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Study on perceptually-based fitting line-segments

Raquel Plumed, Pedro Company, Peter A.C. Varley

Department of Mechanical Engineering and Construction, Universitat Jaume I, Spain

Abstract
This Technical Report revisits the problem of fitting the strokes of a sketch into straight lines. Our purpose is to calculate a reasonably good and very fast fit applying a perceptual approach. Hence, the experiments carried out to determine how people perceive straight lines in sketched strokes are described in detail, and the main conclusions are derived.

Index Terms: Sketch-based modelling, Stroke recognition, Straight-line perception.

1. INTRODUCTION

The core of a Sketch-Based Modelling (SBM) application, the geometrical reconstruction engine, produces 3D geometric models from 2D drawings. Readers may refer to [1] for a broad picture of the whole problem, and [2] for a recent state of the art in reconstruction. The required input 2D drawing may have been obtained in different ways, and this result in a variety of tasks aimed at transforming the initial input into an intermediate output valid to start the reconstruction stage. The term *recognition* roughly encompasses the variety of different procedures (vectorisation, refinement, etc.) used at this end. In the most common case of line-drawing recognition from pen-sketches the input is a set of strokes, and the output is a plain line drawing.

Reviewing related work on sketch recognition, we shall conclude that at least two main aspects still need further improvement.

Firstly, most of the approaches are nearly exclusively based on geometrical considerations, while it is already well known that perceptual considerations are equally important.

Secondly, although it is commonly realized that sketch recognition is a complex problem that should be disintegrated into multiple tasks, it is much less frequently assumed that those tasks mutually interact in complex and sometimes subtle ways not compatible with simple sequential flows.

However, before trying to develop recognition approaches which take into account those interactions, it is necessary to develop basic algorithms to classify each element of the sketch. In the present work we revisit the problem of fitting straight lines on sketched strokes.

Our interest is to apply perceptual criteria to resolve the fitting problem. But, to date studies in the field of visual perception rarely provide sufficient detailed information to develop an algorithmic approach to replicate human perception. On the other hand, most of the current fitting algorithms are time-consuming and add a geometrical precision which is unnecessary for interpretation of sketches. Certainly, some perceptually-oriented algorithms exist. But, from our point of view, claiming that human perception is the goal is not enough. Approaches must be designed to work in a similar way to human perception. Besides, they must also be tuned to reply as close as human perception as they can.

In other works, algorithms should accept what humans accept, should reject what humans reject, and should doubt where humans doubt.

To this end, our approach uses the *Tolerance*, which is a well-known concept in Geometric Dimension and Tolerancing for measuring the “straightness” of a line (ISO 1101-1983). Given the bounding box of the line, defining *x-range* as the length of the side nearly parallel to the line and *y-range* as that of the side nearly perpendicular to the line, the absolute tolerance of straightness is the absolute value *y-range*. The lower this parameter is, the straighter the stroke is considered to be.

To determine the limits of acceptance of humans, we need to ask humans, i.e. we need experiments asking individuals of representative populations.

2. EXPERIMENTS

The intention of the experiments was to validate or reject the following hypotheses:

1. *Tolerance* matches human perception of relative straightness of lines.

2. Humans are more prone to interpret undulations as intended alternative shapes, while they are more prone to interpret oscillations as involuntary errors.

As a result of the experiment conducted to validate the first hypothesis, a new hypothesis was launched:

3. Humans understand that corners break straightness more than undulations do.

Finally, as a result of the experiment conducted to validate the second hypothesis, a new hypothesis was launched:

4. A significant part of the polled subjects mentally filter out oscillations and evaluate the smoothed stroke with a penalty.

Following subsections detail the experiments and the respective analysis.

In our experiments, the bulk of the population was drawn from several departments of the same university, and included industrial engineers, mechanical engineers, architects, designers and artists. The level of experience ranged from undergraduate students to engineering teachers. We also included a few participants from other backgrounds.

2.1 Experiment # 1 to mimic human perception

First experiment consists of comparing the relative straightness of a set of twelve strokes (Figure 1), of similar length and orientation but with increased values of *Tolerance*.

