Automatic Recognition Of Biological Body Landmark

NG, Roger[1, *], LUXIMON, Yan[2] and CHEUNG, Joseli Shuk-Ling[2]
[1]Institute of Textiles and Clothing, Hong Kong Polytechnic University, Hong Kong SAR, China
[2]School of Design, Hong Kong Polytechnic University, Hong Kong SAR, China
[*] Corresponding author: roger.ng@polyu.edu.hk

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Abstract

Many different automated applications require the automatic recognition of biological body landmarks, such as biometric identification, and three-dimensional (3-D) body scanning. Some methods are based on the photographic image of a human subject [1]. Image analysis methods are based on clustering the regions of pixels according to the texture information [2]. Feature-based recognition from photographic image is possible too [3]. Other methods are based on the template matching [4]. In this article, the researchers present a framework that is based on the geometric information with examples and discussion on the actual application with 3-D body scanners.

Introduction

When a human subject is being scanned by a 3-D body scanner for the extraction of body measurements, one type of available information is based on the geometric properties of the body landmarks. Although it is natural to define the biological landmark using the concept of optimal shape, such as defining the hip as the path of maximum cross-sectional circumference of the lower body trunk, it is difficult to create a relatively stable definition that does not change when the ethnic group changes, or when the age changes. The definition of hip satisfies this stability requirement. Yet, if “waist” is defined as the path of minimum cross-sectional circumference of the body trunk, it does not fulfill the stability requirement. A counter example is a pregnant woman, whose waist measurement can be larger than the underbust measurement. A framework is now presented to demonstrate how to create a set of stable definitions of body landmarks according to the geometry of human subjects.

Framework

A naive approach to the problem is to solely rely on the geometry, because the human body shape changes from young to old age, differs between male and female. The researchers now propose a three-stage framework with the stages of profiling, zoning, recognizing landmarks before calculating the measurements. The logic of the first stage of profiling is to extract the profile curves for zoning. During zoning, the heights of the landmarks are defined and found according to their optimal properties. For example, the smallest circumference of a human body does not necessarily imply the waist measurement. Next, in the landmark recognition stage, some body landmarks are readily defined and they are the primary landmarks, which can be used to define other secondary landmarks. For example, the mid-point of the bust span is defined by the left and right bust points. Finally, the measurements can be calculated.

According to the theory of differential geometry, there are a few useful definitions that can help to define the body landmarks, including global optimal points, local optimal points, curvatures, and continuity. In some instances, it is more convenient to work with the polar coordinate system than the Cartesian coordinate system, because the body features or posture may not be perfectly lined up with the Cartesian coordinate system.

Assumptions On Human Body Shape

An average human body is assumed to have one head, one body trunk, two arms and two legs. The head is connected to the body trunk at the neck; the arms are connected to the body trunk at the shoulder; the legs are connected to the body trunk at the pelvis. Further assume that the posture is upright standing. The body can then be defined by the following zones: (a) head to neck, (b) neck to bust, (c) bust to waist, (d) waist to hip, (e) hip to crotch, (f) below crotch, and (g) left (right) arm being cut from shoulder to underarm, (h) left (right) leg being cut at crotch. Next, a coordinate system should be defined. Following the convention of ergonomics, the frontal plane is the *yz*-plane; the sagittal plane is the *xz*-plane; and the transverse plane is the *xy*-plane. Finally, the origin is defined a point on the floor that is directly below the center of gravity of the body. Some body proportions are used to speed up the search of the landmarks.

Profiling

There are six profile curves, namely, front, back, left outer, left inner, right outer, and right inner. They are the projections onto the *xy*-plane, *yz*-plane, *xz*-plane. Since the definition of the left and right profile curves are symmetric, so only the left hand side are listed in Table 1.

Table 1. Definition of Sample Profile Curves

Profile Curve	Definition
Front Profile Curve	FPC = $\{\mathrm{Max}\{(y_i, z_i)\} \mid (x_i, y_i, z_i) \in$ Data Cloud$\}$
Back Profile Curve	BPC = $\{\mathrm{Min}\{(y_i, z_i)\} \mid (x_i, y_i, z_i) \in$ Data Cloud$\}$
Left Outer Profile Curve	LOPC = $\{\mathrm{Min}\{(x_i, z_i)\} \mid x_i < 0$ & $(x_i, y_i, z_i) \in$ Data Cloud$\}$
Left Inner Profile Curve[1]	LIPC = $\{\mathrm{Max}\{(x_i, z_i)\} \mid x_i < 0$ & $(x_i, y_i, z_i) \in$ Data Cloud$\}$

Note [1]: The inner part of the arm will be handled later after the arm is recognized.

Zoning

The zoning is defined horizontally, then vertically. Some zones are defined with the assistance of height and special landmark points. The defining process is sequential. Similar definitions omitted.

