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A virtual environment to emulate tailor's work

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ABSTRACT

In fashion industry, 2D and 3D CAD systems to design garments already exist; however, some tasks of the process are neglected. We refer to made-to-measure garments and focus the attention on the first step of garment design, i.e. acquisition of customer's measurement. In this paper we present an application based on mixed reality, named Tailor LABoratory (TLAB), which permits to take measures for clothing design as traditionally done by the tailor. TLAB has been developed using open source libraries (e.g., VTK and Blender) and low cost devices, such as Microsoft Kinect v2 to scan the human body, Oculus Rift v2 to create the 3D virtual reality and Leap Motion device to track hands motion. In particular, a virtual tape measure is made available to take measures interacting with the human avatar. To replicate the customer's posture with her/his digital model, Blender has been adopted. It permits to manage body animations and automatic association of an animation to the 3D human avatar. Finally, preliminary tests are illustrated as well as results reached so far and future development.

1. Introduction

Mixed reality allows people to interact with virtual worlds as a person interacts in the real life. Even if the mixed reality finds its main development field in videogames, during last decades it is attracting attention in other contexts, such as automotive, aerospace, textile/clothing [15, 39] and medicine. The last two fields are particularly interesting since related products often need to be customized according to the human body shape.

This paper refers to the development of IT solutions for clothing design and, in particular made-to-measure garments. Virtual clothing environments are already available on the market. In particular, 3D body scanners, 2D and 2D and 3D CAD/CAM systems for virtual clothing modeling and simulation have been developed and introduced into the fashion industry [9, 10, 37, 38, 40]. 2D CAD systems allow the modellist to design the 2D patterns of the customer's garment according to her/his measures; then, the 3D CAD system can be used to create the 3D garment assembling/sewing the 2D patterns and to emulate its behavior on the 3D customer's avatar. Furthermore, many companies are using IT solutions (e.g., PLM suites) systems to improve product development process and reduce costs. However, some of these solutions, especially 3D CAD systems for garment design, are still far from be extensively used in the clothing industry, due also to the skilled-labor dependent nature of apparel

design. For example, the Italian fashion industry relies on a traditional design process, based on tailors' and modellists' skills and experience. However the introduction and use of mentioned ICT tools can give a competitive advantage.

In this context, our aim is to implement a fully virtual platform to design made-to-measure garments introducing low cost devices for augmented interaction. The basic idea is to realize a virtual design process where each step of the traditional workflow can be emulated through innovative IT solutions and the tailor can interact with the customer's avatar in a natural way. In this paper, we focus the attention on the first step of the garment design process during which the tailor takes customer's measurements by using a flexible tape measure. This task heavily relies on tailor's experience and is one of the keys to realize highly customized garments that will fit the customer's body.

We present a mixed-reality application, named Tailor LABoratory (TLAB), which exploits low cost hardware and software solutions and create a virtual environment to design made-to-measure garments.

First, we introduce low cost devices as well as the possibilities that open-source Software Development Kits (SDKs) offer to emulate tailor's work. Then, TLAB is presented with particular emphasis on how to exploit basic SDKs to develop an application based on virtual reality

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for industrial purpose. Finally, conclusions are drawn as well as future developments.

2. Low cost devices for TLAB

During last two decades, several solutions have been proposed in order to improve and automate the product process development for clothing. For example, [14] proposes a systematic method to reconstruct 3D mannequins, [18] presents a new approach to design 3D garment by composing 3D parts from garment examples rather than 2D patterns. However, the major part of these research works is related to both modelling and simulation of a garment [19, 36, 37].

A fully virtual approach to design made-to-measure garments requires not only the 3D scanning of the customer's body but also the acquisition of her/his measurements. Traditionally, the tailor takes the measurements with the customer in different postures using a flexible tape measure. As an example, Fig. 1. shows the arm posture to take the sleeve length for a man shirt. It should be bent and the sleeve length measurement is taken from the point of the shoulder following the bent arm down to where one wants the sleeve to end.

Figure 1. Arm posture for sleeve length.

Many researchers demonstrated how to obtain measurements for garments design from the 3D model of the human body [21, 32, 36–38]. However, the developed solutions do not fully take into account the traditional process made by tailor for getting measurements.

As mentioned before, our aim has been to reproduce, adopting a low-cost philosophy, a virtual atelier where the tailor can take the measures on the virtual avatar of the customer using hands.

