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Calculation of bloodstain impact angles using an Active Bloodstain Shape Model

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ABSTRACT

Objectives: Traditional Bloodstain Pattern Analysis (BPA) estimates impact angles for bloodstain spatters by employing ellipses and an inverse sine. This approach is based upon a simplification of the stain formation process, and ignores the physical properties of blood, and its intricate interactions with the target surface. This research presents a data-driven approach, starting from experimental bloodstain spatters. No assumptions about the shape of stains or about the relation between the shape and their impact angle are made a priori.
Materials and methods: Experimental bloodstain data is gathered, after which shape variations are extracted by employing an Active Shape Model. A non-linear regression is then used to explain the relation between stain shape and impact angle.
Results: Experimental results show that traditional width–length ratios may deviate from the assumed inverse sine. The proposed approach, on the other hand, closely follows the experimental data through its regression. Additional experiments have shown an increased accuracy on impact angle estimates for the proposed approach when compared to automatic ellipse fitting.
Conclusion: The proposed method performs better than automatic ellipse fitting. The higher accuracy and faster and more objective analysis suggest that the developed model is applicable in real-life scenarios, and can provide a valuable update to Bloodstain Pattern Analysis.

1. Introduction

Bloodstain Pattern Analysis (BPA) is a subspecialty in forensic sciences, borrowing from fields as chemistry, biology and physics. The calculation of impact angles for bloodstains is an important part of this process, as the area of origin (AO) for a set of stains can be found through stringing [1], the tangent method [1], or directional analysis [2]. One specific type of pattern, named spatter stains, is the result of a force and energy transfer on liquid blood, resulting in spherical- to exclamation mark-like droplets on the impacted surface, depending on impact velocity and impact angle. By calculating the impact angle for a set of stains, and by analyzing the intersections of the approximated trajectories, an estimate of the area of origin can be obtained. This, together with other medico-legal findings, can help the analyst and forensic pathologist in estimating the location of the victim within the crime scene during (subsequent) impact(s), potentially confirming or refuting a suspect's statement in a crime scene investigation [3].

Generally, impact angles for bloodstain spatters are calculated by approximating the stain's outline by an ellipse. Balthazard [4] demonstrated that the ratio of the minor over the major axis of this ellipse is related to the angle at which the stain impacted the surface. This technique, referred to as ellipse fitting, simplifies the complicated process of stain formation to a projection of a spherical droplet onto a flat surface. Bevel and Gardner [1] state that an accuracy of 5–7° on the impact angle can be obtained. They also argue that this number can be improved to about 3° of accuracy when working with impact angles of 45° or less. The approach of fitting an ellipse to a stain, and consequently using the width and length of that ellipse to predict the stain's impact angle is therefore useful in practice. Several computer-assisted methods have also been introduced, relieving some of the analysts' work. HemoSpat [5] and BackTrack [6] are two example software packages, employing (semi-) automatic ellipse

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fitting in their analysis. They both provide tools for estimating impact angles and calculating corresponding AOs. Reynolds et al. also use a computer to manually fit ellipses to stains, employing Microsoft® Office Excel® 2003 AutoShapes [7]. Another way to manually fit an ellipse to a stain using a computer was described in [8], where Microsoft® Office Visio® Professional 2003 was used. A fully automated approach is proposed in [9], where the authors employ simple image processing techniques to enclose bloodstains in a rectangle. The rectangle is then subdivided into 4 quadrants, which are subsequently used to estimate the width, length and direction of the stain. Though ellipses are not explicitly used here to obtain the stain's dimensions, they are implicitly defined by the width and length of the stain. Shen et al. [10] also propose an automated approach, where stain photographs are first rectified using tile-based markers, after which automatic ellipse fitting is used to analyze individual stains. The approach includes special rules for dealing with stains from oblique impact angles, avoiding elongation of the ellipse towards the tails of such stains.

