Center for Embedded Systems
An NSF Industry/University Cooperative Research Center

Background Invariant Laser-spot Detection and Tracking for Embedded Systems

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Project Overview and Description

PROJECT DESCRIPTION

Develop a methodology to accurately detect laser-spots in low-resolution images and to track the laser-spot in varying background and illumination conditions

- **Applications:**
  - Smart Munitions: Targeting, Guiding, Counter-measure
  - Robotics: Navigation

http://www.popularmechanics.com/technology/military/research/8-laser-weapon-systems

Approach

APPROACH

- **Detection:** Filtering, Segmentation, Feature extraction, Classification
- **Tracking:** Kalman filter, Particle filter
- **Initial Focus:** Static and simple backgrounds.
- **Subsequent Efforts:** Dynamic and noisy backgrounds.
- **Final goal:** Embed the detection and tracking strategy into a multi-core processing architecture

NOVELTY

- Unique problem, unique formulation

Potential member company benefits

- Numerous possible applications

Project Status

- **Progress to date**
  - Acquired laser spots in varying backgrounds
  - Developed Intensity based segmentation
  - Implemented Kalman Filter/ Particle filter

- **Results: video**

Project Tasks/ Deliverables

	Description	Date	Status
1	Study characteristics of laser-spots in varying backgrounds		Ongoing
2	Develop laser-spot detection algorithms		Ongoing
3	Develop laser-tracking algorithms		Ongoing
4	Test detection and tracking algorithms in simple backgrounds		Ongoing
5	Test detection and tracking algorithms in complex backgrounds including missing objects in frames		
6	Embed the detection and tracking strategy into a multi-core processing architecture		

Executive Summary

- **Develop method to**
  - Detect and track laser-spots
- **Applications**
  - Military
  - Robotics
  - New applications
- **Approach**

Detection: Filtering, Segmentation, Object extraction

Tracking: Kalman filter, Particle filter

http://www.fastcompany.com/welcome.html?destination=http://www.fastcompany.com/1823017/darpa-unveils-drone-slaying-war-laser

Technical Detail

Detection

- Filtering: Min filter, Gaussian filter, median filter
- Segmentation: adjacent frame difference
- Object extraction: combine optical flow and mean shift/frame difference

➢ optical flow: assume intensity of objects do not change over time and objects move slowly.

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t)$$
$$I_x V_x + I_y V_y = -I_t$$

➢ Mean shift:

$$m(x) = \frac{\sum_{x_i \in N(x)} K(x_i - x) x_i}{\sum_{x_i \in N(x)} K(x_i - x)}$$

Technical Detail

- **Tracking**

Dynamic system model:

$$x_{k+1} = f(x_k) + w_k$$
$$z_k = h(x_k) + v_k$$

x_k : target state;

z_k : measurement;

f: state transition function;

h: state-to-measurement function;

w_k: state transition noise;

v_k: measurement noise.

Q: covariance matrix of w_k

R: covariance matrix of v_k

Technical Detail

Kalman filter: recursively predict new state x_k

Prediction step:

$$\hat{x}_k^- = f(\hat{x}_{k-1})$$
$$P_k^- = AP_{k-1}A^T + Q$$
$$A \equiv \frac{\partial f}{\partial x}\Big|_{\hat{x}_k}$$

P_k : error covariance

Correction step:

$$K_k = P_k^- H^T \left(HP_k^- H^T + R\right)^{-1}$$
$$\hat{x}_k = \hat{x}_k^- + K_k\left(z_k - h\left(\hat{x}_k^-\right)\right)$$
$$P_k = P_k^- - K_k HP_k^-$$
$$H \equiv \frac{\partial h}{\partial x}\Big|_{\hat{x}_k^-}$$

Technical Detail

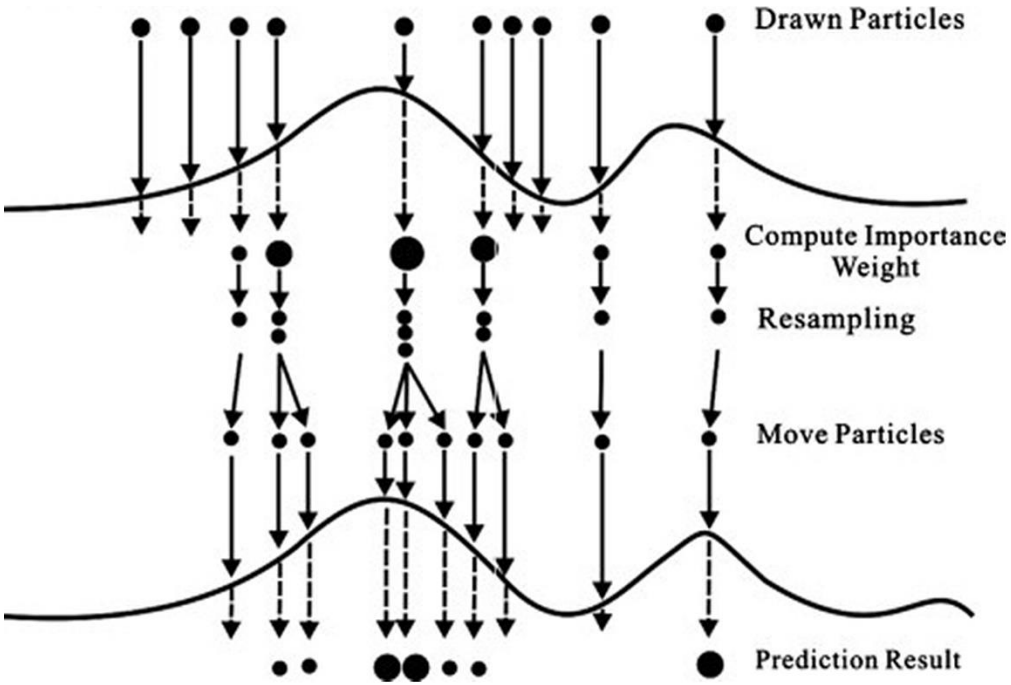
Particle filter: for more general non-Gaussian states

$$\text{Target distribution f}: p(x \mid z_1, z_2, \ldots, z_n) = \frac{\prod_k p(z_k \mid x) \quad p(x)}{p(z_1, z_2, \ldots, z_n)}$$

$$\text{Sampling distribution g}: p(x \mid z_l) = \frac{p(z_l \mid x)\, p(x)}{p(z_l)}$$

$$\text{Importance weights w}: \frac{f}{g} = \frac{p(x \mid z_1, z_2, \ldots, z_n)}{p(x \mid z_l)} = \frac{p(z_l) \prod_{k \neq l} p(z_k \mid x)}{p(z_1, z_2, \ldots, z_n)}$$

Technical Detail



Particle filter algorithm

Current Results

- Detect one laser spot in stationary and very slow moving backgrounds

- Track one missing spot in stationary and very slow moving backgrounds

Technical Detail

Future Work

- Detect multiple spots in stationary and very slow moving backgrounds
- Track missing spots in stationary and very slow moving backgrounds
- Detect multiple spots in dynamic backgrounds
- Track missing spots in dynamic backgrounds