Deploying PAWS to Combat Poaching: Game-Theoretic Patrolling in Areas with Complex Terrain (Demonstration)

Fei Fang,[1] **Thanh H. Nguyen,**[1] **Rob Pickles,**[2] **Wai Y. Lam,**[2,3]
Gopalasamy R. Clements,[2,3,6] **Bo An**[4]**, Amandeep Singh**[5]**, Milind Tambe**[1]

[1]{feifang,thanhhng,tambe}@usc.edu, University of Southern California, USA
[2]rpickles@panthera.org, Panthera, USA, [3]waiyee@gmail.com, Rimba, Malaysia
[4]boan@ntu.edu.sg, Nanyang Technological University, Singapore, [5]as4330@columbia.edu, Columbia University, USA
[6]reuben@myrimba.org, Kenyir Research Institute, Universiti Malaysia Terengganu, Malaysia

Abstract

The conservation of key wildlife species such as tigers and elephants are threatened by poaching activities. In many conservation areas, foot patrols are conducted to prevent poaching but they may not be well-planned to make the best use of the limited patrolling resources. While prior work has introduced PAWS (Protection Assistant for Wildlife Security) as a game-theoretic decision aid to design effective foot patrol strategies to protect wildlife, the patrol routes generated by PAWS may be difficult to follow in areas with complex terrain. Subsequent research has worked on the significant evolution of PAWS, from an emerging application to a regularly deployed software. A key advance of the deployed version of PAWS is that it incorporates the complex terrain information and generates a strategy consisting of easy-to-follow routes. In this demonstration, we provide 1) a video introducing the PAWS system; 2) an interactive visualization of the patrol routes generated by PAWS in an example area with complex terrain; and 3) a machine-human competition in designing patrol strategy given complex terrain and animal distribution.

Introduction

Poaching represents a serious threat to our ecosystems and sustainable development, and the population of many key species is declining at an alarming rate with poaching considered a major driver. For example, over 1400 tigers have been poached in 2000–2012 according to the seizure of tiger parts recorded (Stoner and Pervushina 2013). To combat poaching, law enforcement agencies have been making efforts, with one commonly used approach being conducting foot patrols. However, one main challenge is on improving the efficiency of patrols given the limited patrol resources and the vast areas in need of protection.

Game theory has become a well-established paradigm for optimizing the use of limited security and patrol resources and a number of security-game based decision support systems have previously been successfully deployed in the real-world to protect critical infrastructure such as airports, flights, ports, and metro trains (Tambe 2011).

Inspired by this success, PAWS (Protection Assistant for Wildlife Security) (Yang et al. 2014) has been introduced as a game-theoretic solution for optimizing the use of patrol

resources to combat poaching. PAWS was the first proposed application in the subarea of "green security games" (Fang, Stone, and Tambe 2015; Kar et al. 2015). Specifically, PAWS solves a repeated Stackelberg security game and calculates the optimal patrol strategy while balancing the priorities of different locations with different animal densities. Subsequent research has worked on the significant evolution of PAWS and several novel research advances are made, leading to its current regular use in Malaysia in collaboration with two Non-Governmental Organizations: Panthera and Rimba. One major advance in the deployed PAWS system is that it considers topographic information, which is critically important since high changes in elevation and the access to water source may result in a big difference in the effort needed for patrollers' movement and poachers' movement. PAWS incorporates elevation information and land features and uses a novel hierarchical modeling approach to build a virtual "street map" of the conservation area. Building on the street map, PAWS uses a novel algorithm which handles payoff uncertainty using the concept of minimax regret (Nguyen et al. 2015), while simultaneously ensuring scalability via the cutting plane framework (Yang et al. 2013).

Patrol Strategy Generation in PAWS

The input data of PAWS include elevation and other terrain information, as well as previous patrol tracks and observations (animals and human activities) made during previous patrols. Animal distribution and human activity distribution are estimated from input data.

Based on this information, PAWS builds a repeated Stackelberg security game model where the patrollers (defender) conduct randomized patrols against poachers (attackers) who place snares in the conservation area. The conservation area is discretized into 1km by 1km grid cells and each grid cell is treated as a target. Each target is associated with payoff values indicating the reward and penalty for the patrollers and the poachers. The values are decided by the animal distribution, which is difficult to precisely estimate and may have seasonal change, leading to uncertainty in the values.

In this game, the defender chooses a patrol strategy, which is a probability distribution over feasible patrol routes and the attackers will respond to the patrol strategy by choosing a target to place snares. A feasible patrol route should satisfy constraints such as patrol time limit and starting and

ending at the base camp and should be easy to follow by the patrollers. To find such routes, PAWS incorporates topographical information and builds a virtual "street map" of the conservation area. Essentially, the street map connects the whole conservation area through easy-to-follow route segments such as ridgeline, streams and river banks – terrain features which patrollers find easier to move around than on slopes. In addition, focusing on these terrain features also ensures the patrol routes are effective. The reason is two-fold: (i) they are important conduits for certain mammal species such as tigers; (ii) hence, poachers use these features for trapping and moving about in general. PAWS also uses the SUQR model (Nguyen et al. 2013) to model the bounded rationality of attackers.

