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Editorial Preface

From the Desk of Managing Editor…

"The question of whether computers can think is like the question of whether submarines can swim." ― Edsger W. Dijkstra, the quote explains the power of Artificial Intelligence in computers with the changing landscape. The renaissance stimulated by the field of Artificial Intelligence is generating multiple formats and channels of creativity and innovation.

This journal is a special track on Artificial Intelligence by The Science and Information Organization and aims to be a leading forum for engineers, researchers and practitioners throughout the world.

The journal reports results achieved; proposals for new ways of looking at AI problems and include demonstrations of effectiveness. Papers describing existing technologies or algorithms integrating multiple systems are welcomed. IJARAI also invites papers on real life applications, which should describe the current scenarios, proposed solution, emphasize its novelty, and present an in-depth evaluation of the AI techniques being exploited. IJARAI focusses on quality and relevance in its publications.

In addition, IJARAI recognizes the importance of international influences on Artificial Intelligence and seeks international input in all aspects of the journal, including content, authorship of papers, readership, paper reviewers, and Editorial Board membership.

The success of authors and the journal is interdependent. While the Journal is in its initial phase, it is not only the Editor whose work is crucial to producing the journal. The editorial board members , the peer reviewers, scholars around the world who assess submissions, students, and institutions who generously give their expertise in factors small and large— their constant encouragement has helped a lot in the progress of the journal and shall help in future to earn credibility amongst all the reader members.

I add a personal thanks to the whole team that has catalysed so much, and I wish everyone who has been connected with the Journal the very best for the future.

Thank you for Sharing Wisdom!

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Numerical Deviation Based Optimization Method for Estimation of Total Column CO_2 Measured with Ground Based Fourier Transformation Sepectormeter: FTS Data

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***Abstract*—Numerical deviation based optimization method for estimation of total column CO_2 measured with ground based Fourier Transformation Spectormeter: FTS data is proposed. Through experiments with aircraft based sample return data and the ground based FTS data, it is found that the proposed method is superior to the conventional method of Levenberg Marquads based nonlinear least square method with analytic deviation of Jacobian and Hessean around the current solution. Moreover, the proposed method shows better accuracy and required computer resources in comparison to the internationally used method (TCCON method) for estimation of total column CO_2 with FTS data. It is also found that total column CO_2 depends on weather conditions, in particular, wind speed.**

Keywords—FTS; carbon dioxide; methane; sensitivity analysis; error analysis

I. INTRODUCTION

Greenhouse gases Observing SATellite: GOSAT carries TANSO CAI for clouds and aerosol particles observation of mission instrument and TANSO FTS[1]: Fourier Transformation Spectrometer [2] for carbon dioxide and methane retrieving mission instrument [1]. In order to verify the retrieving accuracy of two mission instruments, ground based laser radar and TANSO FTS are installed. The former is for TANSO CAI and the later is for FTS, respectively. One of the other purposes of the ground-based laser radar and the ground-based FTS is to check sensor specifications for the future mission of instruments to be onboard future satellite with extended mission. Although the estimation methods for carbon dioxide and methane are well discussed [2]-[6], estimation method which takes into account measurement noise is not analyzed yet. Therefore, error analysis for additive noise on estimation accuracy is conducted.

In order to clarify requirement of observation noises to be added on the ground-based FTS observation data, Sensitivity analysis of the ground-based FTS against observation noise on retrievals of carbon dioxide and methane is conducted. Experiments are carried out with additive noise on the real acquired data of the ground-based FTS. Through retrievals of total column of carbon dioxide and methane with the noise added the ground-based FTS signals, retrieval accuracy is evaluated. Then an allowable noise on the ground-based FTS which achieves the required retrieval accuracy (1%) is reduced [7].

In the paper, Numerical Deviation Based Optimization Method for Estimation of Total Column CO_2 Measured with Ground Based Fourier Transformation Spectormeter: FTS Data is proposed. Through experiments with aircraft based sample return data and the ground based FTS data, it is found that the proposed method is superior to the conventional method of Levenberg-Marquardt: LM [8] based nonlinear least square method with analytic deviation of Jacobian and Hessian around the current solution [9]. Moreover, the proposed method shows

[1] http://www.jaxa.jp/projects/sat/gosat/index_j.html

[2] http://ja.wikipedia.org/wiki/%E3%83%9E%E3%82%A4%E3%82%B1%E3%83%AB%E3%82%BD%E3%83%B3%E5%B9%B2%E6%B8%89%E8%A8%88

better accuracy and shorter required computer resources in comparison to the TCCON[3] data [10],[11]) for estimation of total column CO_2 with FTS data. It is also found that total column CO_2 depends on whether condition, in particular, wind speed with aircraft based sample return data [12] and ground based FTS data. The following section describes the proposed method for total column CO_2 estimation with FTS data followed by some experiments with ground based and aircraft based sample return data. Then concluding remarks with some discussions is described.

II. Proposed Method

A. *Ground-based FTS*

Figure 1 shows schematic configuration of the ground-based FTS which is originated from Michelson Interference Measurement Instrument. Light from the light source divided in to two directions, the left and the forward at the dichotic mirror of half mirror. The left light is reflected at the fixed hold mirror and reaches to the half mirror while the forward light is reflected at the moving mirror and reaches at the half mirror. Then interference occurs between the left and the forward lights. After that interference light is detected by detector. Outlook of the ground-based FTS is shown in Figure2.

Figure 3 (a) shows an example of the interferogram[4] (interference light detected by the detector of the ground-based FTS). By applying Fourier Transformation to the interferogram, observed Fourier spectrum is calculated as shown in Figure 3 (b). When the ground-based FTS observes the atmosphere, the observed Fourier spectrum includes absorptions due to atmospheric molecules and aerosol particles. By comparing to the spectrum which is derived from the radiative transfer code with atmospheric parameters, atmospheric molecules and aerosol particles are estimated.

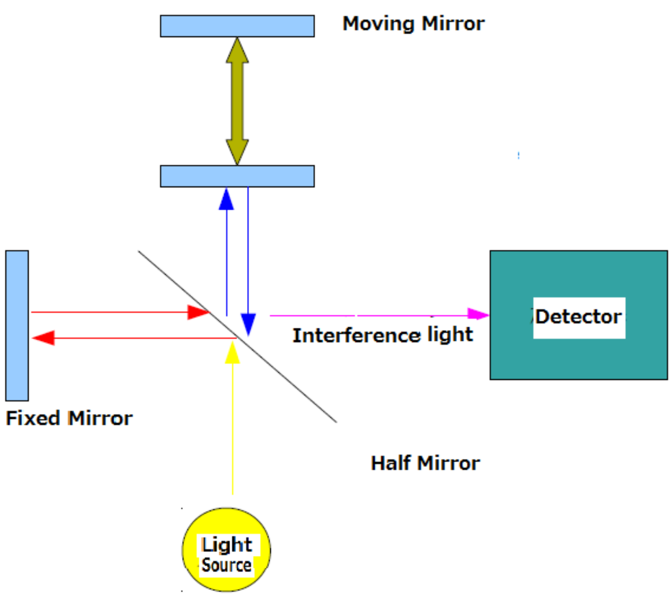


Fig. 1. Michelson Interference Measurement Instrument

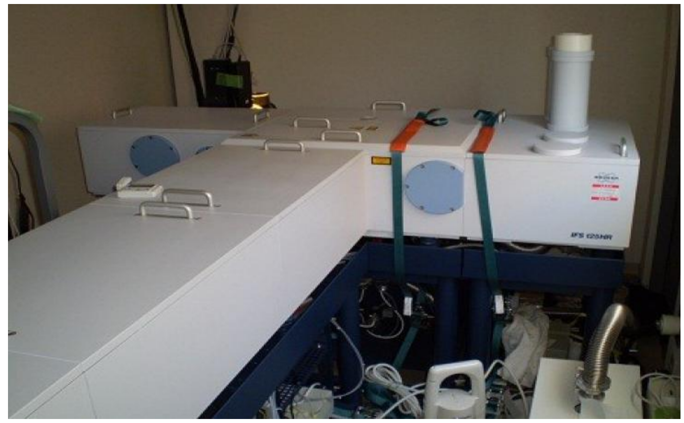
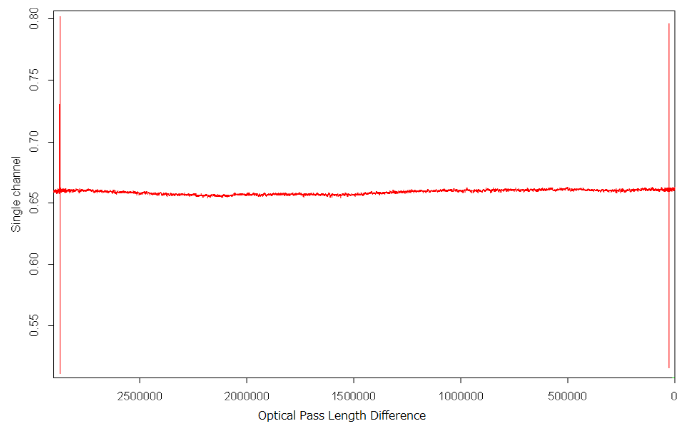
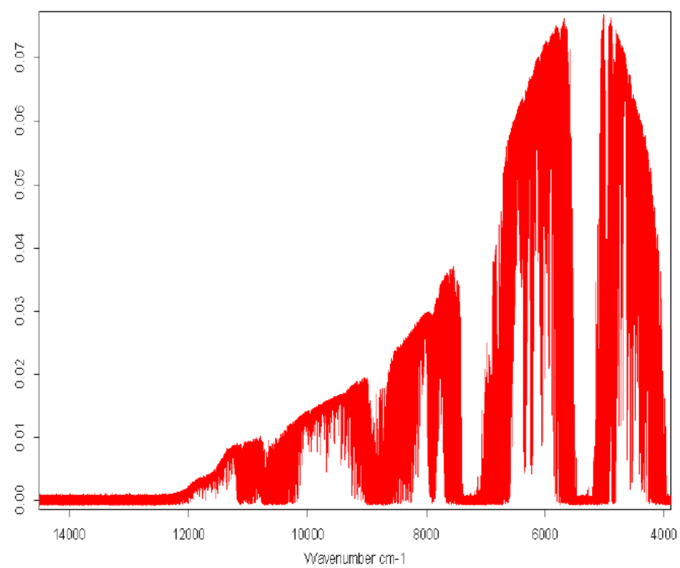


Fig. 2. Outlook of the FTS used



(a)Interferogram



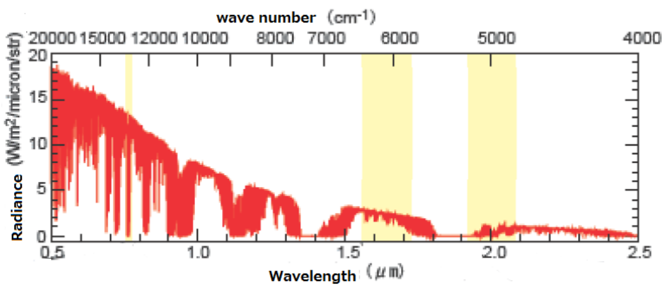
(b)Fourier spectrum

Fig. 3. Examples of interferogram and Fourier spectrum when FTS observes the atmosphere

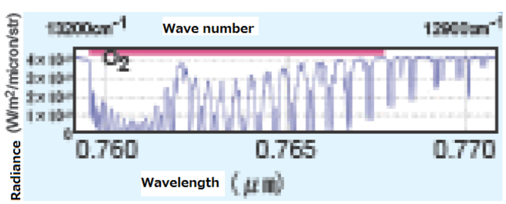
[3] https://tccon-wiki.caltech.edu/Network_Policy/Data_Use_Policy#References_and_Contact_Information
[4] http://en.wikipedia.org/wiki/Interferometry

B. Principle for Carbon Dioxide and Methane Retrievals with TANSO FTS Data

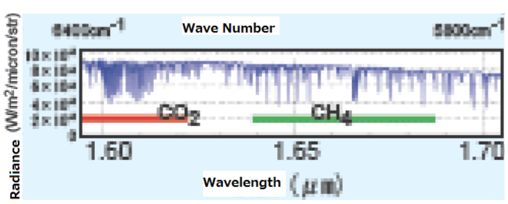
Figure 4 shows a principle of the retrieval method for atmospheric continuants using GOSAT/TANSO data. Figure 4 (a) shows Top of the Atmosphere: TOA radiance in the wavelength ranges from 500 to 2500nm (visible to shortwave infrared wavelength regions). There are three major absorption bands due to oxygen (760-770nm), carbon dioxide and methane (1600-1700nm), and water vapor and carbon dioxide (1950-2050nm) as shown in Figure 4 (b), (c), and (d), respectively. These bands are GOSAT/TANSO spectral bands, Band 1 to 3, respectively. In addition to these, there is another wide spectrum of spectral band, Band 4 as shown in Figure 4(e) which covers from visible to thermal infrared regions..



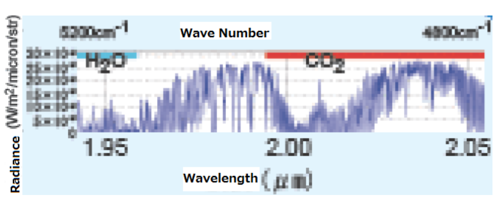
(a)TOA radiance



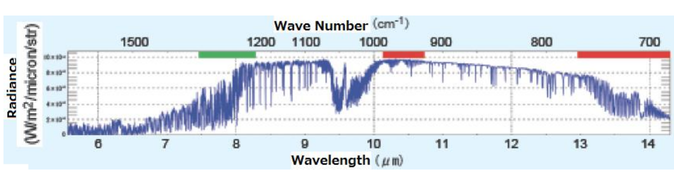
(b)Band 1



(c)Band 2



(d)Band 3



(e)Band 4

Fig. 4. Example of TOA radiance and absorption bands as well as spectral bands of GOSAT/TANSO instrument

C. Estimation Algorithm Description

The conventional method for estimation of CO_2 is as follows, (1) Estimated spectrum derived from atmospheric simulator with atmospheric parameters including CO_2 and the actual FTS derived spectrum is compared, (2) then the initial atmospheric condition are updated for minimizing the square of difference between spectra derived from simulator and the actual FTS data iteratively. In order to minimize the square of difference, LM method is used in the conventional method as follows,

$$min\ S = \sum_{i=1}^{N}(y_i - y(x_i;\mathbf{a}))^2 \tag{1}$$

where S denotes square difference, y_i and $y(x_i,a)$ denote actual spectrum and simulated spectrum with atmospheric condition of a,

$$\mathbf{a} = (a_1, a_2, \cdots, a_M) \tag{2}$$

A can be updated as follows,

$$\mathbf{a_{k+1}} = \mathbf{a_k} + \Delta\mathbf{a_k} \tag{3}$$

where $\Delta\mathbf{a_k}$ is determined as the following equation is satisfied.

$$(\mathbf{H}(\mathbf{a_k}) + \lambda\mathbf{H}(\mathbf{a_k}))\Delta\mathbf{a_k} = \mathbf{J}^T(\mathbf{a_k})\Delta\mathbf{y}(x;\mathbf{a_k}) \tag{4}$$

where H and J denote Hessian and Jocobian, respectively.

$$\Delta\mathbf{y}(x;\mathbf{a_k}) = (\ y_1 - y(x_1;\mathbf{a}), y_2 - y(x_2;\mathbf{a}), \cdots, y_N - y(x_N;\mathbf{a})\ ) \tag{5}$$

$$\mathbf{J}(\mathbf{a_k}) = \begin{bmatrix} \frac{\partial S}{\partial a_1} & \frac{\partial S}{\partial a_2} & \cdots & \frac{\partial S}{\partial a_M} \\ \frac{\partial S}{\partial a_1} & \frac{\partial S}{\partial a_2} & \cdots & \frac{\partial S}{\partial a_M} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial S}{\partial a_1} & \frac{\partial S}{\partial a_2} & \cdots & \frac{\partial S}{\partial a_M} \end{bmatrix} \tag{6}$$

$$\mathbf{H}(\mathbf{a_k}) = \begin{bmatrix} \frac{\partial^2 S}{\partial a_1 \partial a_1} & \frac{\partial^2 S}{\partial a_1 \partial a_2} & \cdots & \frac{\partial^2 S}{\partial a_1 \partial a_M} \\ \frac{\partial^2 S}{\partial a_2 \partial a_1} & \frac{\partial^2 S}{\partial a_2 \partial a_2} & \cdots & \frac{\partial^2 S}{\partial a_2 \partial a_M} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 S}{\partial a_M \partial a_1} & \frac{\partial^2 S}{\partial a_M \partial a_2} & \cdots & \frac{\partial^2 S}{\partial a_M \partial a_M} \end{bmatrix} \tag{7}$$

where

$$\frac{\partial S}{\partial a_l} = -2\sum_{i=1}^{N}\{y_i - y(x_i;\mathbf{a})\}\frac{\partial y(x_i;\mathbf{a})}{\partial a_l} \tag{8}$$

$$\frac{\partial^2 S}{\partial a_l \partial a_m} = 2\sum_{i=1}^{N}\left[\frac{\partial y(x_i;\mathbf{a})}{\partial a_l}\frac{\partial y(x_i;\mathbf{a})}{\partial a_m} - \{y_i - y(x_i;\mathbf{a})\}\frac{\partial^2 y(x_i;\mathbf{a})}{\partial a_l \partial a_m}\right] \tag{9}$$

when the current solution is reached to one of minima, $y_i - y(x_i;\mathbf{a}) \approx 0$ so that the following approximation becomes appropriate,

$$\frac{\partial^2 S}{\partial a_l \partial a_m} = 2\sum_{i=1}^{N} \frac{\partial y(x_i;\mathbf{a})}{\partial a_l}\frac{\partial y(x_i;\mathbf{a})}{\partial a_m} \qquad (10)$$

In the solution space, the updated solution can be determined with relatively small step size for all directions in isotropic manner in the LM method as shown in Figure 5.

