Track before mitigate: aspect dependence-based tracking method for multipath mitigation

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People tracking is a key building block in many applications such as surveillance, abnormal activity detection and the monitoring of elderly persons or persons with restricted mobility. In this reported work, the problem of multipath signals, which is one of the main challenges in indoor and urban environments, is addressed. The proposed method integrates the aspect dependence feature of multipath signals into the tracking framework which allows making full use of more potentially useful information in the time domain in order to make more accurate decisions and to relax some constraints in the space domain such as the large number of antennas that are placed over a large area. An important feature of the proposed method is that it can suppress/mark the entire multipath track; furthermore, it does not assume any prior knowledge of the environment.

Introduction: People tracking is a key building block in many applications such as surveillance, abnormal activity detection and the monitoring of elderly persons or persons with restricted mobility (fall detection, breath detection etc.). Video-based systems have many limitations that make them ineffective in many situations; for example, they require users to stay within the device's line-of-sight, they cannot operate in darkness, through smoke or walls, and they violate people's privacy; furthermore, video-based detection and tracking algorithms suffer from high computational cost and low localisation accuracy. Signal-based systems do not have the limitations of video-based systems; however, one of the main challenges of these systems in indoor and urban environments is the presence of multipath propagation which introduces multipath ghosts in the observed scene.

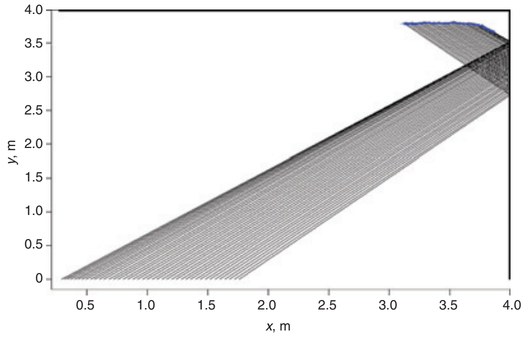

Fig. 1 *Multipath reflections for different positions of person*

A multi-person localisation system that operates in multipath indoor environments has been proposed by Adib *et al.* [1]. They pinpoint users' locations based on the reflections of wireless signals off their bodies. This multipath suppression technique is based on using multiple transmit and receive antennas from different vantage points in the environment, and the results show that it can localise up to five people simultaneously with a median accuracy of 11.7 cm. Several authors have recently proposed static multipath mitigation techniques that can cancel the effect of static objects such as walls; however, only a few of these works were dedicated to coping with the dynamic multipath problem. Unlike the real object, the ghost intensity takes on high values only over a portion of the synthetic aperture, implying a smaller effective aperture for the imaging of ghosts. This important feature of multipath ghosts is called aspect dependence (AD), which is a promising feature to suppress the multipath ghosts. Tan and Song [2] proposed a ghost suppression technique which uses the AD feature in the context of through the wall SAR imaging. In [3], Li *et al.* also proposed a ghost suppression technique based on the AD feature by using sub-aperture imaging. They distributed the antenna array over a large space at the front of the room. Then they used a sub-aperture which cannot receive the multipath reflected by the left wall, and another sub-aperture which cannot receive the multipath reflected by the right wall. Then, the two sub-aperture images are multiplied to form the full aperture image. Hayvaci *et al.* [4] exploited prior knowledge of the environment to help enhance the detection probability in a multipath environment. Leigsnering *et al.* [5] presented an overview of different approaches to deal with multipath (mitigation and exploitation) in indoor scenarios.

The main limitations of existing multipath mitigation techniques are either the large number of antennas that are placed over a large area or the assumption of prior knowledge of the observed environment.

In this Letter, we propose the track before mitigate (TBM) method, which is an efficient tracking-based multipath ghosts mitigation method that uses the AD feature of the multipath ghosts. The proposed method requires a smaller number of antennas in comparison with existing methods. It can accurately suppress/mark the entire multipath track; furthermore, it does not assume any prior knowledge of the environment.

