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An online background subtraction algorithm deployed on a NAO humanoid robot based monitoring system

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HIGHLIGHTS

- A online background subtraction algorithm detecting contiguous foreground.
- A weighted linear regression formulating background model and foreground detection.
- A Nao humanoid robot based monitoring system.
- Implement the background subtraction algorithm on the monitoring system.
- Experiments on both benchmark data and Nao robot data.

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ABSTRACT

In this paper, we design a fast background subtraction algorithm and deploy this algorithm on a monitoring system based on NAO humanoid robot. The proposed algorithm detects a contiguous foreground via a contiguously weighted linear regression (CWLR) model. It consists of a background model and a foreground model. The background model is a regression based low rank model. It seeks a low rank background subspace and represents the background as the linear combination of the basis spanning the subspace. The foreground model promotes the contiguity in the foreground detection. It encourages the foreground to be detected as whole regions rather than separated pixels. We formulate the background and foreground model into a contiguously weighted linear regression problem. This problem can be solved efficiently via an alternating optimization approach which includes continuous and discrete variables. Given an image sequence, we use the first few frames to incrementally initialize the background subspace, and we determine the background and foreground in the following frames in an online scheme using the proposed CWLR model, with the background subspace continuously updated using the detected background information. The proposed algorithm is implemented by Python on a NAO humanoid robot based monitoring system. This system consists of a control station and a Nao robot. The Nao robot acts as a mobile probe. It captures image sequence and sends it to the control station. The control station serves as a control terminal. It sends commands to control the behavior of Nao robot, and it processes the image data sent by Nao. This system can be used for living environment monitoring and form the basis for many vision-based applications like fall detection and scene understanding. The experimental comparisons with most recent algorithms on both benchmark dataset and NAO captures demonstrate the high effectiveness of the proposed algorithm.

1. Introduction

The position of moving objects is an important knowledge for many algorithms and applications based on the humanoid robot. For example, in path planing, it helps the robot to avoid potential obstacles; in navigation, it allows the robot to adjust its velocity; in scene understanding, motion can be a useful prior to distinguish between some objects in the scene; in fall detection, it provides the potential position where the fall can happen. Therefore, a fast and accurate algorithm for moving object detection is desirable in robotic based systems.

A widely used solution for moving object detection on robots is to equip the robot with a video camera, view the moving object

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as the foreground in image sequence and perform background subtraction algorithms on the captured frames. Generally, the framework of background subtraction algorithms includes two components: a background model and a foreground model. The background model estimates the potential background in image sequences, and the foreground model detects foreground regions by comparing between captured frames and the estimated background. Currently, although a large number of algorithms have been proposed for background subtraction [1–16], some problems remain open for a background subtraction algorithm designed for robots. One main challenge is the varying working environment. The working environment of robots changes more frequently compared to static cameras in fixed positions, since a robot can be deployed to any possible positions for monitoring, and the environment like lighting condition, size of moving object and background dynamic can vary in different positions. Therefore, it is a challenging problem to design a background subtraction algorithm for a robot to distinguish between the foreground motion and background changing in varying environment. Another problem is the memory and computational cost. Most of recent algorithms like [13,14] use a batch scheme to handle the background changing. They model the background using the information from the whole image sequence. It improves the detection accuracy at the cost of more memory and computation requirement. However, in a robot based monitoring system, the background subtraction algorithm needs to run in an online scheme with the speed satisfying the requirement of specific applications. It is difficult to reduce the computational and memory cost of the algorithm while preserving a high accuracy.

Recently, low rank model has shown its potential to address the above challenges. The representative algorithms are Principal Component Pursuit (PCP) based algorithms [13,14] and PCP-like online algorithms [17–22]. PCP [13] assumes the potential background images of an image sequence lie in a low rank subspace, and the moving objects (foreground) is spatially sparse. It decomposes the image sequence into a low rank component as the background and a sparse component as the foreground, achieving an impressive perform. Also, recent research has shown that a contiguous foreground prior can be incorporated with the low rank background model, achieving a promising performance for foreground detection [14]. Furthermore, to speed up these PCP-based algorithms, a large number of PCP-like [17–22] online algorithms have been proposed. Some of these PCP-like online algorithms have achieved a real time speed [19,21,22].

