and therefore should be localized by an edge detector. Once we are able to locate them and extract from the image, they can provide useful information about the shell itself. However the nature of the cartridge, which is of a circular shape makes it very difficult to handle and further process these letters. They will be aligned on the circular curve along the edge, so we cannot use directly any of the existing letter recognition algorithms.

Figure 4.6: Gray-scale image of a cartridge rim and the same image with applied Sobel operator.

This problem should be eliminated using accurate image transformation, which would transform the letters from the circular path into the horizontal plane — this means creating a horizontal line of letters and numbers, which is usual way of reading for humans, and due to this also for most computer letter recognition algorithms. The set of algorithms or a systems used for recognition of the letters are called generally Optical character recognition (OCR) and today is widely used for converting existing printed documents, such as books and journals into electronic form.

As noted, we won't need a separate tool for locating the edges of letters on the rim of a cartridge, as this will be done in the same step as locating the boundaries of a whole cartridge object in an image.

Feature extraction — Salient point detection

Apart from reading the text on the rim of the cartridge and it's getting dimensions, we need also a way to compare images (or videos) of a cartridge. Both image of the rim or the video of the cartridge case consist of an amount of data too large to be directly compared with data of some other cartridge. Such comparison would also require a large amount of memory and computational power. Because of this we have to reduce this information and find a way to compare only fragments which would represent the whole input data. One way of doing this was the edge detection mentioned in 4.2. However the edges still won't reduce the information to the level, when we can easile compare the data of two images with each other. To do this we have to obtain a points which will represent the most important and most occuring differencies in the images of the cartridges. We can call this fragments the interest or salient[2] points, and they are later used as a basis for the vectorization. Localization of these interest points is also called **feature extraction**.

There are many existing algorithms used for feature detection and description. Some of the most known are:

- SIFT — Scale-invariant feature transform,
- SURF — Speeded Up Robust Features
- MSER — Maximally stable extremal regions
- Harris operator

We will try and choose a proper algorithm for locating and enconding salient points on the surface of the cartridge case and cartridge rim.

Vectorization will return a vector representing these interest or salient points and thus the whole image. The resulting vector can be then easily used for the final comparison with vectors of other images from some kind of database or test set we are going to create using the provided samples.

4.3 Comparison algorithm

The final stage of the application will be the comparison algorithm itself. Basic comparison means a search for inequality or differences between two or more objects. In our case those objects will be the cartridges and the result of our comparison should be a statement, telling us if the compared cartridges were or were not fired from the same firearm. To be able to do this, there are some requirements, which our transform and comparison algorithm must fulfill if we want to obtain a decent result. We can write them in a few basic points [28]:

- It has to be robust. It must be able to withstand an additive noise to some degree even after after thorough preprocessing.

[2] prominent, conspicuous, or striking [14]

- It has to be flexible. Our algorithm has to be able to fulfill more different recognition tasks.

- It has to maintain shape information. The result must be only shape dependent.

Due to the nature of the mechanism used for photo acquisition, we shouldn't need to worry about distance variation. The fixed distance between the camera and the cartridge case should keep the size of each case on the image nearly the same, with very small marginal error. On the other hand, since there is no strict mechanism for aligning or rotating the case rim during image acquisition, we have to count with certain rotation variance. This can be avoided only with big difficulties and also an algorithm able to surpass this problem would be much more useful and flexible, what is one of our requirements. Also we can take into acccount modifications of the algorithm allowing us to overcome the problem of distance variation, for example when we don't have the option to use the mechanism properly, or if a fixed placement of a cartridge won't be possible. Eliminating this problem would further increase the flexibility of the algorithm.

For the most basic, rotation invariant comparison, a simple difference of the image can be used — a difference of each and every pixel of the image. This is the basic difference and probably won't be very suitable for our algorithm, but the results of this comparison can be helpfull with deciding a direction of future research for our thesis.

$$h_{x,y} = f_{x,y} - g_{x,y} \tag{4.2}$$

$$\delta = \sqrt{\frac{\sum_{x=1}^{N}\sum_{y=1}^{M}(h_{x,y} - \mu_{h_{x,y}})^2}{N * M}} \tag{4.3}$$

There are many ways to enhance this simple comparison, for example we can achieve better performance by using some kind of a correlation parameter with this algorithm. However this would still leave us with the problems mentioned earlier, specifically the translation (on x and y axis) and rotation variations, which are very essential if we are to get a good result from final comparison.

For this we would need a much more robust solution, like the log-polar transform, which is a composition of four basic operations:

- First Fourier Transform — transforms a function $f(t)$ (e.g. dependent on a time) into a frequency domain representation, $\mathcal{F}\{f(t)\} = F(\xi)$, where $\xi[Hz = s^{-1}]$ is a frequency and $2\pi\xi[s^{-1}]$ is an angular frequency [26].

$$\mathcal{F}\{f(t)\} = F(\xi) = \int_{-\infty}^{\infty} f(t)e^{-2\pi i\xi t}dt \tag{4.4}$$

- Rect-to-polar conversion — a conversion of dimensional coordinates from rectangular to polar version.

- Log-scale along the radius axis — obtains the data representation on a logarithmic scale.

- Inverse Fourier Transform — as the name suggests, a transformation inverse to that of a First Fourier Transform.

$$\mathcal{F}^{-1}\{F(\xi)\} \quad = \quad f(t) = \int_{-\infty}^{\infty} F(\xi) e^{2\pi i \xi t} d\xi \tag{4.5}$$

The module of a FT is translation-invariant, i.e. it does not change when the image in the domain is moved provided that scale and orientation is preserved [28].

The algorithm with these properties for a comparison system will be of course much more suitable and flexible and will provide better results for any input files. Combining this algorithm with others and improving its functionality according to other requisitions would be of course needed.

4.4 Implementation tools

The choice of the programming language for this project is C++, considering the nature of this project and the existence of OpenCV library for the C++ programming language.

C++ offers good basis for efficient implementation, great portability and has a plenty of libraries, which may be useful in later stages of implementation, such as the mentioned OpenCV library.

Another advantage of using C++ is the object-oriented approach, which can be used for easier design and programming of the project, especially if it's going to consist of multiple different parts or the volume would get too big.

For specific image recognition tasks, it is possible to use the OpenCV library. OpenCV is an open source computer vision library written mainly in C language and is specifically oriented for area of computer vision. It was designed for computational effieciency and it's goal is to provide a simple-to-use computer vision infrastructure that helps people build fairly sophisticated vision applications quickly [17].

Chapter 5

The data acquisition mechanism

For our system we have to create a data representation of as many parts of a cartridge case affected by a firearm during shooting as possible. The parts which are suitable for further examination from our point of view are these:

- Mark left by the firing pin on the rim of the cartridge. This mark is the most dominating impression left on the cartridge case after the firing process and for this reason we will consider this mark to be the most important in our comparison and the results acquired from comparison of firing pin mark should be decisive.
- Manufacturing marks on the rim of the cartridge — Many weapon shells have specific letters and numbers on their bottom part holding a valuable information about the shell itself and its origin. This feature is not as important in our comparison, as the information about weapon's manufacturer or origin does not have very big influence on the used weapon.
- Markings on the side of the cartridge case. These markings are often less visible then the pin impression on the rim, however they provide an important alternative source for identification, which can be used in order to achieve better results.
- The dimensions of the cartridge can also be used for the most basic comparison of cartridge types. The overhelming majority of weapons is naturally able to use only one type of ammunition due to it's construction. We can exploit this knowledge and compare the dimensions of the cartridge. This data is easy to acquire and can greatly help in filtering the set of the possible matches with much better speed than more sophisticated software comparison.

From these markings we will then choose those which are the most significant and by creating a proper representation in our algorithm we would compare them with the data acquired from the different cartridge.

As mentioned before in the chapter 3.1, there are many options on how to obtain a representation of these marks from a cartridge case.

The most suitable way for this thesis is to create a system capable of capturing the markings as a 2D images, which we can later use in our program for a comparison without destroying or altering the physical shape of the cartridge.

This eliminates all of the destructive methods used for this purpose. As we are going to use the automated system for comparison, we can also eliminate the methods using impressions of the cartridge, as these methods are generally less accurate than other methods and nowadays image algorithms used for comparison require a high amount of detail to be able to provide a good result.

In our system, each cartridge will be represented by a 2D image of it's rim and a series of 2D pictures (or a video) representing the side of the cartridge case. In the image of the rim we can later localize and then extract the marking of firing pin — a hole created in the rim of the cartridge after the shooting. The image of the rim can be created seperately and does not need any specific equipment apart from the camera with good resolution and the lighting which is further explained in the section 5.1.