During the last decades several devices have been realized to implement mixed reality applications. Among them, we focused the attention on 3D scanners, hand-tracking devices and head mounted display for 3D environment rendering.

2.1. 3D scanners

The 3D scanner is used to acquire the 3D human avatar of the customer and detects the skeleton for animations. The 3D virtual skeleton allows repositioning of human avatar in the correct postures and taking measures. This feature is important in order to emulate how the tailor interacts with the human body. Low cost 3D scanners come from the video-gaming world and they have been considered valuable after many research works, in which the researchers demonstrated their potentiality in different contexts. The precision of these systems is related to the precision required by video games. It depends on environment conditions, light and distance from the object. Anyway, the precision value is around 5-10 mm, which is not comparable to industrial laser scanners. This type of 3D scanners uses structured light projection as operating principles with IR beams. The most representative devices are the MS Kinect v1 and v2. We can find other low cost 3D scanners, which have been already used for taking measures of virtual human body, such as Apple PrimeSense Carmine [25] and Occipital Structure Sensor [33]. Apple PrimeSense Carmine acquires 3D human model as a Microsoft Kinect, but it can be only used on IOs platform. It has already been used in an innovative solution to acquire all measures of human body for custom-made garments. Several Carmine sensors were positioned inside a cabin to acquire all measures of human body for custom-made garments. GayGiano shop (http://www.gaygiano.com/en/) is an example of retailer that is currently using this technology.

Occipital Structure Sensors permits 3D scanning by using Apple mobile devices. It makes 3D scanning technology portable and suitable for mobile applications. Proposed 3D scanners permit to scan objects and elaborate the acquired triangular mesh, using low cost software, such as Skanect [31] and ReconstructMe [27].

2.2. Hand-tracking devices

In the last two decades, many researchers have been carried with the aim to simulate human senses [3, 4, 7, 12, 23, 28]. Several IT devices have been developed that permit to emulate the tactile sense in several ways. The sense of touch is one of most studied and its virtual emulation is based on devices with different final aims. The first ones are haptic devices that allow force-feedback emulation for different applications (industrial and not) [29]. There are also the hand-tracking devices that permit to detect and track 3D position of hands and fingers. The last generation of hand-tracking devices have the ability to track each single finger and thin objects held in hand with high precision. The Leap Motion device [17] and

the Duo3D [8] device are the most representative at low cost. At this stage of development we exploited the hand tracking devices since the main goal has been to verify the feasibility of augmented interaction in this field of application.

In literature we can find a number of applications exploiting mentioned hand-tracking devices [22, 25, 26], such as the interaction with CT volumes with the Leap Motion device [30] and several projects in robotics and automotive fields with Duo 3D [23]. However, no specific applications have been found to take measure for made-to-measure garment using hand-tracking device. Inside TLAB, the hand-tracking device is used to track the tailor's hands while s/he is taking measures of the virtual human avatar. This will allow the tailor to interact with the 3D human avatar using hands as s/he usually performs. We selected the Leap-Motion device since we have already experienced its potentiality for the design of lower limb prosthesis [5]. Furthermore, we have developed an application to automatically generate software interfaces for Leap Motion device [6].

2.3. Head mounted displays

The last generation of head mounted displays solves the problems of visualization latency and the quality of the rendering reached the high definition of last generation of HD-TV. These features give the possibility to develop applications, which permit to visualize a 3D virtual environment in the same way we can see the real world. In the last two years, the most important low-cost HMDs have been Oculus Rift, HTC Vive and Google CardBoard.

The cost is reasonably low and, therefore, easily affordable for both users and developers. In addition, several research works have been done [11, 13, 16], such as immersive applications for automotive and health. Even if there are no specific applications using HMD for clothing design, we can find a mixed reality environment, which allows the customer to wear the 3D virtual garment by a virtual mirror and to evaluate the quality of the chosen garment with glasses for 3D vision [39].

We decided to use Oculus Rift because its SDK is totally available and we needed to understand the basic functionalities in order to create a software framework for interfacing all devices used in TLAB.

3. TLAB architecture

As already mentioned, TLAB permits to virtualize the first step of the design process for made-to-measure garments. The operative workflow counts four main steps (Fig. 2.):

- 3D scanning of the human body with automatic skeleton detection.
- Automatic rigging between 3D scanned avatar and detected virtual human skeleton.
- Automatic animation retargeting with a set of animations useful for garments design, such as position of arms and shoulder.
- Augmented interaction to take measures.

