# Comparing3D descriptors for local search of craniofacial landmarks

Federico M. Sukno[1,2], John L. Waddington[2], and Paul F. Whelan[1]

[1] Centre for Image Processing & Analysis, Dublin City University, Dublin 9, Ireland
[2] Molecular & Cellular Therapeutics, Royal College of Surgeons in Ireland, Dublin 2, Ireland

## Additional data: full tables for different neighborhood sizes

Below we provide the values of expected local accuracy curves as defined in Section 2 of the ISVC main paper, for each descriptor-landmark pair, varying the search radius $r_S$ from 1 to 200 mm. Landmarks with bilateral symmetry (left and right) were merged together by considering each a separate instance of the same test.

The descriptor template for each landmark was computed as the median descriptor from a training set, created by means of 6-fold cross-validation. To compute the scores $s(\mathbf{v})$, the descriptor template was compared with the one of each vertex using (minus) the Euclidean distance (i.e. considering each descriptor as a point in $N$-dimensional space, being $N$ the descriptor length). The only exception was the case of spin images, where we used the (2D) cross-correlation, as suggested in the original paper. Nonetheless, we should mention that results using Euclidean distance (with the descriptor normalized to sum the unit) were similar to those using cross-correlation.

Tables 1, 2 and 3 summarize the results. Each cell describes the first plateau of the expected local accuracy curve: the number on the top indicates its median value and the ones below (in parentheses) indicate its limits. Recall that the plateau is only searched for $r_S$ values below the first peak of $\overline{G}_L$. The plateau range was determined as the region for which $\overline{e}_L$ did not vary more than 10%.

The best descriptor for each landmark is highlighted in boldface and those with no significant difference to it are indicated with an asterisk[3]. For example, in Table 2 the best descriptor for the inner-eye corners (*en*) is SI; if we constrain the search to a radius below 22 mm we can expect to locate each of the inner-eye corners at 1.7 mm from their correct (ground truth) position. Clearly, the great majority of landmarks must be constrained to a local search range for all six descriptors and only a few of them could be used globally (e.g. *n*, *prn*, *pg*, *sn*).

We also explored the influence of the neighborhood size used for the computation of the descriptors, testing for $r_N = 20$ mm (Table 1), $r_N = 30$ mm (Table 2) and $r_N = 40$ mm (Table 3).

[3] $p > 0.05$ on a paired Wilcoxon signed rank test.

**Table 1.** Expected local accuracy for neighborhood radius $r_N = 20$ mm. If a plateau is found, its value and limits are indicated, otherwise (n.p - no plateau) only the limit based on the first peak of $\overline{G}_L$ is indicated. For each landmark (rows) the best descriptor is highlighted in boldface and those with no significant difference to it are indicated with an asterisk.