All aforementioned approaches work according to the principle of (explicit [5–10] or implicit [9]) ellipse fitting, and thus use a stain's width and length to determine its impact angle. They are all based on the assumption that any stain can be approximated by an ellipse. It is also assumed that the inverse sine of the width-to-length-ratio of the fitted ellipse predicts the impact angle of the stain. These assumptions are based on the simplification of the stain formation process as proposed by Balthazard in [4]. Numerous physical interactions (such as oscillations, air resistance or surface friction [11]) are ignored in this model, and can cause true stain shapes to deviate from the assumed ellipse or may cause the inverse sine model to perform worse. This article therefore proposes a fundamentally different assumption free point-of-view, using a data-driven approach. No assumptions about the shape of the stains (and thus the underlying formation process) are made. Instead, a database of impact stains with known impact angles is created. From these stains, variations in shape are automatically learned (as opposed to being derived mathematically) and captured by a statistical shape model. This statistical model is then linked to impact angles through a polynomial regression. The model is extended with automatic and robust fitting, enabling the automated analysis of new bloodstains. Using automatic fitting, as opposed to manual model fitting (ellipse or other), allows for an objective analysis, while tail information is automatically ignored. In addition, experimental results suggest an increased accuracy with respect to (automatic) ellipse fitting.

2. Materials and methods

2.1. Approach overview

Fig. 1 gives an overview of all the steps involved in developing and using the Active Bloodstain Shape Model (ABSM). It all starts with stain image data (colored yellow), acquired from one of two sources: firstly, stains with known impact angles come from controlled experiments (Section 2.2.1), and are used to train the ABSM; secondly, stains with unknown impact angles come from real crime scenes, or from experimental data where the known angle has been hidden for validation purposes. All stains are first partially pre-processed (colored red, Section 2.2.2) by extracting their contour. This step is performed in both training and application phases. If the stain is intended for training purposes, it is further pre-processed to remove its tail (manually), and place landmarks along its contour (Section 2.3.1). If it is not intended for training, no further pre-processing takes place. Model training (colored green) is achieved by superimposing the landmark training data (Section 2.3.2), after which a Principal Component Analysis (PCA, Section 2.3.3) is used to automatically learn shape variations from the superimposed data. A polynomial regression is then used to link shape variations to impact angles (Section 2.3.4), completing the ABSM. Non-training stains only have their contour extracted. The ABSM will process them directly (colored blue, Section 2.4), mimicking the models application in practice as closely as possible. An initial robust alignment between model and stain is obtained, after which robust fitting is used to fit the model the new

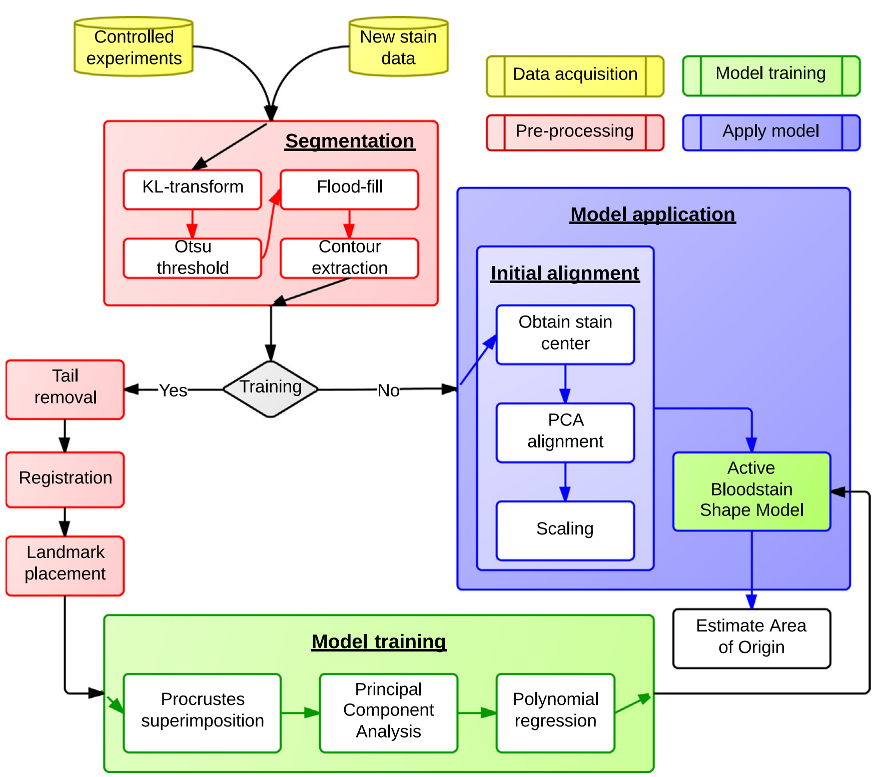

Fig. 1. Overview of the ABSM training and application steps. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)