The side of the case on the other hand is round and for it's representation one image won't be enough. The aim is to represent it in a efficient and easy to use way. For this the best idea is to create a system which is able to create a data representation of preferably the whole case at once, or which would periodically take and store images of subsequent parts of the cartridge case either by moving the camera, or by rotating the cartridge itself. Also for our algorithm it would be necessary to acquire the images under the same (or very similar) lighting conditions, so the comparison would be as accurate as possible without any additional processing of the data.

5.1 Proposed data acquisition mechanisms

Considering the needs and requirements mentioned in the above section, there're a few ways I've proposed as a possible concept of this mechanism.

A static system with mirrors

This system is based on the idea of creating just one image of as many sides of the cartridge as possible. It would eliminate the need to rotate the cartridge around it's axis with the use of multiple, precisely placed mirrors.

The basic idea is to construct a set of fixed mirrors and a camera around a central area, where the cartridge cases would be placed. The system of mirrors should be constructed in such way, that they would cover entire circumference of a cartridge without need to move it or change its position in the process of creating a 2D image. The resulting image will be however very complex and may not be very suitable for our needs, as it would require a specialized algorithm to locate, extract and compose the area which is interesting for further processing — the area with markings on the cartridge case.

Also the lighting in this case would be very problematic. As all of the sides of the cartridge are being examined we would need a light source capable of providing a constant light at all sides, or a specific lighting devices that would highlight all of the parts being reflected in the mirrors. If our goal is to cover as much area as possible, this would result into very complex system of multiple mirrors and lighting devices.

A static system with one fish–eye mirror

The alternative to the system with multiple mirrors is the use of sole hyperbolic mirror, which would serve as a full-value replacement for all the mirrors. The idea of this systems is based on the OmniView system [24] developed at the Brno Technical University.

The mirror would create an image of all the sides of a cartridge at once and this image would be captured by a properly placed camera. The output image wouldn't even need further transformations if we're going to use it in comparison with images of other cartridges

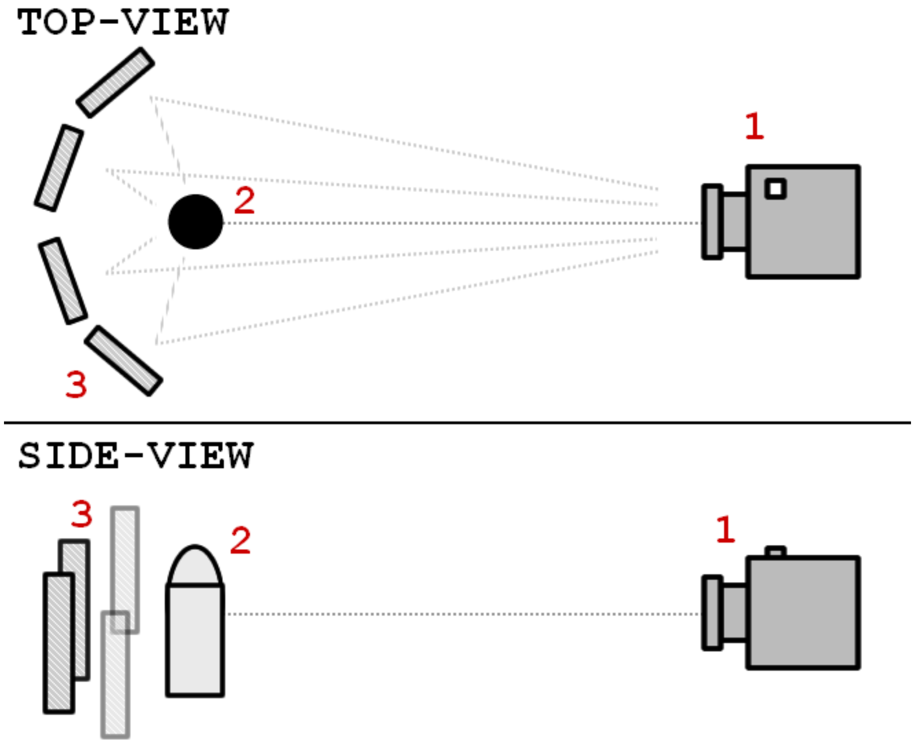

Figure 5.1: A scheme of proposed static system for data acquisition with multiple mirrors covering the circumference of the cartridge case: 1 – The camera, 2 – The cartridge, 3 – Mirrors surrounding the cartridge.

taken with the same system. However we would need to further process the image if it is to be compared with the cartridge data acquired using other existing systems for various databases.

This system is only theoretic and the main problem, which can be inconquerable, is the proper positioning of the mirror, the cartridge case and the camera.

The lighting in this case is even more problematic than in the system with multiple mirrors. Under these conditions we could only use the constant non-directional lighting for data acquisition, without possibility of further sharpening the details on the circumference of the cartridge.

Cartridge rotation

This system is composed of a camera and a holder for a cartridge case, which is rotating with the constant speed around it's own axis. A video or a photo camera, which is secured in a fixed position, is taking images of the cartridge side. The speed of the rotation has to be adequate to the camera and number of pictures we are able take per second, so we can obtain the best quality possible. The rotations of a cartridge holder are powered by a power source which would provide rotations with suitable and constant speed, so we can cover all circumference of a cartridge case with as little images as possible.

This system allows us to use the directional lighting source, which would highlight the the part of the cartridge case being photographed at the moment and therefore increase the quality of the data acquired.

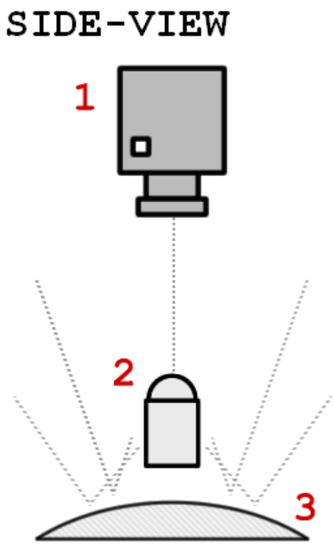

Figure 5.2: A scheme of proposed static system for data acquisition with a hyperbolic mirror: 1 – The camera, 2 – The cartridge case, 3 – The hyperbolic mirror.

Camera rotation

The alternative for a cartridge rotation is a system with solid non-moving cartridge in it's center and a camera rotating around the cartridge, taking images of the sides of this cartridge. Together with the camera we have to move also the light source (if we are using one), so we can get the same lighting conditions for each photo.

The advantage of this system in comparison with the previous one (cartridge rotation) is the stability of the examined cartridge, which eliminates its inaccurate rotation due to the wrong placement of the cartridge or due to the deformations in the physical shape of the cartridge created during previous manipulation and shooting.

Disadvantages are the physical dimensions and construction problems, as well as powering problem.

The dimensions of such system would be much greater and the construction more complicated, because of the fact that movable part is the camera rotating around the center, which is the cartridge. The powering problem is also connected to the fact, that we are moving a camera, which is bigger and heavier than a cartridge, and therefore we would need more potent power source to put it into stable motion around the cartridge.

Conclusion and mechanism selection

From the mentioned possibilities, the most appropriate seems the cartridge rotation, the construction of which looks like the easiest and the least expensive (from the point of construction cost) of the ones mentioned above.

