The Monitoring of Cloud Movements with Visual Sensor Networks

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Background

Photovoltaic (PV) power generation [1]

The installation of PV generation systems is rapidly growing due to concerns related to environment.

Merit

- Renewable energy
- A clean and environmentally-friend source of energy

Demerit

- Depending on weather condition and cloud-cover
- Low conversion efficiency

Renewable energy sources are highly variable, intermittent

It is difficult to maintain the power demand supply balance

However the electricity grid must absorb this variability and intermittently

We need to monitor and forecast cloud movement

Objective

Monitoring [2]

Satellite and ground-based sky imaging tools can be used to monitor and forecast cloud movements.

Forecast of PV energy production is available in advance.

All-sky imaging [3]

- The system includes a camera and wide-angle lens or hemispheric mirror.
- Analysis of image is based on the red-to-blue ratio.

lens distortion is large

Visual sensor networks

- Surveillance
- Tracking
- Catching speeding drivers
- Gathering scientific data

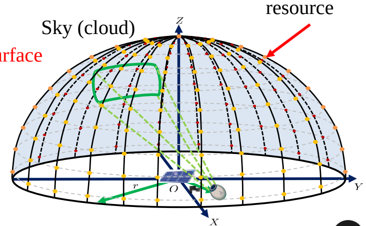
Scenario

Characteristics

- Monitor cloud using network camera
- Choose action (Pan, Tilt) such that the entropy is maximized using potential game[4]
- Use PIPIP(Payoff based Inhomogeneous Partially Irrational Play)[4] as a learning algorithm

Approach

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



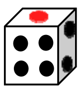
Entropy[5,6]

Entropy

$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

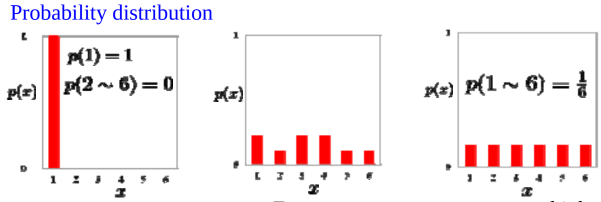
The pip of a dice : $X = \{1, 2, 3, 4, 5, 6\}$

The probability of x : $p(x)$



$$H(X) = -p(1)\log_2 p(1) - p(2)\log_2 p(2) - p(3)\log_2 p(3) - p(4)\log_2 p(4) - p(5)\log_2 p(5) - p(6)\log_2 p(6)$$

Probability distribution



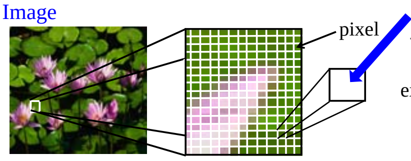
low ← Entropy → high

$-1 \cdot \log_2 1 - 0 \cdots - 0$

$-\frac{1}{6}\log_2 \frac{1}{6} \cdots - \frac{1}{6}\log_2 \frac{1}{6}$

Entropy[5,6]

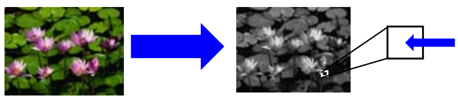
Image



pixel value
$\{0 \sim 255, 0 \sim 255, 0 \sim 255\}$
Red Green Blue

ex $\{0,0,0\}$ Black
$\{255,255,255\}$ White
$\{255,0,0\}$ Red
$\{0,0,255\}$ Blue
$\{255,255,0\}$ Yellow

Converting a image to a gray scale image



pixel value
$\{0 \sim 255\}$
brightness

Red Green Blue → brightness

ex $\{0\}$ Black
$\{255\}$ White

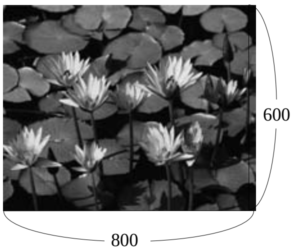
Entropy[5,6]

Calculation of the probability $p(x)$

0	0	0		8	8	10
1	5	7	…	14	9	10
6	3	4		12	7	7
⋮			⋱	⋮		
30	22	11		42	43	39
22	34	34	…	45	45	37
22	18	22		42	41	40

600

800



Total pixels $800 \times 600 = 480000$

Entropy

$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

Probability $p(x)$

$$p(x) = \frac{\text{The number of pixel value x}}{\text{Total pixels}}$$

Entropy[5,6]

0	0	0		8	8	10
1	5	7	…	14	9	10
6	3	4		12	7	7
⋮			⋱	⋮		
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22	34	34	…	45	45	37
22	18	22		42	41	40

600

800

Total pixels $800 \times 600 = 480000$

Probability $p(x)$

$$p(x) = \frac{\text{The number of pixel value x}}{\text{Total pixels}}$$

$$p(0) = \frac{\text{The number of pixel value 0}}{\text{Total pixels}}$$

$$p(1) = \frac{\text{The number of pixel value 1}}{\text{Total pixels}}$$

⋮

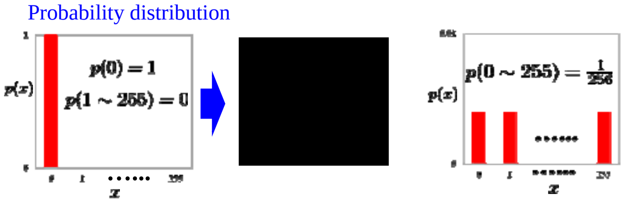
$$p(255) = \frac{\text{The number of pixel value 255}}{\text{Total pixels}}$$