TLAB has been developed in C++ language and the software architecture (Fig. 3.) exploits a set of basic SDKs according to the selected devices:

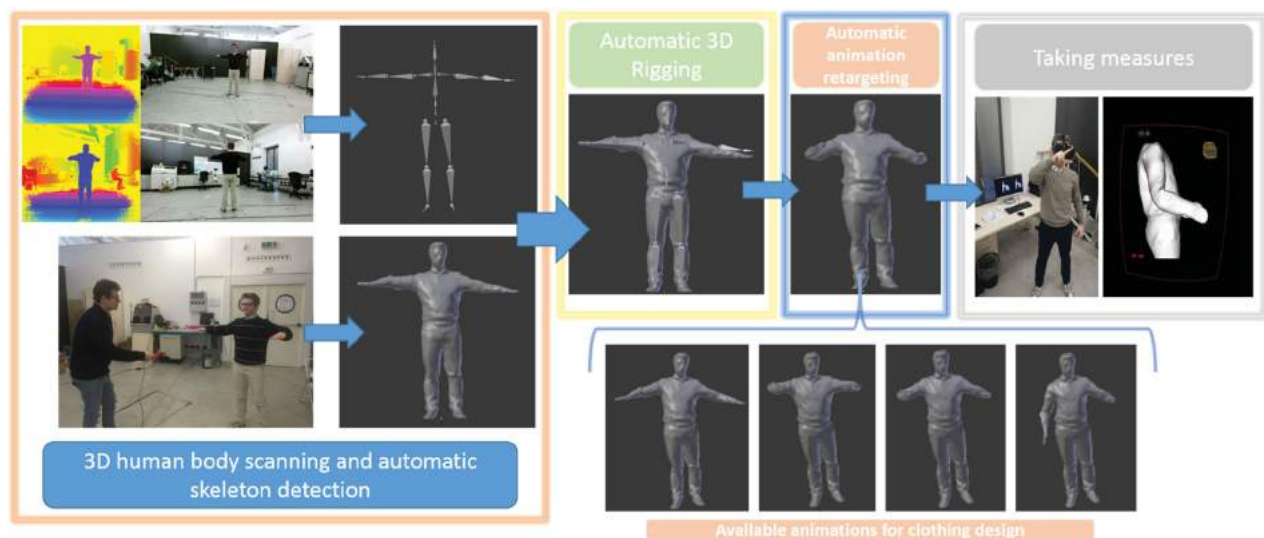- Microsoft Kinect Fusion for 3D acquisition of human avatar and skeleton recognition. It makes available

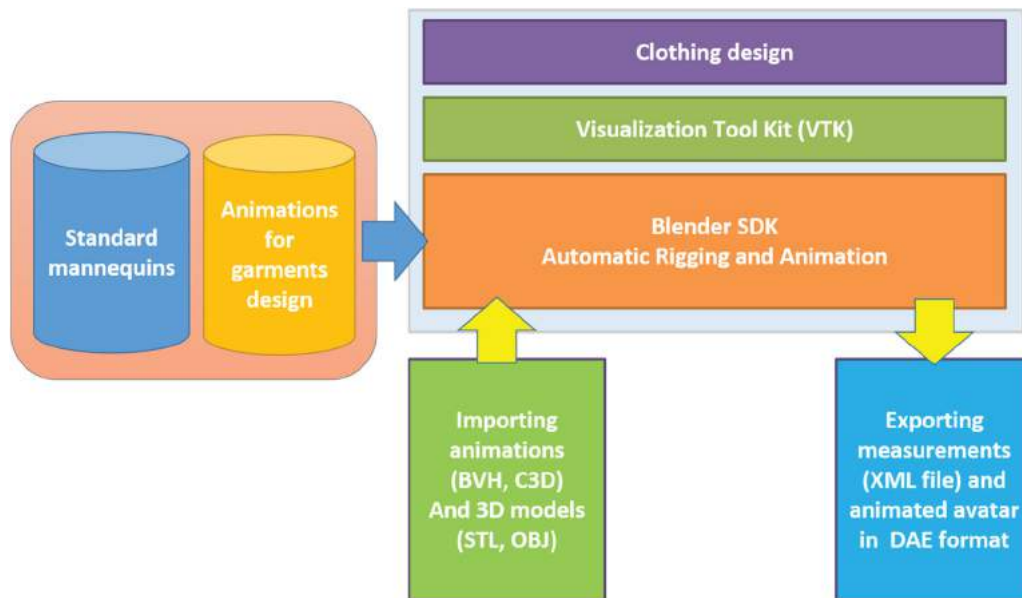**Figure 2.** TLAB workflow.