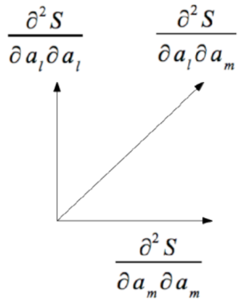


Fig. 5. Solution update directions for LM method

The method proposed here is the solution update direction can be determined arbitrary as shown in Figure 6.

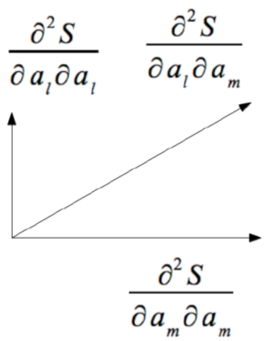


Fig. 6. Solution update directions for the proposed method

III. EXPERIMENTS

A. Ground-based FTS Data Used

The ground-based FTS data used for experiments are acquired on November 14 and December 19 2011. Figure 7 shows the interferograms derived from the acquired the ground-based FTS data.

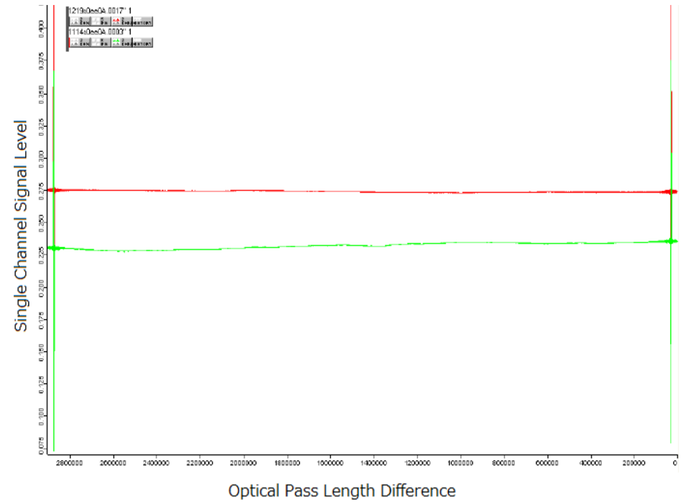


Fig. 7. Example of interferograms used for experiments

B. Experimental Method

Observation noise is included in the observed interferograms. In addition to the existing noise, several levels of additional noises which are generated by random number generator of Messene Twister with zero mean and several standard deviations is added on to the iterferograms as shown in Figure 8.

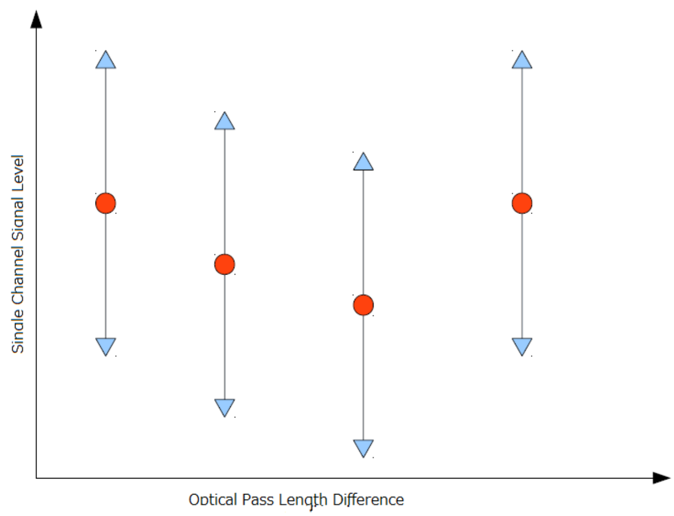


Fig. 8. Method for adding the noises to the acquired interferograms

C. Aircraft Based Sample Return Data Derived Total Column CO_2

Aircraft based sample return data is acquired with aircraft altitude of 500 m and 7km. Therefore, CO_2 for the atmosphere between two altitude can be retrieved. Using GlovalView-CO_2 model, CO_2 for the atmosphere above 7km is estimated. Also, it is assumed that CO_2 for the atmosphere below 500m can be the same CO_2 at 500m.

The conventional method utlizes the vertical profile model of GlobalView-CO_2. The profile can be estimated with the following equation,

$$c_s = \gamma c_a + \left(\frac{VC_{G,ak}{}^{airclaft} - \gamma VC_{G,ak}{}^{apriori}}{VC_{air}} \right) \quad (11)$$

where c_s denotes averaged column density of the dried atmosphere, $VC_{G,ak}$ denotes total column gas amount which is calculated with Rogers and Connor equation and vertical profile derived from the aforementioned model. Also, $VC_{G,ak}{}^{aircraft}$ denotes total column gas amount at the aircraft altitude.

D. Aircraft Based Sample Returnt Data Used

Aircraft based sample return data which are acquired on January 9 2012, January 13 2012 and January 15 2013 are used together with match-upped data of ground based FTS data. The number of data for each day is 116, 52, and 200 files, respectively.

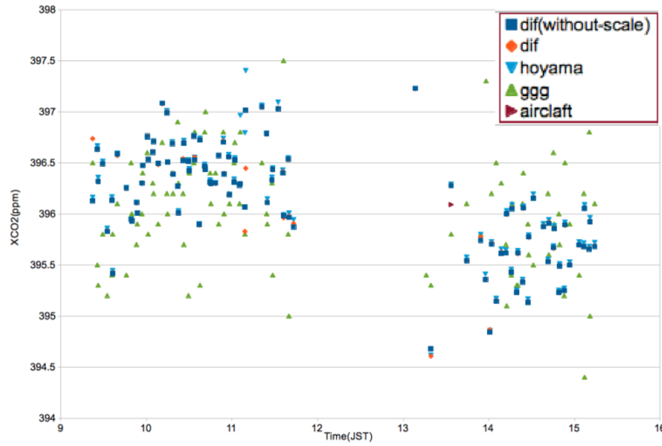
E. Experimental Results

Total column CO_2 for three days of experiments is estimated with the proposed method and compared to the TCCON data, Ohyama (LM method based retrieval) as well as actual aircraft based sample return data derived total column CO_2. Figure 9 shows the results.

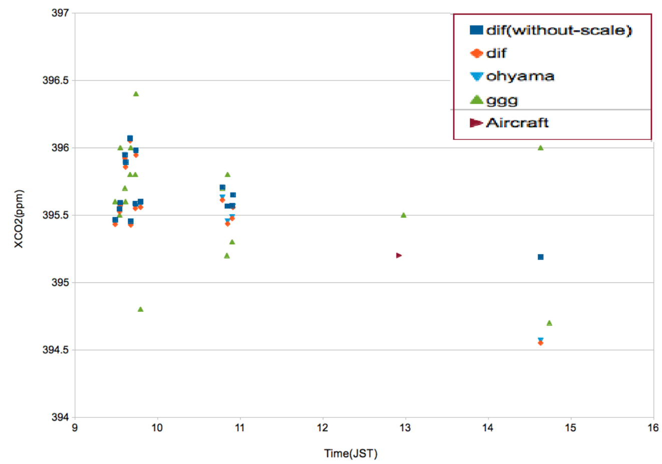
As shown in Table 1, it is found that the proposed method is superior to the other conventional methods in terms of estimation accuracy and the required computer resources. One of the reasons for this is that the proposed method allows update the next solution to the arbitrary directions with relatively large steps.

Table 2 shows weather conditions, atmospheric pressure, air temperature on the ground, Relative Humidity (RH), irradiant flax and the averaged wind speed on the ground. It was cloudy on January 9 and 13, 2012. In particular on January 13 2012, it was poor sun shine time period. Therefore, there are so many data missing.

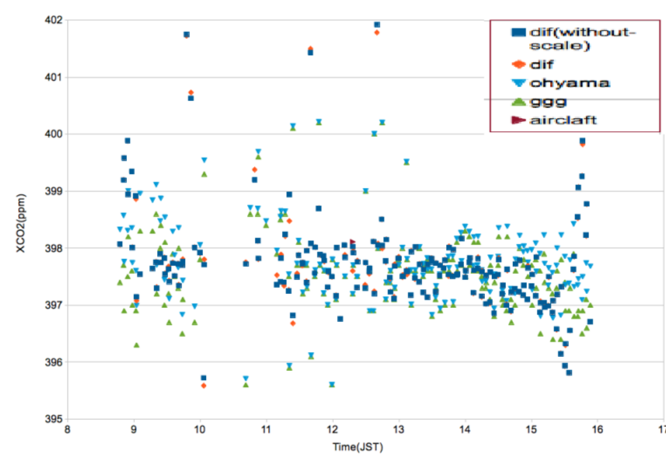
On the other hand, it was fine on January 15 2013. Therefore, the number of data points is greater than the other two days.



(a)January 9 2012



(b)January 13 2012



(c)January 15 2013

Fig. 9. Comparison among the estimated total column CO2 derived from the proposed method, the conventional methods, TCCON and LM method based retrievals

TABLE I. COMPARISON OF THE RESIDUAL RMS ERROR AGAINST TRUTH DATA DERIVED FROM AIRCRAFT WITH VERTICAL PROFILE MODEL AMONG THE PROPOSED, LM METHOD AND TCCON DATA

Date	Proposed	LM	TCCON
2012/1/9	0.429	0.438	0.467
2012/1/13			
2013/1/15	0.315	0.32	0.986

TABLE II. WEATHER CONDITIONS OF THE DATES FOR EXPERIMENTS

Date	Pressure (hPa)	Temp. (℃)	RH(%)	Irradiant Flax(MJ/m^2)	Wind(m/s)
2012/1/9	1022.8	7	66	9.23	2.7
2012/1/13	1020.1	4.8	65	4.99	1.8
2013/1/15	1019	6.7	55	12.39	4.2

IV. CONCLUSION

Numerical deviation based optimization method for estimation of total column CO_2 measured with ground based Fourier Transformation Spectormeter: FTS data is proposed. Through experiments with aircraft based sample return data and the ground based FTS data, it is found that the proposed method is superior to the conventional method of Levenberg Marquads based nonlinear least square method with analytic deviation of Jacobian and Hessean around the current solution. Moreover, the proposed method shows better accuracy and required computer resources in comparison to the TCCON data for estimation of total column CO_2 with FTS data. It is also found that total column CO_2 depends on weather conditions, in particular, wind speed.

Through the experiments with aircraft based sample return data (as the truth data) together with ground based FTS data, it is found that the proposed method is superior to the other conventional methods in terms of estimation accuracy and the required computer resources. One of the reasons for this is that the proposed method allows update the next solution to the arbitrary directions with relatively large steps.

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AUTHORS PROFILE

Kohei Arai, He received BS, MS and PhD degrees in 1972, 1974 and 1982, respectively. He was with The Institute for Industrial Science, and Technology of the University of Tokyo from 1974 to 1978 also was with National Space Development Agency of Japan (current JAXA) from 1979 to 1990. During from 1985 to 1987, he was with Canada Centre for Remote Sensing as a Post Doctoral Fellow of National Science and Engineering Research Council of Canada. He was appointed professor at Department of Information Science, Saga University in 1990. He was appointed councilor for the Aeronautics and Space related to the Technology Committee of the Ministry of Science and Technology during from 1998 to 2000. He was also appointed councilor of Saga University from 2002 and 2003 followed by an executive councilor of the Remote Sensing Society of Japan for 2003 to 2005. He is an adjunct professor of University of Arizona, USA since 1998. He also was appointed vice chairman of the Commission "A" of ICSU/COSPAR in 2008. He wrote 30 books and published 500 journal papers

Proposal of Tabu Search Algorithm Based on Cuckoo Search

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***Abstract*—This paper presents a new version of Tabu Search (TS) based on Cuckoo Search (CS) called (Tabu-Cuckoo Search TCS) to reduce the effect of the TS problems. The proposed algorithm provides a more diversity to candidate solutions of TS. Two case studies have been solved using the proposed algorithm, 4-Color Map and Traveling Salesman Problem. The proposed algorithm gives a good result compare with the original, the iteration numbers are less and the local minimum or non-optimal solutions are less.**

Keywords—Tabu Search; Cuckoo Search; Heuristic Search; Neighborhood Search; Optimization; 4-Color Map; TSP

I. Introduction

A huge collection of optimization techniques have been suggested by a crowd of researchers of different fields; an infinity of refinements have made these techniques work on specific types of applications. All these procedures based on some common ideas and are furthermore characterized by a few additional specific features. Among the optimization procedures, the iterative techniques play an important role; for most optimization problems no procedure is known in general to get directly an "optimal" solution [1].

The general steps of an iterative procedure consists in constructing from a current solution i to the next solution j and in checking whether one should stop there or perform another step. Neighborhood search methods are iterative procedures in which a neighborhood $N(i)$ is defined for each feasible solution i, and the next solution j is searched among the solutions in $N(i)$ [2,3,4].

The origin of the Tabu Search (TS) went back to the 1970s and the modern form of TS was derived independently by Glover and Hansen [4,5]. The hybrids of the TS have improved the quality of solutions in numerous areas such as scheduling, transportation, telecommunication, resource allocation, investment planning. The success of the TS method for solving optimization problems was due to its flexible memory structures which allowed the search to escape the trap of local optima and permitted to search the forbidden regions and explored regions thoroughly [2].

Cuckoo search was inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds (of other species). Some host birds can engage direct conflict with the intruding cuckoos. For example, if a host bird discovers the eggs are not their own, it will either throw these alien eggs away or simply abandon its nest and build a new nest elsewhere [7].

The objective of this paper is to improve the tabu search using the nature-inspired algorithm which cuckoo search. The outline of this paper is as follows. Section 2 describes the concepts of Tabu Search method with two basic algorithms. Section 3 includes the concepts of Cuckoo Search. Section 4 deals with proposal of Tabu-Cuckoo Search (TCS) algorithm. Section 4 presents 2 case studies which are solved by TCS and TS with experimental results of each one. Section 5 includes the conclusions of this paper.

