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impress: Forensic Footwear Impression Retrieval

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***Abstract*— Footwear impressions are a valuable source of evidence for criminal investigations. By comparing them, forensic experts can show that a footwear impression was made by a specific shoe or impressions at different crime scenes were made by the same suspect. However, this process is very cumbersome and the current software solution used by the Austrian Police uses an annotation based search that is very subjective and thus are not accurate enough. Therefore, the goal of the *impress* project is a system that helps searching through databases with thousands of footwear impression images by automatically computing image similarities.**

I. INTRODUCTION

Footwear impressions are frequently found at various crime scenes. They are easily detected, processed and interpreted, and are therefore a valuable source of evidence for criminal investigations. Especially the combination with other types of forensic evidence, e.g. DNA, toolmarks, fingerprints, etc. offers great potential for solving a crime. Additionally to an estimate of the shoe size, the unique patterns of footwear impressions contain clues to the model and brand of the footwear, which in turn help to limit the number of possible suspects. Further, similar footwear impressions at different crime scenes indicate that the crime was committed by the same suspect. This way, criminal acts committed by serial offenders can be identified. For instance burglaries are a great unease for society and are mostly committed by serial offenders. Solving those cases is a crucial factor in improving the subjective sense of security of the people.

In case a suspect is apprehended, the individual features of the footwear can proove that a footwear impression was made by a specific shoe. For this, forensic experts investigate the model characteristics and individual wear, damages and manufacturing marks. If multiple matching features can be found, the forensic evidence can support the prosecution in court. However, for this investigation the actual shoe has to be retrieved, from either the suspect or the evidence locker, and compared to the footwear impression. Since this process is time consuming and cumbersome, a limitation of the number of necessary comparisons to the most similar footwear impressions is desired by the forensic experts.

Therefore, an automated system that helps searching through databases with thousands of footwear impression images is needed. However, the software solution currently used by the Austrian Police is ill equipped to solve this problem. The main issue is, that the footwear impressions have to be classified by the forensic expert by hand. This is done by describing the patterns of the impressions using a set of predefined classes. However, this process is very subjective and therefore the resulting list of similar impressions is not able to accurately depict the footwear impressions that were made by the same shoe. To alleviate this problem the goal of this project is an automated system, which implements an efficient image comparison methodology to find similar footwear impressions in huge databases of images. Further, to allow an identification of the shoe model and brand a footwear impression reference database, i.e. shoe catalog, is created using the huge amount of shoe sole images freely available in the internet.

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II. RELATED WORK

Earlier approaches for the forensic comparison of footwear impressions used for instance frequency analysis [2], [3] or local descriptors like Hu-Moments [1] and Scale-Invariant Feature Transform [11], [10]. In 2014 Luostarinen and Lehmussola [6] published a review paper comparing such approaches. They evaluated the influence of the overall footwear impression quality, variations in the orientation, and impact of partial footprints and showed that even the best performing approaches at that time, by Gueham et al. [3] and Nibouche et al. [7], were not suitable for comparing footwear impressions from real criminal cases. These are especially challenging due to background noise, blur and partial and overlapping impressions. In Figure 1 this is visualized on an example.

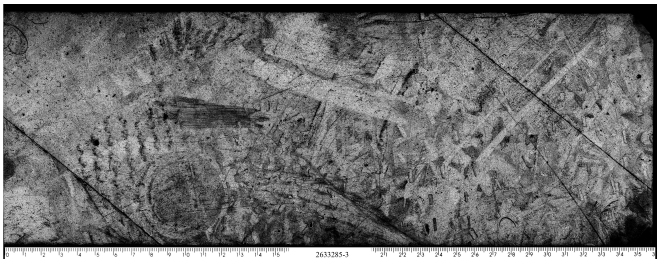

Fig. 1. Footwear impression(s) from a real crime scene collected using a gelatin foil lifter.

More recently, Wang et al. [12] proposed a combination of Wavelets and the Fourier Transform for comparing real impressions. Unfortunately, their approach and all others mentioned above are hard to evaluate, since no results on publicly available datasets were provided. A recent survey from Rida et al. [9] summarizes 21 approaches by listing their published results. According to the listed dataset sizes these results are spread over at least 15 different datasets,

which makes it hard to assess the actual performance of these approaches.

In 2014 Kortylewski et al. [5] published an approach which models the impressions using primitive patterns and contains the first publicly available dataset of footwear impressions. It includes 300 impressions from real criminal cases and 1175 reference impressions. The current state of the art on this dataset is achieved by Kong et al. [4] with an approach based on deep learning; top-1% cumulative match score of 79.7% and a top-5% score of 86.3%.

Another dataset was published in 2017 by Richetelli et al. [8] containing crime scene-like impressions. They used 18 pairs of shoes to create impressions on 4 different substrates using dust or human blood. Their dataset contains in total 180 such impressions and was used in their work to compare methods based on the Fourier-Mellin Transform, phase-only correlation and local interest points. Yet, Zang et al. [13] using established techniques like fine-tuning and data augmentation, show that deep learning based approaches outperform these traditional methods also on this dataset.

III. PROJECT OBJECTIVES

As shown in the previous section, deep learning based approaches are the current state of the art for computing similarities between footwear impression images. However, the two publicly available datasets are not well suited for training such methods. The biggest dataset by Kortylewski et al. [5] contains only 300 crime scene images and 1175 reference impressions. Further, it was not designed to capture the variations among different impressions created by the same shoe which limits the applicable machine learning approaches; e.g. one-shot learning based methods. Additionally, the ground truth is not based on a specific shoe, but on the shoe model and the resolution of the images is less than 1 megapixel. This prohibits a comparison of the individual characteristics which would allow for an exact identification of a specific shoe. In contrast to that, Richetelli et al.'s dataset [8] provides high resolution 600dpi scans of multiple impressions per shoe, but only for 18 different pairs of shoes. Therefore, our first step in the project is the creation of a public dataset with the following properties:

1) *Size*: at least 1000 different shoes
2) *Variance*: multiple modalities (gelatin foil lifters, reference impressions, 3D molds, etc.) and multiple substrates (wood, paper, etc.)
3) *Image quality*: high quality scans of at least 300dpi
4) *Annotations*: ground truth with pixel-precise registration to allow the training of local image similarities

We already started the work on this dataset by creating an acquisition line where participants walk along a given path in order to create predefined footwear impressions. This provides an efficient way to create crime scene-like footwear impressions and using this approach, we already collected multiple impressions of over 300 different pairs of shoes in addition to shoe sole images and model descriptions.

Even though the manual collection of crime scene impressions is inevitable, an automated way to collect reference impressions is desired in order to keep up with the ever changing catalog of shoe models. Therefore, as a second part of the project, it is planned to develop a strategy to automatically download and process images of shoe soles from online retailers like Zalando to create and update a reference database.

Yet, in order to utilize this database, the methodology for the automatic comparison of footwear impressions has to be able to not only handle different modalities of crime scene images, but also images of shoe soles. Furthermore, this comparison of the shoe model characteristics is only the first step to filter the number of possible results. The final goal is to not only identify model characteristics but also individual characteristics, like blemishes or wear, to allow an identification of the specific shoe used to create a footwear impression.

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