

Possibilities for qualitative evaluation of the protection area of protective clothing

Dominik Muenks^{1,*}, Jasmin Pilgrim¹, Yordan Kyosev¹

¹Chair of Assembly Technology for Textile Products, Institute of Textile Machinery and High Performance Material Technology (ITM), Technische Universität Dresden, Germany

*Corresponding author E-mail address: dominik.muenks@tu-dresden.de

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ABSTRACT

Protective clothing, worn for example by police, ambulance and private security services, has the task of protecting against weapon attacks and is becoming increasingly important. International standards specify test methods to ensure the protective effects and classes, but the protective surfaces or the wearing comfort are not defined more detailed in the standards. In the study, a new measurement method is developed and presented for determining the percentage of protected body parts by a stab protective vest. After considering various approaches, the combination of scanned 3D/4D body data and appropriate processing turned out to be the most suitable. With the developed method, the projection of protective surfaces onto scanned bodies or avatars is possible. This study helps defining a key indicator of the protected areas and therefore makes different vest variants more comparable.

Keywords

stab protection,
protective clothing,
comfort,
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body scan,
safety clothes,
coverage

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1 Introduction

According to the Federal Situation Report 2020 of the Federal Criminal Police Office of Germany, 84,831 police officers were victims of violent crimes. Compared to the previous year, an increase of 5.9 % was recorded. The long-term development shows a continuous increase in documented cases since 2013, with the exception of 2017, in Germany [1]. This shows the increasing importance of personal protective equipment in today's world to minimise risks and serious injuries to threatened people. Therefore, the police use different types of vests: ballistic, high-visibility stab protection, stab-resistant as well as stab-protective [2].

Personal protective equipment in the form of stab protection vests can be divided into two groups – so-called “hard” and “soft” protection. Hard stab protection vests use heavy, inflexible metal plates, whereas soft stab protection vests offer protection against knife attacks through a large number of textile layers (mostly made of aramid). Depending on the number of textile layers and their thickness, these layers can also be very heavy and inflexible and offer little thermophysiological comfort [3]. Due to the integrated protective plates in hard protection of metal, steel or other heavy materials, the weight can vary greatly depending on the model [2]. Depending on the structure and protection class, a vest can weigh between 1 kg and 10 kg [4].

The technical guideline of the German Federal states on ballistic protective vest, which also addresses stab protection equipment, provides for the protection of the upper body and uses the term "all-round protection". The regulation mainly defines technical requirements, such as color fastness, wash fastness or flame behavior. For each protection class, the test levels and the associated standards for ballistic, stab protection and impact protection testing are specified. The requirements for wearing comfort and fit of a vest are described in the directive as follows [5]:

- only a minor restriction of movement, no disturbing restriction of arm movement, e.g. when shooting with both hands, and the restriction-free bending and stooping of the user;
- the supply of different ready-to-wear sizes or an individual fitting;
- easy dressing;
- the possible adjustment of the vest to the individual body dimensions by means of e.g. hook-and-loop fasteners.

Product certification indicates a corresponding protective function against the penetration of stab weapons into the body at the covered areas, but there is currently no declaration about the area to be covered. In the current development of protective vests, the main focus has been on the materials used and their protective effect, as well as the short- and long-term wearing behaviour. There are no general applicable guidelines for the correct wearing and fit of protective vest. Currently, there are no key figures or definitions regarding the areas to be covered in order to fulfil the protective effect of the vest. The German test guideline “Stab and Impact Resistance” (KDIW) of the Association of Testing Institutes for Attack Resistant Materials and Structures, which describes the requirements, classifications and test procedures for stab and/or impact resistant protective equipment, does not specify any protective areas or surface ratios [6].

After a computer tomographic survey, Breeze concludes that the size and position of some organs is scalable with body size. The bone structure can be used as a guide to classify the upper body and its vital organs. For protective vests, it has been shown that in the vertical direction, the area between the upper iliac crest and the suprasternal notch covers vital organs in 89% of cases. Since injury to most organs is life-threatening, the time span for live saving is a considerable factor. Assuming a 60-minute period, the critical organs include the heart, spleen, liver, and major blood vessels [7,8]. Other countries have adopted Breeze’s approaches, such as the Body Armour Standard (2017) from the United Kingdom, and have developed initial approaches to improve the definition of vulnerable areas [9].

Wearers of today’s protective vests, but also the manufacturers, have no way of determining the protective effect with regard to the protective surface and of assessing the influence of different body proportions.

For this reason, information about the protected surface of the upper body and the behaviour during movements of protective vest as well as their protective elements are of great importance.