The system consisting of multiple mirrors provides an advantage of having all parts stable and thus negating the effect of irregularities created by motion during the image acquisition. However the disadvantages of this system are higher material cost resulting from the need to use multiple mirrors of good quality and the complexity of acquired image. This image would need to be processed by further algorithms for extraction, so we can get

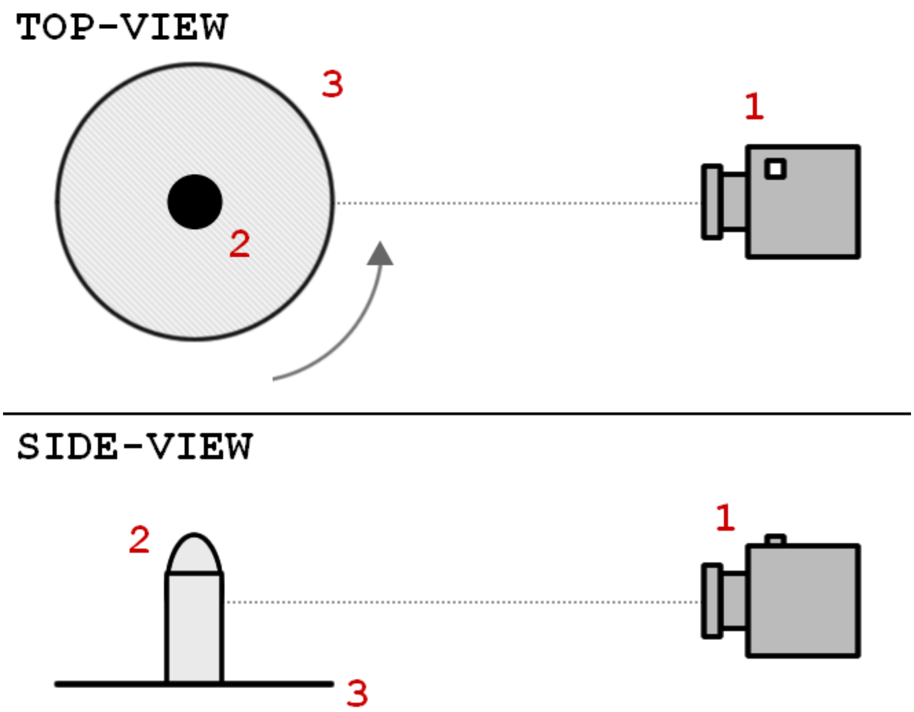

Figure 5.3: A scheme of proposed static system for data acquisition with cartridge platform rotating around its axis: 1 – The camera, 2 – The cartridge case, 3 – The rotating platform underneath the cartridge.

just the area with cartridge case on it.

The same advantages and disadvantages such as the cost of the mirror and the need for further processing apply also to the system with the hyperbolic mirror. Also the composition of this system is only theoretical and as mentioned earlier, it may prove to be impossible to construct.

The two remaining systems are very similar in the construction, however the difference is, that the version with a rotating camera would need much stronger power source for the rotation, due to the weight of the camera (possibly with a light source attached) which we are going to rotate. Also the rotation of the camera would need much bigger and robust construction. Thus logically the rotation of the cartridge case looks like the easiest way.

Lighting

One of the most important requirements for each of the proposed systems is the proper lighting of the cartridge case. Proper lighting can sharpen the small details on the cartridge case and this way greatly enhance the accuracy of the system. On the other hand, improper lighting can lower the quality of the acquired images and hence the overall accuracy.

The system of lighting is very dependant on the final construction for data acquisition, however we can assume the position of the light source should be relative to the position of the camera, therefore those two have to be physically connected.

Another conditions for the lighting device are:

1. The Intensity of the light. The final light source should be strong enough to provide

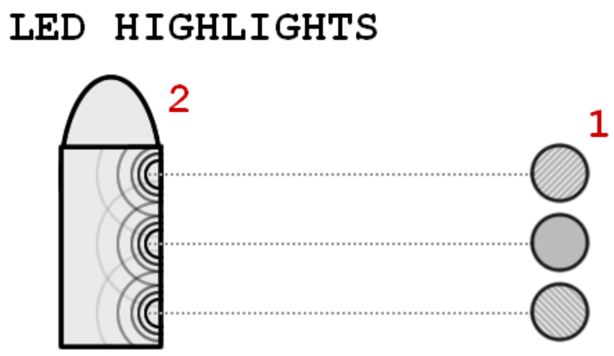

Figure 5.4: Unwanted patterns created on the surface of the cartridge case after using three directional light sources with small dispersion: 1 – Three different light sources horizontally positioned, 2 – The cartridge case with the highlighted light intensity on its surface.

enough light for a good quality of acquired images, however it also can't be too strong, because the metallic surface of the cartridge can create unwanted reflections that can compromise the quality of the photos. Probably the most suitable way is to get a light source with adjustable power, so we can experiment and test behavior of reflections and shadows on resulting photos.

2. The dispersion of the light. If we use one or more small directional light sources, we can get patterns of different light intensity upon the surface of the cartridge case (see image 5.4), which can lower the quality of the acquired image. To eliminate this problem we should either use the light with proper dispersion or some kind of filter, which can dim the light and the patterns created on the surface of the cartridge.

3. The color of the light. We have to consider the effect of lights of different wavelenghts on the final image. Based on information from [23], the green color can sharpen especially the narrow striations which is our goal and therefore the green light source would be the best choice for the data acquisition. However this theory has to be further tested and the use of only green light can be problematic due to the fact, that the whole system has to be isolated as much as possible from the lights of other wavelengths (other colors).

Camera

For the purpose of the image creation we should use a camera capable of taking high-resolution photos as well as videos. It is important, that the camera is capable of taking a macro images, to record even the smallest details on the surface of a cartridge case — the impressions and striations we are looking for.

5.2 Realization of proposed data acquisition mechanism

As the most suitable for the acquisition of image data looks a construction based on a proposed system "Cartridge rotation" from the previous section (see 5.1). For the purpose of this thesis two mechanisms were created and tested. Both of them are based on a sketch from the previous section and after some experimentation and testing one I have decided to use the second mechanism which was constructed based on the results acquired while using the first version.

The construction of the first mechanism is described in the appendix B at the end of this thesis. The construction of this mechanism was finished and improved to the stage where it can be easily used for taking pictures or video of a cartridge case. The material needed for construction of this mechanism is cheap and apart from the motor, it can be bought in common store. The reason why we are not using the second mechanism in this thesis is that we are not going to use the impressions and striations located on the circumference of the cartridge case in our comparison. This is the result of testing the data representing cartridge circumference created by this mechanism. This data wasn't very reliable and with the apparatus we've used it proved to be difficult to acquire data of appropriate quality (see 8). This resulted in usage of much simplified version of this mechanism, where the cartridge doesn't need to be rotated.

Detailed description of the second mechanism follows in this section.

Description

The system consists of several following parts:

- **Platform** for placing the cartridge. The platform has to provide some sort of stable base for the cartridge and also it should be of white color for making the cartridge identification on the resulting image easier. White background provides good contrast for the cartridge which is usually of darker golden-brown color.
- **Camera** is statically placed in a fixed distance from the platform and creates digital images or videos of cartridge cases. The fixed distance should be as short as possible, however not beyond the focusing abilities of camera lenses, as the image acquired has to be sharp to highlight all possible details. This fixed distance allows us to exactly calculate the dimensions of the cartridge.
- **Light source** provides the stable lightning conditions in the system, specifically on the surface of the cartridge case. Light source position should be relatively fixed to the position of cartridge (or platform) to provide the same lighting conditions at all times.
- **Filter** is placed between light source and the cartridge case. It allows passage only for a certain wavelengths of light waves, that means it allows us to lighten the cartridge case with colored light. We will use three basic filters: red, green and blue to experiment and find out how the wavelength of the light affects the comparison results.

Platform

The platform is simple flat circle (or a disc) created in our case from the DVD disc covered by a white cardboard paper with a small support pole in the middle directly below the camera. However any solid object can be used as long as it is painted in white color to provide the needed contrast.

I've used a part of the first mechanism construction — the rotating platform in this case which allowed the rotation of a cartridge case. Rotation is useful for taking pictures of cartridge rotated by a various amount. As the light is positioned under some angle from the surface of the cartridge case the more images of a single cartridge with different rotation can be useful even if our comparison algorithm is robust and able to bypass rotation variances. Light under certain angle is highlighting only a fraction of a cracks on the surface of cartridge (see image 5.5).

