EFFECTIVE VENTILATION

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Poster 1

THE LARGE AREA QUANTITATIVE VISUALIZATION METHOD OF AIR STREAMS

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SUMMARY

The project is aimed to develop the quantitative method of visualization of the air steams in application to the indoor problems of heating , ventilating and air conditioning.
The geometrically well defined light sheet is crossing the examined space and determines the plane of observation. The photographic camera is placed perpendicularly to this plane at a distance of a few meters. The flow is seeded with the soap bubbles of the diameter 3-4 mm. The light is reflected from those bubbles which are crossing the illuminating sheet. The film is exposed in the concerned areas: the trajectories of the tracer are recorded in form of alongated tracks.
The photographic images contain the features of the flow which are revealed and quantified in the digitizing operations. The images existing on the colour slides are splitted into six equal square parts and digitized once for each colour with a camera having a 512x512 pixel sensor. The grey scale levels are so adapted that the black slide area obtain the value zero (or any other but small one) in the digital representation matrix. With either Roberts or Sobel operators edges of the bubble tracks (having any orientation) are detected and enhanced.
The above steps are the basis for extracting the velocity vector field from the experimental images.

1. EXPERIMENTAL TECHNIQUE

1.1 Method and Experimental Set-Up (Fig. 1)

The solid tracer, namely soap bubbles are transported with the air streams. The relatively long exposed film is integrating the time - position dependence resulting in the trajectory images. Interpretating the sub-sections of the tracks as being tangential to the stream lines and resulting from the instantaneous direction of the velocity, the Euler - like description of the experiment is revealed.
Taking into account longer sequences of the tracer positions (i.e. longer partitions which cannot be associated with the one point of observation) the Lagrange - like approach is reflecting the experimental method .Finally it is the spacial / time resolution and the interpolation technique which determines which one of the descriptions is taking over another.
The corrections for the tracer behaviour (inertia ,gravity) are planned to be realized.
Method is orientated to be used not necessarily in laboratory chambers but also in the real spaces. The indispensable condition is the darkening of the room. All the instruments needed for experiment are portable and not disturbing the flow pattern in the room.

