A Yet Another Remote Plant Cultivating Tool and a Proposal of 'Information Estrangement'

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Abstract

To cultivate the plants from the distant place, the authors developed a remote plant cultivating tool. This tool was possible to cultivate the plants from distant place using the internet. Through the experiment, the idea of **Information Estrangement** was introduced. This is a kind of information metric corresponding to the real-world distance. In this paper, the authors reported a yet another remote plant cultivating system, its experimental result and a proposal of new metric "Information Estrangement" as informational distance.

1 Introduction

Tomoko Watanabe, one of the authors, had an experiment to cultivate cherry-tomatoes in summer 2007. These plants had grown greatly and required to water 4 times a day in the midsummer. They had been leaved out and required to shore the stems. When she had left out of the house when the typhoon came, she had always been worried about if the tomatoes lodged.

Later, Mrs. Watanabe could be hardly attend the university for blood disease and had a great concern about the laboratory plants. So she had made use of this experience to build a remote plant cultivating tool to monitor and feed plants from the remote location.

In her empirical knowledge derived from the tool, the authors had considered that

- The distance of the plants and the grower had got close when this tool had used.
- It was definable the value of communication frequency between the plants and the grower so called **Information Estrangement**.

This paper reported this remote plant cultivating tool and proposed the new metric **Information Estrangement**.

2 Related studies about the plant cultivation and Human-Plant Interface

In Agronomy, There existed a lot of studies about the remote cultivating tools. In Human Computer Interface, much less studies had been done about the Human-Plant Interface. The authors had shown some examples of both kinds.

2.1 Related studies about hydroponic cultivation

From [1] and [2] papers, **soil culture** meant popular planting using soils and **nutrient solution culture** meant planting with a fertilized water.

The nutrient solution culture was separated according to the support of the roots into 3 groups;

- **Pebble culture** or **sand culture** meant to support roots with the pebbles or sands.
- **Water culture** meant to soak roots directly into the nutrient water using rock wools.
- **Spray culture** meant to hang plants in the air and spray the nutrient water into the roots.

And that was separated into 2 groups of irrigations;

- **Circulating irrigation** meant to use the nutrient water repeatedly.
- **Continuous flood irrigation** meant to use the nutrient water only once.

At the circulating irrigation, plants must be irrigated the same water. So it was necessary to add plant nutrients appropriately. The amount of the nutrients was determined from both *pH* of the water and the amount of Electric Conductance (hereinafter called E.C.) of the water. Inappropriate amounts (more or less) of the nutrients caused a root rot.

These amounts of the nutrients were different from the kind of plants but the typical *pH* of the water was within the range of 5,5〜6,5. And the proper water temperature was within the range of 15°C〜20°C. Under the lower temperature, the lower degree of the root activity inhibited the nutrient absorption. And under the upper temperature, the root respiration accerated but the oxygen concentration of the water lowered and this caused a root rot. These problems of the hydroponic culture were discussed in paper [3]. Paper [4] discussed about the fertilization control by using the water consumption rate of the tomatoes.

2.2 Related studies about remote plant cultivations and remote plant monitoring

A few examples were shown from a lot of studies;

- the remote plant cultivation of the green house melon(paper [5])
- the remote plant growth monitoring using the commercial digital cameras(paper [6])
- the personal remote plant cultivating system “I-terrarium”(site [7])

2.3 Related studies about computer-plant interfaces

These were studies about the computer interfaces using plants as tangible media.

- A plant utilization as a computer output device using the plants’ biopotential measurement(paper [8])
- The interface about the plants’ expression measurement(paper [9])
- To control and display the artificial plants as if real plants(paper [11])

3 Yet another remote plant cultivating tool

To feed the plant from a remote location, following things must be considered;

Monitoring It was very important to monitor the remote plant for its constant care. And the authors always required to watch the house plant not to drought.

Watering The plant required to feed fertilized water in certain intervals and this required a different amount of water at its stage of growth.

Pollinating The cherry tomato must be pollinated to bear fruit. In outdoor, the pollination was done with the wind but in indoors it was required to shake the branches or wind the air to process the pollination.

Lighting To compare with other plants, the cherry tomato required double amounts of illumination because of its higher saturation point(described in [15]).