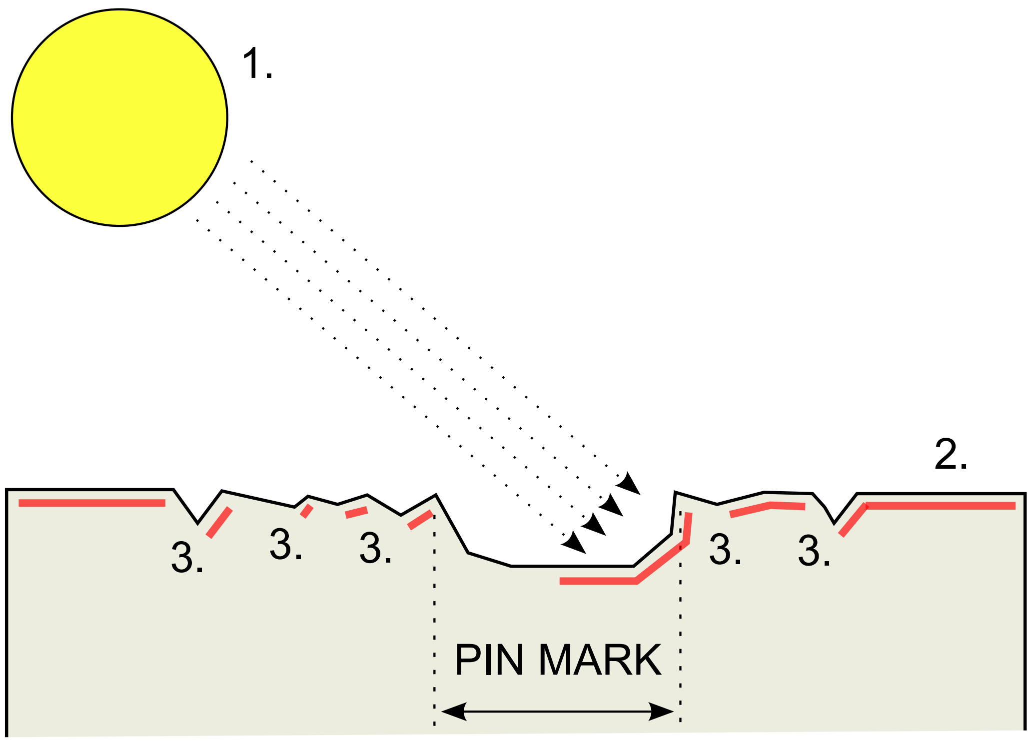

Figure 5.5: A detail of a cartridge rim under the light which is not directly above the cartridge, but it is positioned under certain degree. Red lines marks the highlighted areas of bumps and cracks on the surface of the cartridge. Legend: 1 – light source; 2 – cartridge rim; 3 – highlighted areas.

Camera and holding construction

For purpose of data acquisition we've used the same apparatus as during the construction of first version of mechanism. Two digital single-lens reflex high-resolution cameras:

- Canon EOS 400D capable of acquiring images at resolution of 3888 x 2592 pixels. Continuous shooting is also possible at the speed of 3 images per second.
- Canon EOS 550D with 18 Megapixels capable of saving images at resolution 5184 x 3456 pixels. The continuous shooting can achieve the speed of 3,7 frames per second, which is better then EOS 400D. Camera however supports full HD (high-definition) video recording at selectable frame-rate: 30, 25 or 24 frames per second, which is more suitable for creating a data representation of cartridge case if we're going to use it (see B), which is not our case with the second version of mechanism.

For the purpose of lowering the amount of data needed for the representation of the cartridge case, we can use the cameras in black and white mode. The color is not necessary for the input data images and it is removed during the preprocessing steps of our algorithm, as all the markings are being detected based on their intensity in the BW (black & white) image.

Camera is placed in a fixed and static position above the platform with the cartridge case using the tripod with adjustable height. Adjustable height allows us to choose the best position of camera for taking sharp and detailed pictures of cartridge surface. Fixed height is also very important for calculating exact dimensions of cartridge on taken pictures (see section 6.3 for more information).

Tripod's head is also capable of 3D rotation, to allow us to aim camera directly below from our point of view (see figure 5.7).

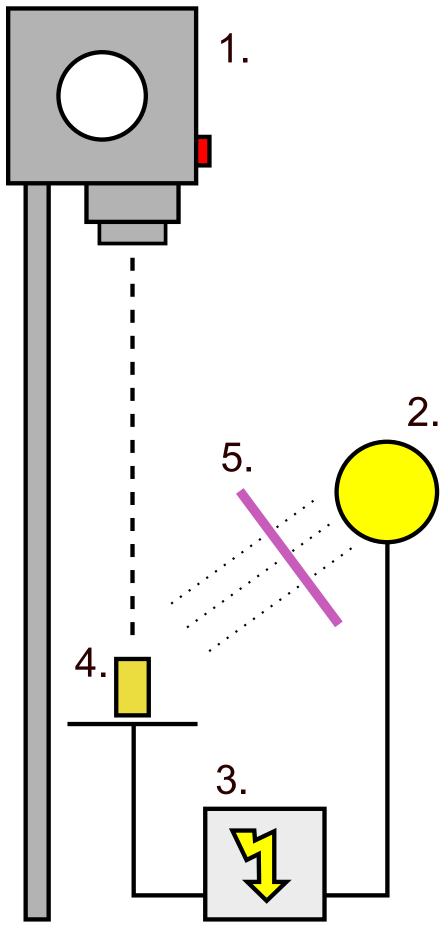

Figure 5.6: Simplified model of used mechanism for data acquisition. Legend: 1 – camera standing on a tripod; 2 – light source; 3 – power source for light source and/or platform (source of platform rotations); 4 – platform with a cartridge case on it; 5 – color filter

Light source

The main task of the light source is to keep the cartridge visible during the image taking and it's second task is to sharpen and highlight all the impressions and striations on the surface of the cartridge.

To avoid the problems and fulfill the conditions set in the section 5.1, I've decided to use the high-intensity bulb of oblong[1] shape, greater than the overall size of the cartridge itself, to provide enough lighting. The bulb is a compact fluorescent light of white color. However any type of the bulb can be used, as long as its intensity is adequate to our needs. The intensity can be regulated to some degree by increasing or decreasing the distance of the light from the cartridge.

The shape of the light helped us to smother the patterns created in the vertical direction and for a further light dispersion in a horizontal direction, a translucent color filter made from PVC material was used. Primary goal of using the filter was to achieve the color lighting for the scene, but the filter also dimmed the light, dispersed it even more and achieved to create the effect similar to that of a non-directional light source.

As a second option for a light source was used a built-in camera flash, which has the advantage of being positioned directly above the cartridge. This affects the highlighted areas and shadows on the cartridge and can be a source of quite different comparison results. The difference between these two variants was examined during the testing of our system (see chapter 7).

Filter

Filter is a thin translucent plastic sheet, placed in the path between the light source and the cartridge case. It allows only the light of certain wavelength to pass, which means that the object is being lightened by a light of some specific color. Effects of color filter can be also achieved by using different color LED lights, however our method is cheaper and easier to construct.

Light is basically an electromagnetic radiation consisting of a waves with certain wavelength. Electromagnetic waves have a specific range of wavelengths which is called or marked as "visible spectrum" (see table 5.2). This spectrum defines which waves are visible to a standard human eye and these waves are known as the light, which we are able to see and which determines the perceived color of every object around us.

Color	**Wavelength [nm]**
Red	625 - 740
Orange	590 - 625
Yellow	565 - 590
Green	520 - 565
Cyan	500 - 520
Blue	435 - 500
Violet	380 - 435

Table 5.1: Table of visible light spectrum. Colors and their respective wavelength range in nanometers [12].

Most light that we interact with is in the form of white light, which contains many or

[1] Deviating from a square, circular, or spherical form by being elongated in one direction [13].

all of these wavelength ranges within them. Shining white light through a prism causes the wavelengths to bend at slightly different angles due to optical refraction. The resulting light is, therefore, split across the visible color spectrum [12].

Figure 5.7: Three images of a cartridge rim, each one taken with different color filter applied in the path of light

The reason for using color filters is to examine the possibility that the highlighting of the details is better under the light of certain wavelength (color). Rays with different wavelengths can refract and reflect differently on the surface of the cartridge and that can result into more (or less) visible markings on the resulting image taken by camera.

We will explore and test this theory in the chapter 7.

5.3 Using the mechanism

Each cartridge case which is going to be used either in our database or as a test piece has to be photographed using our mechanism. We have three color filters available: red, green and blue. Using these filters we can create basic color versions of cartridges and also combining two filters allows us to take even other colors. However each filter is also lowering the overall quality of the acquired photo and for this reason we will use only red, green and blue filtration. So for each cartridge we can create 5 images with different light source and/or color filter. These are:

- Image of cartridge pin enlightened by a directional white LED light.
- Image of cartridge pin enlightened by a directional white LED light filtered by a red color filter.
- Image of cartridge pin enlightened by a directional white LED light filtered by a blue color filter.
- Image of cartridge pin enlightened by a directional white LED light filtered by a green color filter.
- Image of cartridge pin enlightened by a flash light.

All these variation will be later used for testing purposes, to examine their advantages and disadvantages (see chapter 7).

Chapter 6

The data proccessing

6.1 Algorithm input and output

The input data of the algorithm will be an image of the rim of a cartridge and a set of images (or a video) representing the circumference of the cartridge case. These input images are acquired using the mechanism we have constructed before (see 5.2), therefore we should have both pictures with white background and proper lighting.

