Optimal Cooperative Control for Weather Camera Networks via Game Theoretic Learning Algorithm

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Outline

Weather Monitoring

Energy

Large volume injection

Photovoltaic power (PV)

Energy management system (EMS)

Weather prediction [1]

- Cover
- Shape
- Direction
- Height

Only cloud or clear sky

Cloud and clear sky

Visual Monitoring

PTZ camera

All sky camera

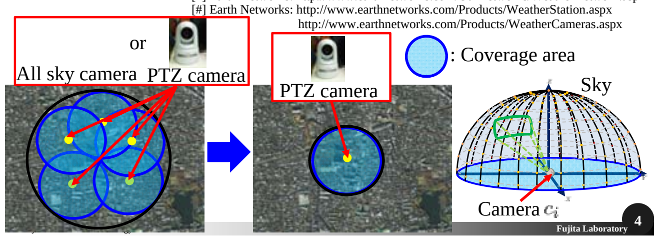
Weather Monitoring

Weather network

Earth Networks [*]

Weather Station and camera[#]

[*] Earth Networks: http://www.earthnetworks.com/OurNetworks/WeatherNetwork.aspx
[#] Earth Networks: http://www.earthnetworks.com/Products/WeatherStation.aspx
http://www.earthnetworks.com/Products/WeatherCameras.aspx



Approach

Monitoring

We use red-blue-ratio (RBR) [4] as the cost function

Cloud and clear sky   Only cloud   Only clear sky

We choose action (Pan, Tilt) such that the cost function is maximized using potential game [3]

We use PIPIP [3] as a learning algorithm

PTZ camera

We can know the size and shape of cloud

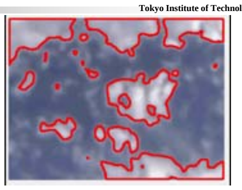
Approach

- Cloud Detection[4]

The pixel Red-Blue Ratio (RBR)

The RBR of a Clear Sky Library (CSL)

Neural Networks

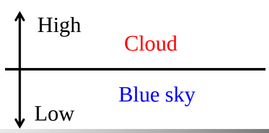


RBR

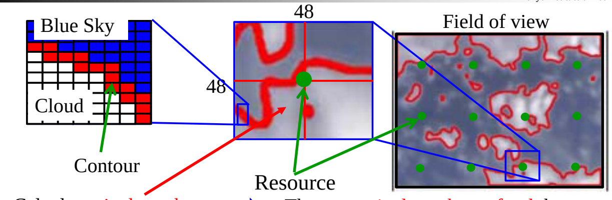
- RBR

Calculate $\frac{\text{The pixel value of red}}{\text{The pixel value of blue}}$ (Red-Blue Ratio) of all pixels

Because blue sky have high pixel value of blue, Red-Blue Ratio is low



Approach



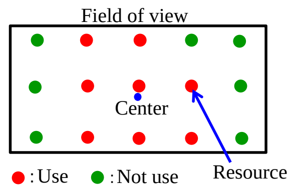
Calculate pixel number of red within this square → The more pixel numbers of red the more the boundaries between blue sky and cloud

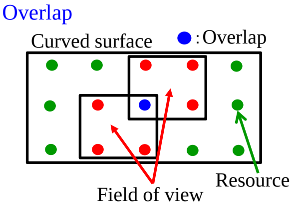
Only cloud or clear sky

Cloud and clear sky

Approach

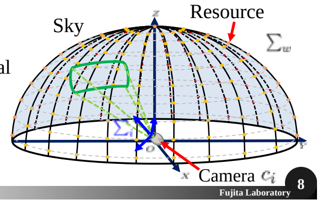
Overlap





Scenario

1. Suppose that sky is a curved surface
2. Arrange resources at an equal interval
3. Compute the value of cost function around resource
4. Move camera such that the value of cost function is maximized