II. Tabu Search

Tabu Search (TS) is a meta-heuristic search which is designed to cross the boundaries of feasibility and search beyond the space of local optimality. The use of flexible memory based structures is the center strategy of the TS method [7]. While most exploration methods keep in memory essentially the value $f(i^*)$ of the best solution i^* visited so far, TS will also keep information on the itinerary through the last solution visited. Such information will be used to guide the move from i to next solution j to be chosen in $N(i)$. The role f the memory will be to restrict the choice of some subset of $N(i)$ by forbidding for instance moves to some neighbor solutions [8]. It would therefore be more appropriate to include TS in a class of procedures called dynamic neighborhood search techniques [7].

Formally let us consider an optimization problem in the following way : given a set S of feasible solutions and a function $f : S \rightarrow \Re$, find some solution i^* in S such that $f(i^*)$ is acceptable with respect to some criterion (or criteria). Generally a criterion of acceptability for a solution i^* would be to have $f(i^*) \leq f(i)$ for every i in S. In such situation TS would be an exact minimization algorithm provided the exploration process would guarantee that after a finite number of steps such an i^* would be reached [5,7].

In most contexts however no guarantee can be given that such an i^* will be obtained; therefore TS could simply be viewed as an extremely general heuristic procedure. Since TS will in fact include in its own operating rules some heuristic techniques, it would be more appropriate to characterize TS as a *metaheuristic*. Its role will often be to guide and to orient the search of another (more local) search procedure [8].

As a first step towards the description of TS, the classical descent method will be illustrated [1]:

Step 1: Choose an initial solution *i* in *S*.
Step 2: Generate a subset *V** of solution in *N(i)*.
Step 3: Find a best *j* in *V** (i.e. such that *f(i) ≤ f(k)* for any *k* in *V**) and set *i* to *j*.
Step 4: If *f(j) ≥ f(i)* Then stop, Else go to Step 2.

In a straightforward descent method, we would generally take *V*=N(i)*. However this may often be too time-consuming: an appropriate choice of *V** may often be a substantial improvement.

Except for some special cases of convexity, the use of descent procedures is generally frustrating since the researchers are likely to be trapped in a local minimum which may be far (with respect to the value of *f*) from a global minimum [1,2].

As soon as non-improving moves are possible, the risk visiting again is a solution and more generally of cycling is presented. This is the point where the use of memory is helpful to forbid moves which might lead to recently visited solutions. If such memory is introduced we may consider that the structure of *N(i)* depend upon the itinerary and hence upon the iteration k; so we may refer to *N(i,k)* instead of *N(i)*. With these modifications in mind we may attempt to formalize an improvement of the descent algorithm in a way which will bring it closer to the general TS procedure. It could be stated as follows (*i** is the best solution found so far and *k* the iteration counter) [1,2]:

Step 1: Choose an initial solution *i* in *S*. Set *i*=i* and *k*=0.
Step 2: Set *k=k+1* and generate a subset *V** of solution in *N(i,k)*.
Step 3: Choose a best *j* in *V** (with respect to *f* or to some modified function *f′*) and set *i = j*.
Step 4: If *f(i) < f(i*)* Then set *i*=i*.
Step 5: If a stopping condition is met Then stop, Else go to Step 2.

Observe that the classical descent procedure is included in this formulation (the stopping rule would simply be *f(i) ≥ f(i*)* and *i** would always be the last solution).

In TS some immediate stopping conditions could be the following [1, 2, 9]:

- *N(i,k+1)=∅*.
- k is larger than the maximum number of iterations that allowed.
- the number of iterations since the last improvement of i* is larger than a specified number.
- evidence can be given than an optimum solution has been obtained.
- tabu list is full.
- no improved solutions.

While these stopping rules may have some influence on the search procedure and on its results, it is important to realize that the definition of *N(i,k)* at each iteration *k* and the choice of *V** are crucial [2].

The definition N(i,k) implies that some recently visited solutions are removed from N(i); they are considered as tabu solutions which should be avoided in the next iteration. Such memory based on recent will partially prevent cycling. For instance keeping at iteration k a list T (tabu list) of the last |T| solutions visited will prevent cycles of size at most |T|. In such case N(i,k)=N(i)-T will be taken. However this list T may be extremely impractical in use; therefore the exploration process in S in terms of moves from one solution to the next [1,2]. In addition to, there are other versions of TS algorithms, but the above is the classical.

III. Cuckoo Search

CS is a heuristic search algorithm which has been proposed recently by Yang and Deb [10]. The algorithm is inspired by the reproduction strategy of cuckoos. At the most basic level, cuckoos lay their eggs in the nests of other host birds, which may be of different species. The host bird may discover that the eggs are not its own and either destroy the egg or abandon the nest all together. This has resulted in the evolution of cuckoo eggs which mimic the eggs of local host birds. To apply this as an optimization tool, Yang and Deb used three ideal rules [10, 11]:

1) Each cuckoo lays one egg, which represents a set of solution co-ordinates, at a time and dumps it in a random nest;

2) A fraction of the nests containing the best eggs, or solutions, will carry over to the next generation;

3) The number of nests is fixed and there is a probability that a host can discover an alien egg. If this happens, the host can either discard the egg or the nest and this result in building a new nest in a new location. Based on these three rules, the basic steps of the Cuckoo Search (CS) can be summarized as the pseudo code shown as below [10, 11, 12].

Cuckoo Search via Levy Flight Algorithm

Input: Population of the problem;
Output: The best of solutions;

```
Objective function f(x), x = (x1, x2, ...xd)^T
Generate initial population of n host nests xi
                                   (i = 1, 2, ..., n)
While (t <Max Generation) or (stop criterion)
    Get a cuckoo randomly by Levy flight
    Evaluate its quality/fitness Fi
    Choose a nest among n(say,j)randomly
    If (Fi > Fj) replace j by the new solution;
    A fraction(pa) of worse nests are abandoned and new
     ones are built;
    Keep the best solutions (or nests with quality
     solutions);
    Rank the solutions and find the current best;
    Pass the current best solutions to the next generation;
End While
```

When generating new solution $x^{(t+1)}$ for, say cuckoo *i*, a Levy flight is performed

$$x^{(t+1)}_i = x(t)_i + \alpha \oplus Levy(\beta) \;\ldots\ldots\; (1)$$

where $\alpha > 0$ is the step size which should be related to the scales of the problem of interests. In most cases, we can use $\alpha = 1$. The product ⊕ means entry-wise walk while multiplications. Levy flights essentially provide a random walk while their random steps are drawn from a Levy Distribution for large steps

$$Levy \sim u = t^{-1-\beta} \quad (0 < \beta \leq 2) \ldots\ldots\ldots (2)$$

this has an infinite variance with an infinite mean. Here the consecutive jumps/steps of a cuckoo essentially form a random walk process which obeys a power-law step-length distribution with a heavy tail. In addition, a fraction *pa* of the worst nests can be abandoned so that new nests can be built at new locations by random walks and mixing. The mixing of the eggs/solutions can be performed by random permutation according to the similarity/difference to the host eggs.

IV. Proposal of Tabu Search Algorithm Based on Cuckoo Search

Generally, in the most heuristic search algorithms, the guarantee of finding the optimal solutions is the big problem. Also, local minimum (or maximum) represent the second big problem. Therefore, the heuristic search algorithms still in continuous developing. In this work, an attempt to improve the performance of TS using CS which is provides more diversity to candidate solutions of TS. CS will call in the TS when there are no more good solutions in TS. Initially, CS will be work with best solutions list (*B*) and replace the old solutions of tabu list by the CS solutions to provide a good diversity to TS candidate solutions. In other words, any iterative exploration process should in some instance accept also non-improving moves from *i* to *j* in *V** (i.e. $f(j) > f(i)$) if one would like to escape from local minimum, CS does this. Therefore the proposed version of TS will be more heuristic and robust to find the optimal solution or at least reduce the local minimum problem. The suggested TCS as following:

Step 1: Choose an initial solution *i* in *S*. Set $i^*=i$ and $k=0$.
Step 2: Set $k=k+1$ and generate a subset V^* of solution in $N(i,k)$.
Step 3: Choose a best *j* in V^* and set $i = j$.
Step 4: Select best subset from $N(i,k)$ add in *B*.
Step 5: If there is no best solution Then call the Cuckoo Search with best subset from Tabu List.
Step 6: Select the best solutions from Cuckoo Search output to add in the Tabu List.
Step 7: If a stopping condition is met Then stop, Else go to Step 2.

where *B* represent the currently best solutions list which is contain the best neighbors of V^*, so the algorithm can recover the best previous states when the route of behavior far of the goal. The update step of *B* means delete the used neighbors and rearrange the others. In the next section illustrates the performance of TCS algorithm compare with others TS algorithms.

V. Case Studies and Experimental Results

Two standard optimization problems were used to test the proposal algorithm and to compare their performances with the original algorithm.

A. 4-Color Map Problem

The celebrated 4 Color Map Theorem states that any map in the plane or on the sphere can be colored with only four colors such that no two neighboring countries are of the same color. The problem has a long history and inspired many people (including many non-mathematicians and in particular countless high school students) to attempt a solution [13].

The proof of the four color theorem by Haken and Appel [14] was so involved it required computational support to complete. It is well known that determining if a graph can be colored by a certain number of colors is NP-complete, but it is also known that even approximating the chromatic number of a graph is NP-hard [15]. There exist two main categories of algorithms: *successive augmentation algorithms* [16], which color a graph one vertex at a time, disallowing vertices from being re-colored and *iterative improvement algorithms*, which allow backtracking and re-coloring. Leighton's [17] RLF algorithm is an example of the first and Tabu searches and genetic algorithms are examples of the second [18].

In 4-color map problem there is a vector (N), where N is the number of cities in the map. An adjacency array of dimension NxN is used to identify the neighborhood of adjacent cities. The neighborhood search operator used is simply swapping two randomly chosen points.

B. Traveling Salesman Problem TSP

TSP is one of the major success stories for optimization because of its simplicity and applicability (or perhaps simply because of its intriguing name), the TSP has for decades served as an initial proving ground for new ideas related to both these alternatives. These new ideas make the TSP an ideal subject for a case study [19].

The origins of the Traveling Salesman Problem (TSP) are somewhat mysterious. It is a classical combinatorial optimization problem and can be described as follows: a salesman, who has to visit clients in different cities, wants to find the shortest path starting from his home city, visiting every city exactly once and ending back at the starting point. More formally [19]:

Given a set of n nodes and costs associated with each pair of nodes, find a closed tour of minimal total cost that contains every node exactly once.

In other words, a set $\{c_1, c_2, \ldots, c_N\}$ of *cities* is given and for each pair $\{c_i, c_j\}$ of distinct cities a *distance* $d(c_i, c_j)$. The goal is to find an ordering Π of the cities that minimizes the quantity

$$\sum_{i=1}^{N-1} d(c_{\Pi(i)}, c_{\Pi(i+1)}) + d(c_{\Pi(N)}, c_{\Pi(1)})$$

This quantity is referred to as the *tour length*, since it is the length of the tour a salesman would make when visiting the cities in the order specified by the permutation, returning at the end to the initial city. The concentrated in this paper would be on the *symmetric* TSP, in which the distances satisfy [19]:

$$d(c_i, c_j) = d(c_j, c_i) \text{ for } 1 \leq i,\ j \leq N$$

In computing terms the problem can be represented by a graph where all the nodes correspond to cities and the edges between nodes correspond to direct roads between cities [19].

In 4-color map problem there is a vector (N), where N is the number of cities in the tour. An adjacency array of dimension NxN is used to identify the neighborhood of adjacent cities. The neighborhood search operator used is simply swapping two randomly chosen points.

C. Results

The researchers of TS have been proposed several modifications and hybrids algorithms with other techniques, one of these are Simulated Annealing Tabu Search (SATS) [20]. In this paper the proposed TCS will be compared with standard TS and SATS to illustrate the performance of each one.

In this paper, results of average 10 independent runs for all of these algorithms have proved that all of these algorithms are good technique capable of finding solutions close to the optimum, but a local minimum problem occur in very special cases. Results indicate that the proposal algorithm TCS have a faster convergence than the original TS and SATS.

Figure 1 illustrates the curve of number of iteration with number of cities in 4-color map problem in only solved cases using TS, SATS and TCS. Figure 2 illustrates the number of local minimum non-optimal solutions occur with number of cities in 4-color map problem using TS, SATS and TCS. Figure 3 illustrates the curve of number of iteration with number of cities in TSP in only solved cases using TS, SATS and TCS. Figure 4 illustrates the number of local minimum and non-optimal solutions occur with number of cities in TSP using TS, SATS and TCS.

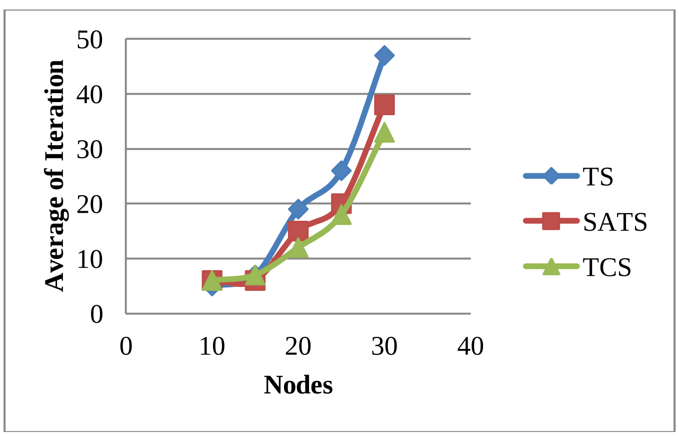

Fig. 1. Average of No. of Iterations for 4-Color Map Problem Using TS, SATS and TCS

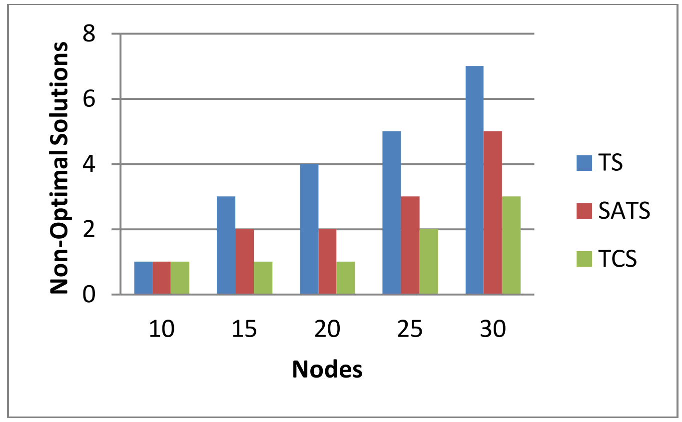

Fig. 2. Average of Non-Optimal Solutions for 4-Color Map Problem Using TS, SATS and TCS

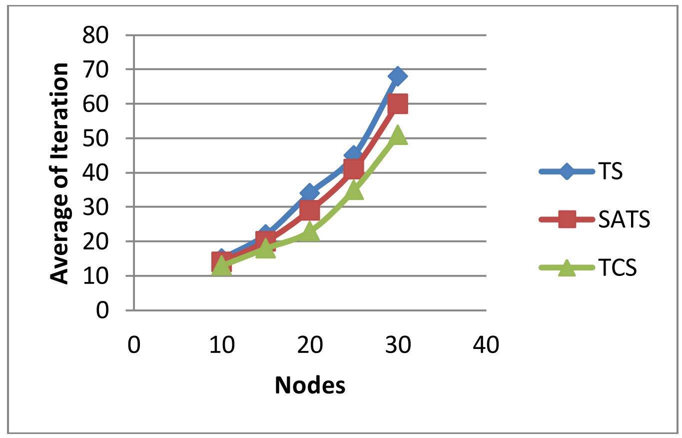

Fig. 3. Average of No. of Iterations for TSP Using TS, SATS and TCS

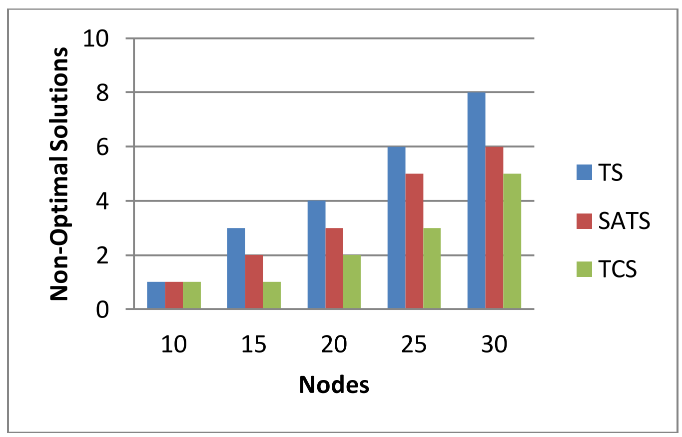

Fig. 4. Average of Non-Optimal Solutions for TSP Using TS, SATS and TCS

VI. CONCLUSIONS

The presented approach TCS is an important version of TS. TCS can increase the performance of optimal solutions finding, also, it can reduce the non-optimal solutions and local minimum problem. TCS depends on storing the best neighbors in the currently best solutions list to use these solutions in the CS to for improving whenever the algorithm in local minimum or cannot find the new best neighbor. The suggested approach achieves two important features of methods' searching which are called intensification and diversification. TCS gives less iteration numbers compare with TS and SATS. Also it has been reduced the non-optimal solutions and local minimum problem.