| Landmark | SI | 3DSC | USC | SHOT | PFH | FPFH |
|---|---|---|---|---|---|---|
| en | **1.9** | 2.2 | 2.8 | 3.3 | 7.6 | 2.2 |
| (2) | **(5 - 23)** | (4 - 24) | (6 - 23) | (5 - 22) | (13 - 22) | (4 - 23) |
| ex | **4.4** | 7.1 | n.p | 5.5 | 7.6 | 6.4 |
| (2) | **(11 - 24)** | (22 - 66) | (< 9) | (10 - 36) | (20 - 53) | (11 - 49) |
| n | 4.2 | **2.1** | n.p | 3.3 | 3.4 | 3.3 |
| | (6 - 200) | **(5 - 145)** | (< 9) | (13 - 53) | (5 - 200) | (7 - 200) |
| a | 1.6* | **1.5** | 2.4 | 2.3 | 3.2 | 3.1 |
| (2) | (4 - 18) | **(4 - 26)** | (5 - 10) | (5 - 18) | (12 - 26) | (7 - 24) |
| ac | 4.3 | **2.5** | n.p | 3.3 | 7.4 | 6.0 |
| (2) | (14 - 22) | **(7 - 24)** | (< 17) | (6 - 12) | (11 - 25) | (18 - 24) |
| nt | n.p | 11.3 | 11.0 | **7.4** | 7.5* | 7.5* |
| (2) | (< 8) | (14 - 200) | (15 - 200) | **(12 - 200)** | (14 - 200) | (13 - 200) |
| prn | 3.8 | **1.5** | 2.2 | 6.7 | 4.0 | 2.5 |
| | (6 - 200) | **(3 - 200)** | (4 - 200) | (7 - 200) | (5 - 200) | (4 - 200) |
| sn | 3.8 | **2.1** | 20.6 | 3.9 | 2.1* | 2.8 |
| | (17 - 38) | **(6 - 23)** | (22 - 29) | (12 - 17) | (4 - 200) | (5 - 200) |
| ch | 2.4 | 2.5 | n.p | **2.1** | 10.1 | 4.7 |
| (2) | (6 - 22) | (8 - 24) | (< 29) | **(5 - 43)** | (18 - 42) | (14 - 40) |
| cph | **2.5** | n.p | 11.7 | 7.7 | 8.1 | 8.7 |
| (2) | **(5 - 8)** | (< 10) | (25 - 30) | (15 - 200) | (14 - 200) | (15 - 200) |
| li | 16.5 | n.p | **4.3** | n.p | 10.5 | 11.1 |
| | (19 - 35) | (< 13) | **(8 - 13)** | (< 10) | (20 - 200) | (21 - 200) |
| ls | 10.3 | 8.3 | 10.2 | **2.5** | 5.1 | 5.5 |
| | (16 - 37) | (15 - 200) | (21 - 30) | **(4 - 13)** | (9 - 200) | (12 - 200) |
| sto | 8.9 | 5.6 | 7.5 | **2.5** | 7.7 | 8.3 |
| | (18 - 39) | (13 - 200) | (18 - 29) | **(4 - 200)** | (9 - 200) | (15 - 200) |
| sl | 8.9 | 2.8 | n.p | **2.3** | 8.3 | n.p |
| | (13 - 21) | (8 - 22) | (< 9) | **(4 - 200)** | (15 - 22) | (< 15) |
| pg | 16.3 | 10.3 | 11.6 | 10.5 | **7.5** | 8.5 |
| | (20 - 200) | (22 - 122) | (19 - 59) | (17 - 38) | **(11 - 200)** | (14 - 200) |
| t | n.p | n.p | n.p | n.p | 11.1 | **4.5** |
| (2) | (< 19) | (< 18) | (< 113) | (< 69) | (21 - 89) | **(7 - 12)** |
| oi | n.p | n.p | n.p | **9.8** | 11.8 | 11.2 |
| (2) | (< 72) | (< 200) | (< 91) | **(17 - 23)** | (20 - 35) | (22 - 29) |

**Table 2.** Expected local accuracy for neighborhood radius $r_N = 30$ mm. If a plateau is found, its value and limits are indicated, otherwise (n.p - no plateau) only the limit based on the first peak of $\overline{G}_L$ is indicated. For each landmark (rows) the best descriptor is highlighted in boldface and those with no significant difference to it are indicated with an asterisk.

