Adaptive Attention Allocation in Mixed Human-Robot Teams

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Incomplete Literature Review

Human Decision Making

Control of Queues

Queues with human operator

Problem Setup: Optimal Information Management

- Support System (SS) collects information from the sensor network
- SS streams collected information to the human operator
- SS specifies the time, the operator should spend of each feed
- Based on the operator’s decisions, the SS collects information from the most pertinent source
Operator Models

Evolution of probability of detection
Pew '68

Yerkes-Dodson effect
Yerkes-Dodson 1908

- the evidence for decision making evolves as a drift-diffusion process
- the probability of the correct decision is a sigmoid function of time
- the utilization of the operator captured by a linear dynamical system
- the expected service time under natural response is convex function of utilization

Dynamic Queue with Penalty and Situational Awareness I

Tasks arrive as a Poisson process with rate $\lambda$
Tasks sampled from a distribution $p$
reward $w_\gamma$ for each correct decision on task $\gamma \in \Gamma$
Latency penalty per unit-time $c_\gamma$, for task $\gamma \in \Gamma$

- State variables: Queue length $n_\ell$ and utilization ratio $x_\ell$
- Decision variables: Duration allocation $t_\ell$ and Rest time $r_\ell$

Dynamic Queue with Penalty and Situational Awareness II

Average Reward

$$\max_{z_\ell t_\ell \geq z_\ell S(x_{\ell-1}), \ell \in \mathbb{N}} \lim_{L \to \infty} \frac{1}{L} \sum_{\ell=1}^{L} \left( w_\ell f_\ell(t_\ell) - \bar{c} \mathbb{E}[n_\ell](t_\ell + r_\ell) - \frac{\bar{c} \lambda (t_\ell + r_\ell)^2}{2} \right)$$

System Dynamics

Queue length: $\mathbb{E}[n_{\ell+1}] = \mathbb{E}[\max\{1, n_\ell - 1 + \text{Poisson}(\lambda z_\ell(t_\ell + r_\ell))\}]$
Utilization: $x_{\ell+1} = (1 - e^{-\frac{t_\ell}{\tau}} + x(\ell)e^{-\frac{r_\ell}{\tau}})e^{-\frac{t_\ell + r_\ell}{\tau}}$, $x_\ell \in [x_{\min}, x_{\max}]$

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Spatial Quickest Detection

- \( N \) region to be surveyed
- any number of anomalous regions
- an ensemble of CUSUM algorithms
- collection + transmission + processing time at region \( k \) is \( T_k > 0 \)
- distance between region \( i \) and \( j \): \( d_{ij} \)

Spatial Quickest Detection: Detection Delay

- Expected detection delay at region \( k \)

\[
E[T^k_d] = \frac{e^{-\eta} + \eta - 1}{q_k D(f^1_k, f^0_k)} (q \cdot T + q \cdot Dq)
\]

Spatial Quickest Detection

- at iteration \( \tau \), pick a region \( k \) from stationary distribution \( q \)
- go to region \( k \) and collect evidence \( y_\tau \)
- update CUSUM statistic for region \( k \)

\[
\Lambda_k = (\Lambda_{k-1} + \log(f^1_k(y_\tau)/f^0_k(y_\tau)))^+
\]
- declare an anomaly at region \( k \) if \( \Lambda_k > \eta \)
Expected detection delay at region $k$

$$E[T^k_d] = \frac{e^{-\eta} + \eta - 1}{q_k D(f^1_k, f^0_k)} (q \cdot T + q \cdot Dq)$$

Two stage quickest detection strategy

1. pick optimal $q^* = \arg\min \sum_{k=1}^N \pi_k E[T^k_d]$
2. adapt $q^*$ with the evidence collected at each stage

Spatial Quickest Detection with Human Input

- human operator allocates time $t$ to an evidence and decides on presence/absence of anomaly
- probability of correct decision at region $k$ evolves as sigmoid function
  $$\begin{cases} 
  f^1_k(t), & \text{if an anomaly is present,} \\
  f^0_k(t), & \text{if no anomaly is present.}
  \end{cases}$$

- support system runs spatial quickest detection algorithm with the decisions of the operator

Critical Issue:
- human decisions are not i.i.d.
- no closed form delay expressions

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Expected detection delay

$$E[T^k_d] \leq \frac{\nu_k}{q_k} (q \cdot T + q \cdot Dq)$$
Adaptive Policy with Human Feedback

1. determine $q^*$ and sample regions
2. set operator performance at region $k$
   
   $$f_k(t) = \pi_k f_1^k(t) + (1 - \pi_k)f_0^k(t)$$
3. determine optimal allocation and rest time
4. update CUSUM statistic using operator’s decision
5. go to step 1.

Simultaneous Information Aggregation and Processing II

Conclusions & Future Directions

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- novel *simultaneous information aggregation and processing* framework
- incorporation of situational awareness models
- incorporation of human decisions in sensor management strategies
- an adaptive strategy that collects evidence from regions with high likelihood of anomalies and optimally processes it
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Future Directions

- re-queuing of tasks and preemptive queues
- validation with experiments
- dynamic anomalies