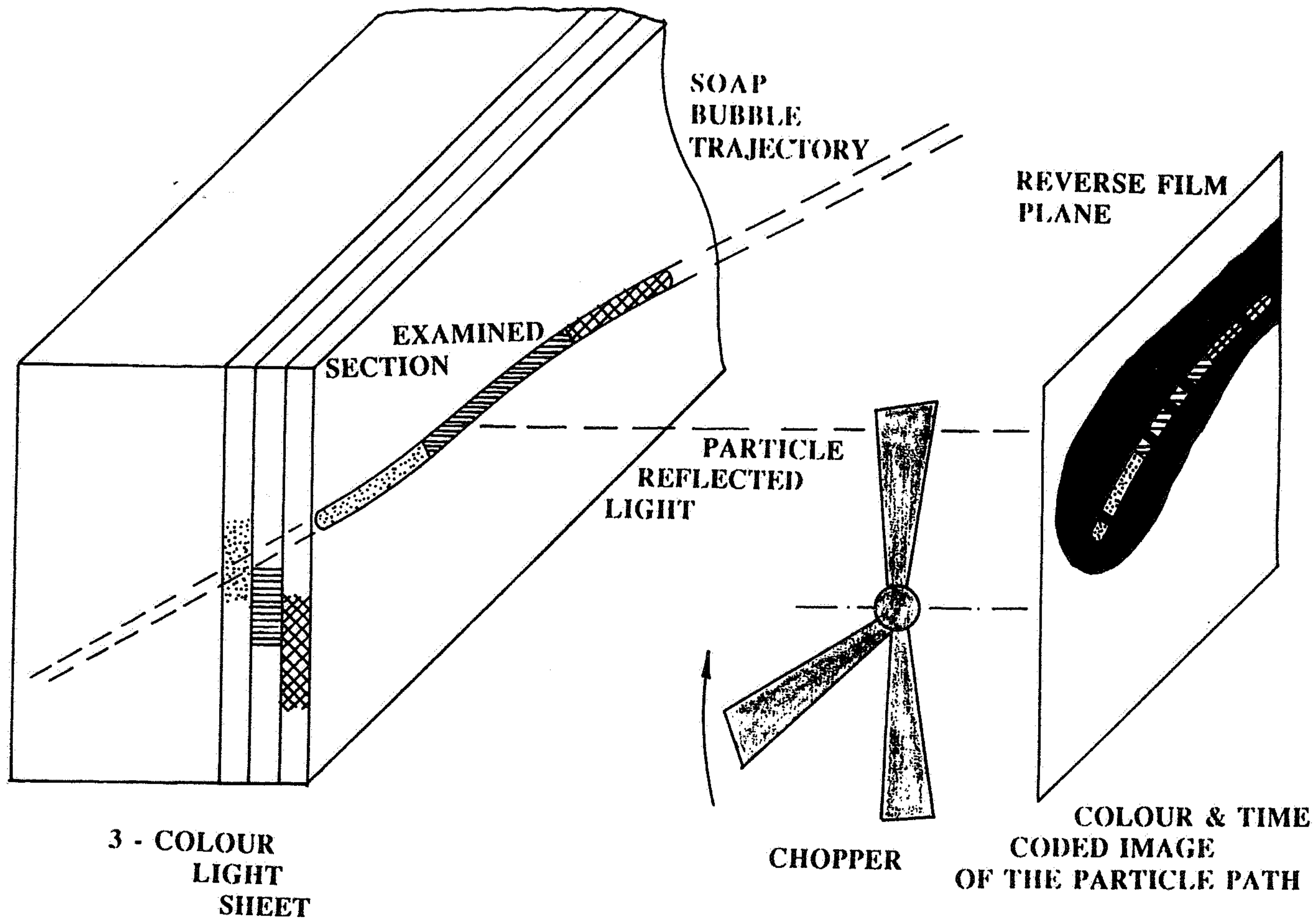

Fig. 1 The scheme of the experiment

1.2 Lighting

The light sheet is consisting of the 3 distinctly separated colours. By that mean the trajectories which are not parallel to the light sheet (ditto observation plane) are resulting in tracks of coloured sequence. Color change is marking the movement of the tracer perpendicular to the observation plane.
Cooling of the light sources is to be realized through the thermally insulated flexible ducting to the outside space.
The light reflected from the room surfaces and other objects should be reduced at the aim to obtain possibly contrast images.

1.3 Tracer and Seeding

The soap bubbles used for seeding the flow are produced by the standard generator (Sage Action Inc., USA). The batch of the bubbles passes through the selector for eliminating those which are too heavy . The homogenous population of bubbles performing the settling velocity in the still air of about 5 cm/s (diameter 3 - 4 mm) is transfered to the experimental space. The average life time is a few minutes .
The helium filling option foreseen by the manufacturer is not utilized. The neighbourhood of the air outlets and other zones of higher speed are the points apt for introducing the tracer. The recorded trajectories of the typical room flow have rectilinear, smooth character indicating the damping effect (like low pass filter). Comparing to the hot wire recording most of the turbulence spectrum is not detectable. The limit frequency of the sinusoidal idealized sollicitation is estimated approximately to f limit = 0.5 Hz. This feature is particulary interesting while investigating the averaged flow pattern and its large scale structures .

1.4 The Photographic Technique

Standard reflex camera 24 x 36 mm is used. The images are taken on the colour reversal film 1600 ASA. The shutter is opened for relatively long time (typically 1 s). Only those bubbles which are actually crossing the light sheet are becoming the visible objects on the darkened background during the entire or part time of the shutter action.

1.5 Control of the Image Recording

At the aim to extract the quantitative information from the images the conditions for photographs taking must be strictly controlled .

a. Space

In the observation plane (xy) the real distances are scaled to the image using the physical marks in the experiment. Another mean taken into consideration is the superposition of the experimental images with the reference grid originating from the test shot.
The depth (3rd dimension: along ' z ', perpendicular to xy) is controlled by the thickness of the middle light plane.