Figure 3. TLAB software architecture.

3D object scanning and model creation using the Microsoft Kinect v2. The user can get a scene with the Kinect camera and simultaneously see, and interact with, a detailed 3D model of the scene.

- Leap Motion SDK [17] for hand tracking. It makes available a set of modules to easily detect a broad type of gestures. In order to make the interaction simple and comfortable, a research study has been made to design the best Natural User Interface (NUI) for application based on interaction by hands. The developed NUI is based on the SDK of Leap Motion as well as an ad-hoc developed module that extends the C++ class of VTK to interact with the virtual environment of TLAB.

- Oculus Rift SDK 2.0 [24] for immersive vision inside a 3D virtual world. The TLAB environment is automatically visualized in the user's field of view of the Oculus Rift when 3D body shape is detected and thus, the tailor can start to take measurements using hands/fingers detected by the Leap Motion device.

- Visualization Tool Kit (VTK) [35]. TLAB is composed by a set of widgets, such as sliders, buttons and the virtual tape. The virtual tape measure is a virtual widget based on the use of a 3D line. The user takes the measure by pinching the initial point and moving the line representing the tape along the human avatar until he reaches the ending point. Once the virtual tape measure has been properly placed, the associated measurement is calculated and visualized in the field of view of TLAB environment.

- Blender [2], an open source 3D modeling and animation library. It is used to manage body animations

and automatic association of an animation to the 3D human avatar [1] to define different body postures. Furthermore, Blender is used to export/import 3D models in several animation format, such as BVH, C3D and DAE. These formats are the most common to manage motion capture in several commercial MOCAP systems, such as iPiSoft [20] and VICON [34]. Its engine permits the tailor to position the selected part of human avatar (e.g., upper arm, shoulders and legs) according to the required measure and type of garment interacting through the Leap Motion Device.

- 3D Animations Library, a set of body animations (composed by BVH files) to define different avatar postures. For example, the postures shown in Figure 2 have been obtained through two different animations that are part of the 3D animation library. Once defined the correct posture, the tailor can take the measurements necessary to design, in this case, a man shirt. The library is composed by several subsets of animations according to the type of garments.

- 3D Standard mannequins. TLAB can be used starting from either a 3D human body acquired with Microsoft Kinect v2 or standard 3D mannequins; therefore is makes available a set of standard mannequins for clothing design whose sizes respect the Europeans standards for both males and females.

Among several software modules ad-hoc developed, the most important ones regard the automatic procedures for both automatic animation retargeting and rigging with the available databases linked to TLAB.
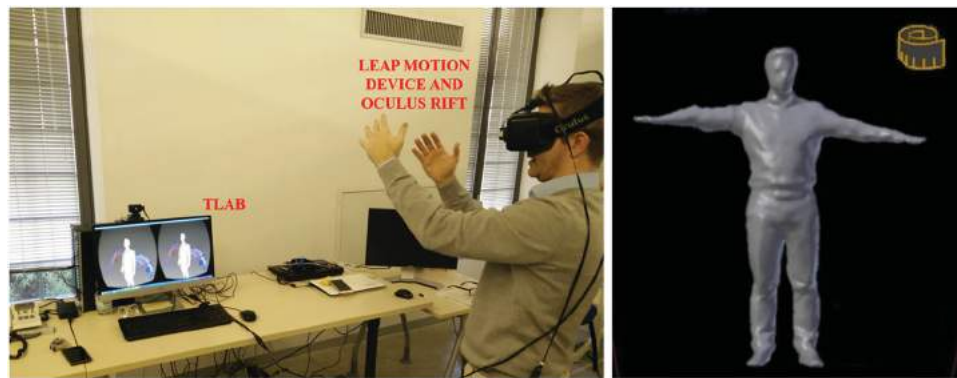
Figure 4. TLAB configuration.

The basic SDKs, previously mentioned, manage the initialization of the TLAB mixed reality environment. In order to simplify the access to the devices SDKs and their synchronization, a software framework, named FrameworkMR, has been developed. It is general purpose and fully independent from the application the developer wants to implement [5].