Given the game model, PAWS calculates the optimal patrol strategy for the defender, which consists of a set of patrol routes and the probabilities with which each route should be taken. PAWS uses a novel algorithm which integrates two threads of prior work in the security games literature, ARROW (Nguyen et al. 2015) and BLADE (Yang et al. 2013). This algorithm generates patrol routes over the street map, while simultaneously addressing payoff uncertainty and bounded rationality of the adversary.

In wildlife protection, there are repeated interaction between patrollers and poachers. When patrollers execute the PAWS strategy over a period (e.g., three months), more information is collected and can become part of the input in the next round.

Demonstration

Our demonstration consists of three parts. The first part is a video introducing the PAWS system. This video presents an urgent need to combat poaching, the problem scenario, the challenges of solving the problem, the PAWS framework, as well as the real-world deployment of PAWS patrols.

The second part is an interactive visualization of the patrol routes generated by PAWS in an example area with complex terrain. We will show the patrol routes on Google Earth (see Figure 1). Thus participants can get a 3-D view of the routes and rotate to check whether the patrol routes are compatible with the terrain and are feasible.

The third part is a machine-human competition in designing patrol strategy given terrain information and animal distribution. The participants will be asked to design their own patrol strategy and compare it to the strategy generated by PAWS. As the first task of the competition, the participants can assign probabilities to a given set of patrol routes. We will compare the results with the optimal probabilities generated by PAWS, the patroller's expected utility against a poacher. As the second task of the competition, the participants will be asked to design a patrol strategy, including a set of patrol routes and probabilities of taking each route, given animal density distribution map overlaid on a topographic map. The patrol routes should start from and end with a given base camp location, and satisfy the total patrol time limit. We will make a descriptive comparison between the strategy generated by participants and the strategy generated by PAWS. Multiple criteria will be included in the comparison, including the patroller's expected utility against
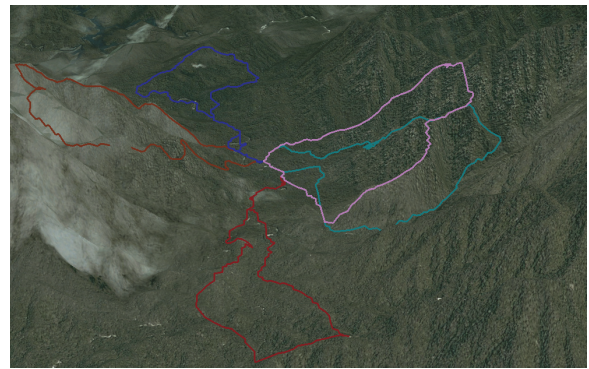

Figure 1: Example patrol routes generated by PAWS.

a poacher, the total distance and total elevation change of the patrol routes, the number of climbing ups and downs if the patrollers follow the patrol routes.

References

Fang, F.; Stone, P.; and Tambe, M. 2015. When security games go green: Designing defender strategies to prevent poaching and illegal fishing. In *International Joint Conference on Artificial Intelligence (IJCAI)*.

Kar, D.; Fang, F.; Fave, F. D.; Sintov, N.; and Tambe, M. 2015. A Game of Thrones: When human behavior models compete in repeated Stackelberg security games. In *AAMAS 2015*.

Nguyen, T. H.; Yang, R.; Azaria, A.; Kraus, S.; and Tambe, M. 2013. Analyzing the effectiveness of adversary modeling in security games. In *AAAI*.

Nguyen, T. H.; Fave, F. M. D.; Kar, D.; Lakshminarayanan, A. S.; Yadav, A.; Tambe, M.; Agmon, N.; Plumptre, A. J.; Driciru, M.; Wanyama, F.; and Rwetsiba, A. 2015. Making the most of our regrets: Regret-based solutions to handle payoff uncertainty and elicitation in green security games. In *Conference on Decision and Game Theory for Security*.

Stoner, S., and Pervushina, N. 2013. Reduced to skin and bones revisited: An updated analysis of tiger seizures from 12 tiger range countries (2000-2012). Report, TRAFFIC: The Wildlife Trade Monitoring Network.

Tambe, M. 2011. *Security and Game Theory: Algorithms, Deployed Systems, Lessons Learned*. Cambridge University Press.

Yang, R.; Jiang, A. X.; Tambe, M.; and Ordonez, F. 2013. Scaling-up security games with boundedly rational adversaries: A cutting-plane approach. In *IJCAI*.

Yang, R.; Ford, B.; Tambe, M.; and Lemieux, A. 2014. Adaptive resource allocation for wildlife protection against illegal poachers. In *AAMAS*.