The aim of this work is to demonstrate possible methods that show the protective surfaces of defensive vests and put protective surfaces in relation to the body surface of an avatar. The method will use virtual models and 4D-Scans to determine the ratio of protected to non-protected area.

2 Methods

In this study, three methods were used to assess the area ratio between the protective elements and the upper body and their suitability for solving the above mentioned problem. In doing so, all methods should not damage the vest.

It is important to define a specific upper body area based on body characteristics of each proband/avatar. Otherwise, a comparison of the results in a later stage is not possible. Suitable boundary points are the upper iliac crest and suprasternal notch in the vertical direction and the shoulder joint points in the horizontal direction. These boundary points were used later in the study.

2.1. Method – manual visualization

To determine the positions of the protective surfaces in a commercially available stab protection vest, two methods for manual visualization of the surfaces were tested. The aim is to visualize the protective surfaces during a 4D scan. For this, it is necessary that the position of the protective surfaces can be reliably marked and evaluated. The stab protection vest from Armadillo Tex GmbH as shown in Fig. 1 was used for the investigation. The flexible, stab-resistant and adjustable underwear vest has a protective area of up to 0.45 m² and weighs 1.3 kg [10]. The figure shows the front protective surface on the outer material, which is normally embedded in a spacer fabric on the inside. This is only to better illustrate the position of the protective surface.



Fig. 1 Stab protection vest with overlying protective elements (yellow) on the shell material (white).

One of the two mentioned methods is the use of contrast yarns. Contrast stitching adds extra material to the structure of the vest, but it can be removed by unstitching without damage. In the first experiment carried out, the corner points of the square panels were made visible with contrasting colored threads by seams. The seams are set manually with a hand sewing needle and red sewing thread, as shown in Fig. 2. The picture also shows the second method, where adhesive strips were used to mark the protective elements.

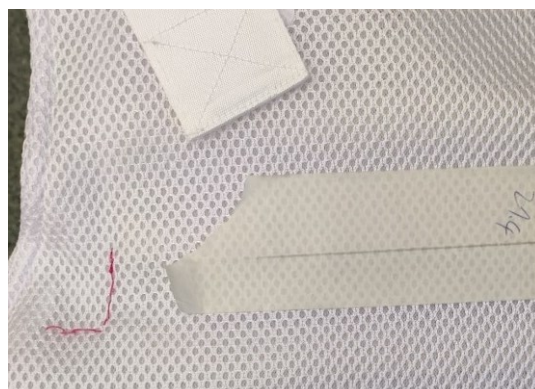


Fig. 2 Position of internal protective elements marked by contrasting yarn and adhesive tape.

The contrasting threads and additional adhesive strips are used as a tool to see the positions of the protective surfaces during the subsequent scanning tests.

Both auxiliary marks can be removed without damage and any visible traces, regardless of the textile structure of the vest.

After marking, the vest was put on a proband to validate both methods. The proband was scanned using a 4D scanner Move4D from the Instituto de Biomecánica (IBV), Spain. For the scan, the proband adopted the A-pose, which involves an upright posture, a hip-width stance and slight sideways spreading of the arms (Fig. 3).



Fig. 3 Proband with stab protection vest worn in the A-pose.

2.2. Method – virtual visualization

The third method examined is the virtual creation of pattern constructions of a stab protection vest. When using the virtual vest model, the individual cut parts, including the protective plates, can be made visible in the simulation program. The vest as shown in Fig. 1 served as a basis and was reconstructed in its basic features, using the 3D design software CLO3D. As shown in Fig. 4, the individual parts were constructed and simulated on an avatar. The yellow sections represent the protective elements.