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Estimation of Protein Content in Rice Crop and Nitrogen Content in Rice Leaves Through Regression Analysis with NDVI Derived from Camera Mounted Radio-Control Helicopter

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***Abstract*—Estimation of protein content in rice crop and nitrogen content in rice leaves through regression analysis with Normalized Difference Vegetation Index: NDVI derived from camera mounted radio-control helicopter is proposed. Through experiments at rice paddy fields which is situated at Saga Prefectural Research Institute of Agriculture: SPRIA in Saga city, Japan, it is found that protein content in rice crops is highly correlated with NDVI which is acquired with visible and Near Infrared: NIR camera mounted on radio-control helicopter. It also is found that nitrogen content in rice leaves is correlated to NDVI as well. Protein content in rice crop is negatively proportional to rice taste. Therefore rice crop quality can be evaluated through NDVI observation of rice paddy field.**

Keywords—nitrogen content; NDVI; protein content; rice paddy field; remote sensing; regression analysis

I. INTRODUCTION

There are strong demands for saving human resources which are required for produce agricultural plants. In particular in Japan, now a day, the number of working peoples for agricultural fields is decreasing quite recently. Furthermore, the ages of the working peoples are getting old. Moreover, the agricultural fields are also getting wide through merging a plenty of relatively small scale of agricultural fields in order for maintain the fields in an efficient manner. Therefore, the working peoples have to maintain their fields in an efficient manner keeping the quality in mind.

Vitality monitoring of vegetation is attempted with photographic cameras [1]. Grow rate monitoring is also attempted with spectral reflectance measurements [2]. Bi-Directional Reflectance Distribution Function: BRDF is related to the grow rate for tealeaves [3]. Using such relation, sensor network system with visible and near infrared cameras is proposed [4]. It is applicable to estimate nitrogen content and fiber content in the tealeaves in concern [5]. Therefore, damage grade can be estimated with the proposed system for rice paddy fields [6]. This method is validated with Monte Carlo simulation [7]. Also Fractal model is applied to representation of shapes of tealeaves [8]. Thus the tealeaves can be asse3ssed with parameters of the fractal model. Vitality of tea trees are assessed with visible and near infrared camera data [9]. Rice paddy field monitoring with radio-control helicopter mounting visible and NIR camera is proposed [10] while the method for rice quality evaluation through nitrogen content in rice leaves is also proposed [11]. The method proposed here is to evaluate rice quality through protein content in rice crop with observation of NDVI which is acquired with visible and NIR camera mounted on radio-control helicopter.

The proposed method and system is described in the next section followed by experiments. The experimental results are validated in the following section followed by conclusion with some discussions.

II. PROPOSED METHOD AND SYSTEM

A. Radio Controlled Helicopter Based Near Infrared Cameras Utilizing Agricultural Field Monitoring System

The helicopter used for the proposed system is “GrassHOPPER” [1] manufactured by Information & Science Techno-Systems Co. Ltd. The major specification of the radio controlled helicopter used is shown in Table 1. Also, outlook of the helicopter is shown in Figure 1. Canon Powershot S100[2] (focal length=24mm） is mounted on the GrassHOPPER. It

[1] http://www.ists.co.jp/?page_id=892
[2] http://cweb.canon.jp/camera/dcam/lineup/powershot/s110/index.html

allows acquire images with the following Instantaneous Field of View: IFOV at the certain altitudes, 1.1cm (Altitude=30m) 3.3cm (Altitude=100m) and 5.5cm (Altitude=150m) .

Fig. 1. Outlook of the GrassHOPPER

TABLE I. MAJOR SPECIFICATION OF GRASSHOPPER

Weight	2kg (Helicopter only)
Size	80cm × 80cm × 30m
Payload	600g

Spectral response functions of filters attached to the camera used are shown in Figure 2.

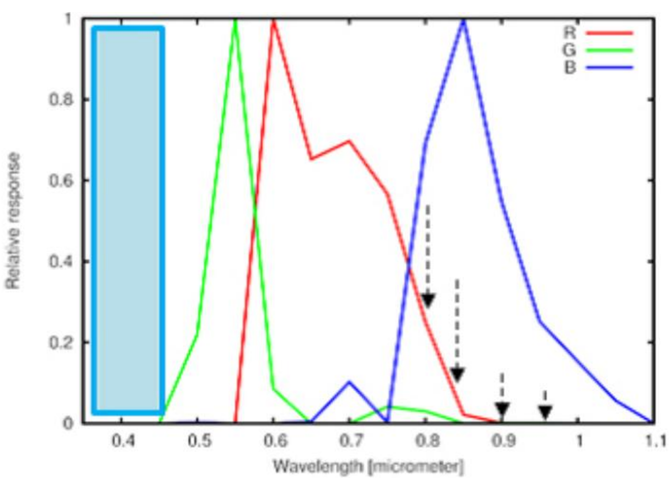


Fig. 2. Spectral Response of the Filter attached to Camera

In order to measure NIR reflectance, standard plaque whose reflectance is known is required. Spectralon[3] provided by Labsphere Co. Ltd. is well known as well qualified standard plaque. It is not so cheap that photo print papers are used for the proposed system. Therefore, comparative study is needed between Spectralon and the photo print papers.

The proposed system consist Helicopter, NIR camera, photo print paper. Namely, photo print paper is put on the agricultural plantations, tea trees in this case. Then farm areas are observed with helicopter mounted Visible and NIR camera. Nitrogen content in agricultural plants, rice crops in this case, is estimated with NIR reflectance.

B. Regressive Analysis

Linear regressive equation is expressed in equation (1).

$$N = a R + b \qquad (1)$$

where N, R denotes measured Nitrogen content in leaves as well as protein content in rice crops, and measured NDVI derived from visible and Near Infrared: NIR reflectance, respectively while a and b denotes regressive coefficients. There is well known relation between nitrogen content as well as protein content in rice crops and NDVI. Therefore, regressive analysis based on equation (1) is appropriate.

C. Proposed Method for Rice Crop Quality Evaluation

Rice crop quality can be represented with nitrogen content which are closely related to NDVI. Furthermore, it is well known that nitrogen content rich rice crops taste good while protein content rich rice crops taste bad. Therefore, rice crops quality can be evaluated with measured NDVI measured with camera data which is mounted on radio-control helicopter.

The proposed method and rice paddy field monitoring system with visible and NIR camera which is mounted on radio-control helicopter is based on the aforementioned scientific background.

D. Rice Crop Field at Saga Prefectural Agricultural Research Institute: SPARI

Specie of the rice crop is Hiyokumochi[4] which is one of the late growing types of rice species. Hiyokumochi is one of low amylase (and amylopectin rich) of rice species (Rice No.216).

Figure 3 and 4 shows layout of the test site of rice crop field at SPARI[5] which is situated at 33°13'11.5" North, 130°18'39.6"East, and the elevation of 52feet.

The paddy field C4-2 is for the investigation of water supply condition on rice crop quality. There are 14 of the paddy field subsections of which water supply conditions are different each other.

There are two types of water supply scheduling, short term and standard term. Water supply is stopped in the early stage of rice crop growing period for the short term water supply subsection fields while water supply is continued comparatively longer time period comparing to the short term water supply subsection fields.

3 https://www.google.co.jp/search?q=spectral+labsphere&hl=ja

4 http://ja.wikipedia.org/wiki/%E3%82%82%E3%81%A1%E7%B1%B3

5 http://www.pref.saga.lg.jp/web/shigoto/_1075/_32933/ns-nousisetu/nouse/n_seika_h23.html

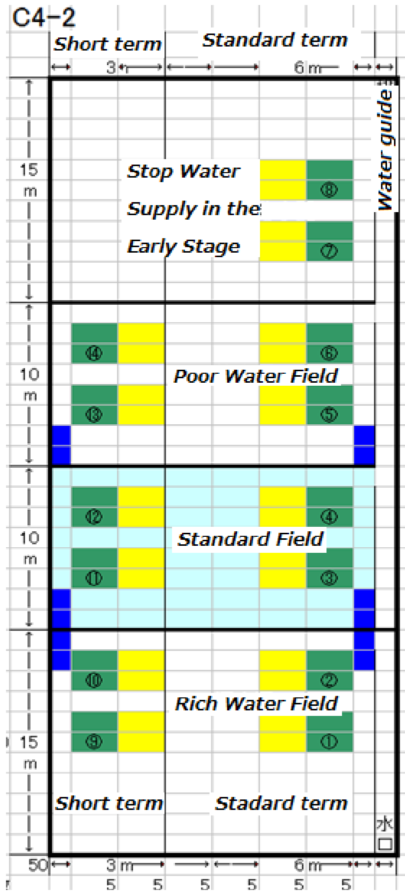


Fig. 3. Paddy field layout for investigation of water supply condition dependency on rice crop quality

Meanwhile, there are three types of water supply conditions, rich, standard, and poor water supply subsection fields.

On the other hand, test sites C4-3 and C4-4 are for investigation of nitrogen of chemical fertilizer dependency on rice crop quality. There are two types of paddy subsections, densely and sparsely planted paddy fields. Hiyokumochi rice leaves are planted 15 to 20 fluxes per m^2 on June 22 2012. Rice crop fields are divided into 10 different small fields depending on the amount of nutrition including nitrogen ranges from zero to 19 kg/10 a/nitrogen.

Nitrogen of chemical fertilizer is used to put into paddy fields for five times during from June to August. Although rice crops in the 10 different small fields are same species, the way for giving chemical fertilizer are different. Namely, the small field No.1 is defined as there is no chemical fertilizer at all for the field while 9, 11, and 13 kg/ 10 a/ nitrogen of after chemical fertilizer are given for No.2 to 4, respectively, no initial chemical fertilizer though. Meanwhile, 9, 11, 13 kg/10 a/nitrogen are given as after chemical fertilizer for the small field No.5, 6, and 7, respectively in addition to the 3 kg/10 a/nitrogen of initial chemical fertilizer. On the other hand, 12, 14, and 16 kg/10 a /nitrogen are given for the small fields No.5, 6, 7, respectively as after chemical fertilizer in addition to the initial chemical fertilizer of 3 kg/ 10 a/ nitrogen for the small field No. 15, 17, 19, respectively. Therefore, rice crop grow rate differs each other paddy fields depending on the amount of nitrogen of chemical fertilizer.

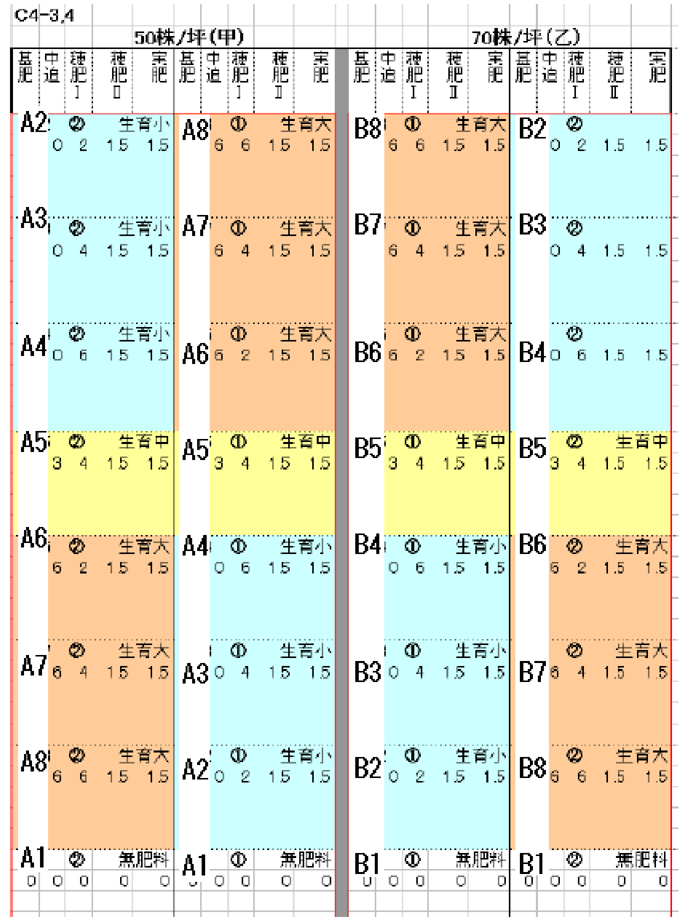


Fig. 4. Paddy filed layout for investigation of nitrogen of chemical fertilizer dependency on rice crop quality

III. Experiments

A. Acquired Near Infrared Camera Imagery Data

Radio wave controlled helicopter mounted near infrared camera imagery data is acquired at C4-2, C4-3, C4-4 in SPARI on 18 and 22 August 2013 with the different viewing angle from the different altitudes. Figure 4 shows an example of the acquired near infrared image. There is spectralon of standard plaque as a reference of the measured reflectance in between C4-3 and C4-4. Just before the data acquisition, some of rice crops and leaves are removed from the subsection of paddy fields for inspection of nitrogen content. Using the removed rice leaves, nitrogen content in the rice leaves is measured based on the Keldar method and Dumas method[6] (a kind of chemical method) with Sumigraph NC-220F[7] of instrument. The measured total nitrogen content in rice leaves and protein content in rice crops are compared to the NDVI.

[6] http://note.chiebukuro.yahoo.co.jp/detail/n92075

[7] http://www.scas.co.jp/service/apparatus/elemental_analyzer/sumigraph_nc-220F.html

Example of the acquired image is shown in Figure 5. Rice field name is annotated in the image. On the other hand, the acquired camera images on 18 August and 22 August are shown in Figure 6 (a) and (b), respectively. Meanwhile, these images have influences due to shadow and shade of rice leaves and water situated under the rice leaves as well as narrow roads between rice paddy fields. In order to eliminate the influences, thresholding process is applied to the acquired images.

Figure 7 shows the processed images of small portion of the images with the different threshold rages from 5 to 25. Through these trials, threshold of 25 is chosen for influences reduction. Geometric correction is applied to the acquired camera images after extraction of intensive study areas. Figure 8 (a) and (b) show the resultant corrected images acquired on 18 and 22 August 2013, respectively.