In order to adapt above situations, the authors were prepared as follows;

- Installed two webcams to monitor the plant status from the remote location.
- Installed a water-supply pump controlled by the computer. This was controlled via Solid State Relay(hereafter called S.S.R.) and fed the fertilized water to the plant.
- Installed a fan to pollinate the cherry tomato. This was controlled by the computer via S.S.R.
- Installed two horticultural LED lights. These were controlled by the computer via S.S.R.
- Installed a thermometer, a water pH sensor and a luminometer, all read out from the computer.

Figure 1 was shown a conceptual configuration of the tool. The description of above items had shown as the following subsections.

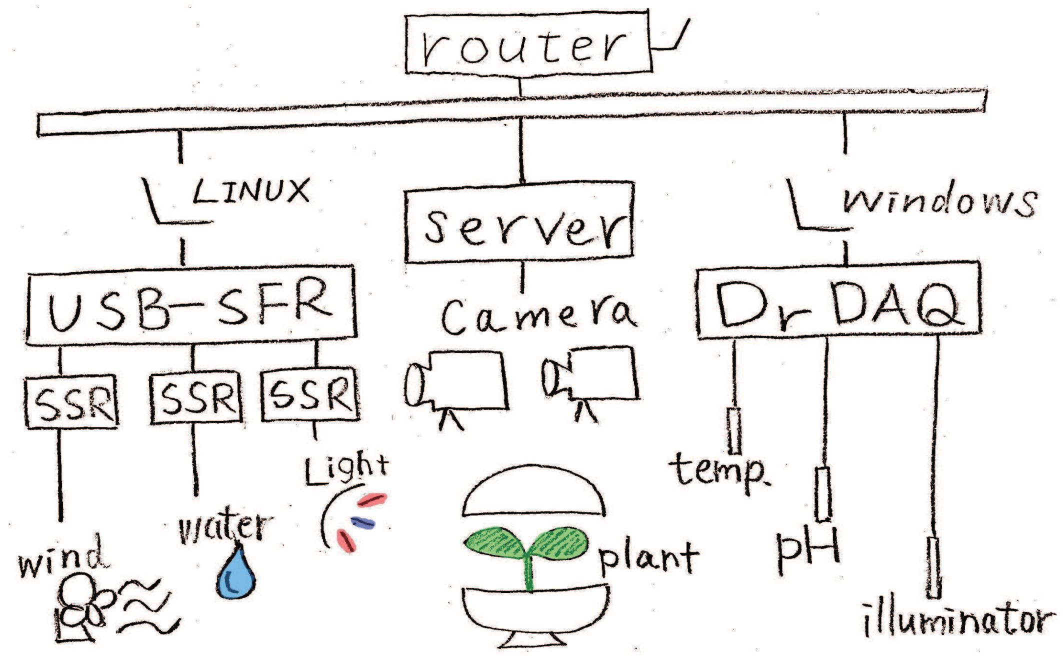

Figure 1: A conceptual configuration of the remote plant cultivating tool

3.1 Cultivating tank

The authors had selected the rock-wool water culture, the most popular way in the home gardening. And also selected a circulating irrigation because the location of the cultivating tool was the corner of the student laboratory and there was no water drain.

The authors selected AeroGrow International, Inc's "AeroGarden Deluxe" as the cultivating tank. The reasons were as follows;

- This one was very popular in U.S. and very easy to get support or maintenance.
- This had been sold in Japan for a brief time and the authors had got some information about it.
- This had horticultural fluorescent tubes and the competitors had only two fluorescent tubes at most. The cherry tomato had required a lot of lights and one more tube was desirable.
- This was possible to prolong the height of light up to the double of the competitors. It was possible to cultivate the larger plant.

But also some defects had known as follows;

Similar to all U.S. and Canada products, this power source was fixed in 120V, 60Hz. When this operated in Japan under 100V,50Hz, the period of a day must be prolonged 20 percent and its light intensity must be 20 percent dimmer.

The authors solved this problem to add LED lights.

This tank costed $209.5 [12]

3.2 Cherry tomato seeds

The cherry tomato seeds were ordered to the AeroGrow and their "Cherry Tomato Seed Kit" was used in this experiment. It would be available to obtain the local dealers in the regular season but the start of the experiment was out of season. This kit consisted of two kinds of tomato seeds, 2 Red Heirloom and 1 Golden Harvest seed pots. The authors bunged up the four holes from the total seven holes of the cultivating tank and planted them.