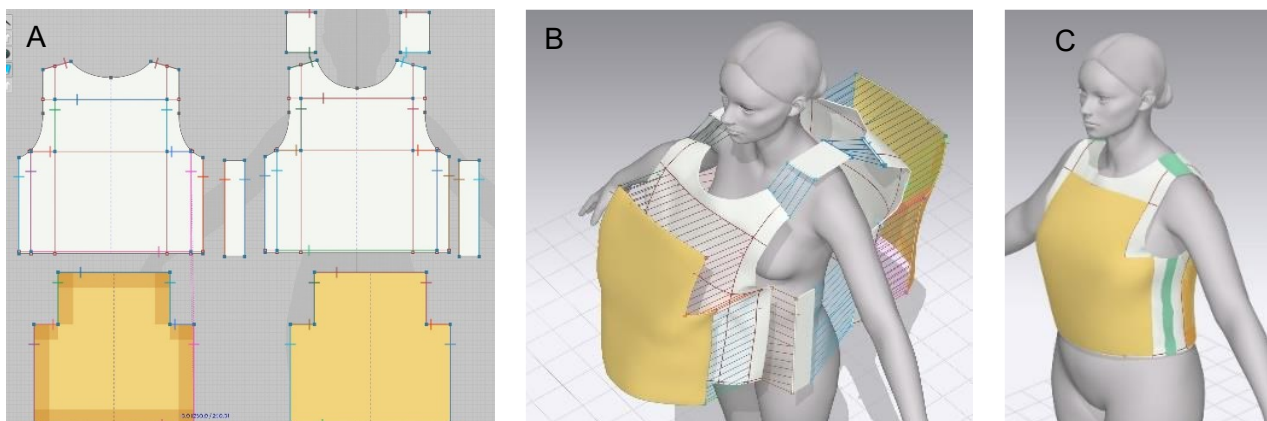


Fig. 4 Pattern construction with CLO3D – (A) 2D cut construction; (B) assembling the cut pieces on the avatar; (C) constructed vest on avatar with protective elements (yellow).

After linking the vest to the avatar, obj-file formats were created to adopt the geometric properties. The files created in this way were edited in Geomagic Studio. The body was trimmed and transformed into a freeform surface using the same software.

As an intermediate step, the freeform surfaces were exported in the iges-file format, for loading the torso and the front and rear protective surfaces (shown in yellow) in the Design Concept program as shown in Fig. 5A. The protective surfaces were then projected onto the torso (Fig. 5B) and then meshed (Fig. 5C). Thus it is possible to calculate the protective surface that lies on the torso.

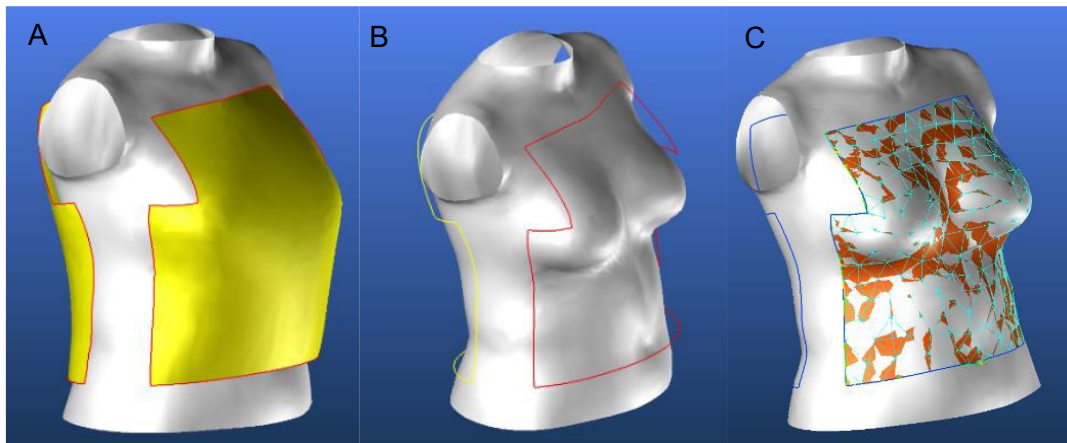


Fig. 5 Design Concept – (A) torso with applied protective elements (yellow); (B) projected borders of the protective elements on the torso; (C) cross-linked protective surface on the torso.

3 Results and discussion

First, the methodology of marking the protective elements with a contrasting thread was investigated. The 4D scanner image and the resulting point cloud were converted to a polygonal surface (Fig. 6A).

The results of the created polygonal areas subsequently show that the markings with the high-contrast thread are not sufficient to make the position of the protective plates visible. It is assumed that the shiny and white spacer fabric reflects the camera images too strongly. The polyester fabric of the carrier vest overexposes the image and transitions and contrasts can no longer be recognized. The surface is only recognized as a white, structureless area. In further experiments, the methodology was used with adhesive strips for marking, which were provided with black lines. The wide adhesive strips were used in an attempt to reduce the reflection of the immediate surroundings of the marking. But here too, the marking was no longer visible after scanning.