Table 2. Definition of Sample Zones With Reference Heights and Points

Zone Mark	Definition
Head height	$z_{head} = \mathrm{Max}\{z\} \mid (x_i, y_i, z_i) \in$ data cloud
Neck height	$z_{neck} = \{ z : \mathrm{Min}(\mathrm{Circumference}(x_i, y_i, z_i)) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{head}/2 < z_i < z_{head})\}$
Hip height	$z_{hip} = \{ z : \mathrm{Max}(\mathrm{Circumference}(x_i, y_i, z_i)) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_i < z_{head}/2)\}$
Waist height	$z_{waist} = \{ z : \mathrm{Min}(y_i) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{hip} < z_i < z_{neck})\}$
Crotch height	$z_{crotch} = \{ z : \mathrm{Max}(z_i) \mid (x_i, y_i, z_i) \in (\mathrm{LIPC} \cup \mathrm{RIPC})$ & $(z_i < z_{hip})\}$
Bust height	$z_{bust} = \{ z : (x_i, \mathrm{Max}(y_i), z_i)\} \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{waist} + (z_{neck} - z_{waist})/3 < z_i < z_{neck})\}$[2]
Shoulder blade height	$z_{shoulderblade} = \{ z : (x_i, \mathrm{Min}(y_i), z_i)\} \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{waist} + (z_{neck} - z_{waist})/3 < z_i < z_{neck})\}$
Lower body	LoB = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_i < z_{crotch})\}$
Middle body	MidB = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{crotch} < z_i < z_{neck})\}$
Upper body	UpB = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in$ data cloud & $(z_{neck} < z_i < z_{head})\}$
NOTE: A screening process is needed to separate the arms from the body trunk.	
cLeft	cLeft$(z_i) = (z_i,$ cluster data around $z_i) \mid z_i < 0$
cCenter	cCenter$(z_i) = (z_i,$ cluster data around $z_i) \mid -\varepsilon < z_i < \varepsilon$; [3]
cRight	cRight$(z_i) = (z_i,$ cluster data around $z_i) \mid 0 < z_i$;
Body cluster	BoC = $\{\mathrm{c}(z_i) = (\mathrm{cLeft}(z_i), \mathrm{cCenter}(z_i), \mathrm{cRight}(z_i)) \mid \mathrm{c}(z_i) \subset (\mathrm{UpB} \cup \mathrm{LoB})$ where $\mathrm{c}(z_i)$ is a tensor of the cluster of a cross-section centered at z_i.

Left leg	LeLg = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in \cup\{\text{data of cluster(cLeft}(z_i))\}$ & $(0 < z_i < z_{crotch})\}$
Left lower arm	LeLa = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in \cup\{\text{data of cluster(cLeft}(z_i))\}$ & (cluster(cCenter(z_i)) $\neq 0$) & $(z_{crotch} < z_i < z_{neck})\}$
Left underarm height	$z_{underarm} = z_i \mid$ (cluster(cLeft(z_i)) $\neq \phi$ & cluster(cCenter(z_i)) $\neq \phi$) & (cluster(cLeft(z_{i+1})) $= \phi$ & cluster(cCenter(z_{i+1})) $\neq \phi$) & $(z_{waist} < z_i < z_{neck})$
Left shoulder point	LeShPt = $(x_i, y_i, z_i) \mid ((x_i, y_i, z_i) \in$ UpB) & $(x_i < 0)$ & (Max(disanceXYZ((x_i, y_i, z_i), cg))
Left underarm point	LeUaPt = $(x_i, y_i, z_{underarm}) \mid$ Min(cCenter($z_{underarm}$), with respect to x)
Left upper arm point	LeUa = $s = (x_i, y_i, z_i) \mid s \in \cup\{\text{data of cluster(cCenter}(z_i))\}$ & $(z_{underarm} < z_i < z_{neck})$ & (CutArmPlane(s) < 0)}[4]
Left hand	LeHd = LeLa $\cup$ LeUa
Upper trunk	UpTk = $\{ s = (x_i, y_i, z_i) \mid s \in$ (UpB – LeUa)}
Lower trunk	LoTk = $\{(x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in \cup$ {data of cluster(cCenter(z_i))} & (CrH < z_i < UaH)}
Trunk	Tk = UpTk $\cup$ LoTk

Note [2]: This definition works for male and female in general, and may not work for pregnant women. The 1/3 proportion coefficient helps to speed up the searching.
[3]: The value of ε is a system parameter for tuning the accuracy of different body scanning technology.
[4]: CutArmPlane(x_i, y_i, z_i) = 0 defines the boundary of arm and trunk.

Body Landmarks

So, the key feature points are now ready to be defined according to their geometric properties. Since there are more than one hundred (100+) landmarks, examples of different types of definitions are listed in Table 3.