This kit costed $19.95 [12].

3.3 Webcams and a controller

The webcam system, consisted of two CM-03 webcams and one ICV-22 controller, was ordered to Mega System Technologies Inc, Taiwan. CM-03 had an ability of the pan tilt control via WEB. And webcam control server ICV-22 had an ability to upload viewing images to WEB site with a certain interval, typically 1〜15 minutes. Maximum picture size of webcams was 640x480, 24 bit colors.

CM-03 costed $72 and ICV-22 costed $65 [13].

3.4 LED cultivating lights

As described above, the built-in lights of a cultivating tank were much dimmer in Japan. The authors prepared two LED cultivating lights as sublights.

According to the website [14], common plants required 400nm〜510nm blue light and 610nm〜700nm red light in the growing phase. The authors prepared two LED mixture lights, each light had 60 cells of blue LEDs with 460nm and 225 cells of red LEDs with 660nm. These were made in China and consumed about 10W each under 100V A.C. condition. LED illuminated with current and not dimmed under 100V condition.

This device costed about $68 each.

3.5 Water-supply Pump

The authers chose Mitsugiron Bath Non-no BP-31 as a water-supply pump. The purpose of pump was to transfer the fertilized water from the preserved bucket to the cultivating tank.

This pump transferred water about 3 liters per a minute and our cultivating tank size was about 6 liters. In this whole experiment period, the maximum water requirement of a day is about 0.5 liter per a day.

In the final stage of the experiment, the cherry tomatoes affected a disease caused by the microbe contaminated from the inadequately-sterilized water. It was very important to use the sterilized water.

3.6 Air blower

To pollinate cherry tomatoes, the authors were prepared a Vornade 183 Circulator . At the beginning of the experiment, the authors thought that the uninterrupted wind would be possible. But it was turned out that this caused the plants damaged heavily and required to control the air blower.

3.7 Thermometer, luminometer, pH sensor and PC interface

To read out sensors from the computer, PICO Technology's DrDAQ was used. This was developed as a educational interface and had a built-in luminometer and thermometer. It had an ability to connect the other external sensors as a pH sensor and any kind of sensors' with a certain range of read-outs.

The authors tried to add an Electrical Conductivity (EC) sensor and made a sample sensor unit. But the read-outs were not stable and gave up to connect DrDAQ.

This one costed $130.35, and the pH sensor costed $57.75 [17].

3.8 AC powerline device control

To control the AC Power line devices such as an air blower, a water-supply pump and LED lights, the authors used the Recursion's USB-SFR and add some Solid State Relays (S.S.R.) on its outputs. an USB-SFR was possible to control at most 7 bits I/O and when used ports as output, each port was possible to set or reset the state. This one worked as virtual COM port connected in USB and had an ability to control from python, ruby and perl.

USB-SFR kit costed $8, [18].

S.S.R.kit costed $2.5, [16].

3.9 Controllers

To control the tool, the authors used two computers.

Computer 1 installed Linux was controlled all the AC Powerline controlled devices. If someone tried to control the water-supply pump, the air blower, and LED sublights, first he/she must login computer 1 via internet, second he/she should type in a proper command.

Those commands were implemented in python 2.6.1, each script size was about 20 lines.

Computer 2 installed Windows-XP was the monitoring and posting purpose machine. This posted pictures obtained via webcams and data logs obtained via sensors to WEB site. The data read-out programs and a file transfer program were also written in python 2.6.1.

3.10 Monitoring intervals and kinds of information

The authors showed the interval time and kinds of information between PLANT and HUMAN in the experiment as follows;

contents	intervals	data format and amount
From PLANT to HUMAN		
webcam pictures	1 min.	640x480x24bit JPEG
thermometer	1 min.	digits (tenth)
pH	1 min.	digits (handredth)
luminometer	1 min.	4digits
From HUMAN to PLANT		
lights on/off	12 hrs.	ON or OFF(bit)
water supply	48 hrs.	specific time ON (bit)
air blower	24 hrs.	specific time ON (bit)

Table 1: The interval time and kinds of information in the experiment

There existed an asymmetricity; PLANT monitoring information transferred from PLANT to HUMAN had short intervals and control information transferred from HUMAN to PLANT had much longer intervals.