The above PCP-based and PCP-like algorithms have shown their power in background subtraction. This is due to several advantages of low rank model. First, the assumption for background in low rank model is simple yet effective. The only assumption of low rank model for background is that the background with local and global variations can be represented by a low rank matrix [13]. The effectiveness of this simple assumption has been demonstrated by the success of batch methods using low rank model to estimate background [13,14,23].

Second, low rank model is a frame level model which can better capture background variation. In comparison to pixel level models which consider the pixels in each frame independently [1–5,7–9], low rank model views the pixels in a frame as a whole, hence it is able to capture the inner correlations between frames, better modeling the background variation.

Third, low rank model can be integrated with other models, combining the advantages of different models. Typical examples are some PCP-like online algorithms [17–20]. These algorithms incorporate representative background model [6,10–12] into low rank model [13,14], achieving excellent performance.

The aforementioned advantages make low rank model an excellent foundation to develop algorithms for background subtraction in challenging environments. However, some problems still exist and restrict the application of low rank based background subtraction algorithms in real robotic systems. First, it has been shown that the contiguous foreground prior contributes significantly to the accuracy of foreground detection [14,20], but using this prior also induces heavy computational burden. It influences the speed of algorithm, even in an online scheme [20]. Second, currently, little research examines the low rank model based background subtraction algorithm in real robotic systems. Little knowledge and study exist for the performance of these algorithms in real applications.

In this paper, we propose a fast online background subtraction algorithm with contiguous foreground prior for background subtraction, and we implement the proposed algorithm in a Nao humanoid robot [24,25] based monitoring system to examine its performance in real applications.[1] The algorithm includes a background model and a foreground model. For background modeling, we use a regression based low rank model. We assume that the potential background images lie in a low rank subspace, so we expect that the background of one frame can be represented as the linear combination of the basis spanning the subspace. Therefore, we represent the background of the current frame as the linear combination of the estimated background of previous frames. In foreground model, we use a contiguity constraint encouraging the foreground to be detected as contiguous regions rather than separated pixels. The proposed algorithm can be solved cheaply in terms of computational load.

The proposed Nao based monitoring system consists of two parts: Nao robot and a control station. Nao robot works as a mobile probe. It can move to a specific position, capturing image sequence using the equipped camera and sending the captures back to the control station for further processing. The control station serves as a control terminal. It sends commands to Nao robot to control its behavior, and it processes the image data sent by Nao robot. We implement the proposed background subtraction algorithm on the control station to detect the moving objects in the images sent by Nao. The proposed monitoring system can be used for living environment monitoring and form the basis for many vision-based applications like fall detection.

The rest of this paper is organized as follows. In Section 2, we introduce the related algorithms. We revisit the state-of-the-art PCP-based and PCP-like algorithms for background subtraction. In Section 3, we describe our background subtraction algorithm. In Section 4, we present the details of the proposed Nao humanoid robot based monitoring system and the implementation of the proposed background subtraction algorithm on this monitoring system. In Section 5, we report the experimental results. Finally, in Section 6, we conclude the paper.

2. The related algorithms

The related algorithms to the proposed algorithm are PCP-based and PCP-like algorithms [13,14,17–23]. PCP [13] is a batch method. It assumes the potential background of image sequences lies in a low rank subspace, and the foreground region is spatially sparse. Therefore, it decomposes image sequences into a low rank component as background and a sparse component as the foreground. However, due to its batch scheme, PCP has high computational cost and memory requirement, and it is difficult to apply PCP in robot based monitoring systems.

Since low rank background assumption has shown its power in background modeling, lots of PCP-based and PCP-like algorithms are proposed to detect moving objects in an online scheme to improve the efficiency [17–22]. Some algorithms perform PCP

[1] This is an extension of our algorithm in [26].