Proposed method: A Wi-Fi system similar to [1] is considered, but with a smaller number of antennas and with a different multipath mitigation method. The received signal after the downconversion is given by (1)

$$y(t) = \sum_{\mathrm{p}} A_{\mathrm{p}} e^{j2\pi f_{\mathrm{d}} t} x(t - \tau_{\mathrm{p}}) + w(t) \tag{1}$$

where $w(t)$ is an additive noise, A_{p} is the attenuation including path loss and reflection, τ_{p} is the delay and f_{d} is the Doppler shift, and $x(t)$ is an OFDM symbol. Two antennas are used: the first one is placed at position (0.125 m, 0 m) and the second one at (0.375 m, 0 m). Fig. 1 shows an example of different multipath reflections along the person path (the person is moving from the left to the right). Only the direct signal is received by the antennas for most of the person path, the multipath signal starts arriving to the second antenna before the person makes the turn and continues for a short time, after which the multipath signal is received by the two antennas.

The tracking approach is the most appropriate framework to mitigate the multipath effect particularly if the AD feature is used, where the accumulation of measurements from multiple scans allows making full use of more potentially useful information contained in the measurements. It also helps in building more confidence when judging whether the object is a ghost or not; for example, the person movement will allow the antennas to observe different variances of the multipath signal. The AD feature cannot be observed over all measurement scans, particularly if a small number of antennas are used; therefore, it is essential to integrate the AD feature into the tracking framework in order to accumulate the variance of the received signal across the antennas and to suppress/mark the entire multipath track. It is also worth mentioning that using a small number of antennas will reduce the reception of multipath signals. The basic idea of the proposed method is to integrate the measurements in the time domain through the use of the tracking framework in order to make more accurate decisions and to relax some constraints in the space domain such as the large number of antennas that are placed over a large area. The proposed method uses the particle filter [6] which is essential for resolving tracking problems in nonlinear and/or non-Gaussian cases. The particle filter algorithm is given as Algorithm 1.

Algorithm 1: Particle filter algorithm

1. Initialise the particles.
2. Prediction (sample particles using the proposal distribution).
3. Measurement update (compute the importance weights).
4. Resample (replace unlikely samples by the more likely ones).
5. Iterate from step 2.

The weight calculation in step 3 is given by (2)

$$w_k^{(i)} = w_{k-1}^{(i)} p\left(y_k | x_k^{(i)}\right) \tag{2}$$

where i is the index of the particle, $w_{k-1}^{(i)}$ is the previous weight of the particle and $p\left(y_k | x_k^{(i)}\right)$ is the probability of the measurement given the state of the particle. Two variants of the TBM approach are proposed. The first one seeks to suppress the multipath track by modifying the weight calculation mechanism of the particle filter to take into account the AD feature. For each object, the variance of the received signal is calculated across the antennas, the larger the variance the more likely that the observed object is a ghost. The new weight calculation mechanism is given by (3)

$$w_k^{(i)} = w_{k-1}^{(i)} p\left(y_k | x_k^{(i)}\right) / (v + q) \qquad (3)$$

where $q > 1$ if the AD featured is observed and $q = 1$ otherwise, q is related to the sampling rate and to the required suppression speed. v is the variance of the received signal across the antennas, the larger the variance the smaller the weights of the particles. The weights will decrease each time the AD featured is observed until the track is completely suppressed. The second variant seeks to mark the entire multipath track without suppressing it; this allows the multipath signals to be used in improving the localisation accuracy. The track will be marked as a multipath track if the sum of the variance v over multiple scans exceeds a threshold t. The first variant of the TBM approach is more suitable when the AD feature can be observed for most of the duration of the multipath signal, because the weights of the particles will increase again when the AD feature is no longer observed.