In this tool, the commands to PLANT were interpreted in the computer and executed several sub orders. These commands may be possible to automate of course. But the authors designed this tool to left laborious to get actual feeling to feed plants.

Some other tasks such as mixture of liquid fertilizer and fugicidal, clipping leaves or branches could not perform from the remote location. At least a caretaker must visit the plant once or twice in a fortnightly.

3.11 Experiment results

The experiment began from October 8th 2008 and ended to mid October 2009, about one year long. October was out-of-season for tomatoes but the cherry tomato plants gave a lot of harvests, over 100, from December to January. And at the end of the experiment, plants had got no harvests but still alive. It was a successful result as an remote cultivation experiment. Total cost of the experiment include the air conditioning would be vast amount. But the authors had considered this cost was paid because the problem in the following sections was presented.

The tools build in this experiment only readied for daily conditions and not readied for clipping and fugicidals. Those tasks had required to work with the plants contiguously, it would be very hard to solve to use the remote tools.

The harvested cherry tomatoes were not so sweet. This result would be predicted in book [2]. To obtain sweeter tomatoes, the authors had to add more stress. But stressful conditions might harm tomato plants. In this experiment, stress of the cherry tomato plants would not distinguished through the webcams. Also from early summer to midsummer, the root rot had occurred. The webcams had not enough resolutions to realize the disease. It might be possible to realize if they had much higher resolutions and was possible to analyze plants. Those might be left for the future issues.

4 Distance and communication rate

The authors had reached one great question through the experiment. That was;

What is the difference between the usual plant cultivation and the remote plant cultivation that uses this tool?

For example, if the plant had brown with the wind and laid down and nobody noticed for a long time, the plant should die down. But in the same situation and anybody could have noticed for monitoring and gave a proper care from the remote location or came back as quickly as possible, the plant should survive.

To answer this question, the authors introduced a new metric 'Information Estrangement' treated like a **distance in information exchange**. This metric might increase if two objects exchange information frequently or exchange much information.

If the distance between the gardener and the plant would be farther, the plant might be kept worse. In the same meaning, if the rate of information exchange would be longer, the plant might be kept worse.

Under the usage of our tool, the plant must be kept at least in a certain interval of time and if the interval would exceed some unseen limit, the plant might get ill-kept and dried slowly.

In the analogy of distance,

- This metric would be interpreted near if the two objects' communication rate might be higher or the two objects might communicate larger amount of information.
- This metric would be interpreted far if the two objects' communication rate might be lower or the two objects might communicate smaller amount of information.

In successive sections, the authors described about the new metric.

5 Related works about informational distance

In the previous researches about informational distance, the authors had referred following papers.

1. Kullback-Leibler divergence([19], [20]).
2. Amari-Nagaoka information divergence(noted in [21] and [22])

In paper [20], Their early idea was similar to ours such as the calculation of arithmetic average of the divergences; the divergence from Object A to Object B and the divergence from Object B to Object A.

There were important suggestions in book [21] and [22]. These books introduced the theory of Amari-Nagaoka information divergence. The authors tried to get the original notes but the original was a laboratory seminar notes and had not got yet.

6 Information Estrangement and informational distance

In this section, the authors introduced "Information Estrangement" and discussed about this.

A and B communicate with a bi-directional complete communication channel.

$P_{A \to B}$ represents the Probability that the communication channel transfer the report that A's state change and λ_A represents the mean occurance times in the certain interval.

$P_{B \to A}$ represents the Probability that the communication channel transfer the report that B's state change and λ_B represents the mean occurance times in the certain interval.

6.1 Poisson distribution

Poisson distribution is defined as follows;

$$Pois(\lambda, k) = \frac{\lambda^k}{k!}e^{-\lambda}$$

which means λ as a expected occurance between the interval and k as an observed occurance.

And use the following notation.

$$Pois(\lambda, k \geq n) = \sum_{k=n}^{\infty} \frac{\lambda^k}{k!}e^{-\lambda}$$

To simplify the situation, the authors set following two assumptions;$A \to B$ and $B \to A$ communicate 1 bit of information and they can confirm the other's state changed when $k \geq 2$.

