Method for Determination of Tealeaf Plucking Date with Cumulative Air Temperature: CAT and Photosynthetically Active Radiation: PAR

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***Abstract*—Method for determination of tealeaf plucking date with cumulative air temperature and Photosynthetically Active Radiation: PAR which is provided by the remote sensing satellites: Terra/MODIS and Aqua/MODIS is proposed. Also, a confirmation of thermal environment at the intensive study tea farm areas with Landsat-9 TIR (Thermal Infrared) image is conducted. Through a regressive analysis between the harvested tealeaf quality and the cumulative air temperature and PAR at the intensive study areas, it is found that there is a highly reliable relation between both. Also, an importance of air temperature environment at the sites is confirmed with Landsat-9 TIR image.**

Keywords*—*Plucking date; elapsed days after sprouting; cumulative air temperature; Landsat-9 TIR; theanine; regressive analysis

I. Introduction

It is obvious that nitrogen rich tealeaves taste good while fiber rich tealeaves taste bad. Theanine: 2-Amino-4-(ethyl carbamoyl) butyric acid that is highly correlated to nitrogen contents in new tealeaves are changed to catechin [1],[2],[3] due to sun light. In accordance with sunlight, new tealeaves growth up so that there is a most appropriate time for harvest to maximize harvest amount and taste of new tealeaves simultaneously. On the other hand, fiber content indicates the age of the tealeaf in concern. Fiber content is getting large in accordance with the age and old tealeaf is getting harder. Therefore, young tealeaf is much tasty rather than the old taleaf.

Depending on the elapsed days after sprouting, tealeaf quality (theanine content) is decreased. On the other hand, tealeaf yield is increased with increasing of the days after sprouting. Therefore, there is most appropriate plucking date and is very important. Usually, it is determined by the Normalized Difference Vegetation Index: NDVI derived from handheld NDVI cameras, drone mounted NDVI cameras, and visible to Near Infrared: NIR radiometer onboard satellites because NIR reflection and NDVI depend on tealeaf quality and yield. It, however, does not work so well in terms of poor regression accuracy (r^2 value: determination coefficient) and there is a species dependency. Moreover, it takes time consumable works for finding appropriate tealeaves for determination from the acquired camera images [4].

Although the previous method for determination of most appropriate plucking date using the elapsed days after sprouting is effective in some extent, reliability of the method is not good enough. The method proposed here for determination of most appropriate plucking date is using the cumulative air temperature together with Photosynthetically Active Radiation: PAR derived from Terra and Aqua satellites at the tea farm areas. PAR represents much more directly connected with the tealeaf quality (theanine content) than the other factors, air temperature, sunshine duration time a day. This approach is totally new and is expected to improve reliability of the method. Experiments with the proposed method are conducted and confirmed its reliability with the thermal environment at the areas with Landsat-9 TIR image (thermal environment). Plucking date determination with PAR and cumulative air temperature is the first attempt, brand new approach.

In the following section, the research background is described followed by the proposed method. Then, the experimental method together with experimental results are described. After that, concluding remarks and some discussions are also described.

II. Related Research Works

There are some related research works to the determination of the most appropriate plucking date determination for harvesting the best quality of tealeaves, theanine content rich tealeaves. This section describes such those research works from a methodology point of view.

A method for estimation of grow index of tealeaves based on Bi-directional Reflectance Distribution Function: BRDF measurements with ground-based network cameras is proposed [5]. Wireless sensor network for tea estate monitoring in complementally usage with Earth observation satellite imagery data based on Geographic Information System: GIS is also proposed and validated through a plenty of experiments [6]. A method for estimation of total nitrogen and fiber contents in tealeaves with ground-based network cameras is, on the other hand, proposed [7].

Monte Carlo Ray Tracing: MCRT simulation for BRDF and grow index of tealeaves estimation is conducted with the ground truth data [8] together with fractal model-based tea tree and tealeaves model for estimation of well opened tealeaf ratio which is useful to determine tealeaf harvesting timing of plucking date [9]. Grow index can be measured with green meter of instruments. Using this, growing processes are monitored.

