# Probabilistic Stand Still Detection using Foot Mounted IMU


Jonas Callmer, David Törnqvist and Fredrik Gustafsson

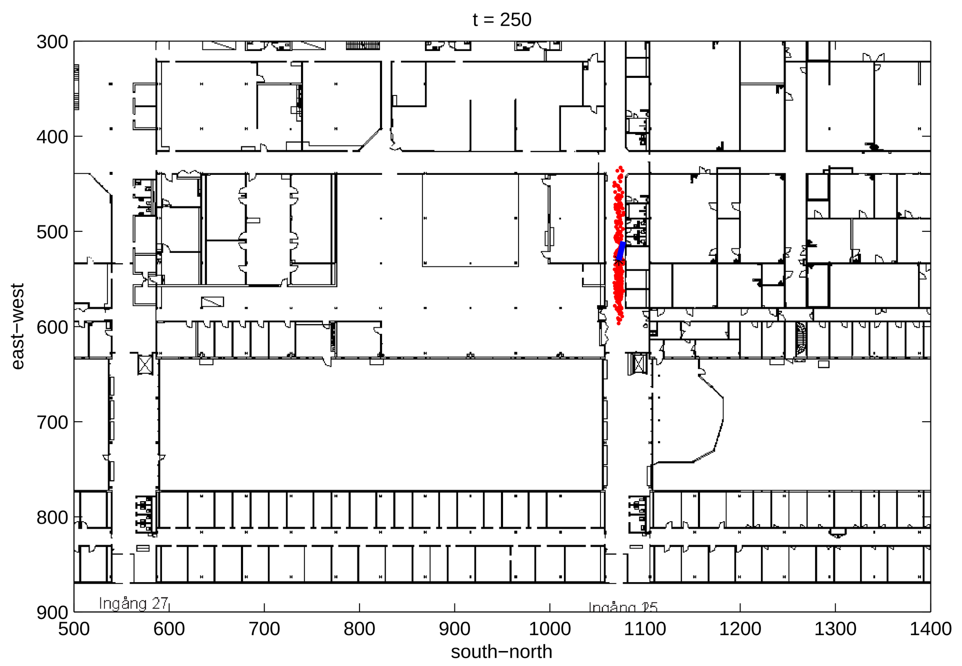
AUTOMATIC CONTROL
REGLERTEKNIK
LINKÖPINGS UNIVERSITET



We consider indoor localization based on observations from a foot-mounted inertial measurement unit (IMU) supported by map matching. A statistical framework for stand-still detection is derived which uses a test statistic with a known stand still distribution and a Hidden Markov Model to describe the mode switching between stand still and walking.


## Introduction

In a map aided indoor localization experiment using an IMU, the uncertainty in position increases fast causing the position hypotheses to spread along the corridors.




To enhance the performance, the IMU can be foot mounted. Then, if the foot stances are detected, the velocity of the foot can be corrected when the foot is stationary, i.e. changed to zero. This reduces the drift from cubical to linear in time.

The problem is how to safely detect that the foot is stationary during a walking sequence using a foot mounted IMU. We propose to use a test statistic with a known stand still distribution based on the IMU data in conjuction with a Hidden Markov Model. This provides the probability of stand still for all time instances.

During the experiments an Xsens MT motion sensor sampling at 100 Hz was used. Here only the gyro data was used to detect stand still but the accelerometer data or a combination of gyro and accelerometer data could also be used in a very similar manner. The performance would though not be equally good.

An extended version of this work has previously been presented in [1].

## Sensor Models

The signal model of the gyro alternates between

$$\begin{aligned} \mathbf{y}_t^\omega &= \mathbf{0} + \mathbf{v}_t^\omega \\ \mathbf{y}_t^\omega &= \boldsymbol{\omega}_t + \mathbf{v}_t^\omega \end{aligned} \tag{1}$$

during a walking sequence. The user induced movement $\boldsymbol{\omega}_t$ has an unknown distribution. The additive noise is assumed Gaussian and independent giving $\mathbf{v}^\omega \sim N(\mathbf{0}, \sigma_a^2 \mathbf{I})$.

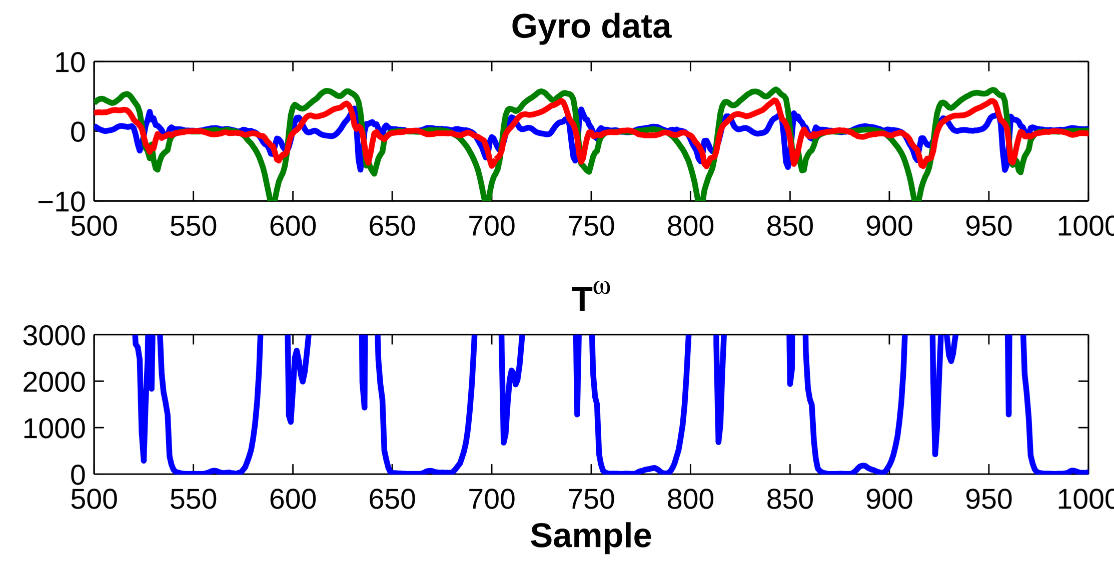
## Angular Rate Magnitude Test Statistic