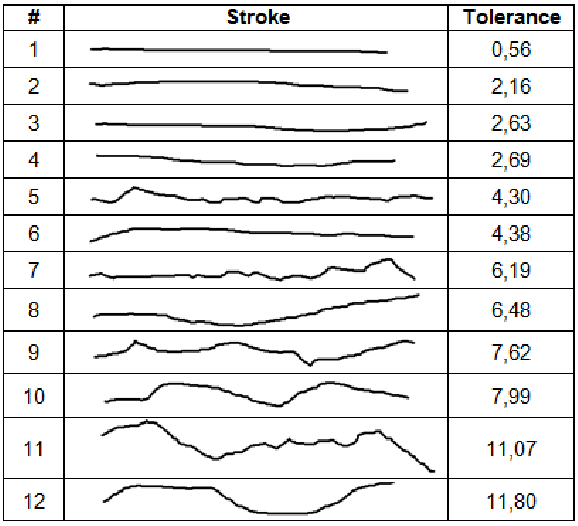

Figure 1: Example strokes for experiment #1

Each example of stroke was given on separate A6 sheets which had been shuffled to randomise. Polled people were asked to re-order the sheets in order of decreasing straightness. We collected a total of 22 responses. The sequences returned are shown in Table 1.

Table 1 shows global information about the experiment. It avoids using statistical parameters, as it is simultaneously quantitative (it includes the detailed answers—for example, Stroke 1 was perceived by all interviewed subjects as the straightest) and qualitative (image variables have been used to show that three groups of strokes are clearly perceived—thick lines to separate *good*, *average* and *poor* strokes—and there are few exceptions—bold and red numbers). Hence, we confirm the thresholds suggested in [3] (*good* < 3.5 < *average* < 7.0 < *poor*), as they also work for this new sets of strokes and interviewed subjects.

Table 1: Strokes as ordered by subjects

	Stroke											
Subject	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	1	2	3	4	6	5	8	7	9	11	10	12
2	1	2	3	4	6	5	8	7	9	11	10	12
3	1	2	3	4	6	8	5	7	9	12	10	11
4	1	2	4	3	6	8	5	7	9	10	12	11
5	1	3	4	2	6	8	5	7	9	10	12	11
6	1	2	3	4	6	8	7	5	10	9	12	11
7	1	2	3	4	6	8	**9**	7	**5**	12	10	11
8	1	2	4	3	6	8	5	7	9	12	10	11
9	1	2	4	3	6	8	5	7	9	10	12	11
10	1	2	4	3	6	5	8	7	9	10	11	12
11	1	2	3	4	6	8	5	7	10	12	9	11
12	1	2	4	3	6	5	7	**9**	**8**	10	12	11
13	1	3	2	4	6	8	5	7	9	12	10	11
14	1	3	2	4	6	8	**12**	7	**5**	9	10	11
15	1	4	2	3	6	8	**12**	**10**	9	**5**	**7**	11
16	1	2	4	3	6	8	**12**	**10**	9	**5**	**7**	11
17	1	2	4	3	6	5	7	8	9	11	10	12
18	1	3	4	2	6	8	7	**9**	**5**	12	10	11
19	1	3	2	4	6	5	8	7	9	10	11	12
20	1	2	3	4	6	7	8	5	9	12	10	11
21	1	2	3	4	6	5	7	**9**	**8**	10	12	11
22	1	2	4	3	6	8	5	7	9	10	12	11

We conclude that *Tolerance* usually matches human perception. 18 subjects out of the 22 classified Strokes 1, 2, 3 and 4 as *good*; Strokes 6 and 7 as *average*, and Strokes 10, 11 and 12 as *poor*.

However, we note certain discrepancies, such as Stroke 6, which is always perceived straighter than Stroke 5, and Stroke 8, nearly always perceived as straighter than Stroke 7. The most remarkable discrepancy between humans and the algorithm happens between Strokes 5 and 9, as they are frequently switched from the average to the poor group and vice-versa.

2.2 Experiment # 2 to mimic human perception

Our hypothesis for discrepancies described at the end of Experiment #1 is that humans understand that corners break straightness more than undulations do. This would imply that they distinguish oscillations from undulations. If we can validate this apparently obvious hypothesis, then we can check whether humans are more prone to interpret undulations as intended alternative shapes, while they are more prone to interpret oscillations as involuntary errors (hypothesis 2). This would imply that oscillations are less distracting (as they are usually perceived as unintentional) than undulations. To validate these new hypotheses we first asked a group of subjects to mark the corners perceived in the strokes of Figure 1.

To know the existence of association between the stroke quality and corner detection, we asked 60 subjects (the maximum number of questionnaires collected in one day) to mark the corners perceived in the strokes of Figure 1. Each questionnaire consisted of a landscape A4 format which contained all strokes. To reinforce independent observations, the strokes were presented in a random order in each questionnaire.

