# Model Based Temporal Object Verification Using Video

- Objective
  - Recognize objects from video by matching detected objects with models, using both appearance and pose continuity constraints.

# General Methods Classification/Recognition

- 3D Model Based Recognition
  - Map 3D Models to 2D Objects
- Appearance Matching
  - Template Matching
  - Principal Components
  - Representative histograms

# General Methods Classification/Recognition

- Classifiers
  - Fisher Linear Discriminant (LDA)
  - State Vector Machines
  - Boosted Classifiers
  - Bayesian Classifiers
  - Neural Networks

# General Methods Classification/Recognition

- Features
  - Color
  - Gradients/ Edges /Filter Responses
  - Interest points/ Corners
  - Motion
    - Periodicity
    - Trajectory Curvature

# Modules of The Video Based Object Recognition System

- Object Detection & Segmentation
  - Sensor Motion Compensation
  - Appearance and/or motion differencing
- Model to Measurement Matching
- Pose Continuity Constraints

# Object Detection & Segmentation

- Motion Compensation using affine transformation

$$P_i' = \begin{pmatrix} r_{11} & r_{21} \\ r_{12} & r_{22} \end{pmatrix} P_i + \begin{pmatrix} t_x \\ t_y \end{pmatrix}$$

- Frame differencing or motion segmentation to extract object
- Change in scale between frames can be calculated in camera motion dominant cases by

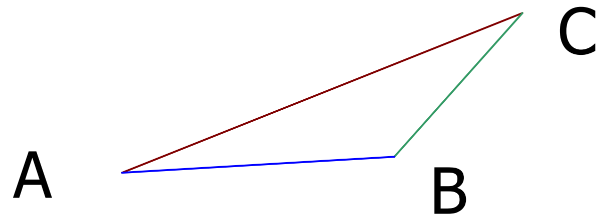
$$s = \sqrt{(r_{11}^2 + r_{12}^2 + r_{21}^2 + r_{22}^2) / 2}$$

# Model to Measurement Matching

- Matching Criterion: A distance measure
  - Preferably  distance measure should be a metric

# Model to Measurement Matching

- A Metric distance measure, between points A and B, D(A,B) has the following properties
  - $D(A,B) \geq 0$
  - $D(A,B)=0$ iff $A=B$
  - $D(B,A)=D(A,B)$
  - $D(A,C) \leq D(A,B)+D(B,C)$



# Model to Measurement Matching

- Hausdorff distance between points sets $A=\{a_1,\ldots,a_p\}$ and $B=\{b_1,\ldots,b_q\}$
  - $H(A,B)=\max\{h(A,B),h(B,A)\}$ , where
    - $h(A,B)=\sup_{a \in A} \inf_{b \in B} \|a - b\|$

# Model to Measurement Matching

- Supremum is the least upper bound of a set S.  For example
  - On the real line , (0,1) , sup is 1, though maximum is unknown
  - (0,1] , sup is 1 and maximum is 1.

# Model to Measurement Matching

- The Hausdorff distance measure is susceptible to noise.
- The $L_p$ measure avoids this.

$$H^p(A,B) = \left[ \frac{1}{n(X)} \sum_{x \in X} \left| \rho(x,A) - \rho(x,B) \right|^p \right]^{\frac{1}{p}}$$

Where,

**X is the set of image pixels**

$$\rho(x,A) = \inf_{a \in A} \{ \rho(x,a) \}$$

$$1 \le p \le \infty$$

# Model to Measurement Matching

- In applications a cutoff function w(t,c)=min{t,c} for a fixed c>0 is incorporated in the distance measure.

$$H^p(A,B) = \left[ \frac{1}{n(X)} \sum_{x \in X} \left| w(\rho(x,A),c) - w(\rho(x,B),c) \right|^p \right]^{\frac{1}{p}}$$