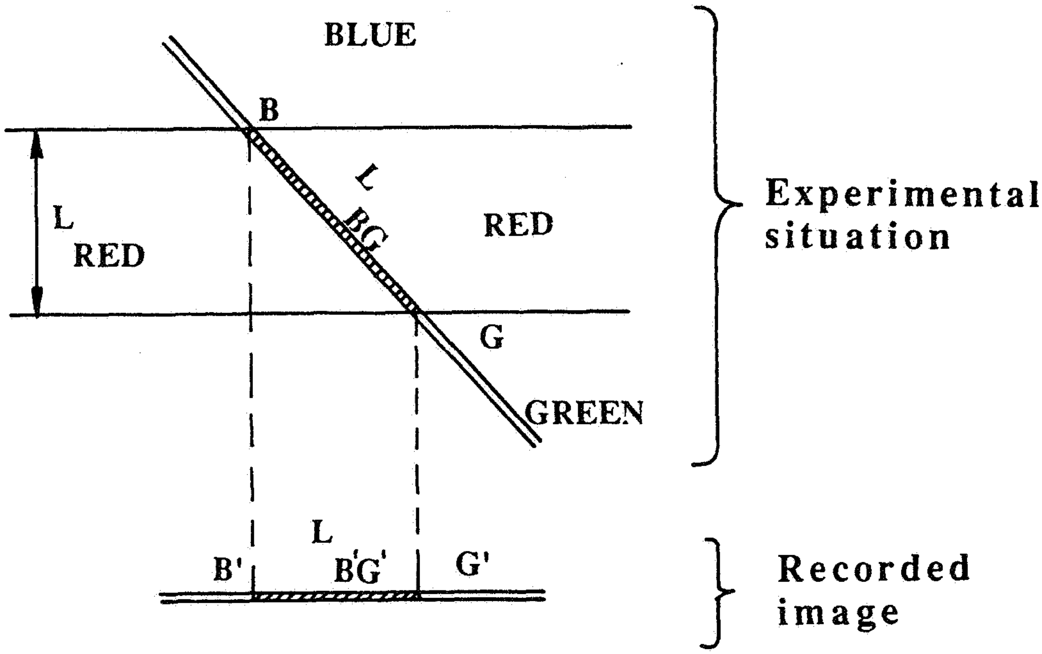

Fig. 2 The reconstruction of the 3rd dimension

The reconstruction of the real depth situation is possible according to Fig. 2:

$$L_{BG} = \sqrt{L^2_{B'G'} + L^2_{RED}}$$

b. Timing

The 3 - arm non-symmetrical chopper is placed ahead the lenses of the camera. Its speed of rotation is adapted to the range of the tracer speeds observed simultaneously in the photographed plane.

The camera shutter is opened relatively long so that a few complete rotations of the chopper are meanwhile accomplished. That is resulting in "cutting" the tracer trajectories into segments: the long one, shorter and the shortest. Knowing the sense of rotation of the chopper the direction of the tracer displacement is determined.
The " cut-outs " on the trajectory image are the time - marks according to the chopper geometry and the speed of rotation.