Meanwhile, a method for tealeaves quality, theanine content estimation through measurements of degree of polarization, Leaf Area Index: LAI, photosynthesis available radiance (PAR) and normalized difference vegetation index (NDVI) for characterization of tealeaves is proposed [10]. On the other hand, optimum band, and band combinations for retrieving total nitrogen, which is closely related to the theanine content, water, fiber, etc. in tealeaves through remote sensing based on regressive analysis is discussed [11].

Appropriate tealeaf harvest timing (plucking date) determination based on NIR images of tealeaves is attempted [12] together with appropriate harvest timing determination referring fiber content in tealeaves derived from ground based NIR camera images [13].

Method for vigor diagnosis of tea trees based on nitrogen content in tealeaves relating to NDVI is proposed [14]. In the meantime, cadastral and tea production management system with wireless sensor network, GIS, based system and IoT technology is created [15].

BRDF model for new tealeaves and tealeaves monitoring with network cameras is well reported [16] together with BRDF model for new tealeaves on old tealeaves and new tealeaves monitoring through BRDF measurement with web cameras [17].

Estimation method for total nitrogen and fiber contents in tealeaves as well as grow index of tealeaves and tea estate monitoring with network cameras is proposed [18]. Meanwhile, multi-layer observation for agricultural (tea and rice) field monitoring is overviewed [19]. Furthermore, Tealeaf plucking workloads and environmental studies is conducted [20].

III. Research Background

Accelerating market-in product creation is desired so that strengthening production area power to win the competition between production areas. Also, special crop is focused. Meantime, further expansion of strategic items is required together with enhancement of safe and secure product supply system and promotion of environment-friendly agriculture, forestry, and fisheries. Further acceleration of structural reform for realization of smart agriculture, forestry, and fisheries. Also, labor saving and efficiency improvement of work.

With the conversion of tea gardens to adultery, the development of base tea factories is underway, and it is important to secure a stable supply of actual demand and profitability commensurate with investment.

The management scale of the contracted tea plantation exceeds 40 ha per corporation, and it is an issue to achieve both work efficiency and proper management at the production site.

Therefore, it is important to establish management technology for the second tea season, when working conditions are strict, and improve quality. The following items are, therefore, major concern,

1) Clarification of criteria for determining the appropriate time for plucking.

2) Development of technology for extending the optimum plucking period.

3) Introduction of physical control technology.

For that, it is developed a diagnostic imaging technology that is supposed to be installed in a field management system and improve labor productivity through advanced use of the system. Development of ichiban-cha[1] (first plucking tealeaves of a year) sprouting day specific technology by image diagnosis is needed which results in the following steps are needed.

Sprouting date identification → Growth diagnosis → Optimal plucking time → Appropriate prediction management

After sprouting (after plucking), the growth of each tea season is diagnosed from the accumulated temperature. Thus, the following items are getting much important,

1) The first tea sprouting day is the reference date for the start of tea growth.

2) In the annual management system until winter dormancy.

3) An important element of growth diagnosis.

In the past, experienced people made judgments based on their own perspective.

To realize the following economic effects by introducing new technology for tea producers, profit improvement by quality improvement for second plucking tealeaves in particular, improvement of labor productivity is needed.

IV. Proposed Method

Although the previous method for determination of most appropriate plucking date using the elapsed days after sprouting is effective in some extent, accuracy and reliability of the method are not good enough. Another attempt for determination of most appropriate plucking date using the cumulative air temperature which is obtained from the meteorological agency in Japan and PAR derived from Terra and Aqua satellite at the tea farm areas is proposed here together with a confirmation of its validity with the thermal environment at the areas with Landsat-9 TIR image. Plucking date determination with PAR is the first attempt, brand new approach together with the cumulative air temperature.

A component with a wavelength of 400 to 700 nm (effective photosynthesis wavelength range) used for photosynthesis of green leafy plants. Normally, the light that passes through clouds and the atmosphere from the sun and reaches the surface of the earth has a wavelength range of 300 to 4,000 nm, of which the energy ratio of the wavelength range of photosynthetically active radiation is about 45%. Some of the light that hits the leaves is not absorbed but is reflected on or inside the leaves or passes through the leaves. Since the photosynthetic pigment absorbs the red and blue wavelength regions of the photosynthetically active radiation well, the reflected light contains a large amount of the green wavelength region. That is why the leaves look green. Photosynthetically active radiation is measured in units of energy (W/m^2) or $mol/m^2/s$ as the photosynthetic effective wavelength region photosynthetic flux density (photosynthetic effective photon flux density). In tea cultivation, around 88 nights, counting from the beginning of spring, is the time to pick the shoots that contain plenty of nutrients stored during the winter. The climate