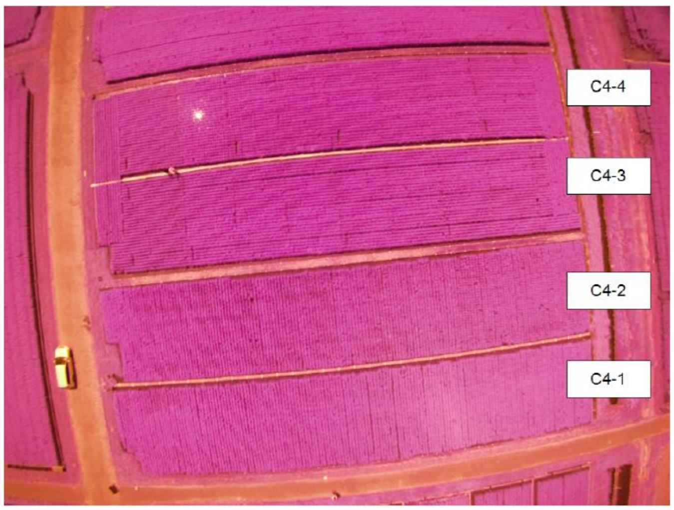
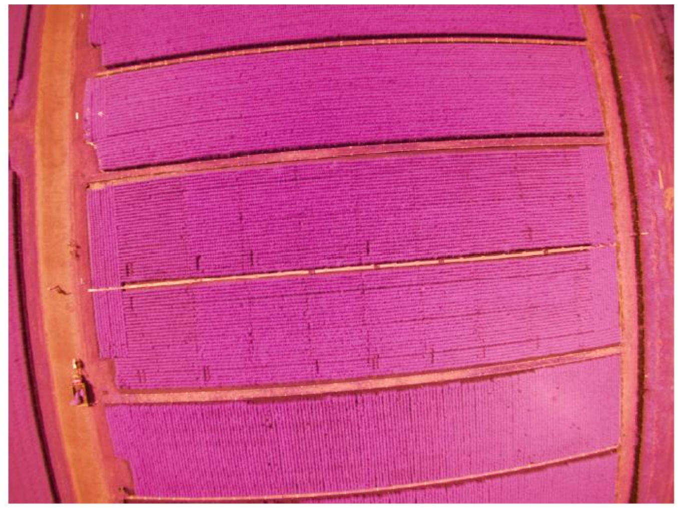


Fig. 5. Example of acquired camera image on 18 August 2013

(a)August 18



(b)August 22

Fig. 6. Camera images acquired on 18 and 22 August 2013

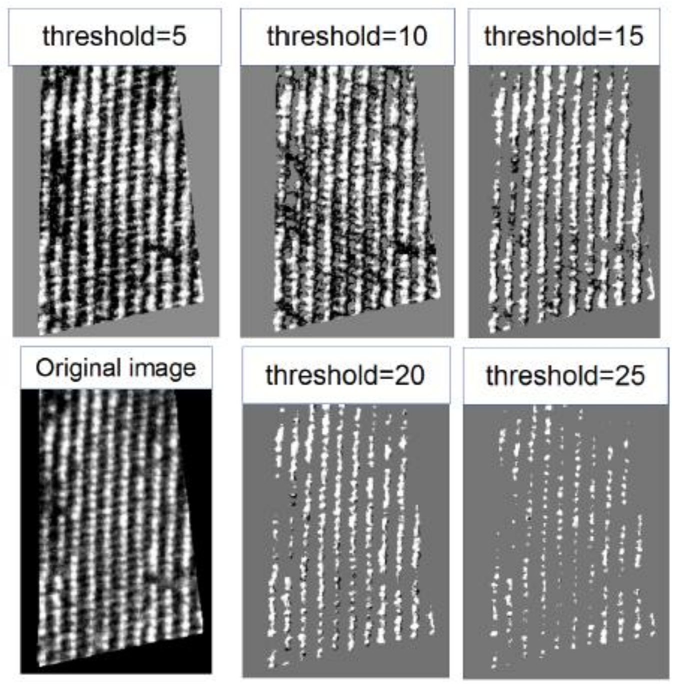
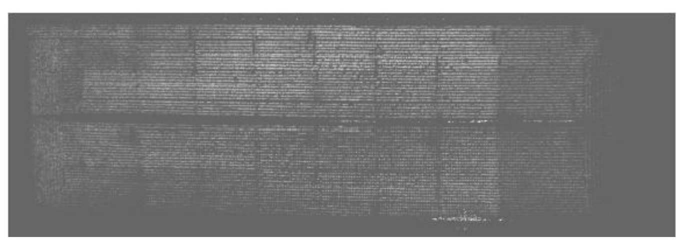
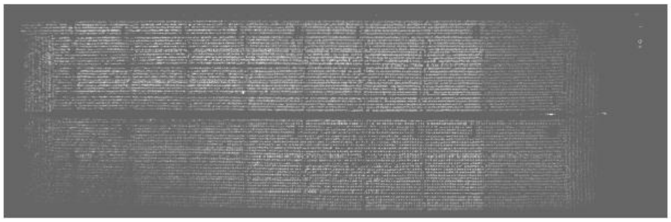


Fig. 7. Processed images of small portion of the images with the different threshold rages from 5 to 25.



(a)August 18



(b)August 22

Fig. 8. Resultant images of geometrically corrected which are acquired on 18 and 22 August 2013

On the other hand, measured nitrogen contents in rice leaves of rice paddy fields of partitioned A1 to A8 and B1 to B8 on 14 and 22 August 2013 are shown in Table 2 and 3, respectively. Nitrogen of chemical fertilizer, water management as well as plant density are different from each other partitioned rice paddy fields as aforementioned. Nitrogen content in the rice leaves seem to reflect the fact of chemical fertilizer of nitrogen, water supply management, and plantation density, obviously.

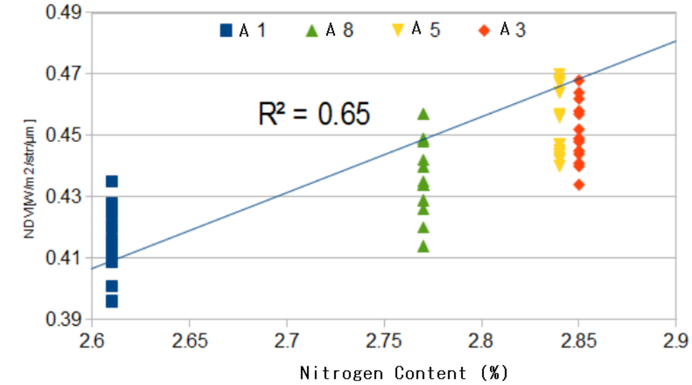
TABLE II. MEASURED NITROGEN CONTENT IN RICE LEAVES ON 14 AUGUST 2013

Farm Area	Nitrogen (%)
A1	2.61
A3	2.85
A5	2.84
A8	2.77
B1	2.82
B3	2.74
B5	3.16
B8	2.78

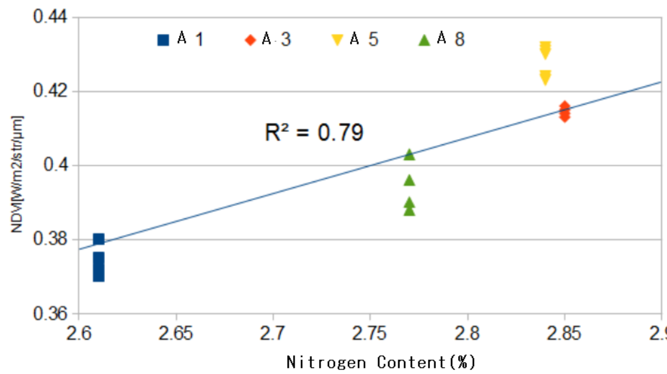
TABLE III. MEASURED NITROGEN CONTENT IN RICE LEAVES ON 22 AUGUST 2013

Farm Area	Nitrogen (%)
A1	2.46
A2	2.88
A4	2.97
A5	2.89
A6	2.67
A8	3.22
B1	2.33
B2	2.79
B4	2.84
B5	2.85
B6	2.96
B8	3.14

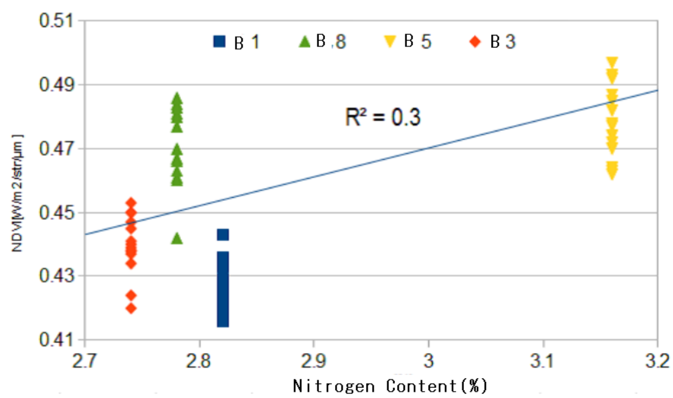
Relation between nitrogen as well as protein contents and NDVI for each paddy fields for August 18 and 22 2013 are shown in Figure 9 to 12.



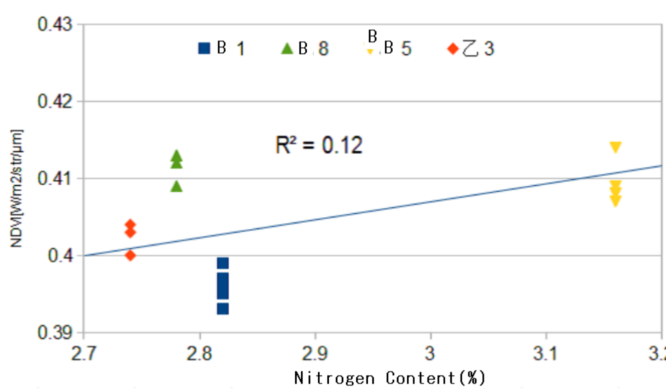
(a)A Site on August18 for all area



(b)A Site on August 18 for sampled areas

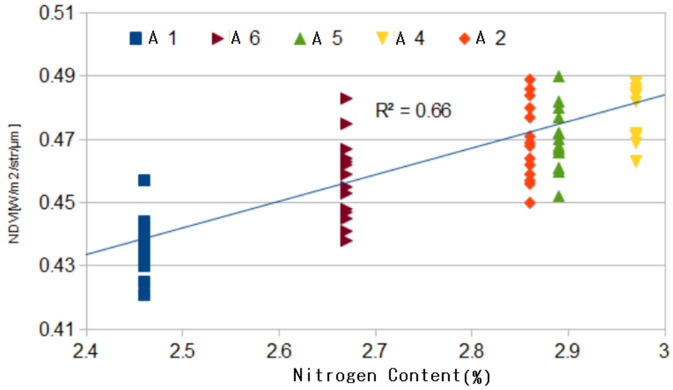


(c)B Site on August 18 for all area

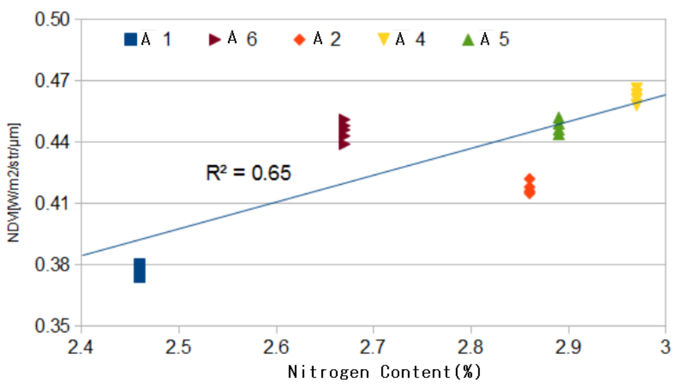


(d)B Site on August 18 for the sampled areas

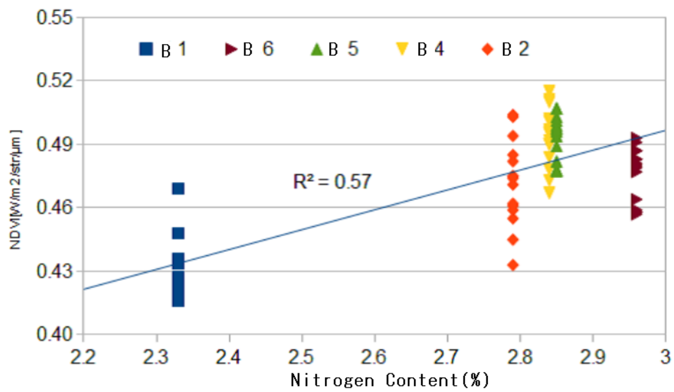
Fig. 9. Relations between NDVI and the measured nitrogen content



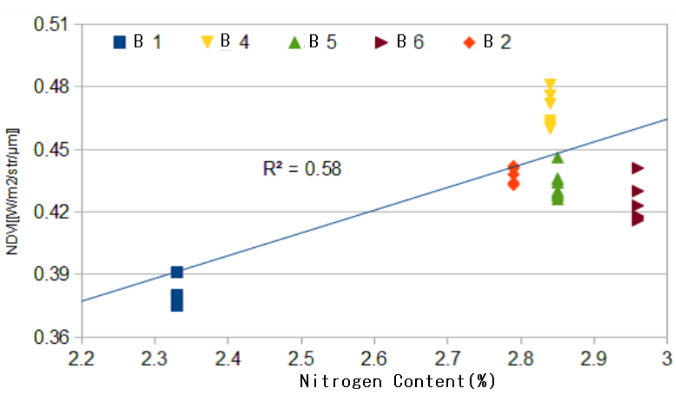
(a)A Site on August22 for all area



(b)A Site on August 22 for sampled areas

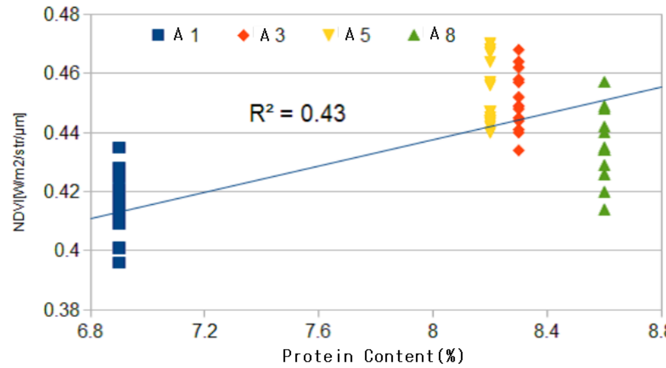


(c)B Site on August 22 for all area

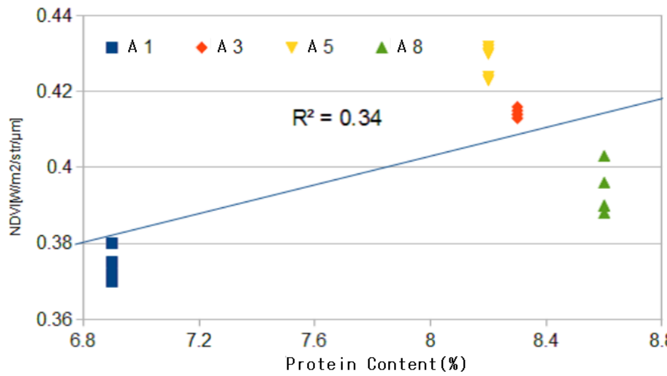


(d)B Site on August 22 for sampled areas

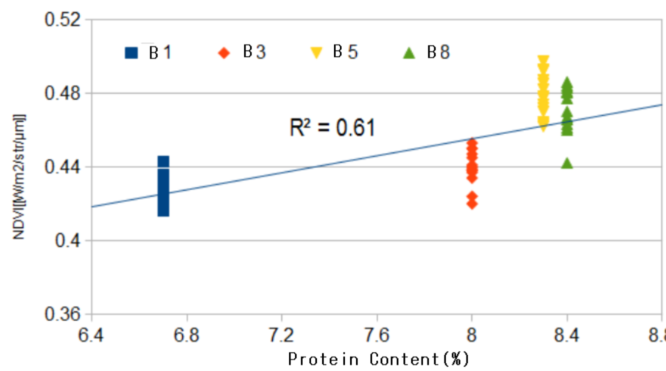
Fig. 10. Relations between NDVI and the measured nitrogen content