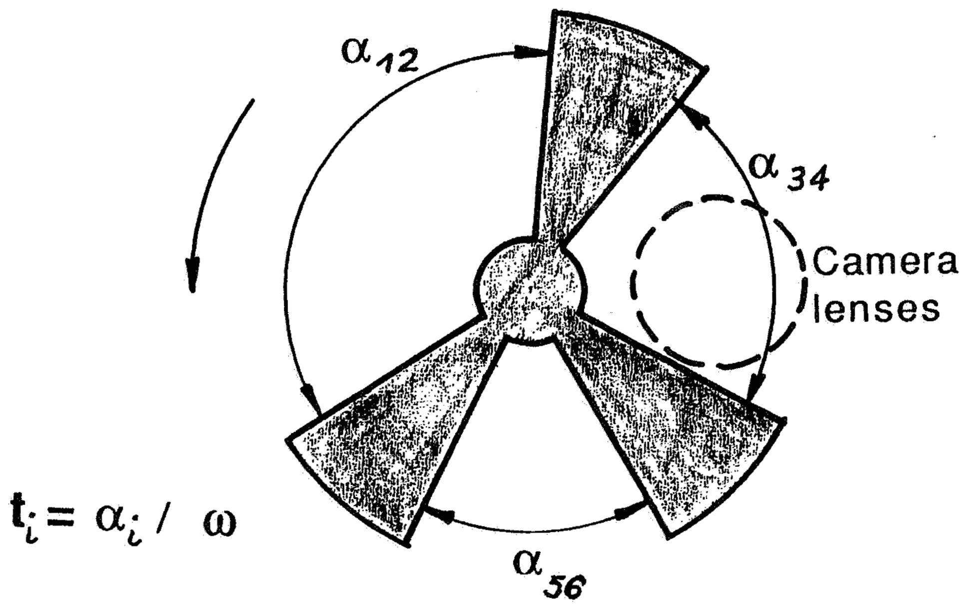

Fig. 3 Chopper

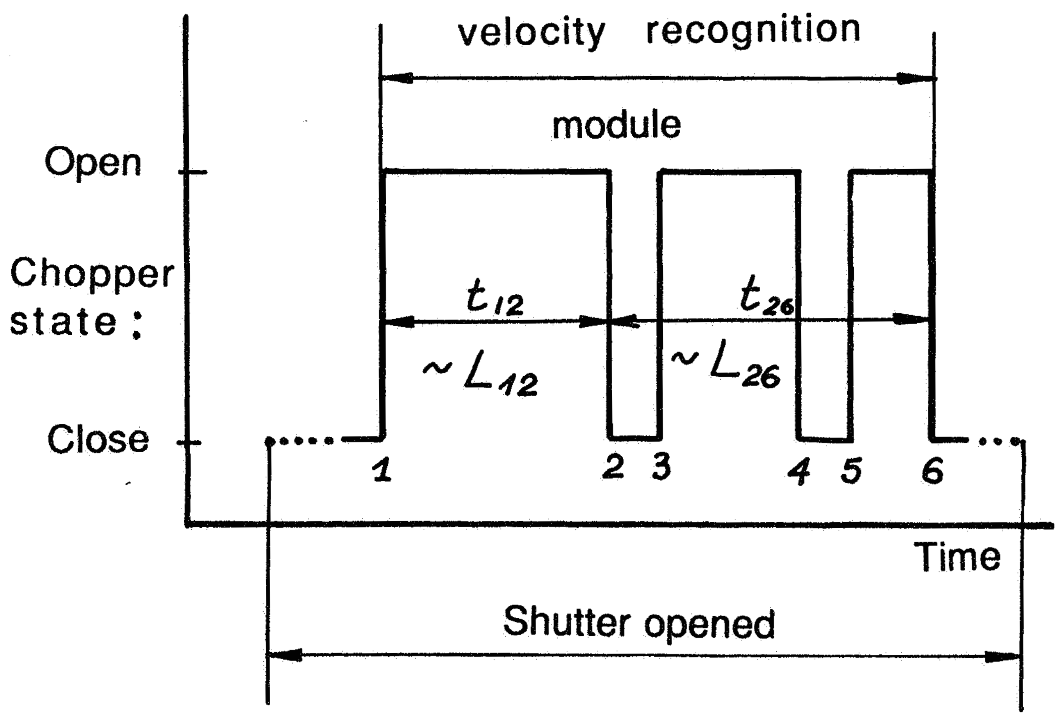

Fig. 4 Timing diagram: chopper/shutter

Taking the sequence of segments: " long - shorter - shortest" as a unit/module of the velocity vector recognition, its value may be calculated for instance:

$$|v|_{xy} = \frac{\frac{L_{12}}{t_{12}} + \frac{L_{26}}{t_{26}}}{2}$$

(see also Fig. 3)

Of course the multiple of the recognition module associated to the same trajectory may be used if that facilitates the velocity determination (e.g. because of the length measurement precision).
The camera and the chopper are not synchronized so that the first / last recorded track length is of no signification.

c. <u>Colour</u>

The distinction of the colour on the trajectory image is the mean to determine the 3rd dimension. The purity of the colours is essential to make that successfully. Each of the colours is associated with the separate LUT (Look Up Table) according to the recognition resulting from the light filtering while digitizing.
To accomplish the task the colour control is performed on the each level of the experiment. Namely,
- the light source temperature is known and possibly high
- the filters for producing the colour light sheets are very selective and adapted to the color reverse film sensitivity.
- the digitizing is performed adapting the light source / filters / CCD-camera settings for the best colour distinction after electronic conversion.