6.2 Definition of Information Estrangement

Information Estrangement $IE(\lambda_A, \lambda_B, mi)$ defines as follows:

$$IE(\lambda_A, \lambda_B, mi) = \frac{1}{\sqrt{H(Pois(\lambda_A/mi, k \geq 1)) \cdot H(Pois(\lambda_B/mi, k \geq 1))}} \quad (1)$$

In above expression, $H(p)$ means Entropy, $H(p) = -p \cdot \log_2(p) - (1-p) \cdot \log_2(1-p)$ and mi means the monitor interval(times/day).

In this definition, **Information Estrangement** would be smaller if the two communicated with larger amount of information.

Assume $P_{A \to B}$ and $P_{B \to A}$ are independent of each other, **Information Estrangement** get the minimum value when a product of $H(Pois(\lambda_A, k \geq 1))$ and $H(Pois(\lambda_B, k \geq 1))$ get the maximum value.

Information Estrangement is defined as a reciprocal of geometric mean of entropies. The authors choose the geometric mean rather than the arithmetic mean.

This is because of the following reason;

When $H(P_X)$ is much greater than $H(P_Y)$, the arithmetic mean is influenced by almost $H(P_X)$ and $H(P_Y)$ has no practical impact on the result.

On the other hand, the geometric mean reflects both $H(P_X)$ and $H(P_Y)$ characteristics equally.

6.3 Case of simplex line

First, the authors argue a simplex communication line. Assume that B always monitors A's state and takes action within ϵ delays when A's state changes. In this situation, the formula is as follows;

$$IE(\lambda_A, \lambda_A + \epsilon, mi) = \frac{1}{\sqrt{H(Pois(\lambda_A/mi, k \geq 1)) \cdot H(Pois((\lambda_A + \epsilon)/mi, k \geq 1))}} \quad (2)$$

Using the assumption that $Pois(\lambda, k \geq 1) = 1 - Pois(\lambda, 0)$
and $H(X) = H(1 - X)$, formula (2) is possible to transform as follows;

$$\frac{1}{\sqrt{H(Pois(\lambda_A/mi, 0)) \cdot H(Pois((\lambda_A + \epsilon)/mi, 0))}} =$$

$$\frac{1}{\sqrt{H(\frac{(\lambda_A/mi)^0}{0!} \cdot e^{-(\lambda_A/mi)}) \cdot H(\frac{((\lambda_A+\epsilon)/mi)^0}{0!} \cdot e^{-((\lambda_A+\epsilon))/mi)})}} =$$

$$\frac{1}{\sqrt{H(e^{-(\lambda_A/mi)}) \cdot H(e^{-((\lambda_A+\epsilon))/mi)})}} = \frac{1}{\sqrt{H(e^{-(\lambda_A/mi)}) \cdot H(e^{-(\lambda_A/mi)} \cdot e^{-(\epsilon/mi)})}} \quad (3)$$

If mi is much greater than ϵ, $e^{-(\epsilon/mi)}$ tends to 1 and formula (3) is possible to approximate by the following formula.

$$IE(\lambda_A, \lambda_A, mi) = \frac{1}{\sqrt{(H(e^{-(\lambda_A/mi)}))^2}} = \frac{1}{H(e^{-(\lambda_A/mi)})} \quad (4)$$