| Landmark | SI | 3DSC | USC | SHOT | PFH | FPFH |
|---|---|---|---|---|---|---|
| en | **1.7** | 2.2 | 2.8 | 6.2 | 4.6 | 2.4 |
| (2) | **(5 - 23)** | (5 - 24) | (6 - 23) | (8 - 21) | (8 - 21) | (5 - 23) |
| ex | 4.0* | 3.8* | n.p | **3.8** | 6.1 | 6.6 |
| (2) | (11 - 37) | (11 - 86) | (< 23) | **(6 - 23)** | (11 - 68) | (14 - 52) |
| n | 3.4 | **1.9** | 3.4 | 3.1 | 5.1 | 2.4 |
| | (6 - 200) | **(5 - 200)** | (6 - 18) | (5 - 17) | (7 - 200) | (5 - 200) |
| a | **1.5** | 1.6* | 2.5 | 4.8 | 6.2 | 5.7 |
| (2) | **(4 - 25)** | (3 - 27) | (4 - 16) | (6 - 26) | (12 - 17) | (9 - 14) |
| ac | **2.5** | 3.9 | n.p | 4.3 | 5.6 | 6.4 |
| (2) | **(14 - 23)** | (10 - 25) | (< 105) | (6 - 21) | (12 - 22) | (13 - 22) |
| nt | n.p | n.p | 13.2 | 8.5 | 7.6 | **7.0** |
| (2) | (< 8) | (< 9) | (14 - 200) | (15 - 200) | (11 - 200) | **(12 - 200)** |
| prn | 2.8 | **1.3** | 1.9 | 3.0 | 4.3 | 1.8 |
| | (4 - 200) | **(2 - 200)** | (3 - 200) | (4 - 200) | (5 - 200) | (3 - 200) |
| sn | 2.0 | **1.7** | n.p | 2.6 | 6.7 | 2.6 |
| | (5 - 60) | **(3 - 200)** | (< 111) | (4 - 200) | (10 - 200) | (5 - 200) |
| ch | 2.7 | 3.1 | 3.4 | **2.2** | 5.7 | 3.7 |
| (2) | (8 - 23) | (7 - 14) | (12 - 30) | **(4 - 43)** | (10 - 24) | (9 - 40) |
| cph | n.p | n.p | 13.9 | 8.5* | **7.9** | 8.3* |
| (2) | (< 9) | (< 10) | (21 - 30) | (16 - 39) | **(12 - 200)** | (15 - 200) |
| li | n.p | 2.7 | 2.5 | **1.9** | 8.1 | 5.1 |
| | (< 11) | (12 - 42) | (8 - 30) | **(4 - 49)** | (9 - 200) | (7 - 200) |
| ls | 10.8 | **2.6** | 10.5 | 3.6 | 5.0 | 4.1 |
| | (21 - 38) | **(13 - 200)** | (20 - 34) | (13 - 123) | (6 - 200) | (8 - 200) |
| sto | 6.3 | 2.7* | **2.4** | 2.8 | 6.1 | 5.3 |
| | (14 - 84) | (7 - 58) | **(6 - 27)** | (7 - 15) | (8 - 200) | (9 - 200) |
| sl | 9.4 | 2.9* | n.p | **2.6** | 5.9* | 6.3* |
| | (13 - 21) | (9 - 200) | (< 16) | **(4 - 200)** | (10 - 97) | (11 - 18) |
| pg | 18.7 | **4.7** | 13.4 | 5.3* | 7.1 | 4.9* |
| | (23 - 200) | **(9 - 200)** | (19 - 200) | (9 - 200) | (9 - 200) | (12 - 200) |
| t | n.p | n.p | n.p | **7.4** | 13.4 | 8.1* |
| (2) | (< 58) | (< 125) | (< 142) | **(20 - 96)** | (23 - 89) | (25 - 100) |
| oi | **7.9** | n.p | n.p | 12.3 | 15.1 | 9.1 |
| (2) | **(17 - 22)** | (< 17) | (< 129) | (23 - 30) | (25 - 37) | (17 - 27) |

**Table 3.** Expected local accuracy for neighborhood radius $r_N = 40$ mm. If a plateau is found, its value and limits are indicated, otherwise (n.p - no plateau) only the limit based on the first peak of $\overline{G}_L$ is indicated. For each landmark (rows) the best descriptor is highlighted in boldface and those with no significant difference to it are indicated with an asterisk.