The algorithm is working with intensity-based grayscale images, but is also capable of accepting color images, which are then processed and transformed into their black & white versions.

The data representing a cartridge case side can be entered either as a video (in a video format) or directly as a set of images. The difference between these two is the amount of useful data extracted and used. For a testing purposes it would be a good idea to try to use both of the versions to compare their impact on overall effectivity and accuracy of the algorithm.

Unfortunately the comparison of circumference of cartridge casing was not implemented, due to the insufficient amount of detail resulting from not using a better equipment (such as specialized macro cameras). The initial comparison of casing was having trouble with locating any features not based on lighting effects, therefore the focus was moved to the cartridge rim.

After getting the input data, the program will begin processing of images to extract the areas which are significant for final comparison.

The output of the algorithm will be a result of comparison with our "cartridge database" represented as numerical value saying the percentage of probability, that the examined cartridge was fired from the same firearm, as the cartridge taken from the "database" and used in comparison. The database was created from the test samples available during the writing of this thesis.

6.2 The flow of the algorithm

The flow of the algorithm represents all of the steps undertaken by the input data of a single cartridge, until the final comparison and output of result values. The flow is created mostly according to our algorithm proposition in chapter 4.

Each of the steps of the algorithm are described below:

1. **Data acquisition** — not actually an algorithm step. The acquisition of a data representation of a cartridge using the constructed mechanism. The algorithm is able to process also a data of cartridges acquired differently, but this will not always work, as there are some requirements for the input data. However the acquisition of a 2D image of a cartridge rim is usually done using similar methods, therefore the comparison of pin impressions is possible.

2. **Greyscale conversion** — a conversion of the image to grayscale version, if it needs to be done, as proposed in the section 4.2. The algorithm automatically creates a black and white image, no matter how many channels does the original have.

3. **Histogram equalization** — histogram equalization as described in the section 4.2 will enhance the input image by evenly distributing its intensity levels. This would in certain cases allow us to obtain better result.

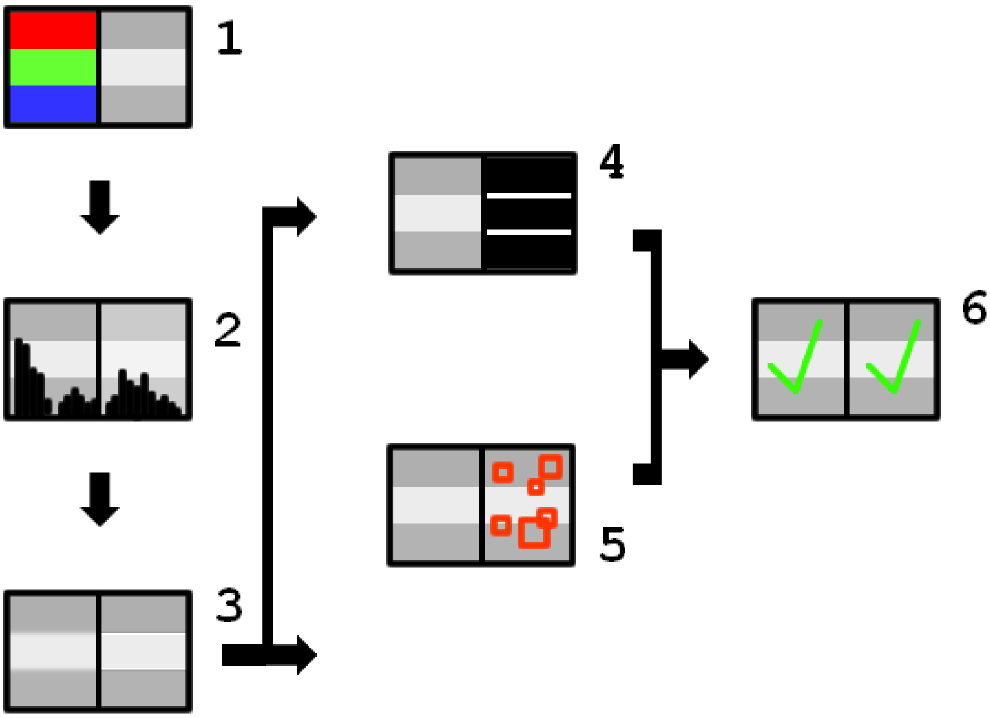

Figure 6.1: The flow chart diagram — 1. Gray-scale conversion, 2. Histogram equalization, 3. Sharpening, 4. Edge detection, 5. Feature extraction, 6. Comparison

4. **Sharpening** — a sharpening process. Sharpening is an automatic part of the edge detection algorithm in our program. It is being done using a convolution matrix.

5. **Edge detection** — a detection of edges in the acquired images to locate the important areas, in our case edges of the cartridge, to be able to calculate its dimensions. Also using the edge detection we are able to exactly locate and identify the letters and numbers on the rim.

6. **Extraction and Image aligning** — extraction of the important areas and preparation for the creation of a vector representation. In this step we are reducing the

information from parts of the image that are not vital — the parts that are not interesting from the view of our comparison algorithm and therefore should be omitted and ignored if possible.

7. **Feature extraction** — localization of the salient points on the images of cartridge and their vectorization. The feature detection and extraction in our algorithm is done using the SURF algorithm (Speeded Up Robust Features).

8. **Comparison** — a comparison of a data representation of the cartridges. In this step we're comparing all of the possible values representing the cartridge obtained in our algorithm during the steps before, such as the dimensions and also vector representation of important features. Combining the comparison of more values would allow us to get more accurate results.

9. **Output** — returning the results of the comparison. The results and statistics about the cartridge are written in a simple output file.

Edge detection — Canny algorithm

The edge detection in the program is done using the standard Canny edge detection algorithm, which is known as an optimal edge detector for step edges corrupted by white noise [26].

Figure 6.2: Image of a cartridge rim and the three results of application of Canny edge detector with different threshold parameters.

The suitability of Canny edge detector is related to three criteria:

- The **detection** criterion expresses the fact that important edges should not be missed and that there should be no spurious responses.

- The **localization** criterion says that the distance between the actual and located position of the edge should be minimal.

- The **one response** criterion minimizes multiple responses to a single edge. This is partly covered by the first criterion, since where there are two responses to a single edge, one of them should be considered as false. This third criterion solves the problem of an edge corrupted by noise and works against non-smooth edge operators.

The work of the algorithm consists of several steps. The first one is the elimination of the noise using the Gauss filter, which can be realized by the convolution filter. Then a Sobel operator is used for finding the vectors of the gradients. The algorithm then eliminates the unwanted gradients by selecting those which are local maximums. In this phase the algorithm selects and marks those points as gradients, whose neighboring pixels in area orthographical to the direction of the gradient have its value of gradient lower. The last of the steps is hysteresis tresholding. Its aim is to assign values to each of the edges found by the algorithm. The phantom edges created due to the unwanted noise have typically lower value than those we're looking for. Canny detector has a two tresholding values (T_1 and T_2) as an input. The values of the gradients found are then compared to these two reference numbers. If the found gradient has a higher value than the input T_2, it is marked as an edge. If the values is lower then T_1 than it's marked as a non-edge gradient. And finally if the value is between T_1 and T_2 then the gradient may or may not be marked as an edge based on the values of neighboring points [16].

6.3 Dimensions calculation

One of the important data we can find out about a cartridge are its dimensions. We are able to actually calculate the dimensions of a cartridge under the assumption, that the image of a cartridge was taken from a fixed distance that is known to us. To get the real dimensions we have to first measure the size of a cartridge in its digital form — the dimensions of a cartridge in pixels on the input image. To be able to do this we have to use an edge detecting sub-algorithm. The edge detector with proper parameters will be able to eliminate the surroundings and mark the areas, where the real borders of the cartridge are. Because of the white background on the data acquired by our mechanism (see 5.2), the edge detection is easily done with good results.

Figure 6.3: Source image of the cartridge rim and image with marked calculated dimensions.

After we have the results of edge detection, the application begins to scan the image from each side (top, bottom, left and right) to the center to find a first pixel, which will represent a border of the cartridge. In order to speed-up the work of the algorithm the search for a nearest pixel is done by estimating the center of the cartridge.

For example to find the top pixel we assume that the center of a cartridge is located very closely to a real center of the picture and so we estimate that the top border will be in the middle of the picture's width. Then we begin to scan the pixels of the image down, until we find the white pixel (see fig. 6.3).

