Learning to Track Persons with Gaussian Process Joint Particle Filtering

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Overview

- **A novel approach to multiple target tracking**
- **Method combines Gaussian Processes (GP) and Particle Filtering (PF)**
- **Multiple target interactions are modelled by Markov Random Fields (MRF)**
- **Binary switch floor sensor is used to detect walkers**

Tracking Methodology

- **Gaussian Process Regression (GPR)**
  - Non-parametric probabilistic method to learn kernel machines
  - GP is a collection of random variables of function $f(\mathbf{x})$ that have a joint Gaussian distribution

$$f(\mathbf{x}) \sim \mathcal{GP}(m(\mathbf{x}), k(\mathbf{x}, \mathbf{x}'))$$

  - GP is specified by its mean and covariance

$$m(\mathbf{x}) = \mathbb{E}[f(\mathbf{x})]$$
$$k(\mathbf{x}, \mathbf{x}') = \mathbb{E}[f(\mathbf{x}) - m(\mathbf{x})] - m(\mathbf{x}')$$

  - Besides point estimates provides the uncertainty directly

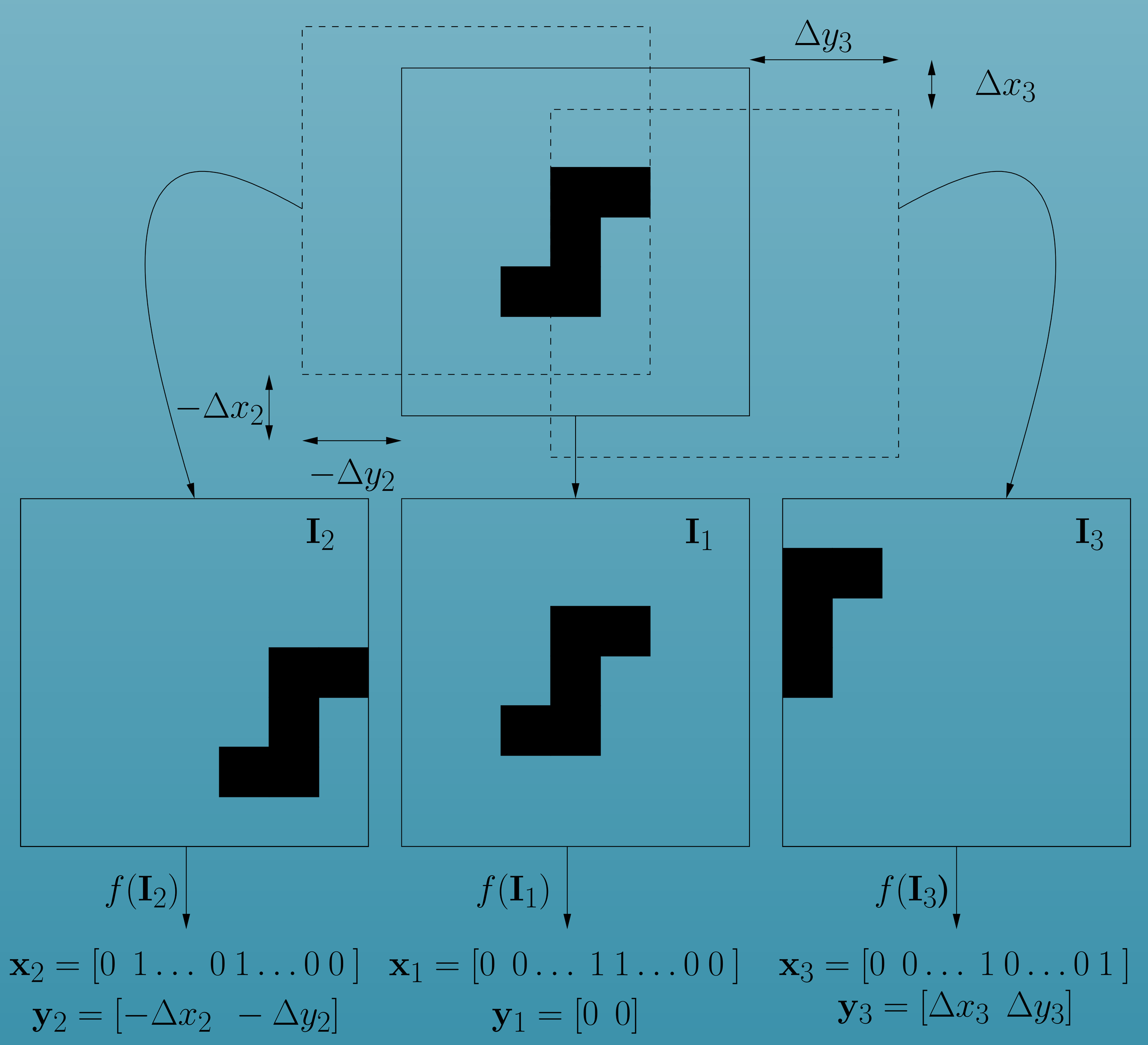
$$\overline{f}_* = \mathbf{k}_*^T (K + \sigma_n^2 I)^{-1} \mathbf{y}$$
$$\mathbb{V}[f_*] = k(\mathbf{x}_*, \mathbf{x}_*) - \mathbf{k}_*^T (K + \sigma_n^2 I)^{-1} \mathbf{k}_*$$