Entropy

$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

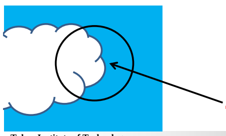
Entropy[5,6]

Probability distribution



low $H(X) = 0$ ← Entropy → high $H(X) = 8$

The more kind of color is , the larger entropy is

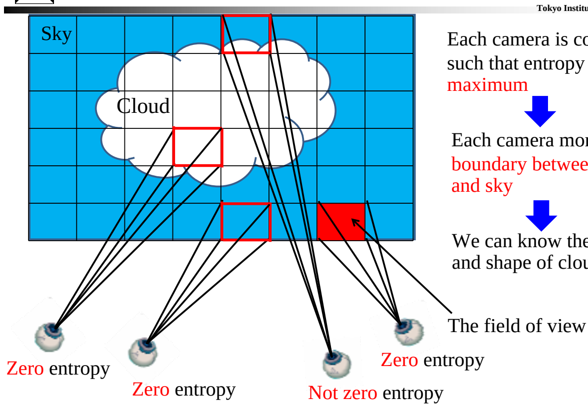


The entropy is large

Entropy

$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

Scenario



Each camera is controlled such that entropy is maximum

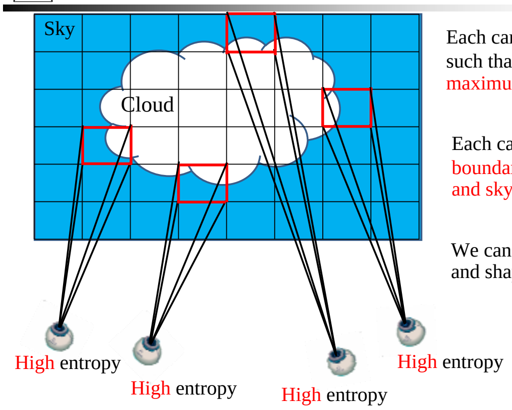
↓

Each camera monitors boundary between cloud and sky

↓

We can know the size and shape of cloud

Scenario



Each camera is controlled such that entropy is maximum

↓

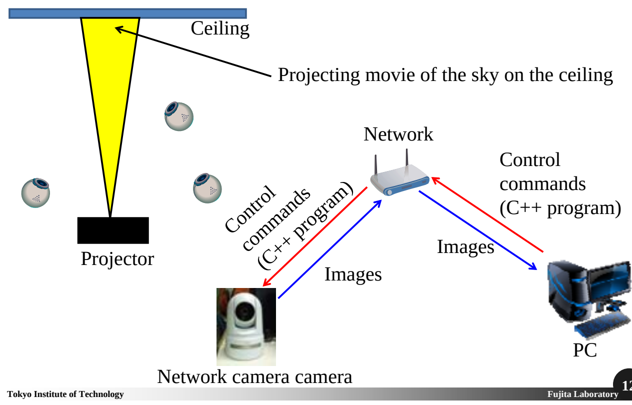
Each camera monitors boundary between cloud and sky

↓

We can know the size and shape of cloud

Experiment Settings

Experimental system [7]



Future Works

Compose experimental system

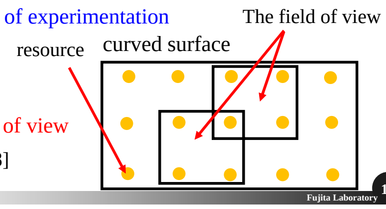
- Display the camera image
- Pan and Tilt control with network camera (one camera)

- Calculating the entropy (one camera)
- Pan and Tilt control with network camera (multiple cameras)
- Calculating the entropy (multiple cameras)
- Application of Potential Game

The analysis and evaluation of experimentation

- Sunlight
- The color of the cloud
- The overlap of the field of view

  Using bearing angle [8]



References

[1] T. T. N. Khatib, A. Mohamed and N. Amin, “A New Controller Scheme for Photovoltaics Power Generation Systems,” *European Journal of Scientific Research ISSN*, Vol. 33, No. 3, pp.515-524, 2009.

[2] E. Bitar, P. P. Khargonekar and K. Poolla, “Systems and Control Opportunities in the Integration of Renewable Energy into the Smart Grid,” *the 18th World Congress of the International Federation of Automatic Control*, Milano, Italy, Aug.-Sep., 2011.

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[4] T. Goto, T. Hatanaka and M. Fujita, ”Payoff-based Inhomogeneous Partially Irrational Play for Potential Game Theoretic Cooperative Control of Multi-agent Systems,” (available at arXiv:1107.4838), 2011.

References

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[7] T. Dinh, Q. Yu, G. Medioni, “Real Time Tracking using an Active Pan-Tilt-Zoom Network Camera,” *the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, St. Louis, Missouri, USA, Oct., pp. 3786-3793, 2009.

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