Computers, Environment and Urban Systems 62 (2017) 19–29

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Developing an online cooperative police patrol routing strategy

Huanfa Chen, Tao Cheng *, Sarah Wise [1]

SpaceTimeLab, Department of Civil, Environmental & Geomatic Engineering, University College London, London WC1E 6BT, United Kingdom

ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form 27 October 2016
Accepted 28 October 2016
Available online 4 November 2016

Keywords:
Police patrols
Multi-agent patrol routing
Bayesian-based decision making
Ant colony algorithm
Agent-based modelling

ABSTRACT

A cooperative routing strategy for daily operations is necessary to maintain the effects of hotspot policing and to reduce crime and disorder. Existing robot patrol routing strategies are not suitable, as they omit the peculiarities and challenges of daily police patrol including minimising the average time lag between two consecutive visits to hotspots, as well as coordinating multiple patrollers and imparting unpredictability to patrol routes. In this research, we propose a set of guidelines for patrol routing strategies to meet the challenges of police patrol. Following these guidelines, we develop an innovative heuristic-based and Bayesian-inspired real-time strategy for cooperative routing police patrols. Using two real-world cases and a benchmark patrol strategy, an online agent-based simulation has been implemented to testify the efficiency, flexibility, scalability, unpredictability, and robustness of the proposed strategy and the usability of the proposed guidelines.

1. Introduction

Patrolling is defined as "the act of walking or travelling around an area, at regular intervals, in order to protect or supervise it" (Abate, 1997, p 578). Police patrol occupies a central place in crime control efforts (Koper, 1995). As Cook (1980) stated, a visible police presence can increase the public's certainty of punishment, and a frequent police presence enhances potential criminals' perceptions of risk in the local area. In daily operations, approaches to police patrols range dramatically across varying contexts and cultures. Among them, one effective and promising approach is hotspot patrolling, or place-based patrolling, which focuses on crime hotspots, i.e., small geographical units with high crime intensity, such as street segments or small groups of street blocks (Braga, Papachristos, & Hureau, 2012). The effectiveness of hotspot patrolling in reducing crime has been proved by a range of experiments, such as the Minneapolis Hot Spots Patrol Experiment (Sherman & Weisburd, 1995) and the study conducted in Philadelphia (Ratcliffe et al., 2011). In patrolling, when there is more than one hotspot to cover, typically, police officers rotate randomly between hot spots, as in the field trial in Sacramento, California (Telep et al., 2014). However, the randomised strategy cannot be applied to situations where police resources are limited and there are many "hotspots" areas. Rather, the successful operation of patrolling to cover the "hotspots" requires a detailed patrol routing strategy. A relevant topic for policing is determining the efficient spatial distributions of police patrol areas to provide maximal and multiple coverage of incidents (Curtin et al., 2010). However, such strategies are focused on the location of centres of patrol areas, and do not consider a detailed routing strategy for patrol teams.

Designing a routing strategy for police patrolling is never a simple task due to several challenges. First, officers are required to cover hotspots regularly and repetitively (Curtin et al., 2010) as well as responding to emergencies. Thus, the performance of covering hotspots should not deteriorate significantly when emergencies occur and some patrollers are dispatched to handle them. Second, to cover the whole hotspot area effectively, police patrol requires cooperation among patrollers. Third, to confuse criminals and deter crime, the patrol routes should be somewhat difficult to predict. Additionally, hotspots may have different levels of importance and thus require different levels of attention. This problem is called the optimal design of patrol routes (ODPR) problem (Reis et al., 2006) or patrol route planning problem (Chen & Yum, 2010). This work focuses on designing patrol routes for foot patrol, rather than vehicle patrol.

All these challenges are very similar to the multi-agent patrolling problem (Almeida et al., 2004), or multi-robot patrolling problem (Portugal & Rocha, 2011), which focuses on surveillance tasks using multiple mobile robots to frequently visit important places in the environment. Here, we review the routing strategies in both police patrol and robot patrol because of their similarities. More importantly, the advances of multi-agent robot patrolling can benefit police patrol. Distinct solutions have been proposed to design patrol routes, which present different strategies in terms of routing, cooperation, evaluation, and other features. In general, they can be divided into pioneer strategies (Almeida et al., 2004; Machado et al., 2002; Portugal & Rocha, 2013a), operations research strategies (Chevaleyre, 2004; Elmaliach, Agmon, & Kaminka, 2009; Portugal & Rocha, 2010), alternative coordination strategies (Chen & Yum, 2010; Chu et al., 2007; Santana et al., 2004; Sempe & Drogoul, 2003), and interaction strategies (Reis et al., 2006; Tsai et al., 2010).

* Corresponding author.
E-mail addresses: huanfa.chen@ucl.ac.uk (H. Chen), tao.cheng@ucl.ac.uk (T. Cheng), s.wise@ucl.ac.uk (S. Wise).

[1] Bartlett Centre for Advanced Spatial Analysis (CASA), University College London.

http://dx.doi.org/10.1016/j.compenvurbsys.2016.10.013
0198-9715/

Pioneer strategies use simple pioneer architectures to guide patrollers to visit places that have been visited less recently, and it would be convenient for them to consider other factors, such as distance and coordination. These simple and heuristics-based strategies have been shown to achieve good performance in covering hotspots and coordinating patrollers (Portugal & Rocha, 2013a). However, most of the pioneer strategies are developed in the context of robot patrol, and they neglect the aspects of being unpredictable in patrol routes and being robust to the influences of emergency response.