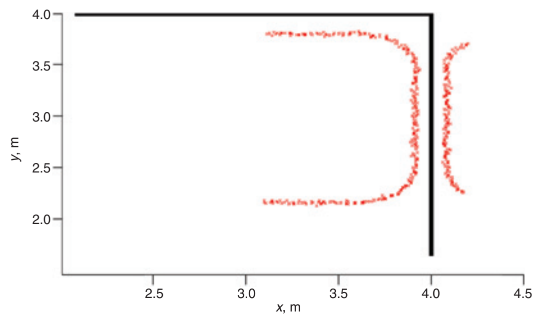

Fig. 2 *Direct signal and multipath measurements*

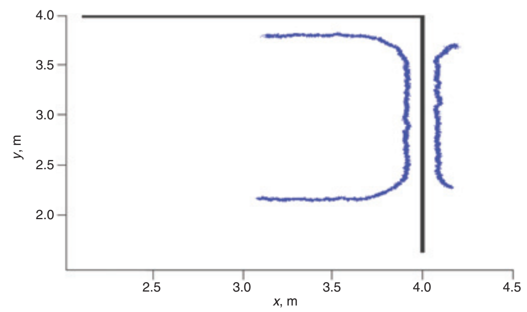

Fig. 3 *Using particle filter without any multipath mitigating method*

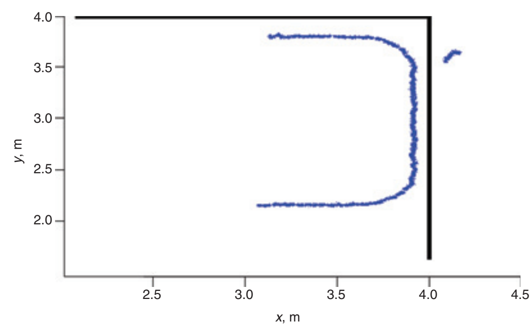

Fig. 4 *Multipath suppression using proposed method*

Simulation results: Computer simulations were performed to evaluate the proposed method. Two antennas are used: the first one is placed at position (0.125 m, 0 m) and the second one at (0.375 m, 0 m). Two walls are considered, both walls are 4 m from the first antenna. We assume that the person is moving in a specific path in the up-right corner; Fig. 2 shows the person path on the left side of the wall, while the measurements on the right side of the wall are caused by the multipath effect. For simplicity, only multipaths reflected from the side wall are considered. The person starts moving in the upper part towards the side wall, only the direct signal is received by the antennas for most of the person path, the multipath signal starts arriving to the second antenna before the person makes the first turn and continues for a short time, after that the multipath signal is received by the two antennas.

Fig. 3 shows the result of using the particle filter without using any multipath mitigating method, where the multipath ghost appears clearly on the right of the sidewall as a track of a new object.

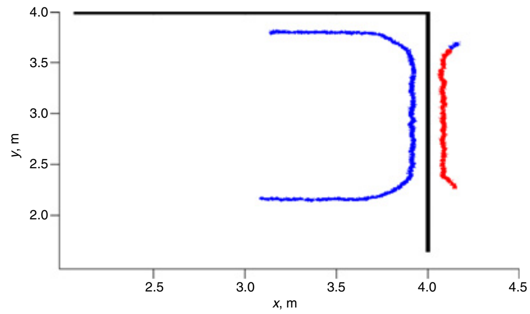

Fig. 5 *Multipath track marking using proposed method*

The method initiates a new track when it starts to receive the multipath measurements. For the first variant of the TBM approach, the weights of the particles of the new track start to decrease when the AD feature is observed until the track is totally suppressed; Fig. 4 shows the result of the first variant of the proposed method. For the second variant of the TBM approach, when the sum of the variance v over multiple scans exceeds the threshold t, the particles of the new track are only marked for future exploitation; Fig. 5 shows the result of the second variant of the proposed method where the particles of the multipath track are marked in red.

Conclusion: This Letter has presented an efficient tracking-based multipath ghost mitigation method that integrates the AD feature of multipath signals into the tracking framework. The proposed method is more accurate, requires a smaller number of antennas and can suppress/mark the entire multipath track. Simulation results demonstrated the effectiveness of the proposed method.

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One or more of the Figures in this Letter are available in colour online.

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