# Verfication using $H^p$

- Given an Edge map R, and ‘m’ models $M_{i,}$ the task is to find a model Mj and a transformation $T \in \tau$ such that,

$$H^p(R, T'(M_j)) = \min_{i=1}^{m} \min_{T \in \tau} H^p(R, T(M_i))$$

# Defining Orientation

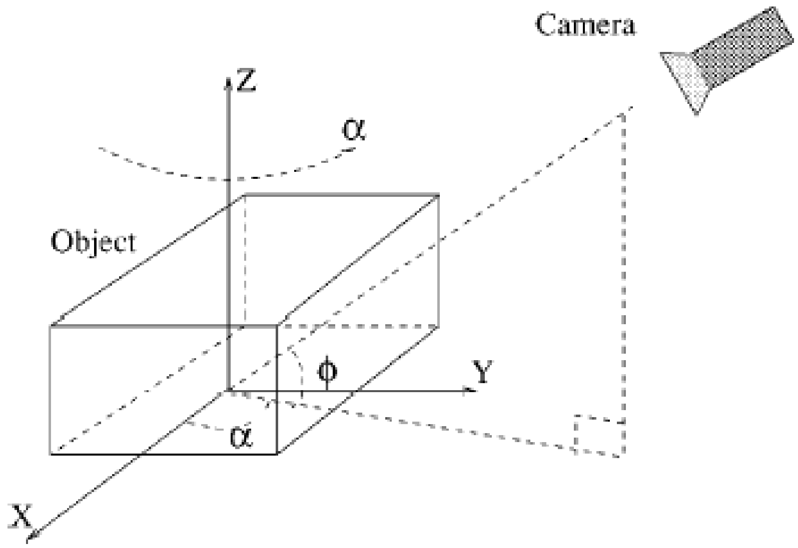



Fig. 2. Two angles defining the object orientation with respect to the camera under the assumption of level ground (i.e., the $X$–$Y$ plane is horizontal).

# Estimating Orientation

- Assuming tilt $\phi \in [0°, 90°]$ Orientation can be constrained if velocity is known

$$\phi \in 0°, then, V_x < 0 \Rightarrow \alpha \in (0°, 180°)$$

$$\phi \in 0°, then, V_x > 0 \Rightarrow \alpha \in (180°, 360°)$$

$$\phi \in (0°, 90°), then, V_x > 0 \,\&\, V_y > 0 \Rightarrow \alpha \in (180°, 270°)$$

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$\phi \in (0°,90°), then, V_x > 0 \,\&\, V_y > 0 \Rightarrow \alpha \in (180°,270°)$

# Estimating Orientation

- Object orientation can be estimated as
  - $$(\hat{\alpha}, \hat{\phi}) = \arg\min_{\alpha,\phi \in \mathrm{A} \times \Phi} H^p(R, M(\alpha, \phi))$$
    - Where M is the model with orientation parameters

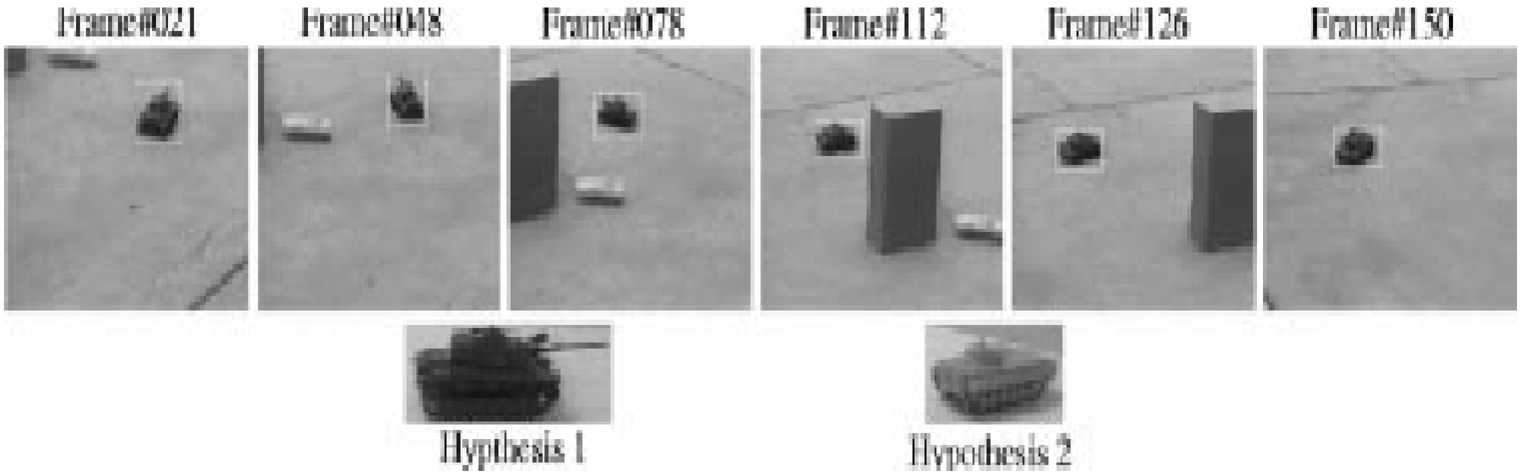
# Pose Evolution Curve

- Pose should change smoothly over time
- The smoothness can be computed as

$$S = \frac{1}{n} \sum_t (p(t) - q(t))^2$$

- Where,
  - N is the number of frames
  - t is frame index
  - p(t) is pose evolution curve
  - q(t)=p(t)*window(t) , q(t) is smoothed version of p(t)