Application of Potential Game

Global Objective Function

$$\phi(a) = \sum_{r \in R_{\mathcal{V}}} Px(r)$$

The sum of pixel number around resources n cameras are using

$\mathcal{V}$: A set of cameras

R_i : A set of resources that camera i uses $i \in \mathcal{V}$ $\mathcal{V} = \{1, \cdots, n\}$

R_{-i} : A set of resources that cameras (except for camera i) use

$$R_{-i} = \bigcup_{j \neq i} R_j \quad j \in \mathcal{V}$$

$Px(r)$: Pixel number of red around resource r

Utility Function

$$U_i(a) = \sum_{r_i \in R_i} Px(r_i) - \sum_{r_l \in R_i \cap R_{-i}} Px(r_l)$$

The sum of pixel number around resources camera i is using

The sum of pixel number around overlapping resources

Wonderful Life Utility [5]

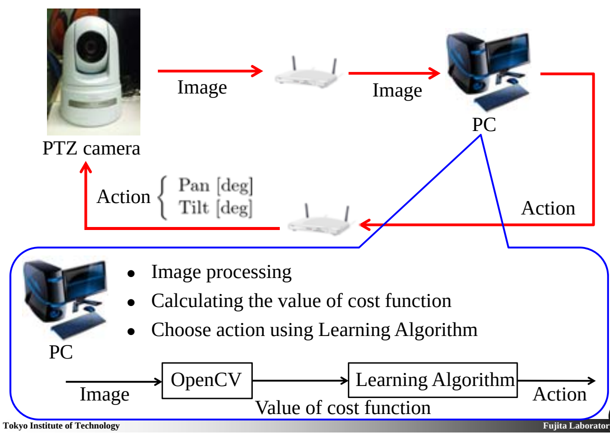
$$U_i(a) = \phi(a_i, a_{-i}) - \phi(a_i^0, a_{-i})$$

$a_i := (a_1, \cdots, a_n)$

$a_i := (a_1, \cdots, a_{i-1}, a_{i+1}, \cdots, a_n)$

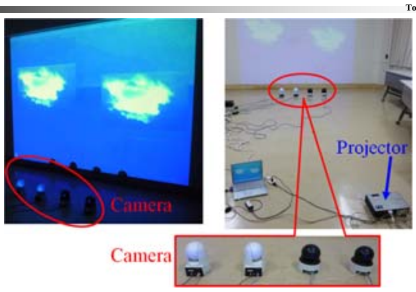
a_i^0 : Null action

Experimental System



Experiment

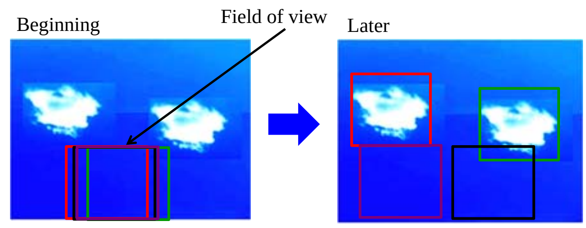
Indoor



Outdoor

Experiment in the roof

Experiment (Indoor)



Field of views are overlapping

Cameras are monitoring the place that exists only blue sky

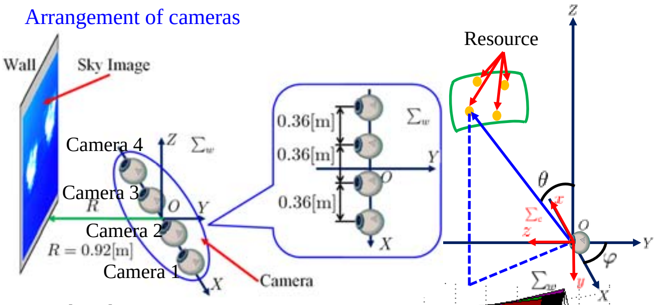
Cameras are monitoring the place that exists cloud and blue sky

Cameras monitor widely

	Only cloud or blue sky	Existing cloud and blue sky
Pixel number of red	0	Greater than 0 ～