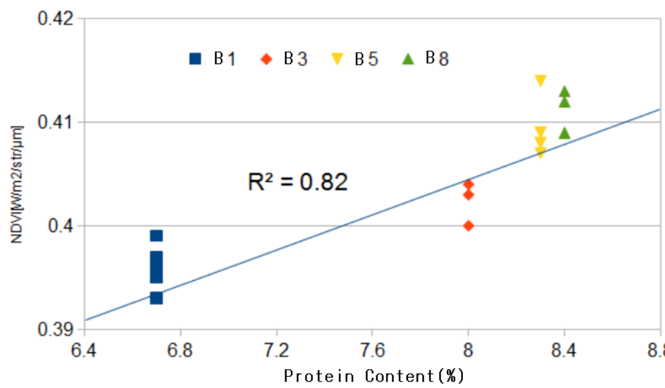
(a)A Site on August18 for all area



(b)A Site on August 18 for sampled areas

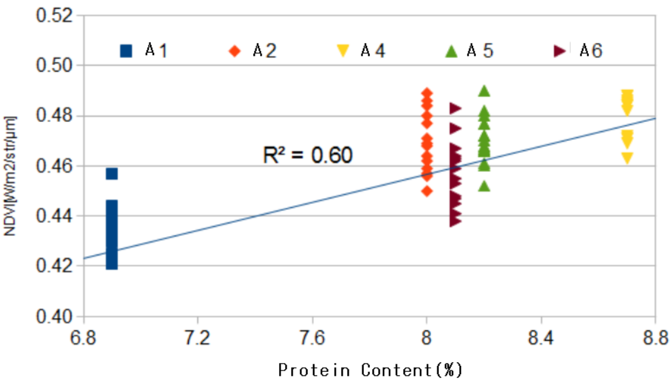


(c)B Site on August 18 for all area

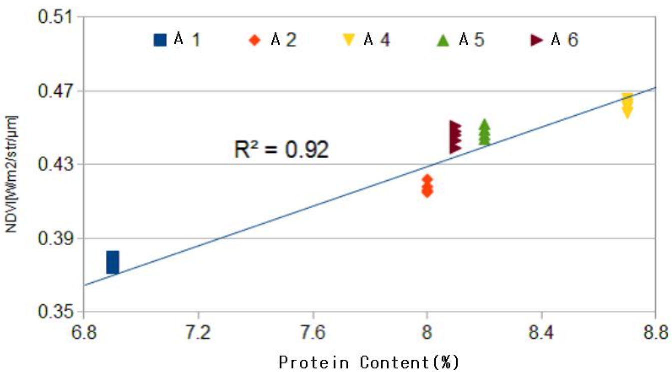


(d)B Site on August 18 for sampled areas

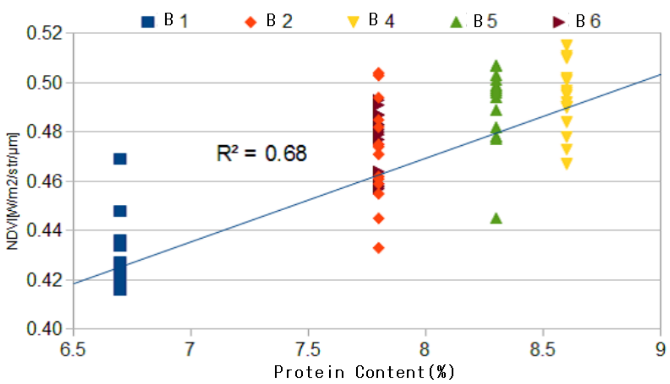
Fig. 11. Relations between NDVI and the measured Protein content



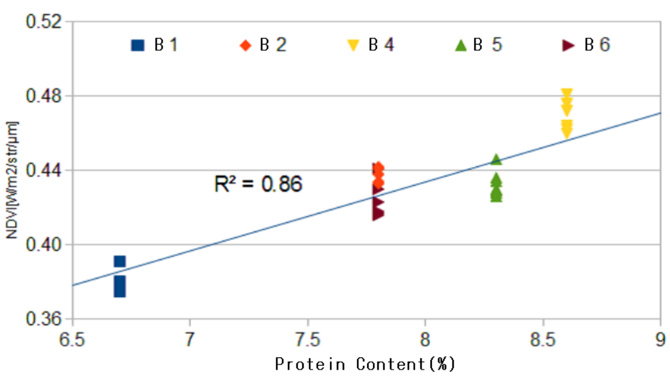
(a)A Site on August22 for all area



(b)A Site on August 22 for sampled areas



(c)B Site on August 22 for all area



(d)B Site on August 22 for sampled areas

Fig. 12. Relations between NDVI and the measured protein content

The sampled areas imply that the locations of surrounding areas at which rice leaves are picked up for measurement of nitrogen content. Meanwhile, all area implies whole area of the strip of the rice paddy field. The correlation coefficients for the sampled areas are much greater than those of all area. Also variances for the sampled areas are much smaller than those for all area. More importantly, R square values of protein content are greater than those of nitrogen content. This implies that rice crop quality which represented by protein content is much reflected by the nitrogen of chemical fertilizer, water supply management, and rice leaves density rather than nitrogen content in rice leaves directly.

IV. Conclusion

Estimation of protein content in rice crop and nitrogen content in rice leaves through regression analysis with Normalized Difference Vegetation Index: NDVI derived from camera mounted radio-control helicopter is proposed. Through experiments at rice paddy fields which is situated at Saga Prefectural Research Institute of Agriculture: SPRIA in Saga city, Japan, it is found that protein content in rice crops is highly correlated with NDVI which is acquired with visible and Near Infrared: NIR camera mounted on radio-control helicopter. It also is found that nitrogen content in rice leaves is correlated to NDVI as well. Protein content in rice crop is negatively proportional to rice taste. Therefore rice crop quality can be evaluated through NDVI observation of rice paddy field.

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Acknowledgment

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Optimum Band and Band Combination for Retrieving Total Nitrogen, Water, Fiber Content in Tealeaves Through Remote Sensing Based on Regressive Analysis

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***Abstract*—Optimum band and band combination for retrieving total nitrogen, water and fiber content in tealeaves with remote sensing data is investigated based on regressive analysis. Based on actual measured data of total nitrogen, fiber and water content in tealeaves as well as remotely sensed visible to near infrared reflectance data with 5nm of wavelength steps and ASTER/VNIR onboard Terra satellite, regressive analysis is conducted. As the results, it is found that 1045nm is the best wavelength for retrieving total nitrogen content while 945nm is the best wavelength for fiber content retrieval. Also it is found that 545nm is the best wavelength for water content. On the other hand, it is found that 350 and 750nm wavelength combination is the best for estimation of total nitrogen content while 535 and 720 wavelength combination is the best for fiber content estimation. It also found that 545 and 760nm wavelength combination is the best for water content retrieval.**

Keywords—regressive analysis; total nitrogen content; tealeaves; fiber content;; water content

I. INTRODUCTION

It is highly desired to monitor vitality of crops in agricultural areas automatically with appropriate measuring instruments in order to manage agricultural area in an efficient manner. It is also required to monitor not only quality but also quantity of vegetations in the farmlands. Vegetation monitoring is attempted with red and photographic cameras [1]. Grow rate monitoring is also attempted with spectral observation [2].

This paper deals with automatic monitoring of a quality of tealeaves with earth observation satellite, network cameras together with a method that allows estimation of total nitrogen and fiber contents in tealeaves as an example. Also this paper describes a method and system for estimation of quantity of crop products by using not only Vegetation Cover: VC and Normalized Difference Vegetation Index: NDVI but also Bi-directional Reflectance Distribution Function: BRDF because the VC and NDVI represent vegetated area while BRDF represents vegetation mass, or layered leaves.

Total nitrogen content corresponds to amid acid which is highly correlated to Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid for tealeaves so that total nitrogen is highly correlated to tea taste. Meanwhile fiber content in tealeaves has a negative correlation to tea taste. Near Infrared: NIR camera data shows a good correlation to total nitrogen and fiber contents in tealeaves so that tealeaves quality can be monitored with network NIR cameras. It is also possible to estimate total nitrogen and fiber contents in leaves with remote sensing satellite data, in particular, Visible and near infrared: VNIR radiometer data. Moreover, VC, NDVI, BRDF of tealeaves have a good correlation to grow index of tealeaves so that it is possible to monitor expected harvest amount and quality of tealeaves with network cameras together with remote sensing satellite data. BRDF monitoring is well known as a method for vegetation growth [3],[4]. On the other hand, degree of polarization of vegetation is attempted to use for vegetation monitoring [5], in particular, Leaf Area Index: LAI together with new tealeaves growth monitoring with BRDF measurements [6].

It is not well known that the most preferable wavelength bands for observation of vegetation. Vitality of vegetation can be expressed with nitrogen, fiber and water contents in the leaves. Therefore, it is better to determine appropriate wavelength for retrieving theses parameters. In order to determine appropriate wavelength bands for estimation of total nitrogen, fiber and water contents in tealeaves, regressive analysis is conducted. Through regressive analysis, it is clarified that appropriate single wavelength and double wavelength for the retrievals with respect to the actual truth data sets of the parameters and hyperspectral data of reflective radiance from the tealeaves.

In the following section, research background is described followed by method for determination of appropriate single and double wavelength for retrievals. The regressive analysis results are summarized followed by conclusion and some discussions.

II. RESEARCH BACKGROUND

A. Vegetation Area Monitoring and Agricultural, in Paticular, Tea Farm Area Monitoring System

The proposed tea estate monitoring system is illustrated in Figure 1. Visible and NIR network cameras are equipped on the pole in order to look down with 10-80 degrees of incident angle (these angles allow BRDF measurements). The pole is used for avoid frosty damage to the tealeaves using fan mounted on the pole (for convection of boundary layer air). With these network cameras, reflectance in the wavelength region of 550nm (red color) and 870nm (NIR) are measured together with BRDF assuming that vegetated areas are homogeneous and flat. BRDF is used for estimation of Grow Index (GI) and BRDF correction from the measured reflectance of the tealeaves.

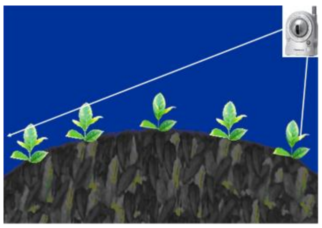
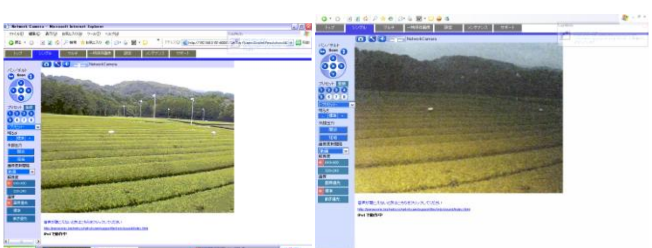


Fig. 1. Illustrative view of the proposed vegetation monitoring system with two network cameras, visible and NIR

These are controlled through Internet terminals. Visible Pan-Tilt-Zoom: PTZ network camera and NIR filter (IR840) attached network camera is equipped on the pole. PTZ cameras are controlled by mobile phone as well with "mobile2PC" or Internet terminal with "LogMeIn" of VNC services [7] through wireless LAN connected to Internet. Acquired camera data are used for estimation of total nitrogen and fiber contents as well as BRDF for monitoring grow index. An example of visible camera image acquired in daytime is shown in Figure 2 (a) while that for NIR camera image acquired in nighttime is shown in Figure 2 (b).

The cameras are connected to the Internet through the network card of W05K that is provided by AU/KDDI. Through http://119.107.81.166:8080, the acquired image data are accessible so that it is easy to access the data from Internet terminals. Panasonic BB-HCM371 cameras are used for the experiments. Solar panel of G-500 (12V, 500mA, 8.5W) with battery of SG-1000 is used together with Xpower75 (60W) of inverter.



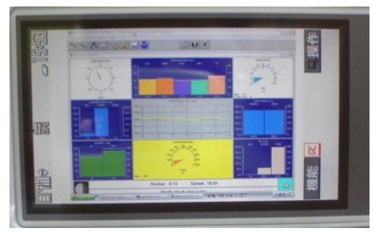
(a)Daytime (b) Nighttime

Fig. 2. Examples of farmland monitored visible camera images.

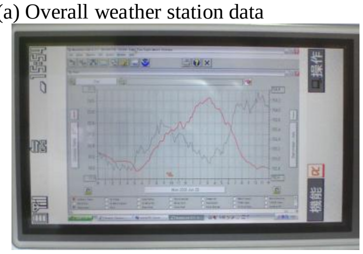
On the other hand, weather station data can be accessible from the URL of http://katy.jp/mapstation/ of data server provider through wireless LAN connection from the weather station to the Internet terminal. Figure 3 shows examples of the images displayed onto mobile phone. Not only camera imagery data, but also weather station data can be monitored with mobile phone. Figure 4 (a) and (b) shows overall weather station data of atmospheric pressure, solar direct and diffuse irradiance, leaf wetness, soil moisture, etc. and time duration of air-temperature and relative humidity of the tea estate while Figure 4 (c) shows web camera imagery data.

(a) New tealeaves appears partially (b) New tealeaves covers all over the surface

Fig. 3. Typical photos of new tealeaves grow process taken with network camera at tea estate of the prefectural tea research institute of Saga in the begging of April (a) and the late of April (b).



(a) Overall weather station data



(b) Air-temperature and relative humidity

(c) Camera image data

Fig. 4. Data displayed onto mobile phone

B. *Tea Farm Area Monitoring with HyperSpectrometer*

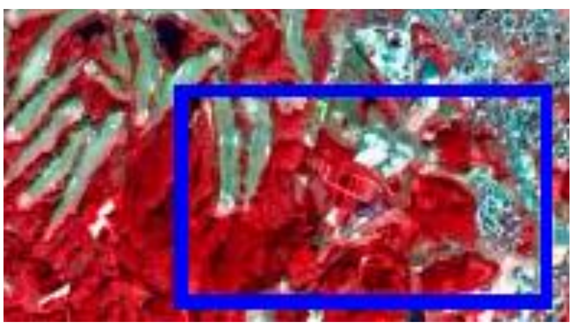
Other than these, hyper-spectral sensor can be equipped at the tea farm areas. Due to the fact that two bands of visible and near infrared cameras are not good enough in terms of estimation accuracy of nitrogen, fiber and water contents of tealeaves. Therefore, single and double wavelength bands for getting better accuracy of nitrogen, fiber and water contents have to be determined.

C. *Dataset for Determination of Approporiate bands for Nitrogen, Fiber and Water Content Estimat5ion*

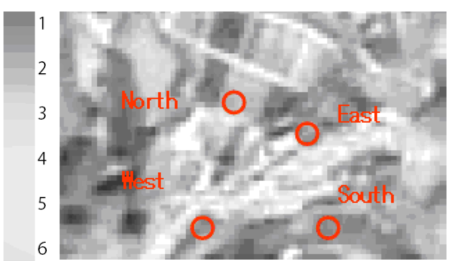
Intensive study area is situated at the Saga Prefectural Tea Institute in Ureshino-city, Saga, Japan. ASTER/VNIR image of the site is shown in Figure 5.

Fig. 5. Terra/ASTER/VNIR images of Saga acquired on May 16 in 2008 (False color representation: Blue Band #1, Green Band #2, Red Band #3).

Figure 6 shows enlarged image of ASTER/VNIR image of Saga Prefectural Tea Institute: SPTI. In particular, nitrogen content in tealeaves is shown in Figure 6 (b). Red circles shows four tea farm areas which are situated in East, West, South and North direction of Saga Prefectural Tea Institute.