To maintain accuracy while using the estimation of center pixels, the algorithm is running iteratively for a preset number of steps. During each of the step a new cartridge width center and height center is calculated from the results of previous steps. This way we're able to find out the real center and border pixels of the cartridge in a fast and accurate manner.

Once we know the positions of these border pixels, the application calculates the distances and multiplies them with the predefined constants to get a real distance values.

6.4 Feature extraction — SURF

The main feature detector in our application is SURF. SURF or Speeded Up Robust Features detector is a robust image detector and descriptor, used as one of the most advanced feature extractor nowadays. SURF is a very young algorithm (created in 2006), that can be used in computer vision tasks like object recognition or 3D reconstruction.

We can describe the SURF algorithm by describing separately its detection and description phase:

Interest point detection

SURF algorithm uses basic Hessian matrix approximation, which has good performance in accuracy and leads to the use of so-called Integral images. Integral images are used to greatly speed-up the algorithm by allowing easy and fast computation of box type convolution filters.

Value of integral image $I_{\sum}(A)$ at location $A = (x, y)$ represents the sum of all pixels in the input image I within a rectangular region with the top-left corner at the origin of input image and the bottom-right corner at $A = (x, y)$ [15].

$$I_{\sum}(A) = \sum_{i=0}^{i \leq x} \sum_{j=0}^{j \leq y} I(i, j) \tag{6.1}$$

The aim of the Hessian Matrix is to detect blob-like structures (areas that are either darker or brighter than the surrounding) at locations where the determinant of the Matrix has the highest value. Given a point $A = (x, y)$ in an image I, the Hessian matrix $\mathcal{H}(A, \sigma)$ in point B at scale $/sigma$ is defined as follows

$$\mathcal{H}(A, \sigma) = \begin{bmatrix} L_{xx}(A, \sigma) & L_{xy}(A, \sigma) \\ L_{xy}(A, \sigma) & L_{yy}(A, \sigma) \end{bmatrix} \tag{6.2}$$

where $L_{xx}(A, \sigma)$ is the convolution of the Gaussian second order derivative $\frac{\partial^2}{\partial x^2} g(\sigma)$ with the image I in point A, and similarly for $L_{xy}(A, \sigma)$ and $L_{yy}(A, \sigma)$ [15].

Further approximation of the Hessian matrix is then performed using the box filters. These approximate second order Gaussian derivatives and can be evaluated at a very low computational cost using integral images and also can be used together with them to analyze scale space of an image. Scale spaces are image pyramids used for finding salient (interest) points ad different scales, so we can compare them in images scaled differently.

To localize certain salient point, the SURF algorithm uses a non-maximum suppression in a 3 x 3 x 3 neighborhood and the maxima of the determinant of the Hessian matrix are then interpolated in scale and image space[15].

Interest point description

SURF algorithm describes the distribution of the intensities within certain area around the interest point (neighborhood). First order Haar wavelet responses in x and y direction are used to exploit integral images for speed, and use only 64 dimensions. This reduces the time for feature computation and matching, making SURF algorithm one of the fastest salient point detector. This method is also very robust [15]. SURF is also using a simple first-step decision based on a sign of the Laplacian for feature matching to increase the robustness and speed of the algorithm.

The description process itself consists of a few basic steps:

1. **Orientation assignment** - The algorithm defines a reproducible orientation based on information from a circular region around our interest point.

2. **Defining square region** - Then a square region is constructed in such manner, that it is centered around the interest point and oriented along the orientation selected in the previous step.

3. **Haar wavelet responses** - Square region from a previous step is split into smaller 4 x 4 sub-regions over which the algorithm is computing a Haar wavelet responses in horizontal and vertical directions.

4. **Descriptor concatenation** - The final descriptor for each interest point is concatenation of vectors representing each of the sub-regions described by a Haar wavelet responses mentioned in the previous step. This vector is $V = (\sum d_x, \sum d_y, \sum |d_x|, \sum |d_y|)$, where d_x and d_y are Haar wavelet responses in horizontal and vertical direction.

SURF was partly inspired by other popular descriptor SIFT (Scale-invariant feature transform). However the standard version of SURF is several times faster than SIFT and also more robust against different image transformations.

After obtaining salient points with the SURF algorithm, our application saves them and creates a memory representation, which is then processed and compared with the salient points of other cartridges saved in a database.

6.5 Comparison of feature vectors

During the final comparison, we take the list of features representing all the salient points of a cartridge and begin a comparison with these points for each cartridge from our database. Each of the features extracted from the image using the SURF algorithm is represented by the feature description vector which holds the valuable information about orientation, strength and other properties of the feature.

Figure 6.4: Image of a cartridge rim with extracted salient points by SURF algorithm.

To be able to compute a difference of two sets of features in our program, we are using a nearest neighbor method for finding the most similar features among the list of source cartridge and database cartridge features. After obtaining a list of "neighbors" among the features of compared cartridges, we then compute a percentual value comparing their description vectors.

This percentual value holds the information about the difference between the two examined cartridges. The application proceeds with the comparison using all items from our database and returns a subsequent values of difference between the two cartridges.

All the results of the application are displayed on the screen, as well as saved to a simple text file, together with two images — first one representing the borders of the cartridge and second one with marked features extracted by SURF algorithm.

Chapter 7

Testing of the proposed solution

The testing phase consisted of creating several scenarios which would best describe the capabilities and also weaknesses of proposed solution. For the testing purposes, we were using a set of used caliber .45 Auto S&W cartridges.

7.1 Lighting test

First test consisted of examining the suitability of constructed mechanism and used lighting. We've tried several variants of capturing the photos of cartridges, each time using a different source of light and with complete set of cartridges available. The test of ligthing was done:

1. Using a strong white fluorescent light with adjustable position. The intensity of this light was very high and the resulting image was full of strong shadows. On the other hand, the light was able to illuminate even the smallest scratches on the surface. During this test the light source was placed under various different angles to see how it would affect the resulting image.

2. Using a built-in camera flash. The built-in flash eliminated the problem of external light source, which we coudn't position directly in front of the cartridge case or cartridge rim, but the disadvantage of this solution is the fixed distance of the flash (due to the fixed distance of the camera). The fixed distance eliminated the possibility of affecting the reflections created on the metallic surface of a cartridge by moving the light source.

3. Using just a natural daylight. The natural daylight without any other directional light source is creating much softer shadows and provides more difused light over whole cartridge case. On the other hand the strength of the natural light was too low to highlight all the small details on the surface of a cartridge. Also this solution is highly impractical, because it depends on current weather conditions.

The second part of this test was using the implemented application to conduct a comparison with cartridge images taken under different lighting conditions, as mentioned above. We have used images of cartridges taken under three different lighting settings. The image taken under natural daylight was intentionally blurred to simulate a lack of light, which can occur without any additional light source. The results can be seen in table 7.1.

From the results it is clear that the cartridge taken under natural light didn't even qualify for the comparison with the first three reference cartridges. The rest of the results

	camera flash	directional light	natural light
DB item 1	93.45%	94.84%	not defined
DB item 2	91.08%	93.61%	not defined
DB item 3	**94.41%**	**96.01%**	not defined
DB item 4	90.20%	95.68%	(95.35%)
DB item 5	**95.15%**	**96.20%**	(94.69%)
DB item 6	92.44%	95.16%	(95.51%)
DB item 7	92.39%	95.00%	(95.00%)

Table 7.1: Test results for a cartridge photographed under different lighting conditions — the numbers represent possible match of same firearm used with the cartridge (the numbers doesn't represent a real probability, they are only referential).

shouldn't be qualified as well — the SURF algorithm extracted very limited number of features because the image was blurred.

The remaining two versions were more successful and image taken under the directional light has better results than the one taken with camera flash. This can be however influenced by the fact that all database items were created using the same directional light and not a flash. Also note that both versions have the highest hit rate with database items 3 and 5. Database item number 5 was the same cartridge as the tested one and database item number 3 was fired from the same firearm.

