# A COMBINED CORNER AND EDGE DETECTOR

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Team 18

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# PROJECT SUMMARY

- A robot that can be remotely controlled in contagious environment;
- A 6 DOF robot that is able to interact with various modalities (knobs, buttons, etc.);
- Due to geographical limitations, our goal for the course is to build a 2D cartesian robot that is able to interact with the oscilloscope through a working GUI;
- Other contributions towards the final goal including object recognition, hand-eye calibration, camera pose matching;

# PAPER SELECTION

- C. Harris and M. Stephens, A Combined Corner and Edge Detector, 1988
- Propose a new method for edge and corner detection;
- Stereo matching is required for finding the relative pose and distance between the camera and the object;
- Both object recognition and stereo matching requires the identification of feature points;
- Harris's corner detector is a powerful tool based on the intensity of the image and has relatively high accuracy;

# BACKGROUND

- Find a solution for edge tracking problem:
  - Earlier tracking of image features requires the features to be discrete;
    - Lack of connectivity of feature points therefore cannot be used for describing surfaces and objects;
    - Some methods (Ayache, N & F Lustman) represent edges as a set of straight line fragments and use them as discrete features;
    - Such methods are followed by junction completion algorithm but might not make much sense

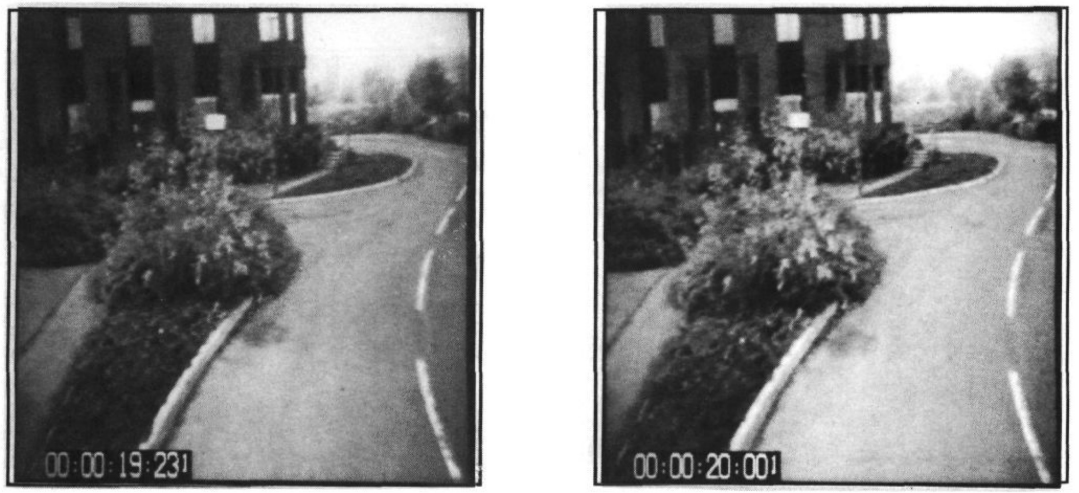



Figure 1

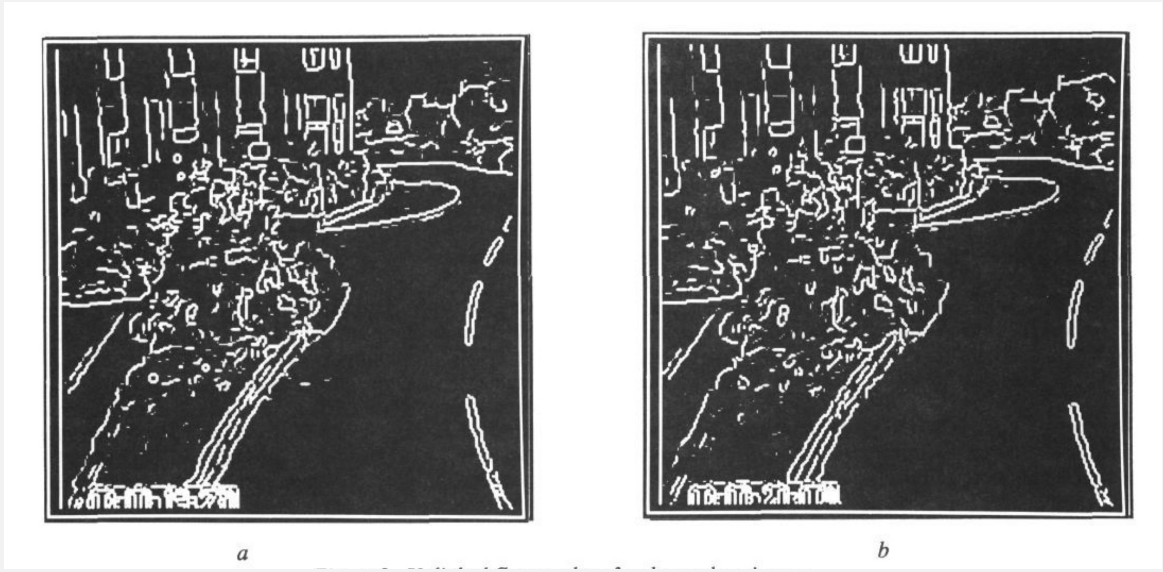



Figure 2

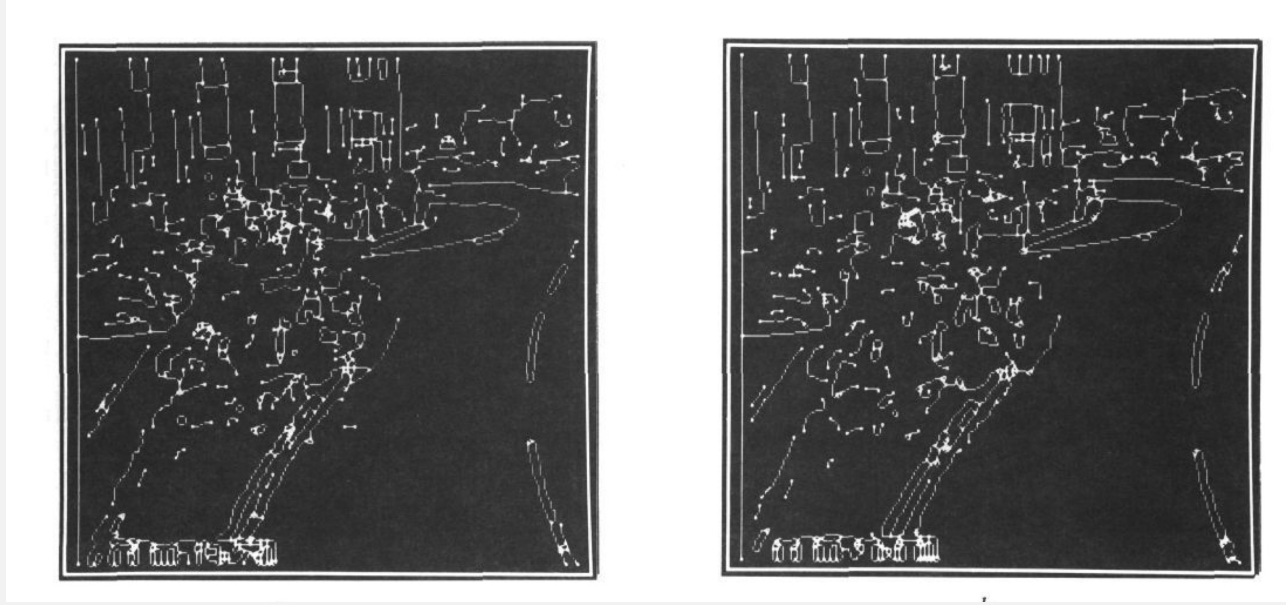
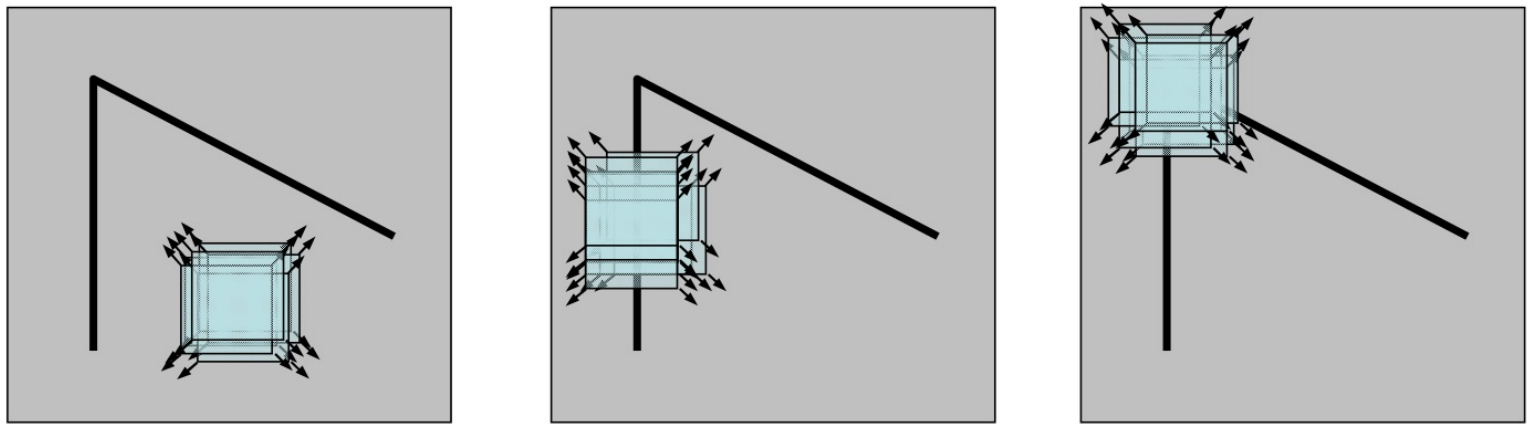