[1]Tea is called "Cha" in Japanese.

differs depending on the production area, so there are various times when new tea is picked. In warm Kagoshima, early April, in Shizuoka, mid-April, and in Kyoto, etc., new tea picking often starts from late April to early May. Therefore, plucking date determination using cumulative days after Lichen: the first day of spring is meaningful but not so accurate. Meanwhile, PAR is directly present a required light energy from the sun. Therefore, it is expected that much accurate plucking date determination can be done with PAR rather than cumulative date from the Lichen.

In order to investigate a relation between nitrogen content in the harvested tealeaf and cumulative air temperature, regressive analysis is conducted together with a relation between NDF: fiber content in the harvested tealeaf. Cumulative air temperature can be gathered from the meteorological agency of Japan. Also, Landsat-9 TIR image can be gotten through EO browser site provided by European Space Agency: ESA[2]. On the other hand, PAR data can be downloaded from the NASA Earth Data Search site[3]. It is MODIS/Terra and MODIS/Aqua Photosynthetically Active Radiation Daily/3-Hour L3 Global 5km SIN Grid V006 data.

V. Experiment

A. Intensive Study Area

The intensive study area is situated at Oita Prefectural Agriculture, Forestry and Fisheries Research Center, Bungo Ohno in Oita Prefecture, Japan 32.99 N, 131.59 E). The institute is established by Oita prefectural local government for promoting agriculture, forestry and fisheries as well as training and guidance of farmers and fishermen. Fig. 1 shows the location of the intensive study area. There is experimental tea farming area in which several species of tea trees (Okumidori, Fushun, Sayama-Kaori, Meiryoku, and Yabukita) are planted.

The tea tree ``Okumidori", which is the basis of sencha, is a breed made by crossing ``Yabukita", ``Yabukita" and ``Shizuoka Zairai No. 16", and it reaches its season after ``Yabukita". It is characterized by its mild taste and low bitterness. It is also attracting attention as tencha (a raw material for tencha and matcha) and gyokuro. Okumidori tea tree has a large number of buds, so you can expect a large yield.

In ``Fushun", which has a slightly upright tree, if the spacing between plants is 60 cm and the row spacing is changed from the customary 50 cm to 25 or 60 cm, the annual yield of fresh leaves will decrease. In the case of Fushun, when the row spacing is 50 cm, the annual fresh leaf yield decreases when the plant spacing is increased from the conventional 60 cm to 75 cm and the planting density is reduced to 80% of the conventional planting density (1481 plants/10a).

“Sayamakaori” is characterized by its strong aroma. The leaves are firmer and have a better shape than Yabukita tea. Because it contains a lot of catechins, which are tannins, the tea has a strong and astringent taste.

The plucking period of ``Meiryoku" is the same as or slightly earlier than that of ``Yabukita", and the tree is vigorous and grows vigorously. Four or five years after planting, the total yield of first and second tea leaves is relatively high. The quality is the same as or slightly better than that of Yabukita. It is suitable because it is rather strong.

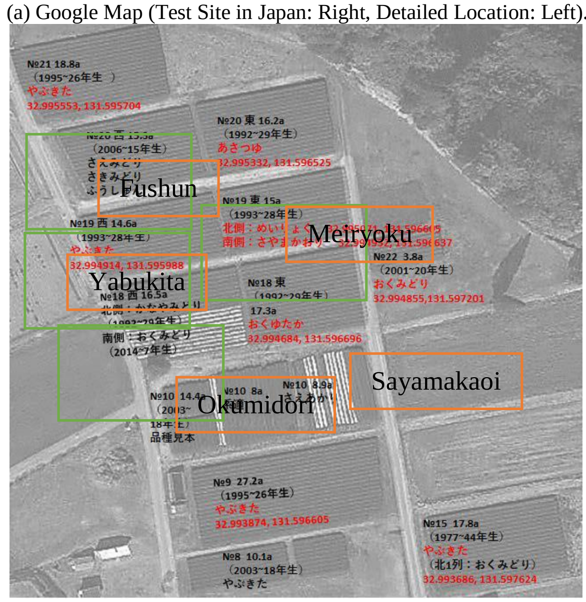
One of the characteristics of "Yabukita" is its strong cold resistance. It is resistant to red wilt, blue wilt, and frost damage. It is also characterized by good rooting and is highly adaptable to various soils. Another strength in terms of growth is that the roots and shoots are uniform and grow quickly, making it easy to replant. For this reason, it is highly rated by farmers as an easy-to-grow variety.

