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Research Article

k-Step Viterbi Algorithm with Discrete Control for Tracking an Unknown Number of Targets

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Abstract – This study is related to the development of the Viterbi algorithm for finding the most likely path to reach an uncertain number of targets. In this context, the Viterbi algorithm is enhanced to perform future best path calculations more accurately using a symbolic approach to discrete control synthesis within the framework of optimization for the K-step. The results of this work combine the guarantees of safety offered by discrete control synthesis with the optimization, ensuring that the path calculation yields the optimal value, representing the best path. The accuracy of our results is substantiated by an illustrative case study, demonstrating the superiority of our approach over the standard Viterbi algorithm. Specifically, our findings showcase that the proposed algorithm not only ensures the desired system behavior but also provides the optimal path value, outperforming the conventional Viterbi algorithm.

Keywords – Target Tracking, Hidden Markov Models, k-Step Viterbi Algorithm, k-Step DCS, Multiple Target Tracking, Optimization

I. INTRODUCTION

The traditional Viterbi algorithm is a dynamic programming technique employed for solving the decoding problem within a Hidden Markov Model (HMM) [1]. This algorithm is designed to determine the most likely hidden state sequence that can generate an observation sequence produced at discrete time intervals [2]. It is widely used in various applications, particularly in problems requiring the identification of the optimal path [3].

To yield superior results, the Viterbi algorithm necessitates a well-trained Hidden Markov Model. In an HMM where model parameters have been optimized, the Viterbi algorithm excels at deducing the most probable state sequence, effectively identifying the optimal sequence of states. This is especially crucial in scenarios where finding the best path or state sequence is of paramount importance [4]. The algorithm's ability to deliver accurate results is contingent upon the quality and accuracy of the underlying HMM, which relies on appropriately calibrated model parameters.

The control of discrete-event systems was originally developed as a theory by [5], [6]. The primary objective of discrete control synthesis is to provide a controller that ensures the desired system behaviors. Various pioneering studies have been conducted in this regard, employing automata, Petri nets, and finite state machines [7], [8].

Early works focused on Boolean problems and optimization objectives, as pioneered by [9]-[11]. Subsequently, [12], [13] expanded upon these studies, extending them infinitely. Discrete control synthesis has found applications in a wide range of fields, yielding highly efficient results. For instance, [14]-[16] conducted power-sensitive operations using clock gating techniques in hardware circuits.

This area of research has advanced significantly and made substantial contributions to various domains, thanks to its foundational principles and practical implementations.

The remainder of the paper is organized as follows: Section 2 gives the materials and our methodology for k-Step Viterbi Algorithm with Discrete Control for Tracking an Unknown Number of Targets. In section 3 we experimentally evaluate our approach and show the results. At last, Section 4 concludes with conclusions and future works.

II. Materials and Method

The traditional Viterbi algorithm is concerned with determining the most probable sequence of hidden states that generates the observed events as shown in Figure 1. In other words, given a hidden Markov model and an observation sequence, it finds the most likely hidden state path that generates the given observation sequence using the model's parameters. This is akin to using a dynamic algorithm to find the most optimal path from a starting point to an endpoint on a map.

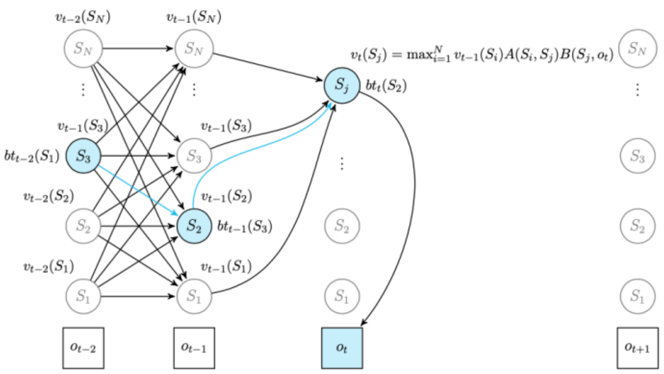

Fig. 1 The Viterbi computation and the backtrace keeps the most probable path that leads to the state.

The fundamental principle of discrete control synthesis is exemplified by the parallel synchronization of two Mealy machines with a controller to yield the desired behaviors. In the context of an uncontrolled system, this approach enables the achievement of predefined objectives when specific targets are provided. Accordingly, we utilize synchronous data flow languages, such as ReaX, to model stochastic systems within the context of dataflow synchronous languages. Subsequently, we structure the system to facilitate the best path calculation in an optimized manner, considering a cost function that guides the optimization process for k-step.

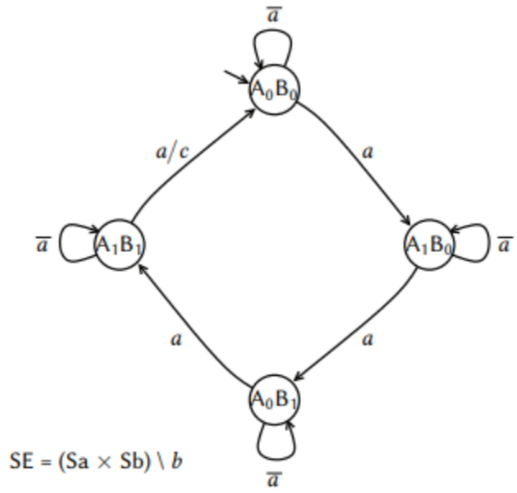

Fig. 2 The principle of our modeling approach.

In this study, the k-step Viterbi algorithm is inspired by the idea that it can work in conjunction with k-step discrete control synthesis. The goal here is for k-step discrete control synthesis to control future steps in two-step increments to find the best path for k=2 and eliminate inappropriate paths. We already know that k=1 corresponds to the traditional Viterbi algorithm. When progressing with k=2, it calculates the probabilities for the next two steps to find the most suitable state sequence, making it easier to eliminate unsuitable paths with lower probability values.

III. Results

First and foremost, within our case study, we undertook the task of encoding diverse stochastic systems, including the standard Hidden Markov Model and the Hidden One Counter Markov Model, into dataflow equations in the ReaX environment—a discrete control synthesis tool. These stochastic models were systematically coded in a parallel and synchronized manner.

Subsequently, we executed our safety and K-Step Limited Optimal Discrete Control algorithms within the ReaX environment, thereby generating a controller. Simultaneously, we transferred these stochastic models into the Python environment for further analysis.

To compare and contrast the outcomes, we conducted two distinct executions. The first involved implementing the Viterbi algorithm for the purpose of best path calculations. The second execution was centered around the best path calculations achieved by the controller generated through symbolic discrete control synthesis in the Python environment. The results consistently indicated that the best path calculations attained through discrete control synthesis outperformed those achieved by the Viterbi algorithm, with a margin of improvement ranging from %3 to %17.

IV. CONCLUSION

In this study, we introduced the "K-Step Viterbi Algorithm with Discrete Control for Tracking an Unknown Number of Targets." As an alternative to the widely used K-step Viterbi algorithm in the literature for finding the future best path, we harnessed the K-step discrete control synthesis management to achieve more accurate results. These advancements were validated through a comprehensive case study, further strengthening the credibility of our findings.

Our safety algorithm was instrumental in guaranteeing the desired system behaviors, while optimization was conducted by minimizing a cost function, thereby enabling the determination of the best path. The significant contribution of our research lies in its applicability to stochastic systems, where it can be employed to enhance best path calculations.

In summary, our study not only provides an innovative approach to target tracking with improved accuracy but also has the potential to inspire further advancements in stochastic systems' best path calculations.

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