FrameworkMR exploits the Oculus Rift SDK, the Visualization ToolKit and the Leap Motion SDK with no direct access to the basic modules of each SDK.

Fig. 4 shows the developed mixed reality environment.

In the following sections, we describe, first the automatic procedures for both animation retargeting and rigging with the animation databases as well as the augmented interaction in TLAB.

4. Automatic avatar animation

Automatic rigging and automatic animation retargeting are crucial issues. They have been implemented by using the open source Blender as an SDK. Blender makes available a set of automatic and semiautomatic operations for rigging and animation retargeting. The current version of Blender permits to use it as a Python module. Furthermore, C++ embeds Python in very simple way and thus, TLAB exploits the functionality of Blender with no problems interfacing C++ classes and the other SDKs and Python modules.

4.1. Automatic 3D rigging

The 3D rigging prepares the mesh for animation by organizing the mesh points in vertex groups. Each vertex group can change its position and orientation according to the motion available by the animation. Several motion capture systems allow generating animation relative to

human beings by automatically creating a virtual skeleton through algorithms for body shape recognition. For each bone of the skeleton, the position and orientation of each frame allow the execution of the animation.

The automatic procedure, based on Blender, permits the automatic association of an animation to the 3D model of the human body. First, the acquired skeleton (Fig. 5(a).) is linked to the 3D human avatar (Fig. 5(b).) in the correct position (Fig. 5(c).). Then, the vertex groups are generated and populated according to the position of each vertex to the nearest bone of the skeleton (Fig. 5(d-e). When the automatic 3D rigging is completed, the skeleton can be moved and the 3D human avatar is animated accordingly.

4.2. Automatic animation retargeting

Animation retargeting allows translating an animation from a skeleton to another one, which can has either the same or different set of bones. TLAB uses this operation when the skeleton of the acquired human avatar is different from the skeleton used for animation into database of TLAB. This usually happens when the animation is acquired with marker-based Motion capture system, such as VICON. In this case, TLAB has to reconstruct the skeleton according to the markers positions. The creation of skeleton is performed using templates for marker positioning, as shown in (Fig. 6.). Each virtual bone of the generated skeleton sets its motion according to the makers used to define its position and orientation. Once the skeleton is available, the automatic animation retargeting of Blender maps the animation of generated skeleton with the skeletons of the available animation database. Finally, the automatic animation retargeting is executed when an animation of the database has applied to the initial skeleton with same hierarchy of bones.
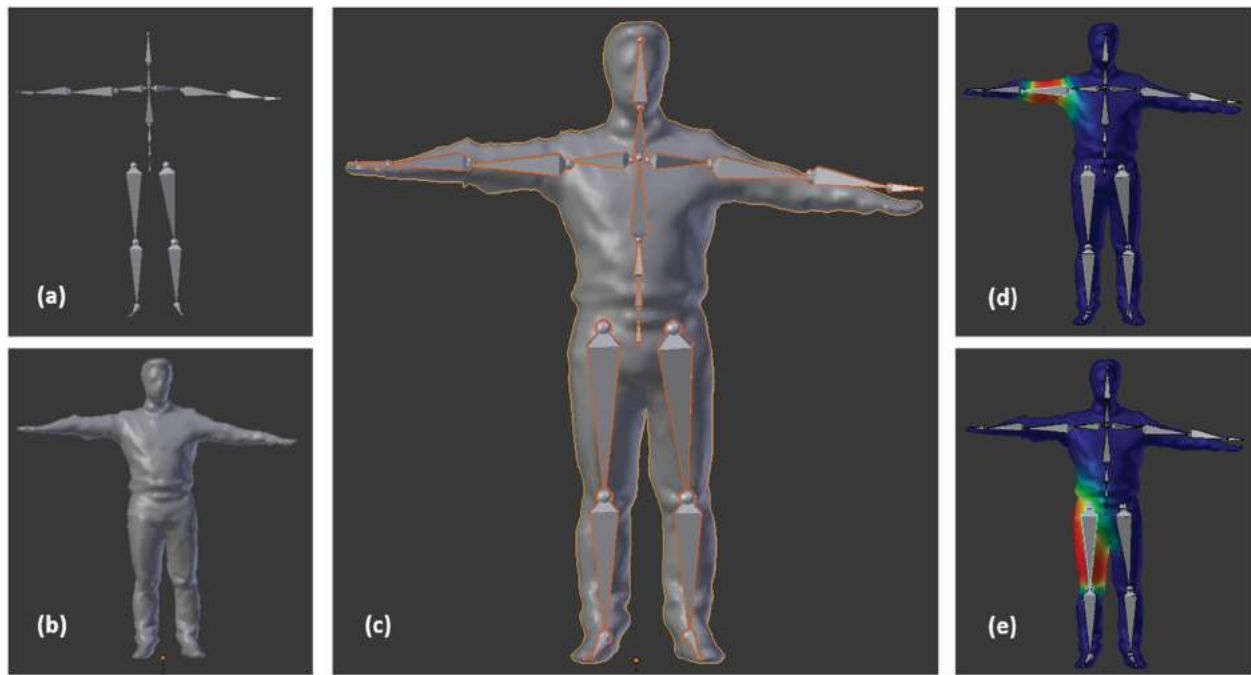
Figure 5. Automatic 3D rigging.