(a)Portion of ASTER/VNIR image of Ureshino, Saga



(b)Enlarged image of Saga Prefectural Tea Institute

Fig. 6. Enlarges ASTER/VNIR image and total nitrogen contents in tealeaves at the tea estate (Red circles shows tea estates. Grayscale shows TN% of nitrogen contents in tealeaves derived from equation (1) of TN=22.474 Ref (Band#3)-10.177).

SPTI is situated at (33:07'2.9"N, 129:59'42.5"E,elevation: 130m) at the center location. In terms of species of the tea farm areas, East tea field has Yabukita tea farm area while North tea field has Yabukita tea farm and Okumidori.

Meanwhile, West tea field has Benifuki tea farm while South tea field has Ohiwase tea farm. Just before the harvesting tealeaves, in May 2008, spectral reflectance is measured. Figure 7 shows the reflectance. Meantime, total nitrogen, fiber and water content in the tealeaves are also measured. Thus, correlation can be calculated with these dataset through correlation analysis. Figure 8 shows the calculated correlations

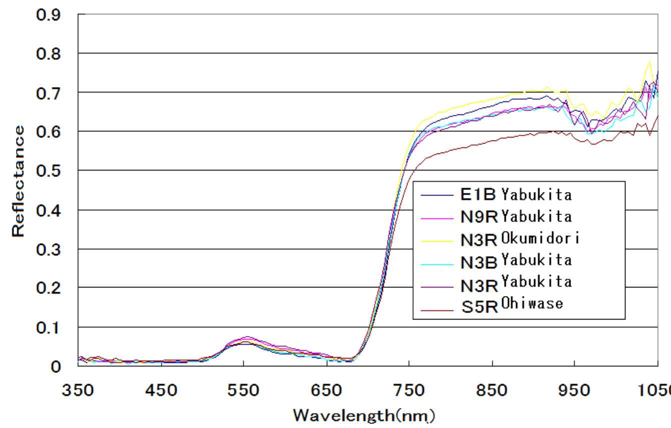


Fig. 7. Spectral reflectance measured at East, North and South tea farm areas situated at SPTI on 5 May 2008.

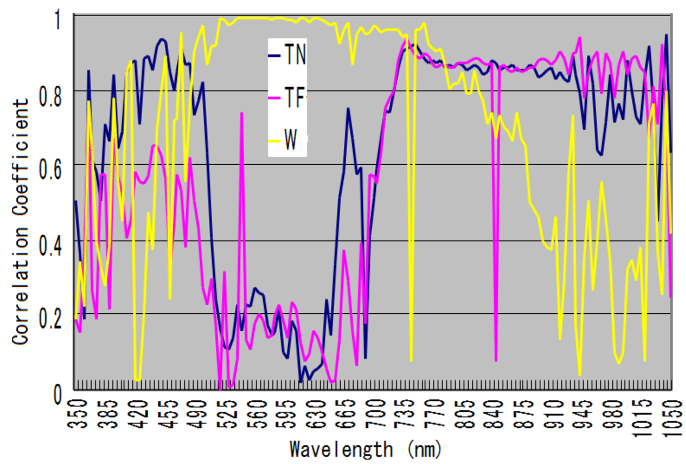


Fig. 8. Correlations between of total nitrogen, fiber and water contents in the tealeaves and the measured spectral reflectance

III. EXPERIEMNTS

A. Single Spectral Band for Estimation of TN, Fiber, and Water Contentsin TealeavesSlope Effect

Using the correlations between TN, fiber, and water content in tealeaves and spectral reflectance measured at SPTI, Saga Japan on May 5 2008, just before the harvesting tealeaves, regressive analysis is conducted. Through regressive analysis with single band with 5nm band width, the most appropriate spectral bands for estimation of TN, Fiber, and Water contents in tealeaves are estimated. Table 1, 2, and 3 show the results from the regressive analysis for TN, Fiber, and Water contents in tealeaves, respectively.

TABLE I. RESULT FROM REGRESSION FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Nitrogen	1045nm
R	0.9502
R^2	0.9029
StDev	0.3375
No.	6

TABLE II. RESULT FROM REGRESSION FOR FIBER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Fiber	945nm
R	0.9502
R^2	0.9029
StDev	0.3375
No.	6

TABLE III. RESULT FROM REGRESSION FOR WATER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Water	545nm
R	0.9999
R^2	0.9997
StDev	0.0004
No.	6

As the results, it is found that the most appropriate spectral bands for estimation of TN, Fiber and Water contents in tealeaves are 1045, 945, and 545 nm. The regressive analysis is conducted based on Pearson's correlation with 95 % of confidence level. The regressive errors of TN, Fiber, and Water contents in tealeaves are shown in Table 4, 5, and 6, respectively.

TABLE IV. REGRESSION ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	TN(%)	Est.TN	Reg.Error
E1B	Yabukita	4.7	4.168	0.283
N9R	Yabukita	4.6	4.938	0.114
N3R1	Okumidori	4.9	4.914	0.000197
N3R2	Yabukita	5	4.889	0.0123
N3B	Yabukita	5	5.099	0.00983
S5R	Ohiwase	2.5	2.691	0.0367

TABLE V. REGRESSONE ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	Fiber(%)	Est(Fiber)	Reg.Error
E1B	Yabukita	20.4	14.99	29.2681
N9R	Yabukita	17.3	16.66	0.4096
N3R1	Okumidori	1.5	4.98	12.1104
N3R2	Yabukita	19.6	21.66	4.2436
N3B	Yabukita	17.2	16.45	0.5625
S5R	Ohiwase	32.2	33.46	1.5876

TABLE VI. REGRESSION ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	Water(%)	Est(Water)	Reg.Error
E1B	Yabukita	0.7623	0.7625	4E-08
N9R	Yabukita	0.7318	0.7314	1.6E-07
N3R2	Yabukita	0.7555	0.7754	0.000396
N3B	Yabukita	0.7271	0.7424	0.000234

As the result, it is found that fiber content in tealeaves is the most difficult followed by TN content and water content There are not available data of water content of truth data for the test sites of N3R1, S5R.

B. Double Spectral Band for Estimation of TN, Fiber, and Water Contents in Tealeaves

The most appropriate two spectral bands with 5 nm of band width for estimation of TN, Fiber, and Water contents in tealeaves are determined through regressive analysis using the aforementioned correlation data between truth data and estimated data. The results from the regressive analysis are shown in Table 7, 8, and 9, respectively.

TABLE VII. REGRESSION RESULT FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Nitrogen	350&750nm
R	0.9906
R^2	0.9812
StDev	0.1713
No.	6

TABLE VIII. REGRESSION RESULT FOR FIBER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Fiber	535&720nm
R	0.9798
R^2	0.96
StDev	2.538
No.	6

TABLE IX. REGRESSION RESULT ERROR FOR WATER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Water	545&760nm
R	0.9999
R^2	0.9999
StDev	0.0003
No.	6

As the results, it is found that the most appropriate band combination for estimation of TN, Fiber, and Water contents in tealeaves are 350 and 750 nm, 535 and 720 nm, 545 and 760 nm, respectively.

C. Comparison of Estimation Accuracy Among Single,Double Spectral Band, and ASTER/VNIR Spectral Bands for Estimation of TN, Fiber, and Water Contents in Tealeaves

Estimation accuracy for TN, Fiber, and Water contents in tealeaves is evaluated with ASTER/VNIR spectral bands and is compared to the aforementioned estimation accuracy with the most appropriate single, and double spectral bands with 5 nm band width. The results from the comparisons are shown in Figure 3, 4, and 5, for TN, Fiber, and Water contents in tealeaves.

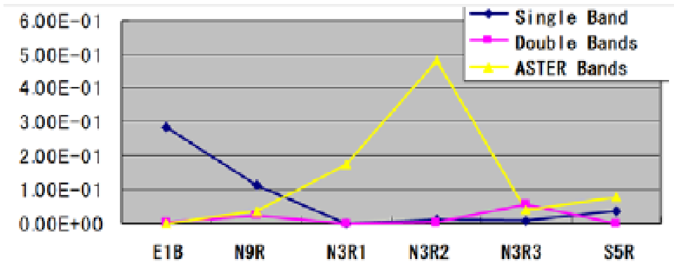


Figure 9 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of TN content in tealeaves

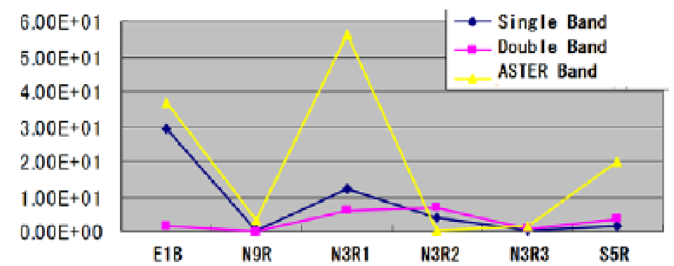


Figure 10 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of Fiber content in tealeaves

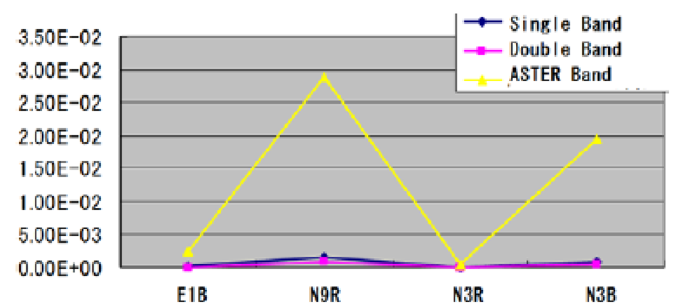


Figure 11 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of water content in tealeaves

The results show that two spectral bands case (double) shows the best estimation accuracy followed by single spectral band, and ASTER/VNIR. Due to the fact that ASTER/VNIR spectral bands are broad in comparison to the single and double spectral bands with 5 nm of band width, ASTER/VNIR spectral bands case shows the worst estimation accuracy. Also it is found that estimation accuracy depends on the tea farm areas of intensive study areas.

IV. CONCLUSION

Optimum band and band combination for retrieving total nitrogen, water and fiber content in tealeaves with remote sensing data is investigated based on regressive analysis. Based on actual measured data of total nitrogen, fiber and water content in tealeaves as well as remotely sensed visible to near infrared reflectance data with 5nm of wavelength steps and ASTER/VNIR onboard Terra satellite, regressive analysis is conducted.

As the results, it is found that 1045nm is the best wavelength for retrieving total nitrogen content while 945nm is the best wavelength for fiber content retrieval. Also it is found that 545nm is the best wavelength for water content. On the other hand, it is found that 350 and 750nm wavelength combination is the best for estimation of total nitrogen content while 535 and 720 wavelength combination is the best for fiber content estimation. It is also found that 545 and 760nm wavelength combination is the best for water content retrieval. The results show that two spectral bands case (double) shows the best estimation accuracy followed by single spectral band, and ASTER/VNIR. Due to the fact that ASTER/VNIR spectral bands are broad in comparison to the single and double spectral bands with 5 nm of band width, ASTER/VNIR spectral bands case shows the worst estimation accuracy. Also it is found that estimation accuracy depends on the tea farm areas of intensive study areas.

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A Study of Routing Path Decision Method Using Mobile Robot Based on Distance Between Sensor Nodes

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Abstract—**We propose Robot Wireless Sensor Networks (RWSNs) management method for maintaining wireless communication connectivity for a mobile robot teleoperation with considering a distance between sensor nodes. Recent studies for reducing disaster damage focus on a disaster area information gathering in underground spaces. Since information gathering activities in such post disaster underground spaces present a high risk of personal injury by secondary disasters, a lot of rescue workers were injured or killed in the past. On basis of this background, gathering information by utilizing the mobile robot is discussed in wide area. However, maintaining wireless communication infrastructures for teleoperation of a mobile rescue robot in the post-disaster underground space by various reasons. Therefore we have been discussing the wireless communication infrastructures construction method for teleoperation of the rescue robot by utilizing the RWSN. In this paper, we evaluated the proposed method for changing routing path by utilizing the RWSN in field operation test in order to confirm the availability of performance of communication connectivity and the throughputs between End-to-End communications via constructed network.**

Keywords—Wireless Sensor Networks; Moblie Robot Tele-Operation; Maintaining Throughput; Routing Path

I. INTRODUCTION

Gathering information in disaster areas is very important for assessing the situation, avoiding secondary disasters and managing disaster reduction [1]–[7]. However, if a disaster occurs in a congested city, the rescue team cannot gather information because of the complicated urban structure. In general, gathering information from a bird's eye view with an unmanned air vehicle (UAV) is a useful method in a disaster area. However, in an urban area with many underground spaces where information gathering by using a UAV is difficult, checking on the extent of the damage, which is important for avoiding secondary disasters, is difficult [8]. Also, rescue teams cannot organize a rescue plan for underground spaces. In this situation, the rescue team has to gather damage information by entering into the underground spaces directly and share them. However, when the communication infrastructure is broken, rescue teams cannot cooperate because of disconnect between above-ground and underground spaces.

Therefore, rescue workers face secondary disaster risks increasing by a sudden situation changes. For example, in the underground disasters in Korea in 2003, many casualties occurred among rescue workers because of smoke damage. The rescue workers could not expect the smoke damage because they could not gather enough disaster area information beforehand. This is a typical case of underground secondary disaster that occurred due to the rescue team having entered into underground space without adequate information. In the future, disaster area information gathering in a closed area such as an underground spaces is important to contribute the reducing secondary disaster risks and formulating an appropriate rescue plan. On the basis of above background, recent researches have focused on disaster area information gathering method using wireless sensor networks (WSNs) in closed areas. Thus we have proposed robot wireless sensor networks (RWSNs) that include the WSN and a mobile rescue robot.

The WSN consists of spatially distributed sensor nodes (SNs) to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion and so on. Then, the WSNs can provide a wireless communication infrastructure in place without established communication infrastructures. Therefore, the WSN is discussed as one of methods to construct the communication infrastructure and gather information in disaster area. However, existing construction method of the WSN is difficult to deploy SN in underground space such as post-disaster environment where rescue worker cannot enter.

The RWSN enables construction of wireless communication infrastructure by using the WSN and the mobile rescue robot in post-disaster underground space (Fig. 1). In our WSN deployment method for constructing the RWSN, we adopt a method that the mobile rescue robot deploys SNs which are wirelessly connected by defined routing path in advance. The mobile rescue robot moves into the underground space, and deploys SNs onto the own movement path. Deployed SN is connected to adjacent SNs wirelessly one by one, and then the WSN is expanded in underground space. An operator remotely controls the mobile rescue robot via constructed WSN communication infrastructure. In the network topology of this WSN, each SN is linearly connected to prevent the error of routing control. Generally, the WSN is able to decide the routing path of data transfer automatically by utilizing the RSSI between SNs, the throughput of End-to-End communication or the rate of packet loss. The routing path of the WSN is reconstructed by changes of these communication qualities. However, the routing path is repeatedly reconstructed in the situation that the communication connection between SNs is disconnected frequently. This situation is a problem for the system of the mobile robots teleoperation. An abeyance of the wireless communication connection degrades an operability of the mobile robot teleoperation and the performance of the disaster area information gathering. Then the communication qualities are often changed in disaster area by the disaster damages, the routing path is repeatedly reconstructed in the WSN. Therefore, in order to prevent the decline of the mobile robot activity, we adopt the network topology that routing path of the WSN is linearly connected. For such system, this paper describes a strategy of a routing path decision method using a mobile rescue robot for maintenance of the communication quality between SNs.