| Landmark | SI | 3DSC | USC | SHOT | PFH | FPFH |
|---|---|---|---|---|---|---|
| en | 1.6* | **1.6** | n.p | 3.8 | 6.9 | 2.1 |
| (2) | (5 - 24) | **(4 - 25)** | (< 38) | (6 - 21) | (11 - 20) | (4 - 22) |
| ex | 3.9* | **3.8** | n.p | 5.4 | 8.2 | 6.7 |
| (2) | (12 - 90) | **(12 - 89)** | (< 22) | (12 - 20) | (16 - 88) | (14 - 59) |
| n | 3.0 | **1.6** | 2.6 | 3.2 | 5.6 | 2.5 |
| | (8 - 200) | **(4 - 200)** | (5 - 23) | (7 - 52) | (7 - 200) | (5 - 200) |
| a | **1.6** | 1.6* | 2.6 | 3.6 | 9.7 | n.p |
| (2) | **(6 - 23)** | (3 - 27) | (5 - 15) | (6 - 20) | (13 - 22) | (< 25) |
| ac | **1.8** | 3.1 | n.p | 3.4 | n.p | 6.6 |
| (2) | **(6 - 22)** | (12 - 24) | (< 90) | (6 - 23) | (< 200) | (14 - 20) |
| nt | **2.3** | 6.7 | 13.2 | 7.1 | 12.6 | 7.3 |
| (2) | **(4 - 8)** | (12 - 200) | (16 - 145) | (10 - 200) | (15 - 200) | (13 - 200) |
| prn | 2.3 | **1.2** | 1.9 | 3.6 | 6.2 | 2.1 |
| | (4 - 200) | **(2 - 200)** | (3 - 200) | (4 - 200) | (8 - 200) | (3 - 200) |
| sn | 2.0 | **1.8** | n.p | 5.2 | 10.8 | 2.8 |
| | (5 - 22) | **(4 - 200)** | (< 107) | (9 - 26) | (14 - 200) | (5 - 200) |
| ch | 3.0 | **1.9** | 3.4 | 2.1* | 5.1 | 3.4 |
| (2) | (11 - 24) | **(4 - 13)** | (6 - 37) | (5 - 42) | (8 - 40) | (8 - 23) |
| cph | 8.0 | **2.5** | n.p | 7.1 | 10.1 | 9.0 |
| (2) | (17 - 200) | **(5 - 9)** | (< 10) | (8 - 200) | (16 - 200) | (15 - 200) |
| li | n.p | 2.2 | 2.8 | **1.8** | 8.2 | 4.1 |
| | (< 11) | (6 - 43) | (8 - 200) | **(3 - 200)** | (11 - 200) | (7 - 200) |
| ls | 3.5 | 1.8* | 2.2 | **1.8** | 8.2 | 5.2 |
| | (7 - 12) | (6 - 14) | (4 - 9) | **(3 - 200)** | (13 - 200) | (14 - 200) |
| sto | 4.1 | 2.1 | 2.4 | **1.8** | 9.5 | 4.7 |
| | (11 - 92) | (9 - 200) | (6 - 13) | **(4 - 200)** | (12 - 22) | (8 - 200) |
| sl | 8.3 | 3.2 | 2.9 | **2.2** | 9.9 | 8.7 |
| | (15 - 21) | (9 - 200) | (10 - 15) | **(4 - 200)** | (12 - 200) | (15 - 200) |
| pg | 10.5 | **3.6** | 8.4 | 3.8* | 9.2 | 4.3 |
| | (18 - 23) | **(7 - 200)** | (20 - 164) | (5 - 200) | (10 - 200) | (10 - 19) |
| t | n.p | n.p | n.p | **8.1** | 15.4 | 11.7 |
| (2) | (< 58) | (< 15) | (< 149) | **(23 - 86)** | (21 - 131) | (25 - 134) |
| oi | **7.6** | n.p | n.p | 9.4 | 23.0 | 8.1* |
| (2) | **(20 - 27)** | (< 122) | (< 139) | (15 - 34) | (25 - 30) | (17 - 28) |