We can of course use this resulting number to calculate the answer to question whether one cartridge was fired from the same gun as another. For this however we have to use some threshold number defining what percentage of resemblance is enough to claim that the cartridges were really fired from a same gun. For instance we can decide that our threshold value will be a fixed value of 95%. Or we can calculate normed variable to get more accurate results. This table is the example of using fixed threshold value — the algorithm is fooled by the overall greater score of cartridges photographed with directional light.

	camera flash	directional light	natural light
DB item 1	no	no	not defined
DB item 2	no	no	not defined
DB item 3	no	**yes**	not defined
DB item 4	no	**yes**	no
DB item 5	**yes**	**yes**	no
DB item 6	no	**yes**	**yes**
DB item 7	no	**yes**	**yes**

Table 7.2: Test results for a cartridge photographed under different lighting conditions — saying whether two cartridges were fired from a same gun

But using the normed numbers (see table 7.1) we can achive better results and for instance a threshold number of 1.0080 would mark exactly the true positives.

	camera flash	directional light	natural light
DB item 1	1.0077	0.9961	not defined
DB item 2	0.9822	0.9832	not defined
DB item 3	**1.0181** — same gun	**1.0084** — same gun	not defined
DB item 4	0.9717	1.0049	1.0022)
DB item 5	**1.0260** — same gun	**1.0104** — same gun	0.9953)
DB item 6	0.9969	0.9994	1.0039)
DB item 7	0.9963	0.9978	0.9987)

Table 7.3: Test results for a cartridge photographed under different lighting conditions — normed values or resemblance.

7.2 Rotation test

Second test was aimed at testing a rotation invariant properties of SURF algorithm. SURF algorithm is very robust and our results confirmed, that the rotation of the cartridge has only slight impact on the results (see table 7.3). The first and second column represent image of cartridge rim and its rotation by 180° and third column shows difference of these two calculated values for each database item. The fourth and fifth column show results for a different cartridge and the calculated difference. The real test was made with all seven available cartridges. The data in the table however represent only one of them, as the results were always very similar and we never reached a difference so low as with the rotated cartridge.

	original image	rotated image	difference	different image	difference
DB item 1	95.20%	94.82%	0.38%	93.12%	2.08%
DB item 2	93.04%	92.07%	0.97%	91.08%	1.96%
DB item 3	**95.74%**	**95.73%**	**0.01%**	93.55%	2.19%
DB item 4	89.66%	89.90%	0.24%	**95.72%**	6.06%
DB item 5	93.68%	94.46%	0.78%	95.15%	1.47%
DB item 6	91.94%	92.09%	0.15%	92.41%	0.47%
DB item 7	92.02%	91.95%	0.07%	92.39%	0.37%

Table 7.4: Test results for a robustness test of our algorithm.

7.3 Color test

Third and last test is testing the possibility, that the light with a specific color (which means a light with a specific wavelength) is capable of influencing the results of our comparison algorithm. According to [**?**], the green light, or the light with a wavelength between 520 - 565 nm, is capable of enhancing the smaller details on the surface of the cartridge. It's true that visually the green photo of cartridge seems to be the sharpest and most detailed one, but I didn't manage to find any other literal source backing up this theory.

The results of my testing couldn't choose the most suitable color for data acquiring, as the differences between all three colors are in limit of standart deviation between two

	red filter	green filter	blue filter	no filter
DB item 1	96.88%	95.22%	96.88%	93.44%
DB item 2	90.86%	93.59%	90.86%	91.08%
DB item 3	96.80%	94.95%	96.80%	94.40%
DB item 4	92.11%	94.31%	92.11%	90.20%
DB item 5	94.24%	94.87%	94.24%	95.15%
DB item 6	93.89%	95.41%	93.88%	92.44%
DB item 7	95.25%	93.72%	95.25%	92.39%

Table 7.5: Color test results of our algorithm — cartridge match.

identical input images caused by imperfection of our algorithm. However there is small, but more significant difference between colored versions of the cartridge and the version taken without color filter. This leads me to an assumption, that the light of certain wavelength can highlight some details more and some details less. I'd suggest using a comparison based on combination of all three colors for a proper use. Also this theory should be checked and verified by a ligting system in combination with dark chamber, as my testing was influenced by external light source (e.g. sun).

Chapter 8

Conclusion

My thesis analyzed the possibility of creating and operating a low cost system which would be able to fully substitute a human investigator in the field of criminal ballistics. The system would be able to examine and extract useful information from used cartridge cases and decide automatically whether two cartridges were fired from the same firearm or not. Many systems which are able to partially fulfill this task (see chapter 3.1) already exist, however most of them are too expensive to be used commonly, or they still need a human operator which is having a final decision on the examination results. My goal was to examinate the possibility of creating a cheap and fully automatic system which would be able to extract, locate and compare the important markings on the surface of cartridge cases. The system should be able to compare the images of cartridges automatically and with decent accuracy.

8.1 The mechanism

The first part of the solution is focused on a proposition and construction of a mechanism capable of acquiring the data needed for the comparison — images and video representing the cartridge. This data is then used as an input for our comparison algorithm. There are many propositions for the construction of this algorithm and not all of them were physically constructed during the writing of this thesis, so this can be one of the ideas worth additional research in the future. However even during the construction of the the final blueprint, I've encountered many problems. Some of them were solved successfully but some of them not.

The most difficult obstacle was to provide the algorithm with enough detail to distinguish scratches on the side of a cartridge. This goal at the end wasn't accomplished and that's the reason we had to abandon the original mechanism for data acquisition (see appendix B) and use its simplified version.

However the first version had also its problems, which can be mendioned here, so it can be examined in the future. One of such problems was the right choice for a power source. The motor (see appendix B) which was used has good rotation speed for our needs, however the stability of our final mechanism was lower due to the construction of this motor. The other option (a computer fan) was more suitable from this view, however the high speed of this solution was its disadvantage.

Another problem connected with the construction of our mechanism was the lighting. Our solution of strong white light, seemed to work well for finding and highlighting the small scratches, but the intensity of the light was also responsible for creation of strong shadows in the bigger impressions, such as the pin hole on the cartridge rim. On the other hand, using the light with smaller intensity, we were able to eliminate strong shadows, but the light itself was not strong enough to highlight the thinner impressions and striations on the surface of the cartridge. This is one the areas which need further research and developement. The good idea would be to try different patterns of more light sources with adjustable output in a different patterns — for example lights positioned in a shape of ring. Also to eliminate other light sources and to examinate more the impact of lights of specific vawelengths, the usage of dark chamber would be wise here.

Last of the construction problems was connected with the equipment used for image taking. The use of EOS 400D camera didn't bring the expected results, because even if the camera has good parameters, it doesn't have the option of recording a video and the continuous shooting has its delay too high. The second camera used was an EOS 550D which is in every aspect better than the first one, but still the level of detail of final pictures proved to be too low for a more accurate results. To overcome this we should use at least a macro lens with very high level of detail or some other macro-specialized camera.

8.2 The algorithm

The second part of the solution for this thesis concerns the algorithm for the comparison of the data acquired with the use of the constructed mechanism. This algorithm locates and extracts the useful information about the markings from the images of the cartridge and also reveals other important information about the cartridge, which can be used in the comparison.

There are many possible improvements for this algorithm available in the future, as the implemented application still lacks some aspects of proposed comparison. However most of the problems encountered during the implementation of the algorithm resulted from the lack of proper equipment able to provide us with the high-level detail of captured images representing the cartridge case and cartridge rim.

In this case it is also good to ask whether we can still match the quality of three dimensional cartridge comparison machines with the classic 2D methods. The three dimensional machines use a laser to scan the surface of a cartridge and create the 3D representation of the whole cartridge, which is far more accurate then classic 2D photo or video we can make using variations of our method. Even though the 3D comparison requires expensive and highly sophisticated machinery, it's a good idea for a possible future research which can show the comparison of effectivity between classic 2D and new 3D methods.

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Appendix A

Glossary

Barrel (Gun barrel) A tube through which a bullet travels when a gun is fired. [8]

Black powder Also called gunpowder. It is a mixture of saltpeter(KNO_3), carbon from charcoal(C), and sulfur(S) [25]. Upon ignition it produces heat and gases, which makes the bullet fly out of the weapon.

Bore size A measure of the inside diameter of the barrel in inches (or in hundredths of an inch) or in millimetres [11]. The minimal bore in artillery is equal to 20 millimeter [2].

Breech The end of a barrel into which a cartridge is inserted [22].

Rifling Rifling is the process of making spiral grooves in the barrel of a gun or firearm, which imparts a spin to a projectile around its long axis. This spin serves to gyroscopically stabilize the projectile, improving its aerodynamic stability and accuracy [9].

Oblong Deviating from a square, circular, or spherical form by being elongated in one direction [13].

Histogram A histogram is basically a graphical representation of the tonal distribution in the digital image — a graph which shows the size of the area of the image that is captured for each tonal variation that is available [27].

Salient Something that is prominent, conspicuous, or striking [14].