Figure 6. Automatic animation retargeting with MOCAP acquisition by VICON system.

5. Augmented interaction within TLAB

As mentioned, TLAB permits to take the measures interacting by hands with the customer's digital model. We have analyzed the tasks traditionally performed by the tailor when s/he manufactures a garment, such as a shirt or a jacket. Fig. 7 shows some examples of measures taken by the tailor to design a man shirt and related postures of the human digital model. Accordingly, a Natural User Interface (NUI) based on the use of Leap Motion device has been implemented. A limited set of gestures has been defined (Tab. 1.).

To manage the interaction style of TLAB, the designed NUI follows the paradigm of Final State Machine (FSM),

which permits to manage interaction modes as set of states that can be activated with defined gestures or actions detected by Leap Motion.

To emulate the tailor's operation, we have developed a virtual tape measure. It is a virtual widget, which extends the VTK contour widget. Its main features are: (i) the motion of the line (representing the tape measure) along the 3D mesh and (ii) getting the value of the measure.

A set of control points allows the user to modify its path. For each measure, TLAB visualizes the calculated value, so that the tailor can compare and evaluate their correctness in easy way. Fig. 7. shows some examples.
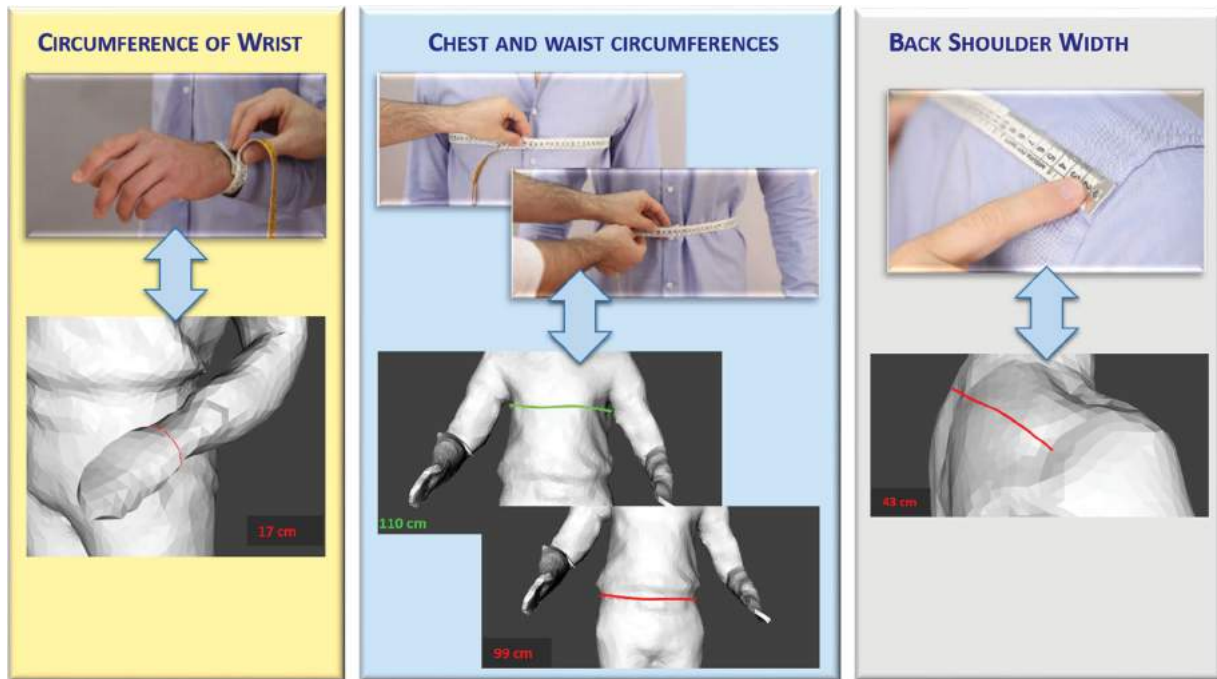
Figure 7. Measures to design a shirt with TLAB.