To differentiate between stand still and swing, a test statistic

$$T_t^\omega = \frac{\|\mathbf{y}_t^\omega\|^2}{\sigma_\omega^2} \tag{2}$$

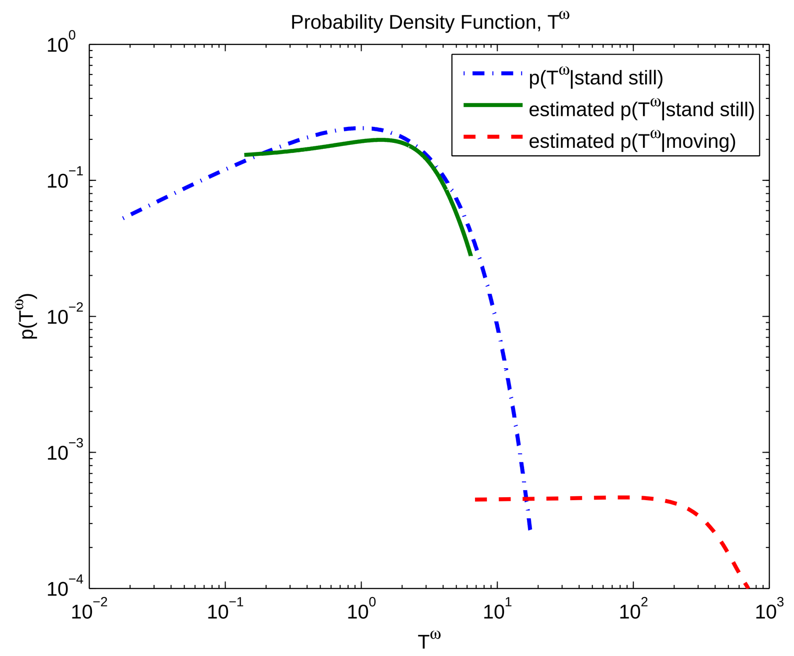
is used. $T^\omega \sim \chi^2(3)$ during stand still since $\mathbf{y}^\omega$ then has zero mean.

Gyro data from an experimental walking sequence and the corresponding test statistic looks like




The foot is stationary around time instants 550, 660, 770, 870 and 980.

The distribution of $T^\omega$ was validated by comparing the theoretical stand still distribution with the empirial one estimated using experimental data. Also note the large separation between the stand still distribution and the empirical moving distribution which enables robust stand still detection.




## Hidden Markov Model

To determine the probability of stand still, a Hidden Markov Model (HMM) is used. The mode transition probability matrix is

$$\Pi = \begin{bmatrix} 0.95 & 0.05 \\ 0.05 & 0.95 \end{bmatrix} \tag{3}$$

which states that the probability of going from stand still to moving or vice versa, is 5%.

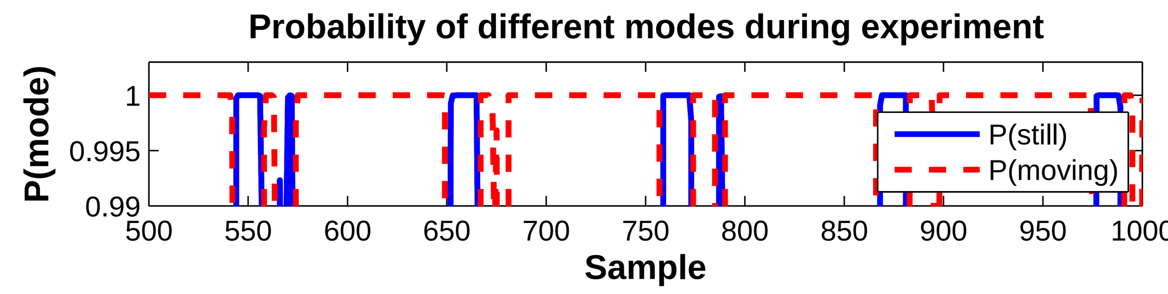
The mode probabilities at time $t$ are calculated using the recursion

$$\mu_t^i = \frac{p(T_t|r_t = i)\sum_{j=1}^{N_r}\Pi_{ji}\mu_{t-1}^j}{\sum_{l=1}^{N_r} p(T_t|r_t = l)\sum_{j=1}^{N_r}\Pi_{jl}\mu_{t-1}^j}. \tag{4}$$

The probability density function of movement used in the HMM is an approximation that is set to resemble the empirical movement density function that was estimated using experimental data.

## Experimental Results

The mode probabilities provided by the HMM of the experimental data sequence shown above is




A distinct detection of every foot stance is achieved. No false positives occur during the stride phase of the steps. Further experiments with 174 stationary phases were performed. All stand stills were detected, but also 2 false ones during sequences with small movements like when doors were opened.

## Summary

A test statistic using the gyro magnitude has been used in conjunction with an HMM for probabilistic stand still detection. Experiments indicate that the stationary phases are detected with very few false positives.


## Acknowledgment

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## References


[1] J. Callmer, D. Törnqvist, and F. Gustafsson. Probabilistic stand still detection using foot mounted IMU. In *Proceedings of the 13th International Conference on Information Fusion*, Accepted for publication, 2010.