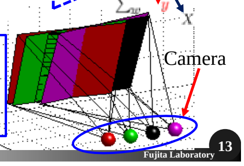
Settings (Indoor)

Arrangement of cameras



Initial angle

Camera 1	Camera 2, Camera 3	Camera 4
$\mathrm{Pan} = 10^\circ$	$\mathrm{Pan} = 0^\circ$	$\mathrm{Pan} = -10^\circ$
$\mathrm{Tilt} = 20^\circ$	$\mathrm{Tilt} = 20^\circ$	$\mathrm{Tilt} = 20^\circ$



Settings (Indoor)

Agent

$N = 4$ (PTZ camera)

Action

$a_i = (\mathrm{Pan}, \mathrm{Tilt})$ [deg] $i = \{1, \cdots, N\}$

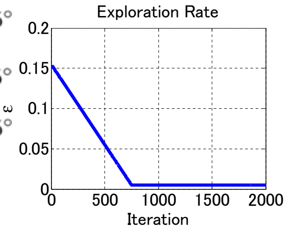
Restricted Action Set

$$\mathcal{R}_i(a_i) = \{a_i + 5(b_1, b_2) | b_1 \in \{-1, 0, 1\}, b_2 \in \{-1, 0, 1\}\}$$

Camera 1
$-5^\circ \le \mathrm{Pan} \le 35^\circ$ $20^\circ \le \mathrm{Tilt} \le 45^\circ$

Camera 2, Camera 3
$-35^\circ \le \mathrm{Pan} \le 35^\circ$ $20^\circ \le \mathrm{Tilt} \le 45^\circ$

Camera 4
$-35^\circ \le \mathrm{Pan} \le 5^\circ$ $20^\circ \le \mathrm{Tilt} \le 45^\circ$



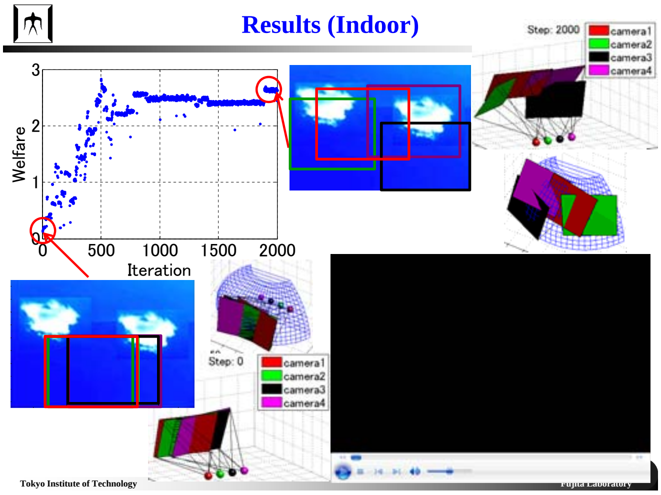
Learning Algorithm

PIPIP

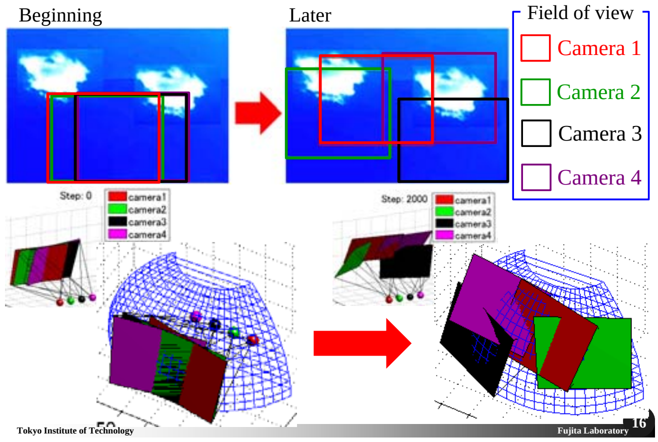
Exploration Rate

$$\varepsilon = \begin{cases} 0.155 - 0.0002 \times Iteration & (0 \le Iteration < 750) \\ 0.005 & (750 \le Iteration) \end{cases}$$