Appendix B

First realization of proposed data acquisition mechanism

This is the first mechanism constructed for the acquisition of data I've decided to create. It's based on a proposed system "Cartridge rotation" from the section (see 5.1). Description of this mechanism can provide a useful clues for a future works on examination of cartridge markings, especially those not covered by this thesis, that is the impressions left on the side of a cartridge case. This mechanism consists of several following parts:

- The rotor, or the rotating part, on which the cartridge case will be placed and rotated for the purpose of creating its data representation. It will further consist of:
  - Platform for placing the cartridge. The platform has to provide some sort of stabilizing element for the cartridge, otherwise the centrifugal force will push it away from the center of the rotation (assuming that the perfect central positioning is impossible). Also the platform should be of white color for making the cartridge identification on the resulting image easier.
  - The motor. The actual part which provides the rotations in the system. This can be any rotating object to which a platform is attached. The speed of the rotation has to be adequate to the used camera so we can create a map of whole circumference of the cartridge surface.
  - The power source. Power source provides the power to the motor.
- The camera, which is statically placed in a fixed distance from the rotating part of the system and creates digital images or videos of cartridge cases.
- The light source, which provides the stable lightning conditions in the system, specifically on the surface of the cartridge case.
- The shader, which is basically a white wall behind the rotating platform (in the direction of the camera). This shader together with white platform provides the final images with the contrast white background. This will ease the work of the algorithm for extraction of the useful information from aquired images.

The motor

As a motor I've used two different mechanisms. The first mechanism was the computer cooler (or fan) EZCool EZF8025 (see image B.1), based on the final solution from the thesis

[23].

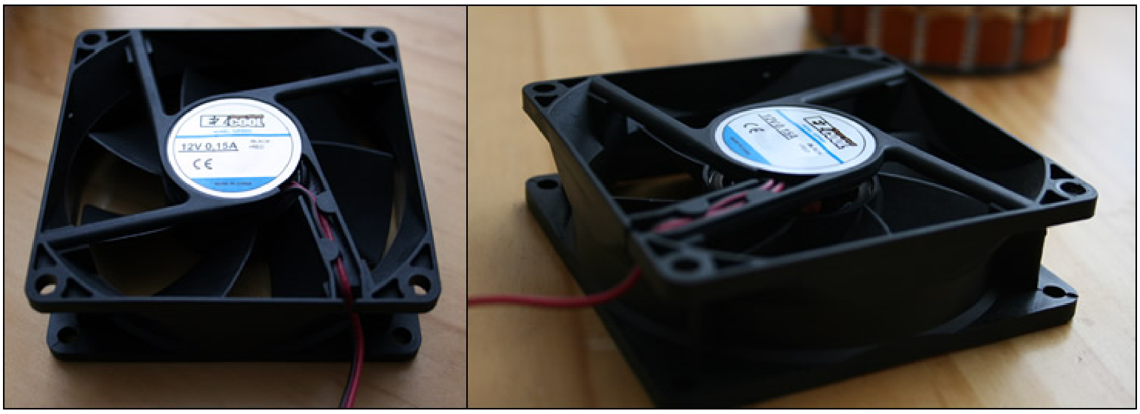

Figure B.1: EZCool EZF8025 computer cooler used as the first attempt for a rotation source in the system.

This fan however proved to be rotating too fast even after applying various methods for slowing its angular speed, like providing the power source with low voltage or sticking paper retarders in the path of the fan blades as proposed in the [23]. The lower voltage proved to be effective for slowing down the rotation of the fan to certain degree, however under specific value the fan didn't have enough power to be set in the motion and the lowest acquired RPS (rotations per second) were still too high to be used in our system.

As we were aiming for a value around 1 rotation per second or lower, even the application of paper retarders couldn't get us nowhere near the needed speed.

The second and final attempt was using a low speed motor F-GM13-050SK (see image B.2) with a built in transmission which could directly provide the low rotation per second value.

The initial motor speed was 66 rotations per minute (that is equal to 1.1 rotation per second) under the recommended voltage of 7 volts. However using the power source with lower voltage (6 volts) we've also lowered the speed of the motor even more, reaching the value of around 60 rotations per minute (1 rotation per second), which was optimal for the cameras used in our mechanism (see B).

Power source

The power source was chosen in order to provide a lower voltage for the motor than the one specified in the motor's characteristics. The output of the motor is 6 volts, whereas the motor's specified voltage is supposed to be 7 volts. This was done in order to decrease the final rotation speed of the motor.

Platform

The platform is placed above and connected to the shaft of the motor and is being rotated this way. The platform is the simple flat circle (or a disc) created in our case from the DVD disc covered by a white cardboard paper with a small support pole in the middle.

The support pole is supposed to serve as a supporting element for both marking the center of the rotation and also stopping the cartridge, which is placed with it's hollow end on the pole, from being moved away from the rotation centre by the centrifugal force.

Figure B.2: F-GM13-050SK motor with built-in transmission.

The pole is about the size of the cartridge and there's a small spring placed on it, so the cartridge can be firmly attached to the pole. This would eliminate any non desired movements of the cartridge on the pole, while rotating the platform.

Camera

For purpose of data acquisition we've used two digital single-lens reflex cameras capable of taking high-resolution photos:

- Canon EOS 400D capable of acquiring images at resolution of 3888 x 2592 pixels. Continuous shooting is also possible at the speed of 3 images per second. Continuous shooting at this speed can be used for the purpose of creating a set of images representing the cartridge case on our rotating mechanism.

- Canon EOS 550D with 18 Megapixels capable of saving images at resolution 5184 x 3456 pixels. The continuous shooting can achieve the speed of 3,7 frames per second, which is better then EOS 400D. The camera however supports the full HD (high-definition) video recording at selectable frame-rate: 30, 25 or 24 frames per second. In our case is the usage of video record much more suitable and accurate than the set of photographs created with continuous shooting.

For the purpose of lowering the amount of data needed for the representation of the cartridge case, we can use the cameras in black and white mode. The color is not necessary for the input data images and it is removed during the preprocessing steps of our algorithm, as all the markings are being detected based on their intensity in the BW (black & white) image.

Light source

The main task of the light source is to kept the cartridge visible during the image taking and it's second task is to sharpen and highlight all the impressions and striations on the surface of the cartridge.

To avoid the problems and fulfill the conditions set in the section 5.1, I've decided to use the high-intensity bulb of oblong[1] shape, greater than the length of the cartridge itself. The bulb is a compact fluorescent light of white color. However any type of the bulb can be used, as long as its intensity is adequate to our needs. The intensity can be regulated to some degree by increasing or decreasing the distance of the light from the cartridge.

The shape of the light helped us to smother the patterns created in the vertical direction and for a further light dispersion in a horizontal direcion, a translucent filter made from PVC material was used. This filter dimmed the light, dispersed it even more and achieved to create the effect similar to that of a non-directional light source.

Shader

The shader is a simple piece of white cardboard bent in a circular shape and placed behind the rotating platform (from the point of camera). It's purpose is to provide a suitable background with high contrast to the cartridge. Together with the cartboard covering the rotation platform, the shader creates a completely white background for the image of the cartridge and thus makes the work of our algorithm much easier.

The circular shape of the shader also eliminates the light artefacts, that would be created in the edges of the cube-shaped shader.

B.1 Using the mechanism

Using the constructed mechanism is very intuitive and easy. For creating a video representing a cartridge case, we have to position the camera to the designated space, cartridge on the holding pole with the hollow part down, start the rotations and record a video or take images in continuos mode.

Apart from taking a video or images of cartridge case we have to take also a picture of a its rim. This can be done in two ways. First is to position the cartridge with it's rim horizontally on the rotation platform and take the image from the same fixed position as for the cartridge case images. This would eliminate the need to move the camera and we could easily create images of cartridge rim with the known fixed distance, as the cartridge can be aligned to the edge of the rotation platform.

Second option is to leave the cartridge standing on the rotation pole and use a tripod for positioning the camera right above the cartridge rim. We can keep the fixed distance for images if we leave the camera and mechanism untouched, while changing the cartridges on the end of the pole. Also the resulting image would be much better as in the previous

[1]Deviating from a square, circular, or spherical form by being elongated in one direction [13].

Figure B.3: Constructed mechanism with separated light source in three different views.

option, because we will be taking pictures of the rotation platform right from above and not from a side. Therefore the background of such photo will consist purely of a white cardboard paper (the rotation platform is covered by a white paper — see B) and this will made further processing much easier.