B. Estimation of Most Appropriate Plucking Date

The most appropriate plucking date is defined as the date on when the nitrogen content in a harvested tealeaf is getting maximum and Neutral Detergent Fiber: NDF of fiber content in a harvested tealeaf is much lower. Nitrogen content is proportional to Theanine of Amino Acid which is highly correlated to the taste of tea. On the other hand, fiber content is negatively proportional to the age of tealeaf (obviously, young tealeaf is much better quality).

If harvest day is delayed, then Theanine changes to catechin (taste not so good) and fiber content is getting large. Therefore, it is important to determine the most appropriate plucking date. Through a monitor the nitrogen content and fiber content, then the most appropriate plucking date can be determined. In the proposed method, cumulative air temperature after the sprouting is used.

(a) Google Map (Test Site in Japan: Right, Detailed Location: Left).

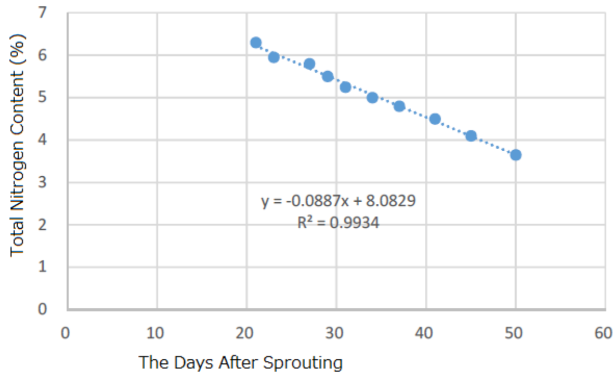


(b) Detailed Location of the Test Site for Five Species of Tealeaves.

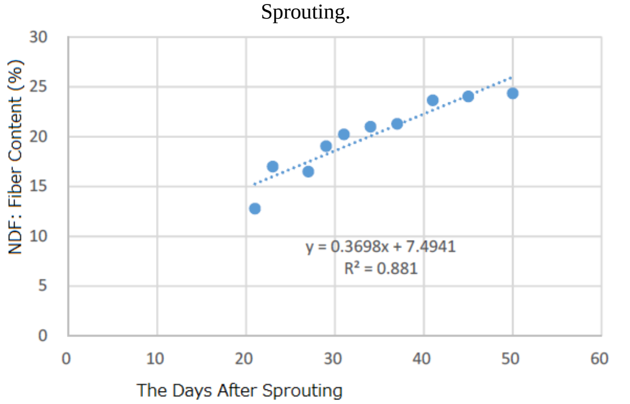
Fig. 1. Intensive Study Area of Bungo Ohno, Oita, Japan.

[2] https://apps.sentinel-hub.com/eo-browser/

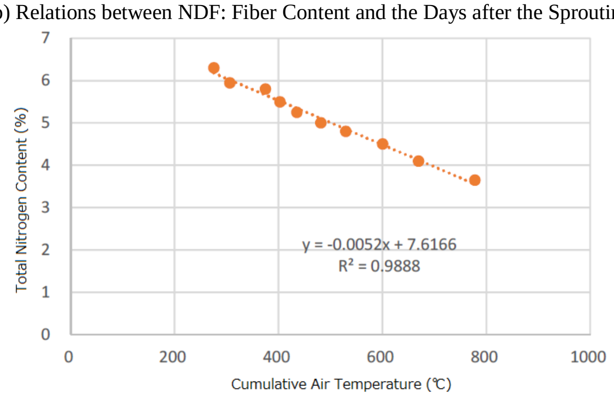
[3] https://search.earthdata.nasa.gov/search/granules?p=C1420474189-LPDAAC_ECS&pg[0][v]=f&pg[0][gsk]=-start_date&q=C1420474189-LPDAAC_ECS&sb[0]=130.85156%2C32.56312%2C131.48438%2C33.19624&tl=1652665964!3!!&lat=30.758713867830966&long=105.046875&zoom=3