Table 3. Definition of Body Landmarks

Body landmarks	Definition
Top of head	ToHdPt = $(x_i, y_i, z_{head}) \mid (x_i, y_i, z_i) \in$ center of cluster(cCenter(z_{head}))
Left side neck point	LeSNPt = (Min(x_i), 0, z_{neck}) $\mid (x_i, y_i, z_i) \in$ data of cluster(cCenter(z_{neck}))
Left bust point	LeBuPt = (x_i, Max(y_i), z_{bust}) $\mid (x_i, y_i, z_i) \in$ data of cluster(cCenter(z_{bust}))
Left middle finger	LeMidF = (x_i, y_i, Min(z_i)) $\mid (x_i, y_i, z_i) \in$ LeHd
Nose point	NoPt = (max(r_i), θ_i, z_i) $\mid (r_i, \theta_i, z_i) \in$ UpB [5]
Left elbow point	LeElPt = $(x_i, y_i, z_i) : \partial z / \partial x_+ \neq \partial z / \partial x$ & $z_{wrist} < z_i < z_{shoulder}$ & $(x_i, y_i, z_i) \in$ LeHd
Crotch point	CrPt = (x_i, 0, z_i) : min(z_i) of {(x_i, y_i, z_i) : concave down on xz-plane & concave up on yz-plane

Note [5]: (r_i, θ_i, z_i) is the cross-sectional polar form of (x_i, y_i, z_i) under the cylindrical coordinate system.

Practical Consideration

Certainly, the above definition is theoretical, and there are additional considerations required to handle the real life data, such as those data cloud that is scanned by handheld body scanner. The full body scanners that takes about ten seconds or less can produce more reliable data cloud than the handheld body scanners. There are a few reasons. Firstly, the subject who is standing inside the full body scanners can hold on some handles to stabilize their posture during scanning. Secondly, the scanning speed is stable throughout the scanning progress, and so the data cloud has relatively stable density. Thirdly, the scanning heads move in the designated track and hence the orientation of the data cloud is stable. Fourthly, the scanning process is fully automated and independent on the skill of the operator.

Two examples of difficulties are now presented. The first example of uneven density of data points can lead to errors in arm-trunk separation as in Fig. 1. The missing data separate the arm from the trunk unexpectedly. Part of the front arm segment is incorrectly classified to trunk as in Fig. 2, while the rest of the arm is incorrectly linked to part of the back segment of the trunk as in Fig. 3. The second example is the missing data in the original data cloud as in Fig. 4.

Unfortunately, the hole patching function of most 3-D CAD systems sometimes cannot produce smooth and reasonable patches, and consequently affects the ability of automation.

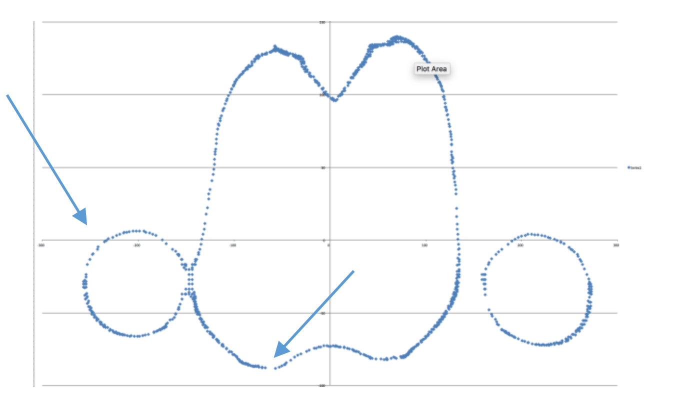	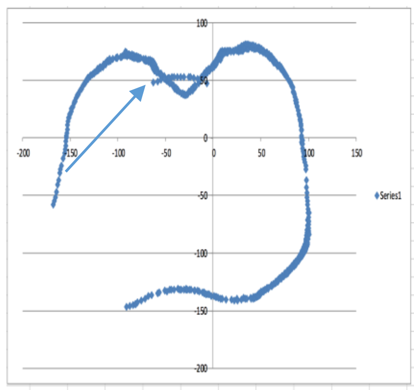
Fig. 1 Full Cross Section	Fig. 3 Cross Section of Body Trunk
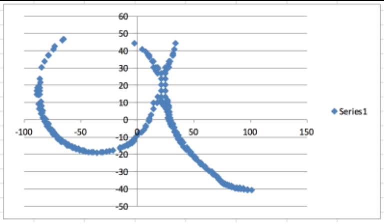	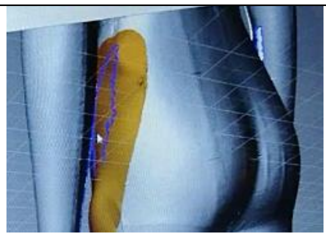
Fig. 2 Cross Section of Left Arm	Fig. 4 Result of Hole Patching

Conclusion

This article explored the possibility of defining the body landmarks of a human subject by using the geometric properties. In order to automate the recognition process, the 3-D data cloud should be processed in a three-stage framework with profiling, zoning, and recognizing landmarks before calculating the measurements. The profiling stage provides the rough estimation of the silhouette of the body shape. Zoning can then be defined according to the geometric properties of the critical points on the body profile curves. Without the zoning, some definitions can be unstable. For example, the largest circumference of a horizontal cross-section may either include the arms and the body trunk or may correspond to the bust instead of the hip depending on the subject. In practice, this theoretical framework is subject to errors if the 3-D data cloud is not sampled systematically and evenly.

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