Results are shown in Figure 2. The corner-points remarked in red have been perceived over the 75% of subjects. Those remarked in blue have been perceived between 50-75% of polled subjects.

Corner-points 1 and 2 are perceived by 95% of subjects, followed by Corner-point 3 perceived by 92.3%, Corner-point 4 by 84.6%, 5 by 55% and 6 by 51.7%.

These results provide response to the discrepancies found in the previous experiment. It is clear that people perceive corner-points, and also that they break the straightness perception of sketched strokes. Hence, we conclude that, for that reason, Strokes 5 and 7 are perceived as less straight than Strokes 6 and 8, respectively. And Stroke 11 (with Corner-points 4 and 6) is perceived most often (77.3%) as the least straight stroke of the group than Stroke 12 (22.7%).

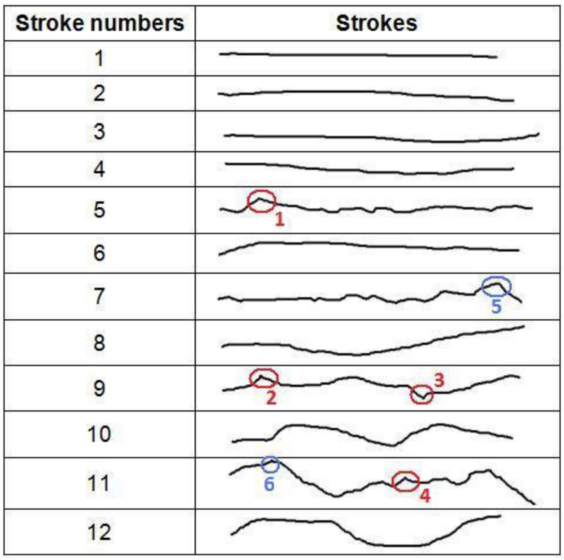

Figure 2: Corner-points perceived by over 75% (red), or between 50-75% (blue) of subjects

To evaluate whether a significant relationship between the stroke quality and corner detection exists, we apply a contingency table. Table 3 shows the observed and expected frequencies for each cell based on the assumption that there is no relationship.

The stroke quality is assessed grouping the strokes as the common classification obtained in Experiment #1: Strokes 1, 2, 3 and 4 were classified as good quality, Strokes 5, 6, 7 and 8 as average, and Strokes 9, 10, 11 and 12 as poor quality.

Then we applied the Chi-square test. Results show that the Chi-square p-value= 0 is lower than α= 5%. Thus, results are statistically significant and the null hypothesis of no relationship between quality and corner detection can be rejected. In other words, we conclude that there is an association or dependency between the trace quality and corner detection.

Table 3: Contingency table and Chi-square test between the trace quality and corner detection

Quality*Corner detection crosstabulation

			Corner detec-		
			No	Yes	Total
Quality	Good quality	Count	238	2	240
		Expected	168.	72.0	240.0
	Aver. quality	Count	67	53	120
		Expected	84.0	36.0	120.0
	Poor quality	Count	73	107	180
		Expected	126.	54.0	180.0
Total		Count	378	162	540
		Expected	378.	162.0	540.0

Chi-square test

	Value	df	Asymp. Sig.(2-sided)
Pearson Chi-square	183.03[a]	2	**.000**
Likelihood Ratio	228.81	2	.000
Linear-by-linear Association	173.97	1	.000
N of valid cases	540		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 36.00.

2.3 Experiment # 3 to mimic human perception

Once we have proved that people distinguish between oscillations and undulations, we decided to prove hypothesis 2. At this end, we produced a modified experiment.

For the new experiment we defined a new set of strokes, similar to the previous group but including oscillations, as shown in Figure 3.

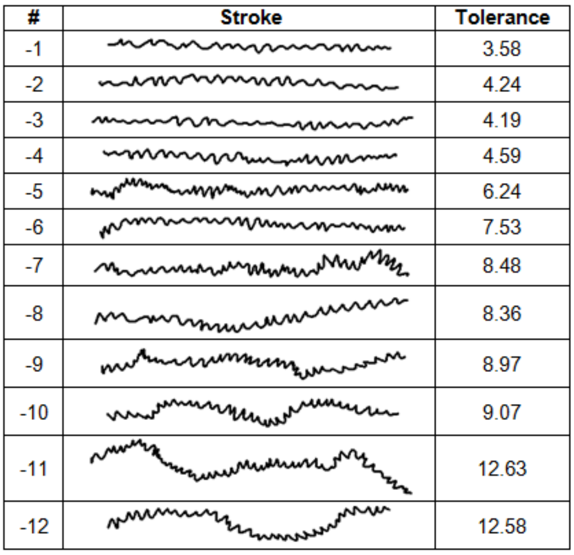

Figure 3: Example strokes with oscillations for the relative straightness test

Then we asked another 22 subjects to order A6 sheets containing the twelve oscillating strokes in order of decreasing straightness.