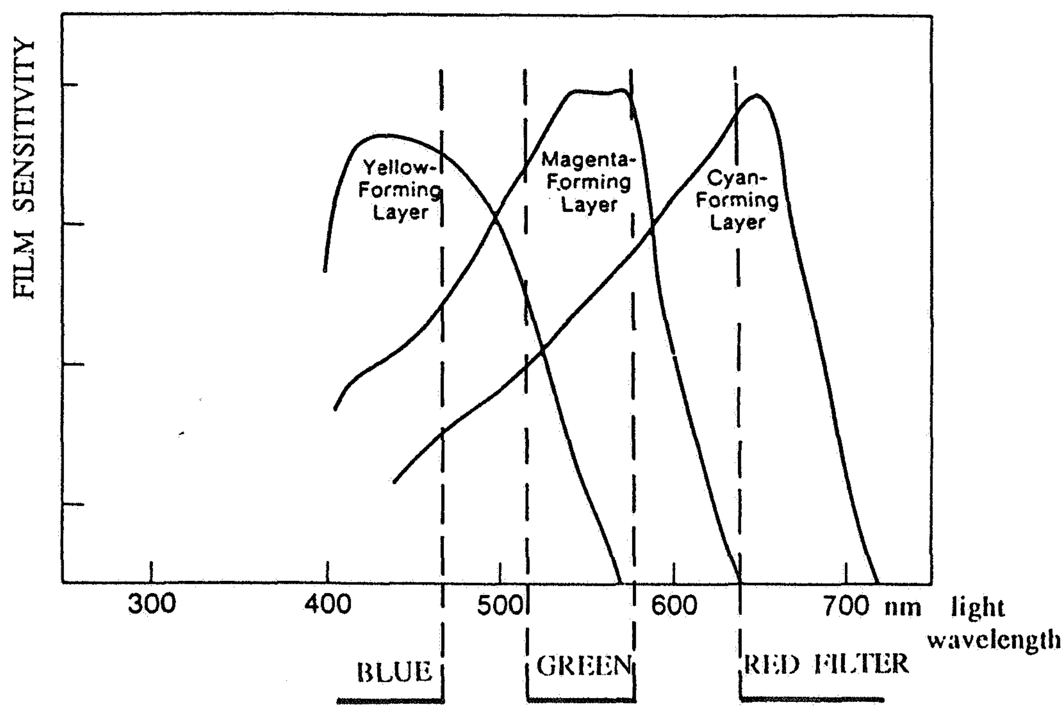

Fig. 5 Reverse film sensitivity vs. light filtering

2. DIGITIZING AND THE BASIC IMAGE PROCESSING PROCEDURES

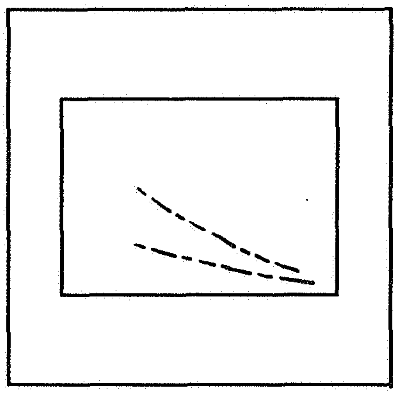

Fig. 6 Image from experiment

The area marked in the slide above is digitized three times (once for each colour) with a CCD-camera (containing a 512x512-pixel sensor). For every colour, information is stored in a specific channel in the computer, that means per slide-area one obtains three different matrices in the computer (three LUT's= Look Up Tables).

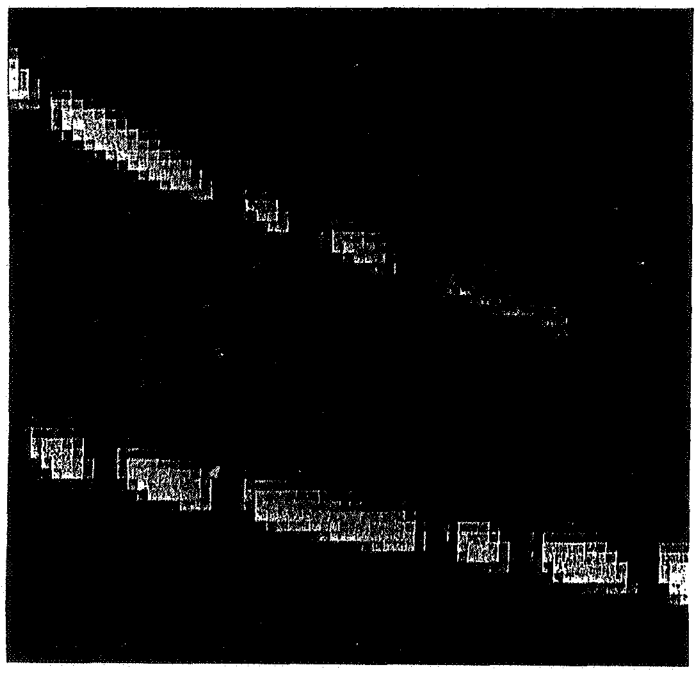

Fig. 7 Digitized image

Shown above is an electronic image, i.e. one 512x512-array for one specific colour. The image consists of pixels with different gray-levels (values between 0 and 128).

