ABSTRACT
In this paper we present a method for the analysis of motion that is applicable to low quality images. The method uses two-dimensional steerable filters for orientation analysis and computes velocity fields out of the orientation information. We introduce a projection method that allows to use the two-dimensional filters instead of three-dimensional filtering. In addition this projection method is a very powerful tool for the restoration of motion information out of very low quality images.

1 INTRODUCTION
Motion detection and motion analysis methods are used in a wide range of applications, e.g. medical imaging or video data compression. Motion detection deals with the pure indication of motion without extracting any information about the characteristics of the movements that are taking place. Motion analysis results in velocity fields, which indicate the speed and the direction of the motions. Common approaches like the use of difference images and optical flow computation [1, 2] are very noise sensitive. Since orientation in time space corresponds to velocity motion analysis can be done by applying three-dimensional steerable filters for orientation analysis.

In this paper a method is presented which allows the use of two-dimensional steerable filters for the analysis of motion in temporal image sequences. This alternative to the use of three-dimensional steerable filters is based on a projection method, which allows the computation of the x- and y-directional velocities out of the orientation found in the x-time and the y-time planes, respectively.

It will be shown that the projection method acts as a powerful tool for the restoration of motion information out of very low quality images.

The presented motion analysis method can be split up into the following steps:

- Local projection of x-time and y-time planes
- Computation of orientation maps of projected x-time and y-time planes
- Deduction of velocity out of orientation
- Thresholding of velocity vectors for the extraction of valid velocities

2 PROJECTION METHOD
By using two-dimensional filters in the x-time and y-time planes it is necessary to consider the neighbouring planes of each plane, too, because otherwise the information about the motion in the direction of the plane that takes place in the neighbouring planes would be lost.

The projection works as follows:
For calculating the velocity in y direction dy/dt at each point of the plane f(x₀,y,t) the neighbouring planes are added to f(x₀,y,t).

\[ f_p(x_0, y, t) = \sum_{n=-N}^{n=N} f(x_n, y, t) \]

This procedure is repeated for all other x = x₀ in order to obtain projected planes for each existing y-time plane. The same is done with the x-time planes with constant y values.

The choice of N depends on the desired result. If a relatively high value is taken for N, motion with a high velocity in x direction compared to the velocity in y is also considered, which would be lost if N is low. On the other hand, the higher the N value, the less accurate is the x position of the calculated y-directional velocity. Hence, if the focus of the analysis is on the direction of motion, N is chosen to be relatively large, if the focus is on the position at which the motion takes place a smaller value is chosen for N. In any case information will be lost compared to a three dimensional approach. However, we believe that the exactness of the velocity field obtained by using this method is sufficient in most cases.

3 ORIENTATION ANALYSIS
For the analysis of the orientation in the projected x-time and y-time planes a methods introduced in [3, 4] is used. Seven basis filters, which are directed versions of the
second derivative of the Gaussian and its Hilbert transform, are applied to the planes. Out of the filter responses the dominant orientation and the strength of the contrast along that orientation is measured for each point of the plane.

4 DEDUCTION OF VELOCITY

The x-directional velocities are given as the tangent of the dominant orientation for each point of the x-time planes, the same applies to the y-directional velocities. Given the x- and y-directional velocities the direction of the overall velocity is given by:

\[
\arg(v_x) = \arctan \left( \frac{v_y}{v_x} \right)
\]

and its strength by:

\[
|\vec{v}| = \sqrt{v_x^2 + v_y^2}
\]

The strength is given in pixel/time unit.

In practice, an exception from the relationship velocity = \(\tan(\theta)\) occurs in the case that \(\theta\) equals 90°, i.e. perpendicular to the time axis. In theory this corresponds to infinite velocity but in practice this case is also given if an object appears or disappears suddenly in an x-time or y-time plane by moving in a direction that is different from the orientation of the plane. For this reason all orientations close to 90° are set to 0°, which corresponds to no motion. The choice of the deviation of orientation around 90°, which is set to zero is a critical decision. If the value is chosen to consider a relatively wide range around 90° high velocities could be set to zero, which would lead to a wrong result. On the other hand, if it is chosen too small it could cause horizontal orientation that is measured inaccurately by the calculation of the dominant orientation to be interpreted as a high velocity.