Figure 3

# METHODS (ALGORITHM)

- Basic idea: looking through a small window, while moving, the intensity change within the window varies for continuous texture, edges and corners;



# ALGORITHM (CONT'D)

$$G_{\chi} = \left( \frac{\partial I(u,v)}{\partial x} \right) \qquad \mathrm{G_y} = \left( \frac{\partial \mathrm{I(u,v)}}{\partial \mathrm{y}} \right)$$

Where the partial derivative can be computed via convolution

$$\partial_{\mathrm{x}} = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad \partial_{\mathrm{y}} = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

The local structure matrix is computed as:

$$M = \begin{bmatrix} \sum_{u,v}^{W} G_x{}^2 & \sum_{u,v}^{W} G_X \times G_{\mathrm{y}} \\ \sum_{u,v}^{W} G_X \times G_{\mathrm{y}} & \sum_{u,v}^{W} G_{\mathrm{y}} 2 \end{bmatrix}$$

The R- value (Harris score) is given by: $R = Det(M) - k * Trace(M)^2$

# GENERAL STEPS FOR STEREO MATCHING

1. Input image I(u, v)
2. Gradient calculator
3. Partial derivative unit
4. Finding corners
5. Non maxima suppression
6. High and low threshold operator
7. Displaying corners
8. Feature matching

# EVALUATION

- Based on result from *Evaluation of Interest Point Detectors* (Schmid, C., Mohr, R. & Bauckhage, C. Evaluation of Interest Point Detectors. *International Journal of Computer Vision* **37,** 151–172 (2000).
- Repeatability: detection is independent of changes in the imaging conditions (parameters of the camera, camera position relative to the scene, illumination conditions, etc.)