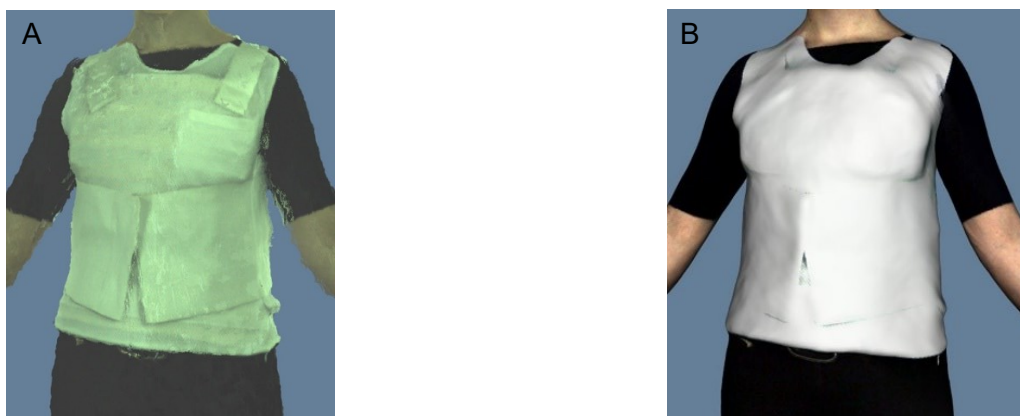


Fig. 6 (A) 4D scan and the recorded point cloud of a proband; (B) create polygon surface of the protective vest – marks of the protective surfaces cannot be recognized.

As shown in Fig. 6Fig. B, only a white area of the stitch protection surface is visible with very few contours and contrasts. On the scanned vest, the markings of the protective surfaces with contrasting yarn and also the markings on adhesive strips should have been visible. Attempts to reduce the vest's reflections did not bring any improvements, either. However, the 4D high-performance scanner needs a lot of light to record motion sequences. Since movements are also to be examined in later investigations, the 4D scanner was used. However, a hand-held scanner might have achieved better results, but this would not have made it possible to record movements.

Furthermore, both methods turned out to be very time-consuming. In addition, protective plates are usually only loosely inserted into the actual vest, and it has been shown that the protective surfaces have

changed with movements during the scanning process. The markings, however, would not show this. Thus, both methods turn out to be unsuitable.

The virtual visualization of a constructed vest, as shown in Fig. 4 and Fig. 5, makes it possible to determine the protective surface (elements) of the vest and to calculate the actual covered and protected surface of the avatar's torso. Accordingly, the ratio can be calculated as follows:

$$\text{Surface area ratio} = \frac{S_{\text{vest}}}{S_{\text{torso}}} \times 100\% \quad (1)$$

The measured areas using the design concept of the vest and torso protection plates are shown in Table 1.

Table 1. The identified surfaces in Design Concept.

Measuring area	Surface area (cm ²)
Torso	4872.7
Front protection plate	1336.6
Back protection plate	1373.2

From equation (1), the virtually created vest results in a total protected area protective surface S_v (front and back) of 2709.8 cm² and of the torso protective surface S_t of the avatar with an area of 4872.7 cm². This results in a protected torso area of 56%, which represents a covered and protected area. The methodology has shown that the calculation of the projection area of the protective plates is possible and thus a measurement method has been found. In addition, initial tests have shown that this method can also be used very well to represent the behavior (displacement, change in protective surface) of protective elements during virtual movements. The application of the methodology to movements will be used in a further study.

4 Conclusions and Outlook

Taking into account the given requirements for a method of determining the protection area of stab protective vest in relation to the body surface and representation of possible movements, various approaches to the solution were carried out and evaluated. The manual methods provided marking and subsequent scanning of the vest in the worn state. However, the contrasting seams and adhesive strips used were no longer recognizable in the virtual scan after scanning, so the method was judged not to be effective and was discarded.

The virtual section simulation method proved to be feasible. The projection area of the protective surfaces and the ratio of the protective and upper body surfaces could be determined accordingly. The method can also be applied to study defined motion sequences with a protective vest. In the study, the ratio between the protected and the non-protected body part was put into perspective. If there were a definition of which body parts and/or which organs were in need of special protection, we would have considered this, but no areas are defined in the norms. Should areas requiring special protection be defined in the future, e.g. in the norms, the virtual visualization is an applicable methodology.

In further studies, different movement sequences will be defined and examined in the future, and it will be investigated to what extent the position of the stab protection elements changes during movements and whether the protective surface changes. In the future, the method presented could be used to develop a key figure that indicates to the purchaser and wearer how much protective surface a vest offers (viewed on a standardized avatar). In addition, an individual check through a personal 3D body scan could determine the correct protective vest and the accompanying protected area.

Author Contributions

D. Muenks: conceptualization, writing – original draft preparation, visualization, supervision, project administration; J. Pilgrim: methodology, formal analysis, investigation; Y. Kyosev: writing – review and editing, supervision, project administration. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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