Table 1. Set of defined gestures.

Action	Gestures	Notes
Basic Interaction		
From basic interaction to acquisition of measures		It's a neutral gesture, which permits to change the possible actions the user can perform on the 3D human avatar. There are two interaction modes: the *Camera mode* to allow basic operation on 3D model, such as rotation and zooming, the *Tailor mode* to the tailor's work.
Moving 3D human avatar		The orientation of the palm defines the rotation of the human avatar. Horizontal motion of a palm permits to zoom-in/zoom-out 3the D human body.
Clothing Design Operations		
Activation of tape measure		If the tailor mode has been activated, the horizontal moving away of both index fingers allows the activation of a new tape measure.
Interaction with tape measure.		A index finger permits to act on the line of the tape measure in order to create the corret measure.

Acting on the control points is possible to add, remove and move a point selected with the index. The user can add a new control point by touching a point of the line for more than 10 seconds. If an existent control point is selected for more than 5 seconds, it becomes green and the user can move it along the customer digital body until he reaches the right position to get the measure. Each time the user modifies the virtual tape measure; its length is updated and visualized in the field of view of Oculus Rift.

6. Preliminary tests

We carried out preliminary tests to verify the potential of the interaction with Leap Motion device (e.g., the NUI) and the use of the virtual tape measure.

Two potential customers and a tailor have been involved to take the set of measures required to design a shirt. First, the tailor measured with real tape measures the body features of both persons. Then, we acquired the two customers with the body scanners and the tailor

took the same measures using the virtual tape measure inside TLAB. The application permitted to define necessary postures and acquire all measures that have been also compared with the real ones. In general they are comparable and the differences were no more than +/- 5 mm. The most critical measures were the waist and chest circumferences that require a tailor's expertise. The tailor appreciated the application but further tests have been planned. First, we will consider different types of garments, such as pant, skirt, and dress, since different avatar postures could be necessary.

TLAB has been also experimented with ten testers with no specific expertise in clothing design. They were able to execute all the operations necessary to take the customer's measures; however other functionalities operations have to be added to simplify the way to take measures, such as moving the virtual tape measure with a single gesture along the mesh without using single control point one by one.

For future development, haptic gloves will be also taken into account in order to properly detect the key points (e.g., the shoulder bone for the design shirt) that tailors usually considers to take the correct measures. The emulation of force-feedback will help the user to better understand the correct point on which positioning the virtual tape.

7. Conclusions

This paper introduces the TLAB application that has been implemented to emulate the first phase of garment design process, i.e. customer's measurements. Once acquired the customer's digital model, the tailor can interact by hands as s/he traditionally performs. Acquired measures can be later used to generate the 2D patterns of the garment and, using a 3D CAD system, to numerically simulate its behavior. Therefore, integrated with a body scanner and a 3D clothing system, it will permit to fully virtualize the garment development process.

At this stage of development, the system has been mainly tested considering a shirt as case study and to verify if necessary postures can be easily generated. The database of animation for the shirt permitted to define necessary postures for all customer's measurements that have been also compared with the real ones. However, problems have been identified with regard to the mesh deformation, in particular for the upper arm. In addition, considering the variety of garments (e.g., pant, skirt, and dress), different avatar postures are necessary. New modules will be added to manage a database of postures and movements to be automatically applied to the customer's avatar and guide the users during measures detection.

Regarding 3D measures, the waist and chest circumferences were the most critical because their correct acquisition requires tailor's experience. Therefore, experienced testers (tailors) should be involved to verify the correct position of each measure along the body shape. Furthermore, the measured values of virtual measurements were reliable compared to the real ones.

Finally, since TLAB has been developed within the framework of the national industrial project, named BODY-SCAN, we have planned to test it with the textile-clothing companies participating to the project and to integrate it with a 3D commercial clothing system. Different made-to-measure garments will be considered and users with different skills and expertise involved. This will also permits the acquisition of tailor's knowledge that could be embedded within the system and made available to novice tailors.

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