  - Kernel hyperparameters can be learned from the data by maximizing the log likelihood

$$\log p(\mathbf{y}|X, \Theta) = -\frac{1}{2}\mathbf{y} K_y^{-1} - \frac{1}{2}\log|K_y| - \frac{n}{2}\log 2\pi$$

- **GPR displacement expert**
  - Expert which learns mapping between input features and displacements
  - GPR is trained on displacement dataset sampled from the true position $y \sim uniform(-\Delta, \Delta)$
  - Tracking state estimates can be corrected by GPR displacement expert

$$\mathbf{x}_t = \mathbf{x}_{t-1} + GP_\mu(\mathbf{I}(\mathbf{x}_{t-1}))$$



- **Joint Particle Filter**
  - Numerical approximation method for nonlinear non-Gaussian dynamical systems

$$p(\mathbf{x}_t|\mathbf{x}_{t-1}) \propto \prod_i p(\mathbf{x}_t^i|\mathbf{x}_{t-1}^i)$$
$$p(\mathbf{y}_t|\mathbf{x}_{t-1}) \propto \prod_i p(\mathbf{y}_t^i|\mathbf{x}_{t-1}^i)$$

- **Markov Random Fields for Target Interaction**
  - Multi-target interaction model for data association problem

$$p(\mathbf{x}_t|\mathbf{x}_{t-1}) \propto \prod_i p(\mathbf{x}_t^i|\mathbf{x}_{t-1}^i) \prod_{i,j \in E} \psi(\mathbf{x}_t^i, \mathbf{x}_t^j)$$

Gaussian Process Joint Particle Filter

- **Combines trained GPR model, SIR Particle Filter, and MRF motion model**

$$\tilde{\mathbf{x}}_t = \mathbf{x}_t + GP_\mu(\mathbf{x}_t)$$

$$w_t = w_{t-1} \prod_{i=1}^{n} \mathcal{N}(\tilde{\mathbf{x}}_t^i; \mathbf{x}_t^i, GP_\Sigma(\mathbf{x}_t^i)) \prod_{i,j \in E} \psi(\tilde{\mathbf{x}}_t^i, \tilde{\mathbf{x}}_t^j)$$

