ANHANG I - HAUPTKOMPONENTENANALYSE

Formenraum

Als Ausgangsdaten für die Formanalyse dienen die triangulierten Oberflächen, die aus den Segmentierungen gewonnen wurden - wie in Abschnitt 2.1.2 beschrieben. Die Anzahl der Dreiecke und Knoten (Vertices/Dreieckseckpunkte) ist im Allgemeinen in jedem Schädelmodell unterschiedlich. Des Weiteren ist die Reihenfolge der Knoten willkürlich. Für die Hauptkomponentenanalyse muss daher zunächst ein *Remeshing* durchgeführt werden. Sei M die Anzahl der Knoten im ersten Schädel. Der erste Schädel wird beschrieben durch den Vektor v^i der Koordinaten seiner M Knoten V_i:

$$v^1 = \begin{pmatrix} V_{1x} \\ V_{1y} \\ V_{1z} \\ \vdots \\ V_{Mx} \\ V_{My} \\ V_{Mz} \end{pmatrix}$$

Sei $K^{1\to i} : \Re^3 \to \Re^3$ die Korrespondenzfunktion, die einen Punkt auf der Oberfläche des ersten Schädels auf den korrespondierenden Punkt des i-ten Schädels abbildet. Man kann dann den i-ten Schädel beschreiben, indem man die Knoten des ersten Schädels mit dieser Funktion auf den i-ten abbildet:

$$v^i = \begin{pmatrix} K_x^{1\to i}(V_1) \\ K_y^{1\to i}(V_1) \\ K_z^{1\to i}(V_1) \\ \vdots \\ K_x^{1\to i}(V_M) \\ K_y^{1\to i}(V_M) \\ K_z^{1\to i}(V_M) \end{pmatrix}$$

Auf diese Weise erhält man für jeden Schädel einen beschreibenden Vektor der Dimension $3M$, in dem Einträge mit gleichem Index Koordinaten anatomisch korrespondierender Punkte beschreiben. Die Formvektoren v^i werden im Folgenden auch als Punkteverteilung bezeichnet.

Mittelwert der Punkteverteilung

Der Mittelwert $\overline{v}$ der Punkteverteilung errechnet sich wie folgt:

$$\overline{v} \quad = \frac{1}{N}\sum_{i=1}^{N} v^{(i)} \quad = \frac{1}{N}(v^{(1)} + v^{(2)} + ... + v^{(n)}),$$

wobei N die Anzahl der individuellen Schädelmodelle ist.

Bevor die Mittelung durchgeführt werden kann, müssen die Formvektoren räumlich ausgerichtet werden. Dazu werden alle Formvektoren auf einen Referenzvektor durch eine starre Bewegung transformiert.

Abweichung des Einzelschädels vom Mittelwert

Die Abweichung $\Delta v^{(i)}$ des i-ten Schädels vom Mittelwert wird ausgedrückt durch:

$$\Delta v^{(i)} = v^{(i)} - \overline{v}$$

Kovarianzanalyse

Die Kovarianz beschreibt die Beziehung eines bestimmten Eintrages in einer Menge von Vektoren zu einem bestimmten anderen Eintrag. Die Kovarianz zwischen dem α-ten und dem β-ten Eintrag der Punkteverteilung berechnet sich zu:

$$\operatorname{cov}(\alpha, \beta) = \frac{\sum_{i=1}^{N} (v_\alpha^{(i)} - \overline{v}_\alpha)(v_\beta^{(i)} - \overline{v}_\beta)}{(N-1)}$$

Beträgt die Kovarianz 0, zeigt das, dass die betrachteten Dimensionen unabhängig voneinander sind.

Die Kovarianz aller möglichen Kombinationen wird beschrieben durch die Kovarianzmatrix:

$$C_{\alpha,\beta} = \mathrm{cov}(\alpha,\beta), \quad C \in \Re^{3M \times 3M}$$

Offensichtlich ist die Kovarianzmatrix C symmetrisch, d.h. $C_{\alpha,\beta} = C_{\beta,\alpha}$.

Eigenvektoren und Eigenwerte der Kovarianzen-Matrix

Aus der Kovarianzen-Matrix werden die Eigenvektoren w^{μ} und deren Eigenwerte λ_{μ} bestimmt:

$$C\, w^{\mu} = \lambda_{\mu}\, w^{\mu}, \quad \mu = 1...3M$$

Da im hier betrachteten Fall N viel kleiner ist als $3M$, sind nur N Eigenwerte von Null verschieden. Die Eigenvektoren werden dem Betrag der zugeordneten Eigenwerte nach sortiert. Der Eigenvektor mit dem höchsten Eigenwert ist die Hauptkomponente der betrachteten Menge von Datensätzen. Er beschreibt die Richtung der stärksten Variation.

Man kann nun jeden der individuellen Datensätze als Kombination des Mittelwertes und der berechneten Eigenvektoren beschreiben:

$$v^{i} = \bar{v} + \sum\nolimits_{j=1}^{N} \vartheta_j w_j \text{ , mit geeigneten Koeffizienten } \vartheta_j \text{ .}$$

Auch ein neuer Datensatz, der nicht Bestandteil des Ausgangskollektivs ist und somit nicht in die Berechnung der Kovarianz-Matrix eingegangen ist, kann als Kombination der Eigenvektoren in obigem Sinne beschrieben werden. In diesem Fall handelt es sich jedoch nur um eine Näherung. Je mehr verschiedene Datensätze im Ausgangskollektiv enthalten waren, desto mehr verschiedene Eigenvektoren gibt es und desto genauer lassen sich unabhängige, neue Datensätze auf diese Weise beschreiben. Dies kann ausgenutzt werden, um zu bestimmen wie viele Datensätze für eine ausreichend genaue Beschreibung der Norm benötigt werden.

ANHANG II - MASSE ZUM 3D FORMVERGLEICH

Zur Durchführung des *leave-one-out*-Testes wird der mittlere quadratische (**R**oot **M**ean **S**quare) Flächenabstand zwischen dem statistischen Formmodell S und einer Referenzfläche S' über die Formparameter $\vartheta = \{\vartheta_j\}$ und die Transformationsparameter einer starren Transformation T minimiert:

$$\min_{\vartheta,T} = \{d_{RMS}(S(\vartheta,T),S')\}$$

Flächenabstandsmaß

Bei zwei gegebenen Flächen S und S' definieren wir die Distanz $d(x,S')$ zwischen einem Punkt x auf einer Fläche S und der Fläche S' als:

$$d(x,S') = \min_{x' \in S'} \|x - x'\|_2,$$

wobei $\|.\|_2$ die euklidische Norm angibt. Sei $|S|$ der Flächeninhalt der Oberfläche. Dann ist der Flächenabstand gegeben durch:

$$d_{rms}(S,S') = \sqrt{\frac{1}{|S|+|S'|}(\int_{x \in S} d(x,S')\,dS + \int_{x \in S'} d(x,S')\,dS}$$

Dieses Abstandsmaß ist symmetrisch unter dem Austausch der Flächen S und S'.

ANHANG III – VIDEOANIMATION DER HAUPTMODEN

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