Cooperative Environmental Monitoring for PTZ Camera Networks: Payoff-based Game Theoretic Learning Approach

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Introduction

Environmental monitoring
Large-scale persistent environmental monitoring has become crucial due to recent serious natural disasters.

Objective
Monitoring the environmental change by PTZ camera network

Outline
• Introduction
• Problem Setting
• Formulation of a Potential Game
• Experiment
• Schedule

Problem Setting

player $\mathcal{C} = \{c_1, \cdots, c_n\}$
action $a_i = (\theta_i, \varphi_i, \lambda_i) \in \mathcal{A}_i$
constrained action set $\bar{\mathcal{A}}(a_i) = \{a_i + (5b_1, 5b_2, 2b_3) \in \mathcal{A}_i | b_1, b_2, b_3 \in \{-1, 0, 1\}\}$
resource $\mathcal{R} = \{r_1, \cdots, r_m\}$
visible resources from camera $c_i$ with $a_i$ $\mathcal{R}_i(a_i) \in \mathcal{R}$

Practical Work

Objective
Monitoring the environmental change by PTZ camera network

Control Approach
Game Theoretic Control: Potential Game[2]

Advantages:
- Robustness for environmental change $\phi$
- Scalability
- Adaptability in real time

Component[3]
- Utility Design
- Learning Design: PIPIP[1]

Utility Design

- Utility Design (based on [4])
- Experiment and Analysis

Situation of environmental monitoring
Problem Setting

\[ C = \{c_1, \ldots, c_n\}, \ a_i = (\theta_i, \varphi_i, \lambda_i) \in A_i, \ R = \{r_1, \ldots, r_m\} \]

Information got from the camera image
\[ l \in L_i := \{1, \ldots, L\}_i \]
\[ y_{i,j} \in \{0, \ldots, 255\} \]

Information about resource \( r_j \in R_i(a_i) \)
\[ F_{i,j} \subseteq L_i \]
\[ Y_{i,j}(a_i) = \{y_{i,j} \in F_{i,j}(a_i)\} \]

Cost function
\[ W_{i,j}(a_i) = \frac{\sum_{y_{i,j} \in Y_{i,j}(a_i)} h_{i,j}(y_{i,j})}{|Y_{i,j}(a_i)|} \]
\[ \bar{r}_{i,j}^{\text{cost}}(a_i) = \frac{\sum_{y_{i,j} \in Y_{i,j}(a_i)} h_{i,j}(y_{i,j})}{|Y_{i,j}(a_i)|} \]

Problem Setting (Cost Function)

\[ F_{i,j} \subseteq L_i \]

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Experimental System

- Network
- Zoom
- PTZ Camera
- Tilt
- Network
- Learning Algorithm
- Image Processing
- Numeric Calculation
- PC

Experimental Setting

Experimental Condition
- Monitoring the environmental change on the ceiling (2D surface)
- Experimental change (Light on the ceiling)

Resources arrangement
- divide the monitoring territory (2D surface) into 0.3 × 0.3 [m²] areas.

Experimental Analysis

Experimental Result

Experimental Setting

Experimental problem setting
- \( C = \{c_1, c_2, c_3, c_4 \} \), \( a_i = (\theta_i, \varphi_i, \lambda_i) \in A_i \)
- \( \mathcal{R} = \{r_1, \ldots, r_{150}\} \)
- \( W_{i,j}(n) = \begin{cases} K^\text{real}_{i,j}(n)K^\text{real}_{j,i}(n) > 0.05 \\ 0.05 \\ 0 \end{cases} \)
- \( W_{i,j}(n) = \begin{cases} K^\text{real}_{i,j}(n)K^\text{real}_{j,i}(n) > 0.05, r_j \text{ is visible perfectly} \\ K^\text{real}_{i,j}(n)K^\text{real}_{j,i}(n) < 0.05, r_j \text{ isn’t visible perfectly} \end{cases} \)

Experimental Situation (Environmental change)
- Case 1: 0 light (No environmental change)
- Case 2: 1 light
- Case 3: 2 light

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Schedule

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Experiment
- Try similar experiment again
- Change the Experiment situation (ex. the light number)
- Experiment with another Learning Algorithm (Simple Experimentation with Irrational Decisions)

Reference

Appendix

Learning Algorithm (PIPIP)

Initialisation: Action $a$ is chosen randomly from $A$

Set $a_i = a$, $U_i(a_i) = U_i(a) = U_i(a_i)$ for all $i$ in $A$ and $\Omega = 2$

Step 1: $\Omega = \Omega - 1$

Step 2: If $U_i^2 + U_j^2 > U_i^2 > 0$, then set

$$a_{ij}^\Omega = \begin{cases} r_i(a_i) & \text{if } a_i \neq a_j \wedge \Omega > 0 \\ a_i & \text{if } a_i = a_j \wedge \Omega > 0 \\ a_j & \text{if } a_i = a_j \wedge \Omega > 0 \\ a_i & \text{if } a_i = a_j \wedge \Omega > 0 \\ a_j & \text{if } a_i = a_j \wedge \Omega > 0 \\ \end{cases}$$

Step 3: Execute the selected action $a_{ij}^\Omega$.

Step 4: Set $\Delta_i = \Delta_i - 1$

Step 5: $\Omega = \Omega + 1$

Step 6: $\Omega = \Omega + 1$

Problem Setting

$\mathcal{R} = \{R_1, \ldots, R_m\}$ resources

$\mathcal{R}_i(a_i) \in \mathcal{R}$ visible resources from camera $C_i$ with $a_i$

Information got from camera image

$l = \{1, \ldots, L_i\} \in \mathcal{L}$ the pixel number in the image of camera $C_i$

g_{ij} \in \mathbb{R}$ the visual information about camera $C_i$

Information about resource $r_j \in \mathcal{R}_i(a_i)$

$\mathcal{F}_{ij}(a_i)$ the set of pixels capturing $r_j$ in the image of camera $C_i$

$\mathcal{G}_{ij}(a_i) = \{g_{ij} \in \mathcal{F}_{ij}(a_i) \}$ stored initial visual information about $r_j \in \mathcal{R}_i(a_i)$

$\mathcal{H}_{ij}(a_i) = \{h_{ij} \in \mathcal{F}_{ij}(a_i) \}$ the visual information about $r_j \in \mathcal{R}_i(a_i)$

$\Delta_{ij} = \left\{ \begin{array}{ll} 1 & \text{if } g_{ij} - g_{ij} > \text{threshold} \\ 0 & \text{if } g_{ij} - g_{ij} < \text{threshold} \end{array} \right.$