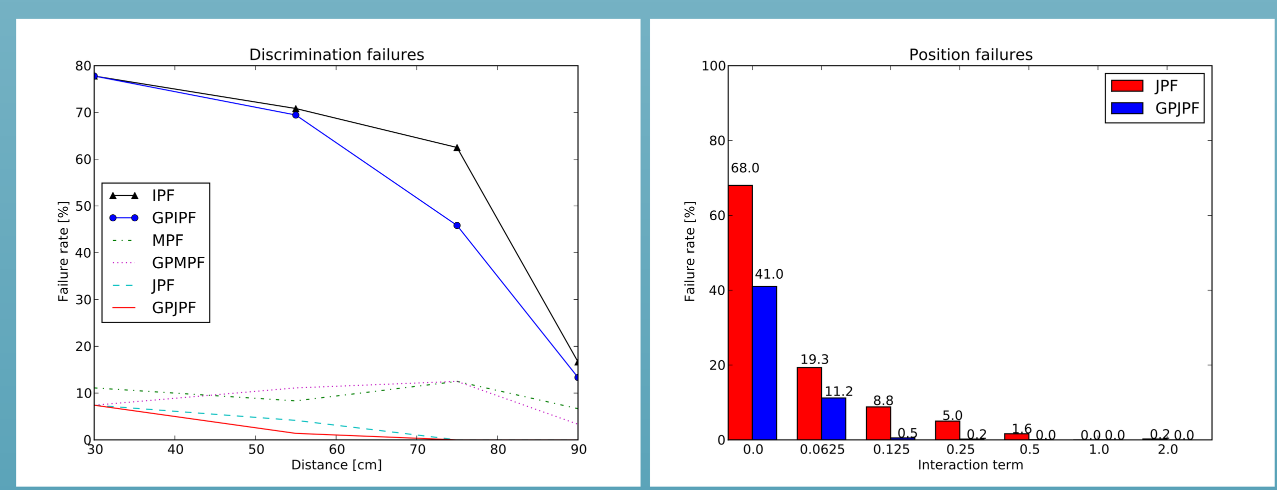
Experimental Results

- **Sensor and environment**
  - Sensor material is mounted on the floor surface
  - 3 m^2 area consists 300 binary switches where the cell size is 10x10 cm
  - 16 Hz sampling rate
- **Dataset**
  - 3 different subjects (1 female and 2 male walkers)
  - Totally 70 different sequences collected from two simultaneous walkers
- **Tracking methods**
  - Stationary motion model applied: $\mathbf{x}_t = \mathbf{F}\mathbf{x}_{t-1} + \epsilon$
  - In conventional PFs Gaussian measurement model applied
  - In GP-based methods learned measurement model applied

$$p(\mathbf{y}_t|\mathbf{x}_t) = \frac{1}{(2\pi)^{1/2}\sqrt{|GP_\Sigma(\mathbf{x}_t)|}} \exp[-\frac{1}{2}(GP_\mu(\mathbf{x}_t))^T GP_\Sigma(\mathbf{x}_t)^{-1}(GP_\mu(\mathbf{x}_t))].$$

		Sequence failures (%)	Frame failures (%)			
Method	Samples	Total	Position	Identity	Number	Total
IPF	50/target	57.14	15.18	6.00	7.18	16.58
GPIPF	25/target	52.86	13.65	5.10	6.92	15.28
MPF	50/target	12.38	0.37	0.37	0.87	1.11
GPMPF	25/target	8.57	0.21	0.25	0.28	0.48
JPF	100	9.05	**0.04**	**0.00**	0.47	0.51
GPJPF	50	**3.81**	0.09	**0.00**	**0.06**	**0.12**

- **Discrimination accuracy and MRF influence**



- **GPJPF in action**

Summary

- **Multi-person position tracking system based on GPJPF**
- **Accurate tracking of two simultaneous walkers on a sensor floor**
- **Outperforms other conventional GP and PF trackers**

References

J. Suutala, K. Fujinami, and J. Röning, Learning to Track Persons with Gaussian Process Particle Filtering, Technical Report, University of Oulu, 2010.

Videos available: `http://www.ee.oulu.fi/\~jaska/gpjpf/`