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Scheduling Tasks for Human Operators in Monitoring and Surveillance Applications

Sai Krishna Kanth Hari * **Kaarthik Sundar** ** **Sivakumar Rathinam** *** **Swaroop Darbha** ****

* *Graduate Student, Dept. of Mechanical Engg., Texas A&M University, College Station, TX 77843. (email: hskkanth@tamu.edu)*
** *Post-doctoral Researcher, Center for Non-Linear Studies, Los Alamos, New Mexico 87544. (email: kaarthik@lanl.gov)*
*** *Associate Professor, Dept. of Mechanical Engg., Texas A&M University, College Station, TX 77843. (email: srathinam@tamu.edu)*
**** *Professor, Dept. of Mechanical Engg., Texas A&M University, College Station, TX 77843. (email: dswaroop@tamu.edu)*

Abstract: We consider a scheduling problem that arises in the context of surveillance or reconnaissance missions by multiple unmanned aerial vehicles (UAVs) where human operators would be present to perform tasks that require a high level of expertise and reasoning. Each UAV performing the mission provides a video stream of the targets it monitors to the human operator who is required to take critical decisions based on the video stream. A single human operator often examines the video stream from multiple UAVs constantly; this can cause his/her visual attention to drop below an acceptable level while performing the tasks. We propose an automated system to ease the operator's work load by breaking up the video streams into parts and scheduling a subset of them for the operator's inspection. We present the architecture for the system, identify the various components involved to build such a system, formulate the associated scheduling problem as a mixed-integer linear program (MILP) and solve the same. Preliminary results are also presented to corroborate the effectiveness of the formulation.

Keywords: human-in-loop; scheduling; unmanned aerial vehicles; intelligence & reconnaissance

1. INTRODUCTION

For over a decade, Unmanned Aerial Vehicles (UAVs) are routinely being used in military applications such as border patrol, reconnaissance and surveillance applications (see Zajkowski et al. (2006)). They are prime candidates for intelligence, surveillance and reconnaissance (ISR) missions due to their several advantages such as portability and low risk, to name a few. A typical ISR mission using multiple UAVs would require them to collect images and videos of targets that require periodic monitoring. The data collected by the vehicles is then examined by a human operator to make other critical decisions. In ISR missions, critical tasks and decisions such as target classification can often only be performed by a human operator and cannot be replaced by an autonomous agent. Hence, it is important to design a system where the chance of the attention of the human operator dropping below an acceptable level is kept as low as possible.

In such ISR missions, we consider the human operator as a processing unit capable of critical decision making, can process the data from a single vehicle at any point of time and requires periodic breaks to operate efficiently. From this point of view, the process of analyzing and examining the data from multiple UAVs reduces to the following two problems: (i) automatically detect and time stamp the events and quantitatively assign a severity measure to each event using the raw video data from the vehicles, and (ii) create a schedule of a subset of events using the severity measures and provide the resulting schedule to the human operator for further decision making (refer to Fig. 1). Severity of an event can be considered to be a similarity measure which takes a high value when consecutive frames from the video data are very different from each other. A widely used similarity measure is the mutual information or the region mutual information (Russakoff et al. (2004))

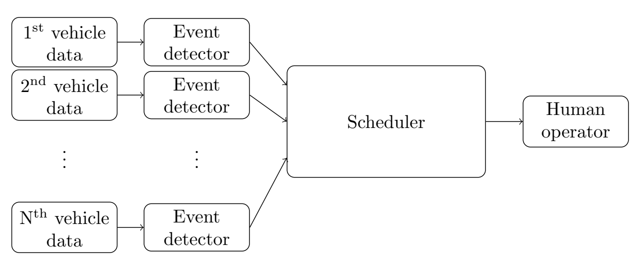

Fig. 1. Proposed framework

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between consecutive frames. For the purpose of this article, we let the severity of an event to take a value in $(0, 1]$. This article addresses the scheduling problem by assuming that event detection has been performed using the raw video data from each vehicle and the events are time stamped and assigned a value for severity. Given the severity and the time of occurrence of each event, we associate with each event a utility; the utility of event is a function of the start time of the event in the schedule. It takes a value that is proportional to the severity if it is started at the time of occurrence and decreases thereafter. In summary, the scheduling problem is formally defined as follows:

Given a set of time-stamped events from multiple UAVs, the utility associated with scheduling the event at a given time, the timing and precedence constraints for the events, the objective of the scheduling problem is to schedule events over a finite time horizon such that at most one event is scheduled at any given time, each mandatory event is scheduled, each event is scheduled after the time it has occurred, the schedule consists of periodic breaks where no event is scheduled (breaks for the human operator), and the sum of the utilities of all the scheduled events is maximized.