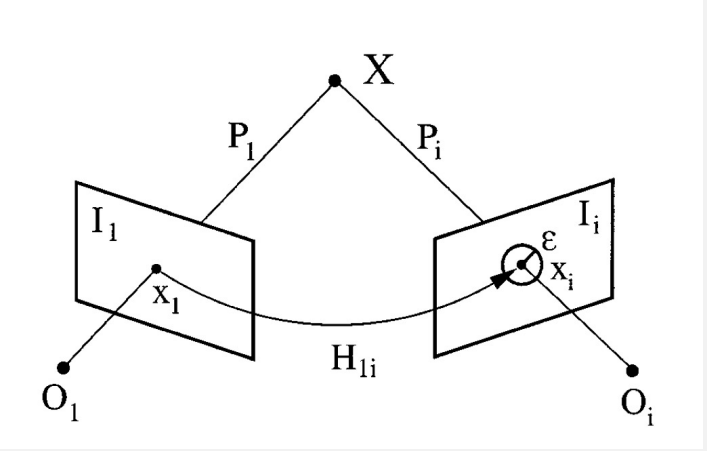



*Figure 2.* The points $x_1$ and $x_i$ are the projections of 3D point $X$ into images $I_1$ and $I_i$: $x_1 = P_1 X$ and $x_i = P_i X$ where $P_1$ and $P_i$ are the projection matrices. A detected point $x_1$ is repeated if $x_i$ is detected. It is $\epsilon$-repeated if a point is detected in the $\epsilon$-neighborhood of $x_i$. In the case of planar scenes the points $x_1$ and $x_i$ are related by the homography $H_{1i}$.

# EVALUATION (CONT'D)
# 1. RESPONSE TO INVARIANCE TO ROTATION

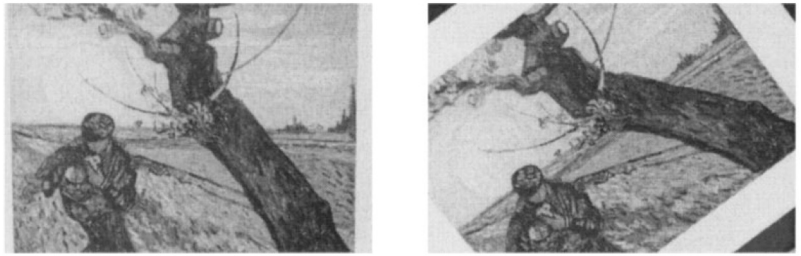
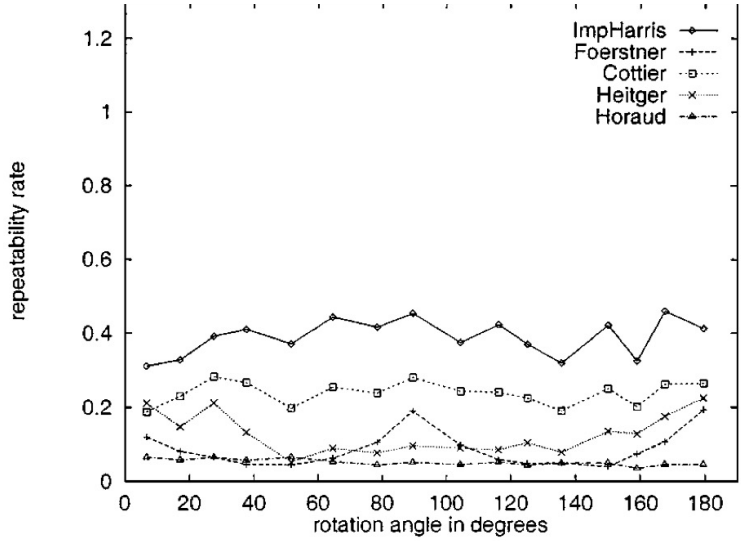