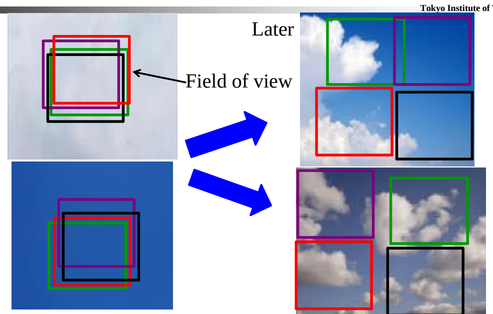
Results (Indoor)



Results (Indoor)



Experiment (Outdoor)



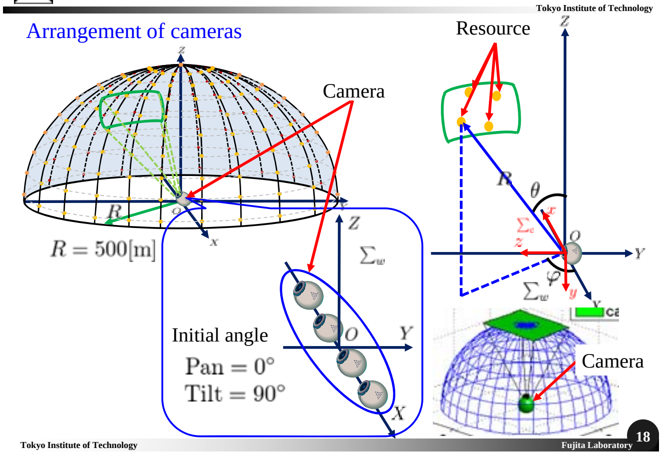
Field of views are overlapping
Cameras are monitoring the place that exists only blue sky or cloud

Cameras are monitoring the place that exists cloud and blue sky
Cameras monitor widely

	Only cloud or blue sky	Existing cloud and blue sky
Pixel number of red	0	Greater than 0 ～ About 200

Settings (Outdoor)

Arrangement of cameras



Settings (Outdoor)

Agent

$N = 4$ (PTZ camera)

Action

$a_i = (\mathrm{Pan}, \mathrm{Tilt})\ [\mathrm{deg}] \quad i = \{1, \cdots, N\}$

Restricted Action Set

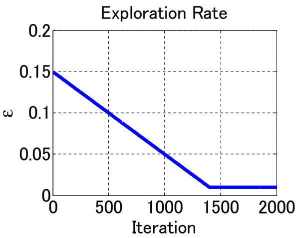
$$\mathcal{R}_i(a_i) = \{a_i + 5(b_1, b_2) | b_1 \in \{-1, 0, 1\}, b_2 \in \{-1, 0, 1\}\}$$