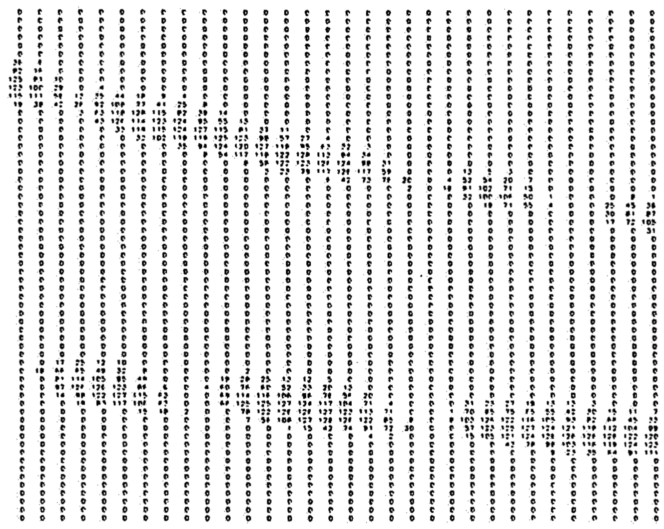

Fig. 8 Numerical representation of the electronic image

Even with this kind of presentation it is possible to visualize the different tracks (there is the advantage that the black background-pixels have the value 0). This matrix represents the basis for the image processing steps which will follow.

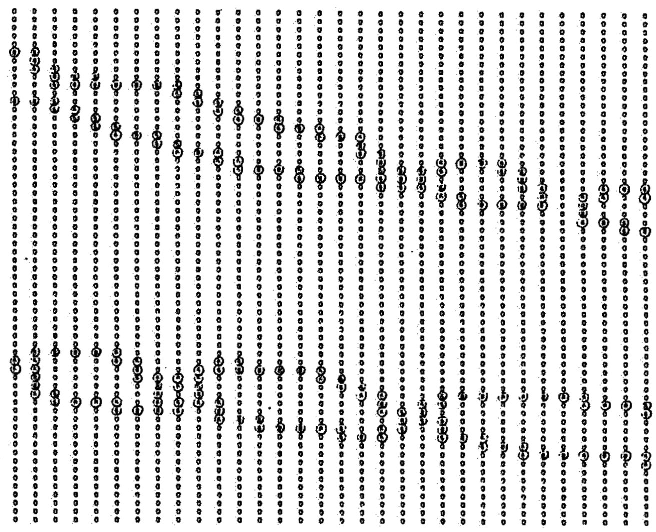

Fig. 9 Effect of edge detection operator

The original matrix looks like this after being modified by an algorithm called "Roberts operator" (for better presentation, pixels which don't have the value 0 are placed in a setting of a circle). Every pixel-value has been calculated with the formulas shown in the next paragraph [4]. The calculation started in the upper left corner and finally stopped at the end of the last row in the corner right below.

2.1 Example of the application of the "Roberts-operator"-algorithm

```
- - - - - - - - - - - > j
| 2 2 2 2 8 8
| 2 2 2 2 8 8
| 2 2 2 2 8 8
| 2 2 2 2 8 8
| 2 2 2 2 2 2
|
V
i
```

Let's consider the surrounded pixel with the brightness-value b(i,j)=2 in the original matrix that should be modified by the "Roberts-operator". The resulting brightness-value must be calculated as follows:

$$C(i,j) = \sqrt{A^2 + B^2}$$

A=b(i,j)-b(i+1,j+1)

B=b(i+1,j)-b(i,j+1)

In this example one gets 0 for A, because b(i+1,j+1)=2 is subtracted from b(i,j)=2.

The value for B is -6 (b(i,j+1)=8 is subtracted from b(i+1,j)=2).

The resulting value for C(i,j) is

$$C(i,j) = \sqrt{0^2 + (-6)^2} = 6$$

After being modified by the "Roberts-operator", the area of the original matrix shown above is as follows:

```
- - - - - - - - - - - - - - - - - - - - - - - - - > j
| 0    0    0    8.5    0     0
| 0    0    0    8.5    0     0
| 0    0    0    8.5    0     0
| 0    0    0   [6.0]   8.5   8.5
| 0    0    0    0      0     0
|

i
```

The example above illustrates how the image edges became "visible" for further recognition operations:
Length and orientation determination of the tracks in x,y,z-space.

3. CONCLUSIONS

The quantitative visualization of the low-speed air streams in the ventilated/ heated spaces using the solid tracer is today technically realistic. The flow pattern of air movement and diffusion may be investigated based on the air velocity vector field. The progress in many associated areas:
particle tracking in water, colour CCD-cameras, image treatment, colour photography, are insistently influencing the evolution of the presented method toward a precise and highly automated engineering tool.

4. ACKNOWLEDGEMENT

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5. REFERENCES

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