Table 4: Oscillating strokes as ordered by subjects

	Stroke											
Subject	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	-1	-2	-3	-4	-6	-5	-8	-7	-9	-12	-10	-11
2	-1	-2	-4	-3	-6	-5	-7	-9	-8	-10	-12	-11
3	-1	-2	-3	-4	-6	-8	-5	-9	-7	-10	-12	-11
4	-1	-4	-2	-3	-6	-5	-7	-8	-9	-10	-12	-11
5	-1	-4	-2	-3	-6	-9	-5	-8	-7	-10	-11	-12
6	-1	-4	-3	-2	-6	-5	-7	-9	-10	-8	-12	-11
7	-1	-3	-4	-2	-6	-5	-7	-9	-10	-12	-8	-11
8	-1	-2	-3	-4	-6	-5	-7	-8	-9	-10	-12	-11
9	-1	-4	-3	-2	-6	-8	-5	-9	-7	-10	-12	-11
10	-1	-3	-4	-2	-6	-5	-7	-9	-8	-10	-12	-11
11	-1	-2	-4	-3	-6	-5	-7	-9	-8	-10	-12	-11
12	-1	-3	-4	-2	-6	-8	-5	-7	-9	-10	-12	-11
13	-1	-2	-3	-4	-6	-5	-7	-8	-9	-12	-10	-11
14	-1	-4	-6	-2	-3	-5	-9	-7	-8	-10	-12	-11
15	-1	-4	-2	-3	-6	-5	-7	-8	-9	-10	-12	-11
16	-1	-4	-2	-3	-6	-7	-5	-9	-8	-10	-12	-11
17	-4	-1	-2	-6	-3	-5	-8	-9	-7	-10	-12	-11
18	-1	-2	-3	-4	-6	-5	-8	-9	-7	-10	-11	-12
19	-1	-4	-3	-2	-5	-6	-7	-9	-8	-10	-11	-12
20	-1	-3	-4	-2	-6	-5	-7	-9	-8	-10	-12	-11
21	-1	-4	-2	-3	-6	-7	-9	-5	-8	-10	-12	-11
22	-1	-2	-4	-3	-6	-8	-5	-9	-7	-10	-12	-11

The sequences returned by the 22 subjects are shown in Table 4, where it is clearly visible that oscillating strokes are ordered by humans in the same way as non-oscillating ones. This result confirms that oscillations are perceived separately from undulations, as when all the compared strokes contain the same sort of oscillations, humans filter out the oscillations and classify the strokes using corners and undulations.

2.4 Experiment # 4 to mimic human perception

Based on results of Experiment #3, we deduce that a significant part of the population seems to mentally filter oscillations and perceive the straightness of the underlying stroke.

To validate or reject this new hypothesis, we randomly mixed two oscillating with ten non-oscillating strokes, without repeating any type in the same set.

We interviewed 32 new subjects, divided into two groups.

In the first group, we performed sixteen different tests using four strokes of types 1,6, 7 and 11 (as they had proved to be more stable in their perception), and only two randomly-chosen strokes of the 12 oscillating types.

In the second group, we asked the other 16 subjects (mainly engineering teachers and students, with a few from other backgrounds) to order these mixed sets. In this case, the sets comprised ten non-oscillating strokes plus two oscillating strokes, where the oscillating strokes were selected only from the *good* and *average* subsets (excluding Strokes -9 to -12).

The first results showed that between 30 and 50% of the subjects listed the two oscillating strokes as the least straight (e.g. Subject 1 in Table 5).

We observe that everybody distinguishes oscillations from undulations, but in two different ways. Some interviewed subjects discarded oscillating strokes because of their poor quality as geometric straight lines. Other subjects mentally filtered out oscillations and evaluated the smoothed stroke. Our observation was reinforced by the queries of some subjects asking whether they had to pay attention or ignore the lack of "smoothness", "flatness" or "horizontality" of some lines (their queries were not answered).