Figure 4



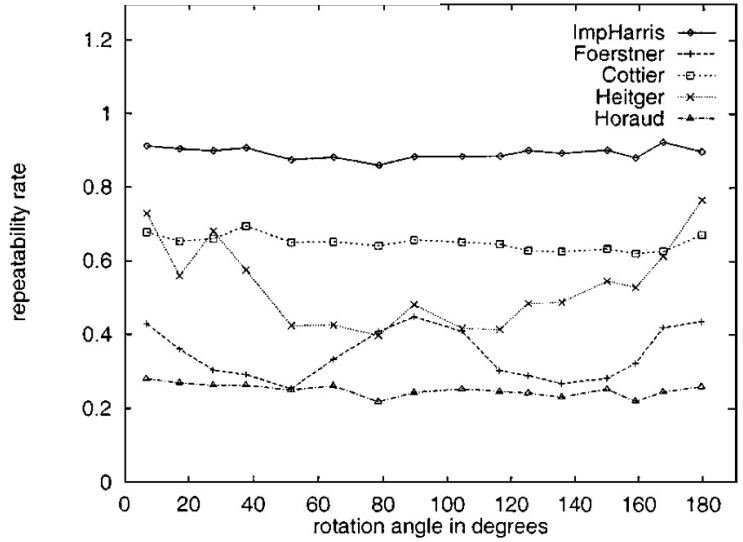
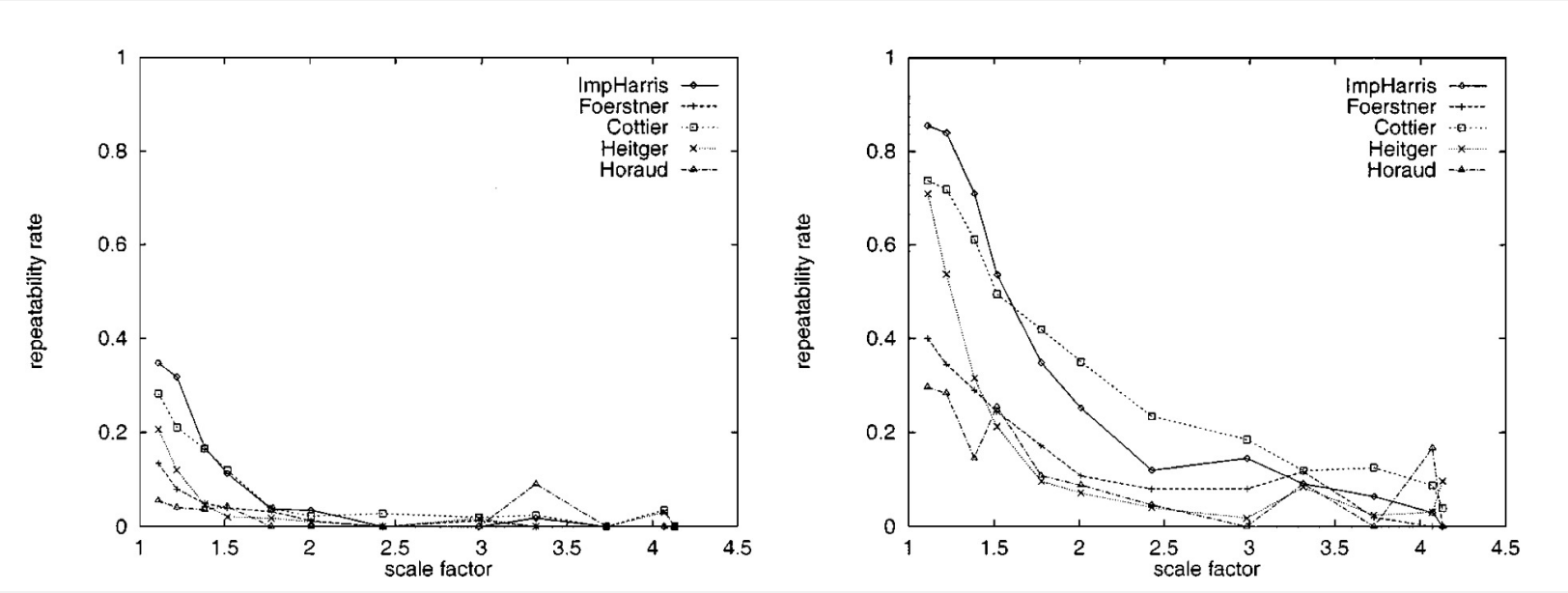
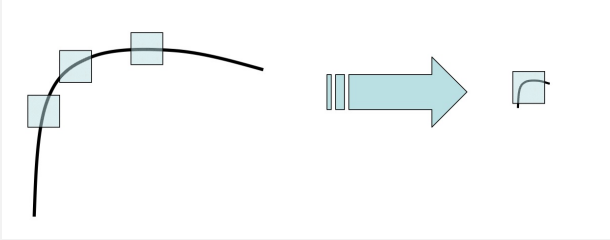