Operations research strategies use graph theory tools to compute low-cost cycles and efficient routes for each patroller. The tools include Travelling Salesman or the Hamilton cycle (Elmaliach et al., 2009; Pasqualetti, Franchi, & Bullo, 2012; Smith & Rus, 2010), spanning trees (Fazli & Davoodi, 2010; Gabriely & Rimon, 2001), and graph partitioning (Sak, Wainer, & Goldenstein, 2008; Stranders et al., 2013). These strategies guarantee high visit frequency on targets and efficient cooperation between patrollers, and they scale well with different numbers of patrollers. However, these strategies are naturally deterministic, which would more easily allow intelligent criminals to predict the patrol routes and take advantage of the idle time between the visits of patrollers. Additionally, Hamilton cycles and other algorithms have high computational complexity and are difficult to generalise to large numbers of targets. Moreover, these strategies would have to re-compute patrol routes if the number of patrollers were to change because of an emergency response.

Alternative coordination strategies aim to solve the routing problem using approaches such as task allocation (Sempe & Drogoul, 2003), reinforcement learning (Santana et al., 2004), cross entropy method (Chen & Yum, 2010), and swarm intelligence (Chu et al., 2007). However, strategies like reinforcement learning and the cross entropy method prove to be very complex in nature, so while they are suitable for designing patrol routes for a single patroller, it is difficult to extend them to cooperative patrol with multiple patrollers.

Interaction strategies have been derived from the interactions between officers and criminals, using agent-based simulation or game theory models. For example, Reis et al. (2006) designed patrol routes based on genetic algorithms and a multi-agent-based simulation, where a set of criminals frequently try to commit crimes and officers try to prevent crimes. Tsai et al. (2010) derived a strategy for police resource allocation based on modelling the interactions between police and terrorists as an attacker-defender Stackelberg game, where a player always predicts his opponent's behaviour and chooses the best response. These strategies can effectively prevent crime in crime hotspots, but only on the basis of a substantial knowledge of crime mechanisms in the area, and it is difficult to generalise these strategies to guiding police patrol in large areas and preventing multiple types of crimes.

In summary, existing approaches for patrol routing are not applicable to guide police patrol, as they omit the peculiarities and challenges of police daily patrol. To facilitate the design of an effective routing strategy for police patrol, the challenges mentioned above need to be specified and formulated using clear guidelines and need to be quantified by appropriate evaluation measures. To our knowledge, few studies have dealt with this issue. Therefore, there is a need for a comprehensive study of guidelines and evaluation measures for designing a routing strategy for police patrols.

In this work, we propose a set of guidelines for an effective police patrol routing strategy and the relevant evaluation measures, which are based on the characteristics and challenges of practical police patrol. Under such guidelines, we develop an effective routing strategy based on heuristics and Bayesian techniques, and subsequently quantify their effectiveness through realistic simulation tests and in comparison with a graph theory strategy.

This paper is a further development of, and substantial improvement on, a previous work (Chen, Cheng, & Wise, 2015). In addition to the broad background introduced above, the current paper is substantially improved in five aspects. First, only three guidelines were discussed in Chen et al. (2015), namely, efficiency, flexibility, and unpredictability. Here two more guidelines—scalability and robustness—are developed, which measure the general applicability of the routing strategy in different situations including different team size, hotspot areas, and emergencies, as this has not be discussed in any previous literature. Furthermore, the guideline of unpredictability is further quantified here, which was only conceptually discussed in Chen et al. (2015). Second, the Bayesian Ant-based Patrol Strategy (BAPS) is further developed in accommodating these guidelines. Third, an agent-based modelling is now implemented as an online mode that simulates the real-world police patrol with the interaction of the controller and patrollers. Fourth, the strategy is now tested to include the emergency scenario, which was not included in the previous paper. Finally, in order to test its applicability to different areas, a new case, namely, South Chicago, is added in addition to Camden. Furthermore, the Camden case is now conducted with different team sizes and more experiments to cover the five measures.

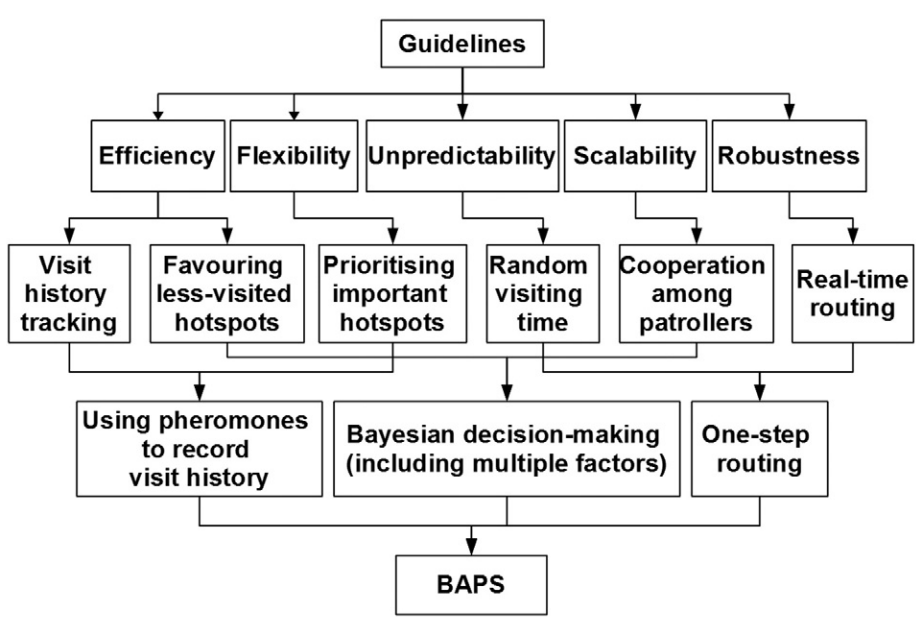

Fig. 1. From guidelines to BAPS.