Analysing in more detail the group of subjects who spontaneously smoothed the oscillating strokes, we found that they did not consider oscillating strokes to be quite as straight as their smoothed equivalents; oscillating strokes are devalued to some extent. There are even cases where *all* oscillating strokes, *good* and *bad* alike, were placed together as an intermediate category, worse than *good* non-oscillating strokes but better than *bad* non-oscillating strokes—instead of reducing the judged quality of the stroke, the oscillations reduced the subjects' ability to judge the stroke.

Table 5: Mixed strokes as ordered by subjects

	Stroke											
Subject	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	1	2	4	3	6	8	10	5	7	9	-12	-11
2	1	2	3	4	6	5	7	9	12	10	-8	-11
3	1	3	6	4	5	10	12	7	9	11	-2	-8
4	1	2	3	6	4	8	5	12	10	11	-9	-7
5	2	3	-1	6	-4	8	9	10	7	5	12	11
6	1	2	3	4	8	5	7	-6	9	10	11	-12
7	2	3	4	-1	6	7	-5	9	8	10	12	11
8	2	4	3	6	7	8	5	9	10	12	-1	-11
9	1	2	4	6	8	5	9	10	-3	-7	12	11
10	1	3	4	2	8	-5	-6	7	9	10	12	11
11	1	2	3	4	7	5	-6	8	9	12	11	-10
12	1	2	-4	3	6	7	5	8	-9	12	10	11
13	1	2	3	4	6	8	5	9	12	10	-7	-11
14	3	2	4	6	5	8	9	-1	7	12	11	-10
15	1	2	4	6	8	5	10	12	9	11	-3	-7
16	1	3	4	8	5	7	-2	-6	10	9	12	11
17	2	4	3	6	-1	-5	7	10	8	9	12	11
18	1	2	6	3	5	-4	-7	8	10	9	12	11
19	1	4	3	5	8	-6	-2	7	9	10	12	11
20	1	2	6	4	8	5	9	10	12	-3	11	-7
21	1	4	3	-2	6	7	5	9	-8	10	12	11
22	2	3	6	-1	-4	8	7	5	9	10	11	12
23	2	4	3	6	8	9	7	10	12	-1	-5	11
24	1	4	6	8	-3	-2	7	5	9	11	10	12
25	1	2	4	6	3	7	-5	-8	9	10	12	11
26	1	2	5	6	-4	-3	7	8	9	10	12	11
27	1	2	4	3	-6	7	5	9	-8	10	12	11
28	1	2	4	-3	6	5	8	9	-7	10	12	11
29	1	4	-2	3	5	6	-7	8	9	10	12	11
30	2	4	-1	3	6	7	5	-8	9	10	11	12
31	1	2	3	4	-6	-5	8	9	7	10	12	11
32	1	2	3	5	7	8	-6	-4	9	10	11	12

To investigate this further, we modified the experiment, including only oscillating strokes of the first two groups (-1 to -8) as we assume that oscillating strokes of the last group (-9 to -12) would not be assessed ahead of their non-oscillating equivalent (and, obviously, cannot be placed behind their equivalents). The results of this modified experiment correspond to subjects 17 to 32 in Table 5. As we suspected that subjects with knowledge of engineering concepts (such as signal/noise or surface imperfections) may be more prone to filter out oscillations, we interviewed only subjects with engineering backgrounds (so our conclusions would not be valid to describe human perception in general, but we are interested here in how engineers perceive sketches). Since some subjects returned segregated sets of strokes, more subjects were interviewed until we had 16 non-segregated classifications (17 to 32 in Table 5).

Since no simple and systematic penalty can be observed (perhaps the sample is too small to quantify it), we cannot validate the fifth hypothesis. However, we still can conclude that the devaluation exists, and many of the subjects (at least 50%, and more in the case of subjects with engineering backgrounds) tend to evaluate the smoothed line for straightness and then reduce the mark from *good* to *average* or from *average* to *poor*.

3. CONCLUSIONS

We have validated experimentally the following hypotheses:

1. *Tolerance* matches human perception of relative straightness of lines.
2. Humans understand that corners break straightness more than undulations do.
3. Humans are more prone to interpret undulations as intended alternative shapes, while they are more prone to interpret oscillations as involuntary errors.
4. A significant part of the polled subjects mentally filter out oscillations and evaluate the smoothed stroke with a penalty, reducing the mark from *good* to *average* or from *average* to *poor*.

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