Figure 5

# 2. RESPONSE TO SCALE

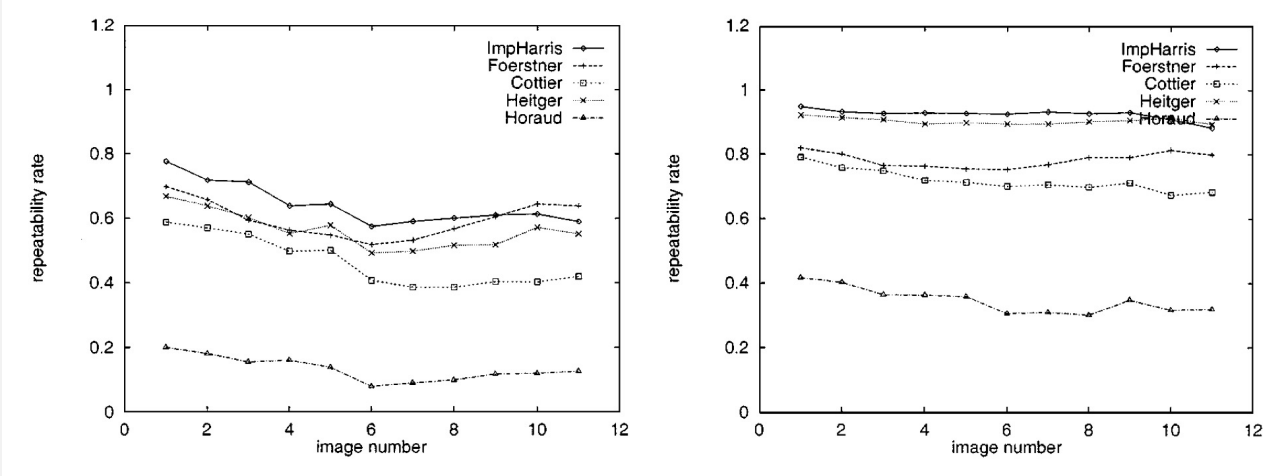
Figure 6

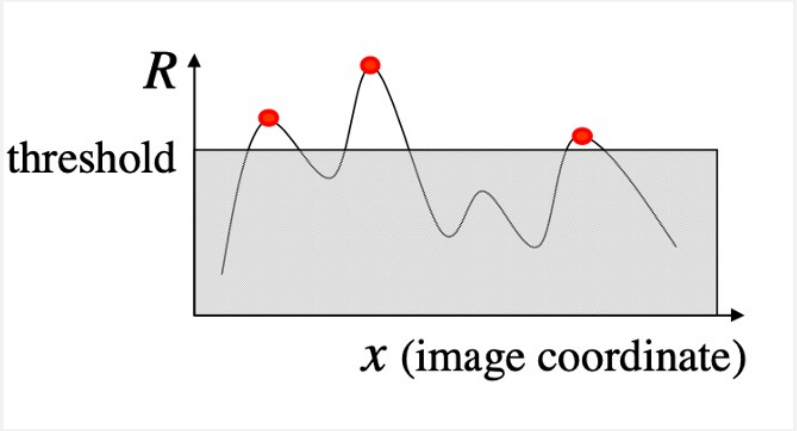


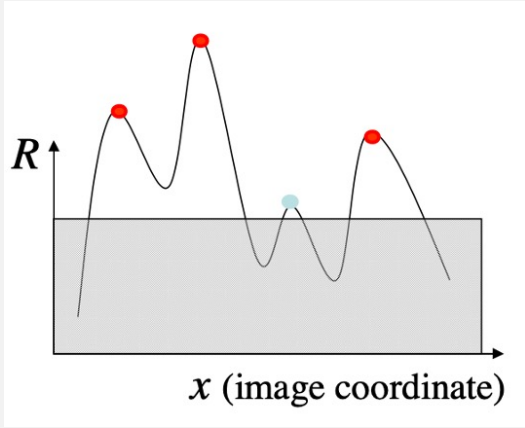



# 3. RESPONSE TO INTENSITY CHANGE

Figure 7



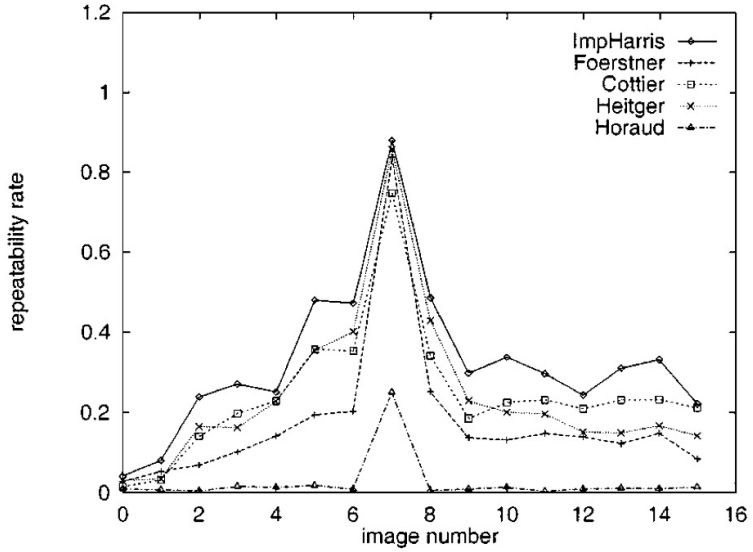



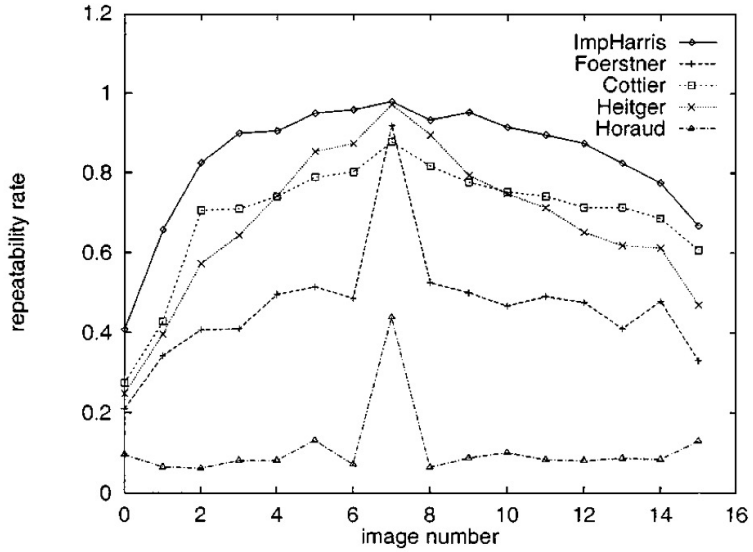



# 4. RESPONSE TO VIEWPOINT CHANGE

Figure 8

Figure 9



# PAPER SIGNIFICANCE

- 1. Harris detector allows for flexible threshold operator for exact corner detection;
- 2. Low memory required and latency is relatively low;
- 3. Invariance to rotation, intensity change;
- 4. Respond well to viewpoint change;

# CRITIQUES

- 1. Respond bad to scaling;
- 2. Does not fix the occlusion problem;

# OTHER DEVELOPMENTS

- Improved version of Harris detector (ImpHarris): change the calculation of the derivative with the derivatives of a Gaussian filter;
- Recursive implementation of the Gaussian filter by Deriche guarantees fast detection;
- Other feature extractors include descriptor extraction and regional feature detector;

# CONCLUSIONS

- Harris's edge and corner detector is a powerful tool for extracting useful features;
- Stereo matching based on Harris's detector is fast and stable;