We formulate the scheduling problem as a mixed-integer non-linear program. We then reformulate the non-linear integer program as a mixed-integer linear program (MILP). We use a branch-and-cut framework to solve the formulation and obtain feasible solutions that are close to the optimal or obtain an optimal solution, given enough computation time. The effectiveness of the formulation is corroborated through extensive computational experiments.

2. RELATED WORK

The problem of collecting information about a set of targets using unmanned vehicles and a human operator has garnered significant attention over the past decade. One of the first instances of such a surveillance mission is the COUNTER scenario (Gross et al. (2006)). In COUNTER, multiple UAVs are used to perform a surveillance mission in an urban terrain and send video data from the targets to a human machine interface (*Vigilant Spirit* control station, Pachter et al. (2006)). A human operator then classifies the targets based on the events shown through the interface.

Similar scheduling problems that arise in scenarios such as the COUNTER are addressed using queueing methods (Savla and Frazzoli (2012)) where the video data from different vehicles is queued for human inspection while minimizing work load or maximizing utility. Human performance models, validation studies, and metrics to reduce the cognitive burden of the operator have also been developed in the literature to address this problem (see Hameed et al. (2009); Girard et al. (2006); Cummings et al. (2007); Atrey et al. (2008); Kalyanam et al. (2016) and the references therein). In particular, Hameed et al. (2009) study the effectiveness of providing peripheral and visual cues to the human operator, and Girard et al. (2006) present strategies for decision making in an uncertain environment, model human operator for small UAV operations, and analyze the effect of operator confusion on the decision making process.

Ortiz and Langbort (2011); Ortiz et al. (2013) formulate and present methods to solve a task scheduling problem that naturally arises when one considers the human operator as a processing unit capable of processing one task at a time; a target inside the field of view of a UAV is defined as a task. They propose a framework where each task is first scheduled for inspection from the human operator for a fixed time and then the UAV trajectories and control inputs are computed in accordance to the schedule obtained. The UAVs are modeled as Dubins vehicles and a linear programming based approach that can accommodate the asynchronous nature of the real-time tasks is presented.

Unlike Ortiz and Langbort (2011) and Ortiz et al. (2013), the architecture we propose separates the data collection, planning problems for the multiple UAVs from the task scheduling problem. We assume that the video data is collected from the UAVs a priori or in real time and provided as input to a scheduler after processing and event detection. The advantage of this architecture lies in the fact that developing computationally efficient techniques to solve the problems separately is an easier task compared to developing techniques to solve the combined problem.

The task scheduling problem that arises in this context is a generalization of the single machine scheduling problem that arises in the scheduling literature. The single machine scheduling problem is known to be strongly NP-Hard (see Graham et al. (1979); Lenstra et al. (1977)). In the presence of multiple human operators, the formulation we propose naturally extends and generalizes the multiple identical machine scheduling problem (Lenstra et al. (1977)) where the objective is to minimize the weighted sum of completion time of all the events scheduled. Furthermore, the application requires the need to enforce a type of precedence relations between events originating from the same vehicle that is modeled as an "on/off" constraint (Hijazi et al. (2012)) which are, in general, non-linear. For these reasons, the scheduling problem that arises in the presence of a human operator is computationally challenging to solve.

The event detection from video stream is a well studied problem in computer vision and pattern recognition literature (Medioni et al. (2001); Piciarelli and Foresti (2010)). Once the definition of an event in the context of the application is established, computationally efficient algorithms can be developed to detect these events in real-time. This article focuses only on modeling, formulating, and solving the scheduling problem. In the next few sections we formally define, formulate, and develop algorithms to compute feasible and optimal solutions to the task scheduling problem.