# Pose Evolution Curve



# Pose Evolution Curve

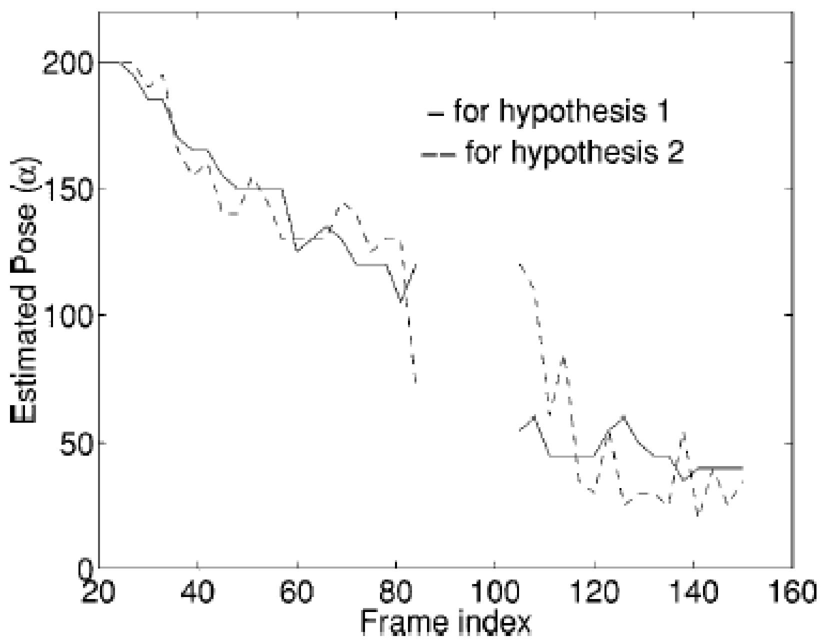



Fig. 10. Pose evolution curves (angle $\alpha$) for the sequence shown in Fig. 8. The computed $S$ values [see (11)] are 8.1 and 64.9 for hypothesis 1 and hypothesis 2, respectively, strengthening the confidence in choosing hypothesis 1.

# Pose Bands

- Several top poses should be considered while matching
- The following quantity ‘C’ should be small for poses of correct hypothesis

$$C = \frac{1}{N} \sum_{t} \{ \frac{1}{B} \sum_{i=1}^{B} (p_i(t) - \bar{p}(t))^2 \}$$

- Where,
  - B is the number of top pose matches for an object
  - $\bar{p}(t)$ is the average of pose angles at time t.