5 THRESHOLDING METHODS

The resulting velocity is true for the points of \(f(x,y,t)\) at which there is a significant contrast, but the other points could belong to a moving or static part of \(f(x,y,t)\). To assure that the calculated velocity corresponds to real velocity the velocity field calculation. The line moves from left to right and when it leaves the range of the image on the right side it enters it from the left again. The velocity of the motion of the line is different in each sequence. We have calculated the mean value of the x and y directional velocities by taking the mean values of all nonzero velocity values of the whole sequence in x and y direction. The maximum values were calculated in the same way. Since the velocity is constant during the sequence the values are comparable with the desired result. Table 1 shows the desired and computed velocities:

<table>
<thead>
<tr>
<th>desired result</th>
<th>computed mean value</th>
<th>computed maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3</td>
<td>0.4910</td>
<td>0.6689</td>
</tr>
<tr>
<td>1/2</td>
<td>0.6652</td>
<td>0.7101</td>
</tr>
<tr>
<td>3/4</td>
<td>0.8392</td>
<td>0.9916</td>
</tr>
<tr>
<td>1</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>2</td>
<td>1.6319</td>
<td>1.9182</td>
</tr>
<tr>
<td>3</td>
<td>3.0667</td>
<td>5.7565</td>
</tr>
<tr>
<td>4</td>
<td>3.4943</td>
<td>7.0808</td>
</tr>
<tr>
<td>5</td>
<td>4.7837</td>
<td>35.9908</td>
</tr>
</tbody>
</table>

Table 1

Tests of the orientation analysis method have shown that the inaccuracy of the results are due to an inaccurate orientation measurement. The performance of the method could be improved by using filters that allow to measure the orientation more accurate. However, we believe that the computed velocity values are relatively satisfying approximations of the actual velocities.
6.2 Velocity Change

As an example we used a sequence containing 16 images showing a disk with an increasing radius. In the second half of the sequence the rate of increase is doubled. The resulting mean velocities are given in Table 2:

<table>
<thead>
<tr>
<th>Image no.</th>
<th>Mean Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.4732</td>
</tr>
<tr>
<td>6</td>
<td>0.38</td>
</tr>
<tr>
<td>7</td>
<td>0.84</td>
</tr>
<tr>
<td>8</td>
<td>1.052</td>
</tr>
<tr>
<td>9</td>
<td>1.387</td>
</tr>
<tr>
<td>10</td>
<td>1.398</td>
</tr>
<tr>
<td>11</td>
<td>1.412</td>
</tr>
<tr>
<td>12</td>
<td>1.365</td>
</tr>
</tbody>
</table>

Table 2

The change of velocity is indicated correctly. In the first half the average of the mean velocities is 0.69, in the second it is 1.39, which corresponds to the doubling of velocity. Because of a weak resolution of the images the particular mean velocities do vary. Figs. 1a and b show the 7th and 12th images and their respective velocity fields. The different length of the velocity vectors in the two fields represent the change of speed.

6.3 Application to Noise Corrupted Images

Gaussian noise with a mean deviation of zero and a standard deviation of 0.4 was added to the sequence images. The N-value for the projection was set to 2 and the threshold to 30%. Fig. 2 below shows the 6th image before and after adding the noise. The 6th and 12th noisy images and their respective velocity fields are demonstrated in Fig.3.

Fig. 1

Fig. 2, 6th Image:

Fig. 3, Velocity Fields:
7 Conclusion

According to the results of the test cases we believe that we have found an efficient way for the evaluation of velocity fields. The results show that the parameters used during the computation process and the thresholding method have to be carefully adapted to the applied sequences.

The projection method enables the use of a much simpler two dimensional orientation analysis method instead of dealing with three dimensional filters. In addition it was found that by using the projection method one can restore information about motion out of very low quality images, which is a very powerful ability. This ability is only given if the 'velocity smoothness constraint' is met by the input images. The better the resolution of the images is the more likely it is that they meet the constraint. In comparison to the optical flow method our approach does not give false results if colour changes occur that are not due to a motion taking place. The proposed projection method is also applicable to motion detection. In this case the orientation analysis part is replaced by an edge detection method in the time direction in the projected x-time and y-time planes. Experimental results have shown that this motion detection method is very of a very high noise robustness.

8 References

1 G.E. Mailloux, et al. Computer Analysis of Heart Motion from Two-Dimensional Echocardiograms
2 G.E. Mailloux, et al. Restoration of the Velocity Field of the Heart from Two-Dimensional Echocardiograms
3 W.T. Freeman and E.H. Adelson. The Design and Use of Steerable Filters
4 W.T. Freeman. Steerable Filters and Local Analysis of Image Structure

1 i.e. the condition that nearby points in an image move in a similar manner.