$$-40^\circ \leq \mathrm{Pan} \leq 40^\circ$$

$$30^\circ \leq \mathrm{Tilt} \leq 90^\circ$$

Learning Algorithm

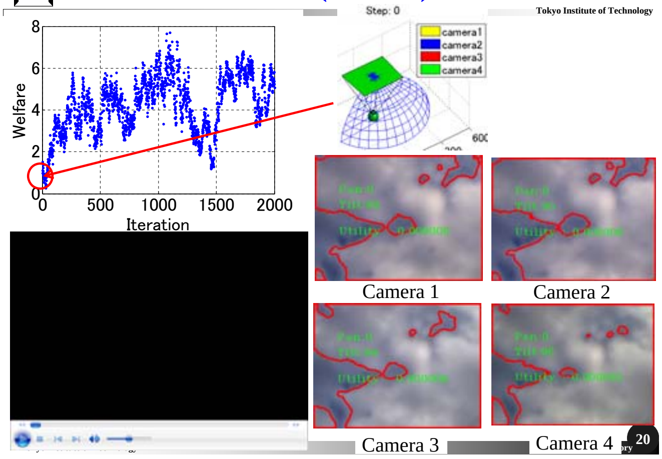
PIPIP



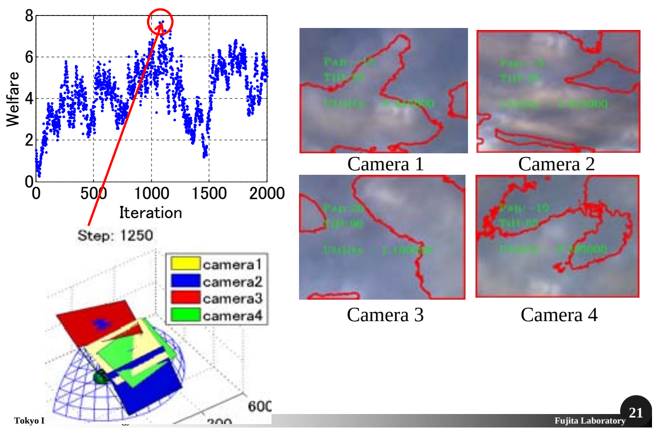
Exploration Rate

$$\varepsilon = \begin{cases} 0.15 - 0.0001 \times Iteration & (0 \leq Iteration < 1400) \\ 0.01 & (1400 \leq Iteration) \end{cases}$$

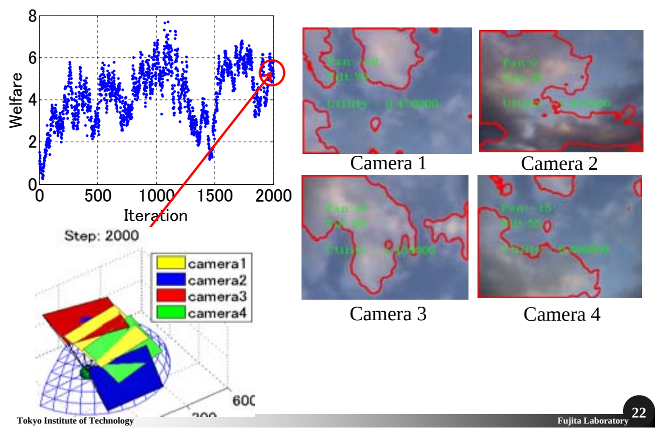
Results (Outdoor)



Results (Outdoor)



Results (Outdoor)



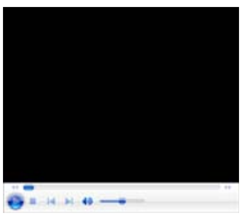
Conclusion

Summary

- Proposing cost function using RBR technique
- Utility design
- Experiment (Indoor)
- Experiment (Outdoor)

Future Works

- Speed-up of processing



References

[1] 気象庁: 気象観測の手引き (1998)

[2] Y. Zhang, M. Rotea, N. Gans, “Sensors Searching for Interesting Things: Extremum Seeking Control on Entropy Maps,” *Proc. of the 50th IEEE Conference on Decision and Control and European Control Conference*, pp. 4985-4991, 2011.

[3] T. Goto, T. Hatanaka and M. Fujita, “Payoff-based Inhomogeneous Partially Irrational Play for Potential Game Theoretic Cooperative Control of Multi-agent Systems,” *Proc. of the 2012 American Control Conference*, pp. 2380-2387, 2012.

[4] M. S. Ghonima, B. Urquhart, C. W. Chow, J. E. Shields, A. Cazorla and J. Kleissl, “A method for cloud detection and opacity classification based on ground based sky imagery,” *Atmospheric Measurement Techniques Discussions*, Vol. 5, No. 4, pp. 4535-4569, 2012.

[5] J. R. Marden, A. Wierman, “Distributed Welfare Games,” *INFORMS Operations Research*, to appear, 2013.