# Pose Bands

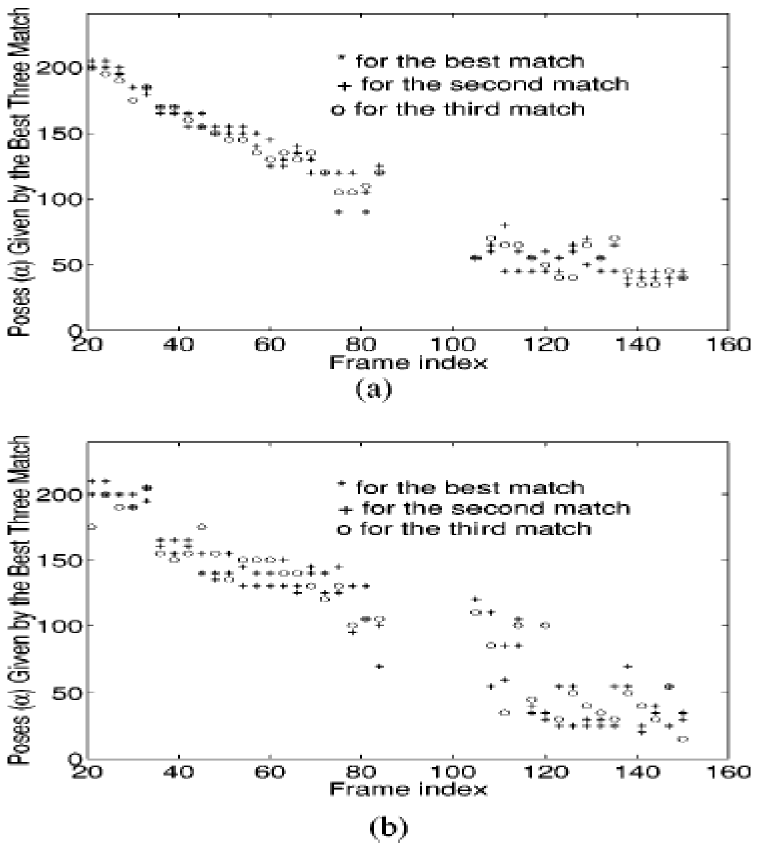



Fig. 11. Bands of the pose estimates (angle $\alpha$) versus frame index. (a) Hypothesis 1 and (b) hypothesis 2. The computed $\mathcal{C}$ values [see (12)] are 20.9 and 80.4 for hypothesis 1 and hypothesis 2, respectively, strengthening the confidence in choosing hypothesis 1.

# Confidence Measure

- A confidence measure for choosing a certain model can be defined as

$$P_c = 1 - \frac{H^p}{1 + H^p}$$

- Note
  - $P_c$ is 1 if $H^p$ is 0.
  - $P_c$ is 0 if $H^p$ is infinity

# Confidence Measure

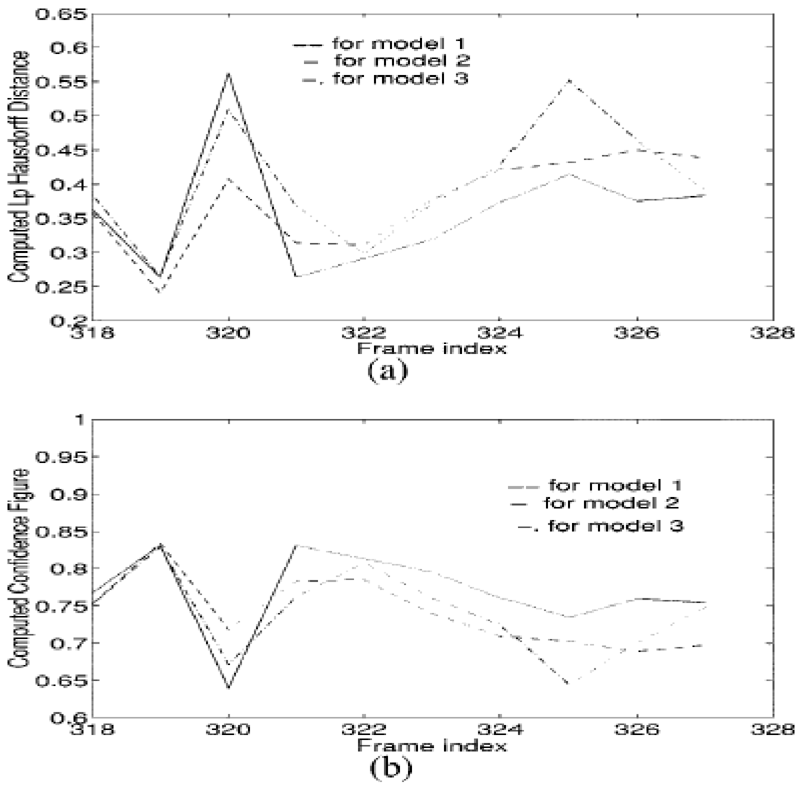



Fig. 6. $H^{lp}$ values and confidence figures for the sequence in Fig. 5, from frame 318 to 327: (a) $H^{lp}$ values versus frame index and (b) computed confidence figure $P_c$.

# More Results

# More Results

TABLE I

PERFORMANCE OF THE ALGORITHM ON SOME TEST SEQUENCES

| Sequence Name | Number of Hypotheses Assumed | Number of Frames Used for Verification | Number of Correct Frames By $H^p$ | Correct By $S$? | Correct By $C$? |
|---|---|---|---|---|---|
| two_tank1 | 2 | 100 | 91 | Yes | Yes |
| two_car3 | 2 | 120 | 107 | Yes | Yes |
| rag16_08 | 3 | 25 | 19 | - | - |
| rag17_01 | 3 | 25 | 21 | - | - |
| rag19_06 | 3 | 25 | 22 | - | - |
| rag19_07 | 3 | 25 | 20 | - | - |
| rag19_18 | 3 | 25 | 21 | - | - |