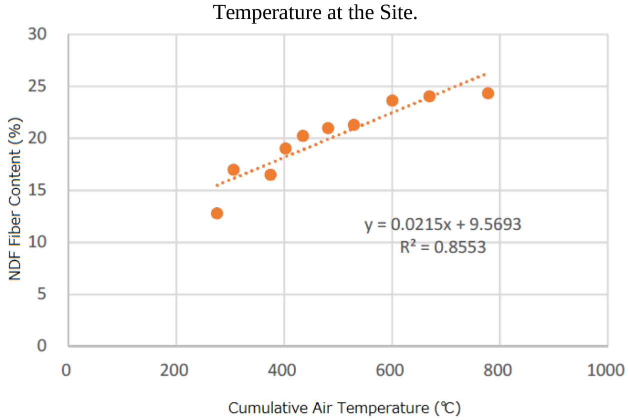
(a) Relations between Total Nitrogen Content and the Days after the Sprouting.



(b) Relations between NDF: Fiber Content and the Days after the Sprouting.



(c) Relations between Total Nitrogen Content and the Cumulative Air Temperature at the Site.



(d) Relations between Fiber Content and the Cumulative Air Temperature at the Site.

Fig. 2. Relations between Total Nitrogen Content and NDF: Fiber Content and the Days after the Sprouting as well as the Cumulative Air Temperature.

Fig.2 (a), (b) shows relations between (1) total nitrogen content and the days after the sprouting as well as (2) fiber content and the days after the sprouting. Fig.2 (c), (d) shows relations between (3) total nitrogen content and the cumulative air temperature as well as (4) fiber content and the cumulative air temperature at the fields.

C. *Relation among Cumulative Air Temperature, Solar Irradiance and PAR*

In these cases, cumulative air temperature and irradiance as well as PAR after the Vernal Equinox Day is shown in Fig. 3. In Fig. 3, PAR data is downloaded through the NASA Earth Data Search site. A screenshot of the site as searching the intensive study area is shown in Fig. 4.

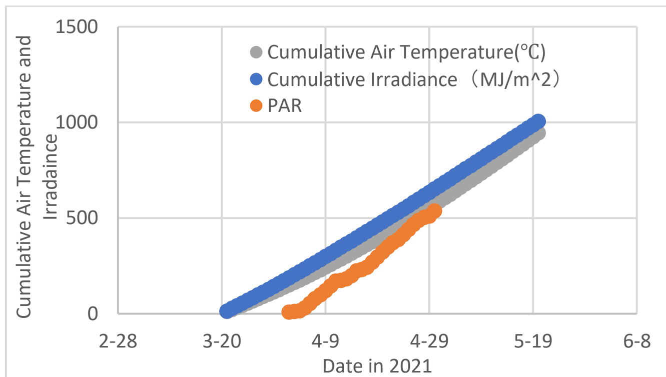


Fig. 3. Relation among Cumulative Air Temperature and Irradiance as Well as PAR after the Vernal Equinox Day.

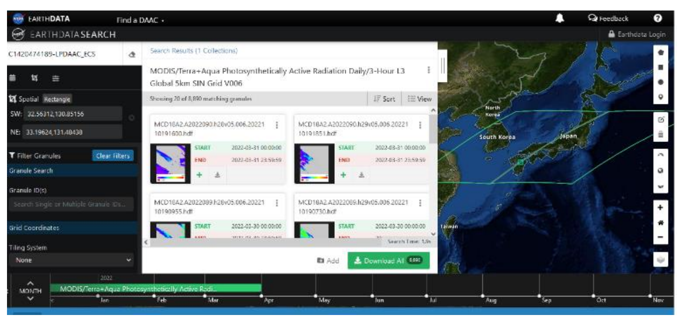


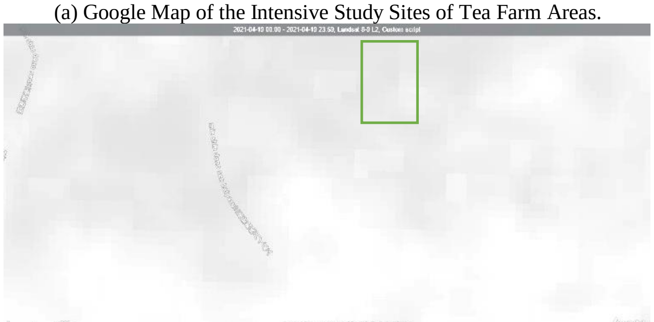
Fig. 4. NASA Earth Data Search Site.