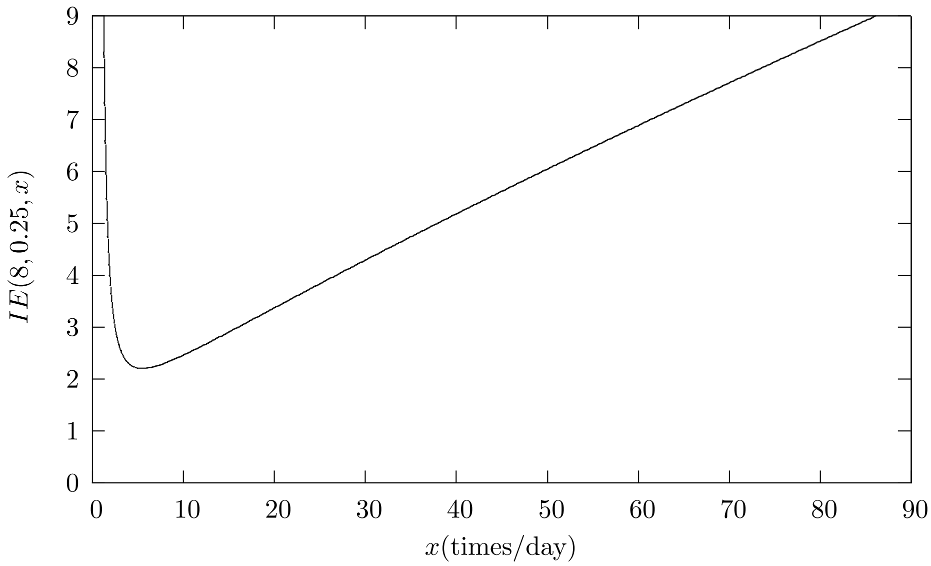

Figure 2: Information Estrangement variation by the monitor frequency (times/day).

It is obvious that formula (4) takes the minimum value when $H(Pois(\lambda_A/mi, k \geq 1))$ takes the maximum value and the desired minimum value is only influenced by the predicted interval of state changed.

This model fits for the agricultural model but not for the horticultural model. In horticulture, people take joy in seeing their cultivating plants and never in keeping an eye out for signs of vermins or diseases.

6.4 Case of duplex line

Under the experiment described in section 3, assume A and B communicate with a bi-directional complete communication channel and both intervals are once/1 minutes.

Assume that I_A as a mean times per a day that plants' state change and I_B as a mean times per a day to feed water. Regard that I_A as 8 times/day and I_B as once/4days tentatively.

Assume that x as a number of times per a day to monitor the bidirectorical communication channel with A and B and $P_{A\to B}$ as a probability of plants' state change in this interval. Under this assumption, λ_A is 8/1440.

And assume that $P_{B\to A}$ as a probability to feed water in state change in this interval. Under this assumption, λ_B is 0.25/1440.

The probability of no state changed from A is derived as follows;

$$Pois(\lambda_A, 0) = \frac{(\lambda_A)^0}{0!} e^{-\lambda_A} = e^{-8/1440}$$

since a day consists of 1440 minutes.

And The probability of no state changed from B is $Pois(\lambda_B, 0) = e^{-1/5760}$, **Information Estrangement** is calculated from formula (1) and those two values and get the result $IE(8, 0.25, 1440) = 89.8953$.

6.5 Interpretation of Information Estrangement

Figure 2 shows a Information Estrangement plot by the monitor frequency x(times/day).

This graph had plotted following function;

$$IE(8, 0.25, x) = \frac{1}{\sqrt{H(e^{-(8/x)}) \cdot H(e^{-(0.25/x)})}}$$

and when $x \cong 5.5364$ (nearly once per 4 hours and 20 minutes) took minimum value 2.2051.
This graph has following features;

- $IE(\lambda_A, \lambda_B, x)$ is defined on the open interval $(0, \infty)$ and tends to ∞ when $x \to 0$ and $x \to \infty$
- $IE(\lambda_A, \lambda_B, x)$ has a certain positive minimum value in this interval.
- When x decreases from the minimum and approaches 0, $IE(\lambda_A, \lambda_B, x)$ increases exponentially.
- When x increases from the minimum value, $IE(\lambda_A, \lambda_B, x)$ increases almost linearly.

$IE(\lambda_A, \lambda_B, x)$ depends on three parameters; I_A,I_B and the interval of observation. In the definition of Information Estrangement, When λ_A and λ_B are fixed, the best interval of observation x can be calculated and find from the formula.

The authors propose Information Estrangement as a first approximation of **distance in information**. There are some merits as follows;

- There is a certain minimum value in the interval of communications.
- More or less frequent interval derive a larger value which means the worse relationship.

7 Conclusions and issues

The authors had developed a yet another remote plant cultivating tool and reported the cherry tomato cultivation using this. From this experiment the authors proposed a new metric named **Information Estrangement**. This metric would be in early stage but it would be worth for more discussion.

Information Estrangement would be applicable to optimize the monitor interval rate and the care rate to the elders, the infants and the pets derived to the incidence rate of the accidents.

And about the user interface study, there is not a good measure of comfortable interaction. The authors have a hope to refine Information Estrangement and bring in this metric in the user interface study.

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The referees suggested to extrapolate results of the experiment to the Poisson distribution. According to the suggestion, the authors completely rewrote Section 6.

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