D. *Confirmation of Uniformity of Air Temperature at the Sites*

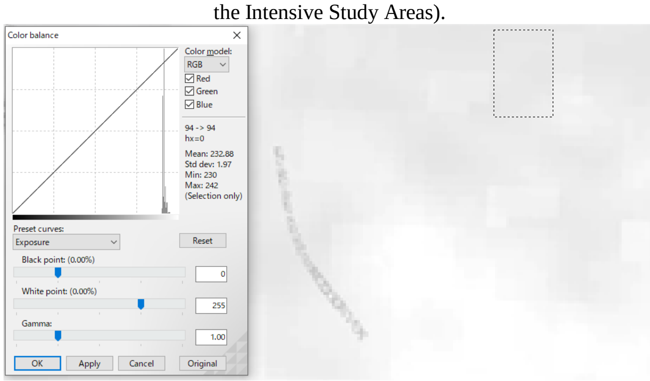
It is found that the most appropriate plucking date can be determined with cumulative air temperature. The next thing it would be better to do is confirmation of uniformity of air temperature at the sites because the temperature environment in the sites is not uniform. In order to check the uniformity, Landsat-9 TIR image which is acquired on 19 April 2021 is used. Fig. 5 shows the intensive study site of tea farm areas and thermal infrared image which is taken by Landsat-9 satellite and, false color composite image which is acquired by Landsat-9 satellite.

Table I shows the specification of Landsat-9 of TIR-1 and 2. Thermal environment can be evaluated with Landsat-9/TIR-2 of band 11 data with 100 m of spatial resolution. As a result, it is found that the temperature environment in the sites is uniform enough with 232.88 (Mean) and 1.97 (Standard Deviation).

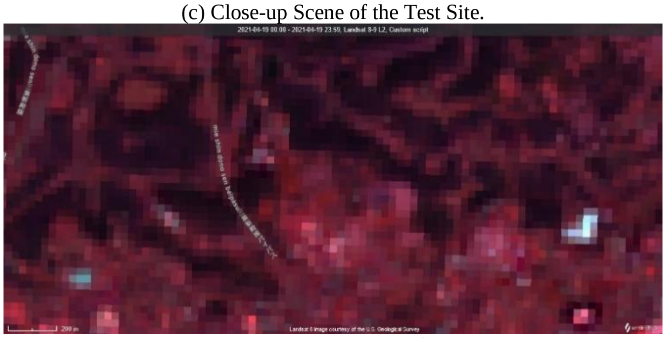
(a) Google Map of the Intensive Study Sites of Tea Farm Areas.



(b) Landsat-9/L2: Brightness Temperature Image (Orange Rectangle Shows the Intensive Study Areas).



(c) Close-up Scene of the Test Site.



(d) False Color Composite Image of Landsat-9/L1.

Fig. 5. Intensive Study Site of Tea Farm Areas and Thermal Infrared Image Which is Taken by Landsat-9 Satellite and, False Color Composite Image Which is Acquired by Landsat-9 Satellite which is Acquired on 19 April 2021.

TABLE I. SPECIFICATION OF LANDSAT-9 OF TIR-1 AND 2

Band No.	Thermal No.	Wavelength Region	Spatial Resolution
Band 10	TIR 1	10.60–11.19	100m
Band 11	TIR 2	11.50–12.51	100m

VI. Conclusion

A method for estimation of most appropriate tealeaf plucking date is proposed. The method uses cumulative air temperature, Photosynthetically Active Radiation: PAR, and thermal environment. These are gathered from the remote sensing satellite data. Through a regressive analysis between the harvested tealeaf quality and the cumulative air temperature at the intensive study areas, it is found that there is a highly reliable relation between both. Thus, the tealeaves quality of theanine content can be monitored and also the plucking date can be determined maximizing the theanine content in tealeaves.

VII. Future Research Works

Next thing it would be better to do is estimation of most appropriate harvest date with deep learning which can be applied to these estimations.

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