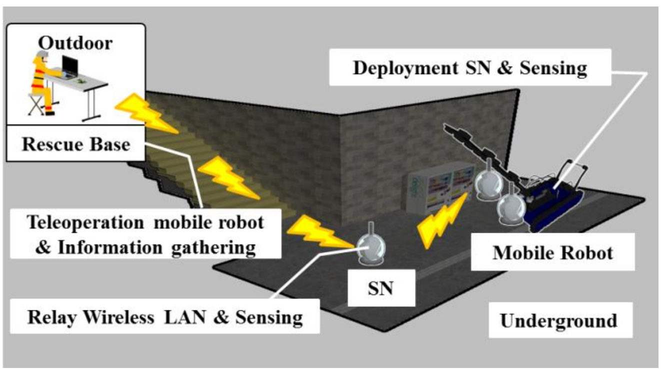


Fig. 1. Information-gathering system utilizing RWSN

II. Related Works

WSN construction methods have been discussed in the many research fields. In these researches, deployment methods have been proposed based on considering evaluation scales of factors such as packet routing, communication connectivity, energy efficiency, and coverage area[9]-[14].

Kumer et al. proposed a scheme for homogeneous distribution of randomly deployed mobile sensor networks to achieve maximum coverage while maintaining connectivity [15]. In this scheme, to achieve the maximum coverage and better connectivity, mobile nodes deploy themselves at the point which is divided other node's communication range into six. Wang et al. proposed a shortest moving path algorithm for the mobile robot to deploy a linear WSN [16]. This algorithm considers that the mobile robot has to return starting point to reload sensors and impact of different deployment strategies. Rizzo et al. proposed the deployment method of a robot team in fading environments [17]. In this method, to maintain constant connectivity and high signal quality in the communication network formed by the robots and the base station, the robot deployment is driven by RSSI measurements.

However, these methods don't consider an End-to-End network connectivity or a communication quality such as throughput. Many researches are premised on communication link being maintained automatically. Moreover, it is possible that the routing path reconstruction is difficult to maintain the communication quality, when the communication connection is disconnected by multi path fading in underground spaces. Therefore, considering routing path and communication quality in the WSN are important to maintain the End-to-End network connectivity.

III. Managemaent Method Of Maintaining Communication Connectivity Utilizing Mobile Robot

A. Prior Conditions

In our proposed system, the SNs are deployed by the mobile rescue robot to construct the WSN. An assumed environment where the WSN is constructed has entrance stairs and the first basement floor.

The entrance stairs in under-ground is required to set up at intervals 30 [m], and passage way is built in line in Japanese building standard low. Therefore, our proposed system gathers this area's information. Then we discussed the WSN construction method by utilizing the mobile robot in this area. In the wireless communication of the RWSN, IEEE 802.11 series are adopted for wireless communication between SNs including the mobile rescue robot, which has been used as proven communication protocol in many studies of mobile robots and WSNs [18]-[22]. Then in our proposed method, we treat a mobile robot as a SN in the WSN. Heterogeneous networks includingsome SNs and various mobile robots are difficult to manage the system control. Especially, maintaining the stability of the system control is not easy under disaster situation in underground spaces. In this environment, to simplify the network structure is necessary to construct the stable communication connection. Therefore we simplified the network structure by treating a mobile robot as a SN. From here onwards, the IEEE802.11 series is also adopted for communication system of the mobile robot in the RWSN.

In our SN deployment method for constructing the WSN, the mobile rescue robot delivers the previously wireless connected SNs. The mobile robot deploys them onto the own movement path to construct the WSN. The operator can control the mobile rescue robot via constructed WSN communication infrastructure. In the network topology of this RWSN, each SN is linearly connected for prevention of the routing control error. As mentioned before, we adopt the network topology that the SNs are linearly connected, and the routing path is defined beforehand to prevent the decline of the mobile rescue robot activity when constructing the WSN.

B. Requested Specification

IEEE 802.11 series are necessary to keep the throughput that is more than 1.0 [Mbps] between the operator and the mobile robot (End-to-End communication) [23]. The throughput is defined as the number of packet transferred per unit time in a communication network. In the WSN construction by utilizing the mobile robot, the throughput between End-to-End communications has to be maintained for comfortable mobile robot teleoperation. The construction length of the WSN is required 50 [m] by concerning the distance of first basement floor 30 [m] and entrance stairs 20

[m]. The communication connectivity by IEEE802.11 series, however, is characterized by decreasing in turn area covered with concrete material such as the underground space. Thus, for WSN construction, our proposed system considers this communication characteristic to avoid a network disconnection risks.

The communication system among the RWSN uses IEEE802.11b standard that is tolerant to communication disruption from obstacles. The theoretical values of throughput by using IEEE802.11b are 11.0 [Mbps], and then the actual measurement values are lowered around 7.0 [Mbps] by the efficiency of the various factors in the real environment. This wireless LAN protocol can connect to SNs within 100 [m] in 1-hop communication on the straight line. The throughput is required 1.0 [Mbps] or more for the mobile robot teleoperation with keeping high communication connectivity.

In the ad-hoc network constructed on IEEE802.11b communication link, the maximum number of SNs to maintain 1.0 [Mbps] or more is five, and then throughput between each SN should be kept 6.0 [Mbps] or more. In the ad-hoc networks constructing the WSN, the delay of data transfer increases with increasing the number of hops between the source and the destination SNs. In order to expand a communication distance with maintaining the throughput in the WSN construction, the necessary number of SNs is decided beforehand, and then the routing path of these SNs is connected linearly. This method provides the high connectivity in an area covered with concrete material such as the underground space by deploying SNs as communication relay nodes to construct the WSN. In this system, the RWSN is constructed by using a source SN for the operator, three SNs for communication relay deployed by the mobile robot and the mobile robot regarded as one SN.

C. SN Deployment method for maintaining communication quality

In our proposed method, the mobile robot simultaneously measures communication quality while moving in the environment, and decides the deployment position of a SN. Therefore, the SN position can be determined flexibly against a change of radio wave condition, the mobile robot can cover with the whole target passageway. We proposed and evaluated the availability of several our deployment method in field operation test in the past [24]-[26].

To keep the throughput of 1.0 [Mbps] in End-to-End communication, two communication qualities between adjacent SNs need to be maintained. One is the RSSI that values over -86 [dBm] between two adjacent SNs (1-hop) communication are required. A wireless LAN module controlling the throughput speed constantly refers the RSSI for stability of the network connection. If the RSSI value is below -86 [dBm], the wireless LAN module controls the upper limit of throughput speed to 5.5 [Mbps]. Our proposed method also measures the RSSI value to predict the throughput speed control of the wireless LAN module. The other is the throughput that values over 6.0 [Mbps] between adjacent SNs (each 1-hop) are required for maintaining the throughput over 1.0 [Mbps] between End-to-End communications. Moreover, for the decision of SN deployment position, measurement of the throughput between the operator and the mobile robot as End-to-End communication is required to evaluate the communication quality. Therefore, both the throughput and RSSI values must be measured to satisfy the required communication performance for mobile robot teleoperation, and the robot measures both the throughput and RSSI value between each SN accordingly. The robot moves continuously to the destination while maintaining the 1.0 Mbps of throughput required for end-to-end communication and an RSSI value of -86 dBm between each SN(Fig. 2).

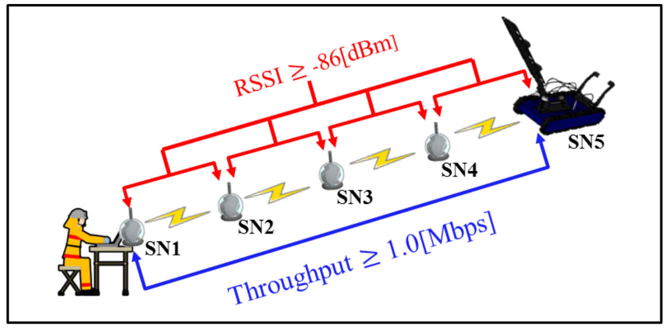


Fig. 2. SN Deployment method

D. Routing Path Decision Method Based on Communication Connectivity Between Adjacent SNs

As mentioned above, the proposed routing path decision method is necessary to prevent the communication disconnection and to maintain the throughput of over 1.0 [Mbps] between End-to-End communications.

In the network topology of the WSN constructed by the mobile robot, SNs are linearly connected and deployed. Then, the mobile robot moves on a straight line along deployed SN. At that time, the mobile robot communicates with a last deployed SN by 1-hop. Then, the distance between the mobile robot and this SN changes by moving the mobile robot. Generally, the throughput decays by degrading the RSSI and increasing the noise signal with the extension of distance between SNs. From this reason, it is necessary to decide the routing path between End-to-End communications flexibly against change of the distance between the SN and the mobile robot.

In order to maintain stability of the communication quality between each SN in the WSN constructed by our SN deployment method, we propose a decision method of a routing path between End-to-End communications based on relative positions of the mobile robot and SNs. When the positions of the mobile robot and a SN are the same, the mobile robot selects the SN of high connection priority, and then switches the routing path. A connection priority is different from the moving direction of the mobile robot. Each SN stores the routing path to the last deployed SN. Hence, using these routing path policies, the mobile robot can decide the routing path between End-to-End communications. Then, the throughput between End-to-End communications is increased or decreased depending on the number of hops by updating the routing path. Though, the proposed method maintains the throughput between End-to-End communications and prevents communication disconnection because the throughput and the RSSI value between SNs are stable.

Figure 3 to 5 show the workflow of this routing path decision method to be applied to the mobile robot (SN5). In the workflow, X is parameter of deployed SN ID, and Y is parameter of the high primary connection SN ID (hpc-SN ID).

Also, we define the source direction is that the mobile robot moves back to the passage, and the destination direction is that the mobile robot moves forward to the passage.

Moreover, Table 1 and 2 show a pattern of routing path. The workflow is outlined below.

1) The mobile robot records the SN deployment position with referring to own odometry and assigns an ID to the SN deployed one by one(X = 1, 2, 3, 4).

2) The mobile robot moves along the constructed WSN. Then the mobile robot measures movement distance by referring to the odometry.

3) The mobile robot compares self-position and the SN deployment position. If their positions match, the mobile robot refers to SN ID (choice SN ID, X). Otherwise, the workflow backs to the process (2).

4) The mobile robot identifies the forward direction and in case the mobile robot is moving the source direction (point of SN1: 0 [m]), the workflow progresses to the process (5). Otherwise (the destination direction: the mobile robot is facing the SN2, SN3, or SN4), the workflow progresses to the process (6).

5) For the movement to the source SN (SN1) direction, the mobile robot selects the SN (ID = X – 1) which has high connection priority, and multicast the packet to run the command changing routing path. Then, the SN which received the packet updates the routing table and connects to the mobile robot (Fig. 4).

6) For the movement to the destination SN (SN4) direction, the mobile robot selects the SN that SN (ID = X) which has high connection priority, and multicast the packet to run the command changing routing path. Then, the SN which received the packet updates the routing table and connects to the mobile robot (Fig. 5).

7) The mobile robot send the packet to the SN1 which is the source SN for the operator, and then each SN transfers received packet to the SN1 while updating the routing table. By repeating this, the mobile robot decides the routing path between End-to-End communications.

TABLE I. ROUTING PATH MOVEMENT TO SOURCE DIRECTION

Mobile Robot Position	Routing Path
SN2	SN1-SN5
SN3	SN1-SN2-SN5
SN4	SN1-SN2-SN3-SN5

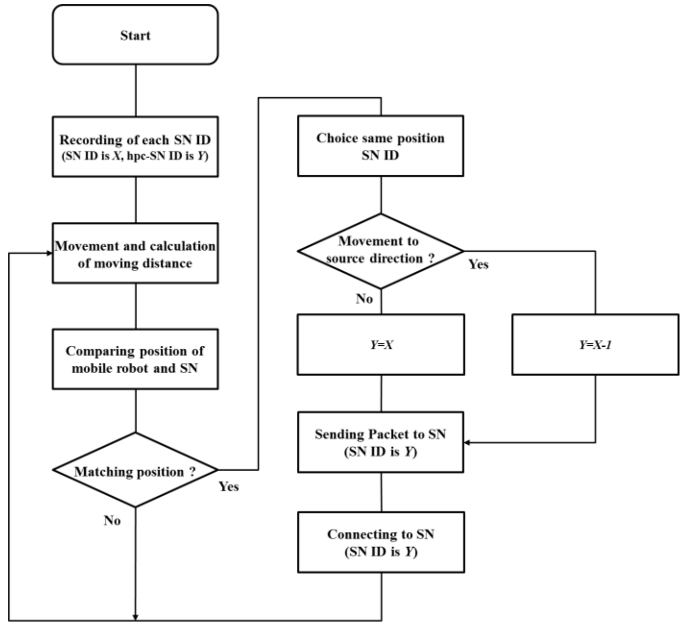


Fig. 3. Workflow of our proposed routing path decision method

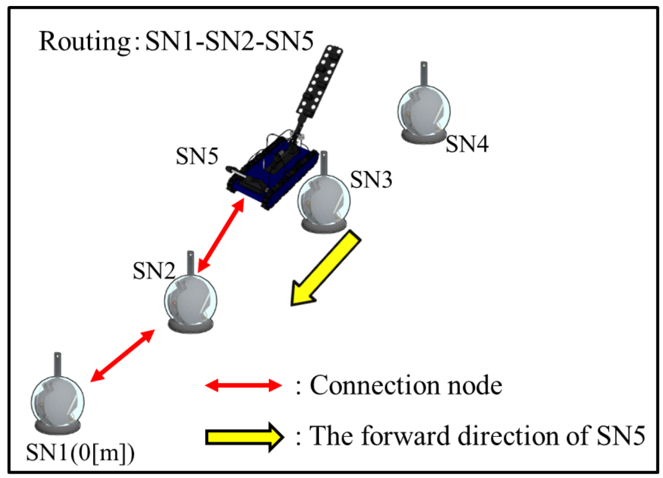


Fig. 4. Decision of routing path at source direction (e.g. mobile robot reaches point of SN3)

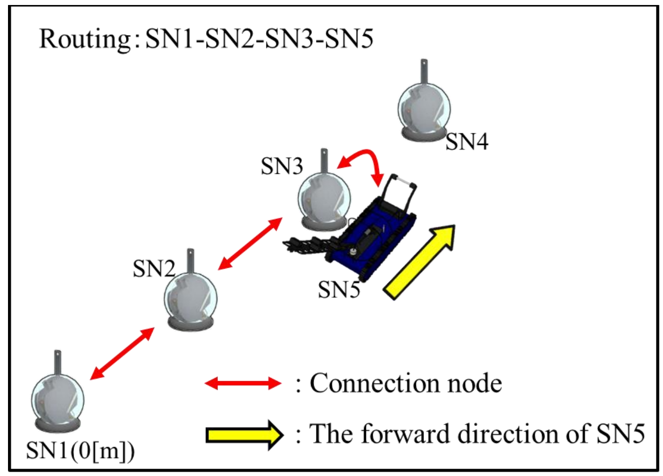


Fig. 5. Decision of routing path at destination direction (e.g. mobile robot reaches point of SN3)

TABLE II. ROUTING PATH MOVEMENT TO DESTINATION DIRECTION

Mobile Robot Position	Routing Path
SN2	SN1-SN2-SN5
SN3	SN1-SN2-SN3-SN5
SN4	SN1-SN2-SN3-SN4-SN5

IV. PERFORMANCE EVALUATION OF PROPOSED ROUTING METHOD

A. Experimental Conditions

This section describes experimental conditions for performance evaluation of proposed routing method. Pseudo failure SN disconnects WSN between the operator and the mobile robot, and then proposed routing method reconstructs the network in this experiment. The experiment verifies maintaining connectivity by measuring throughput between End-to-End communications. Stability of the throughput indicates success of change of the routing pass, and then WSN reconstruction prevents the disconnection of teleoperation between the operator and the mobile robot. In this experiment, we performed a cooperative evaluation of a fixed linear routing method and the proposed routing method.

The experiment was performed in the passageway with a length of 300 [m] or more in Tokyo Denki University, and the WSN was constructed by utilizing RWSN in this environment (Fig. 6). The SN configuring the WSN mounts the CPU board, memory device, CompactFlash disc, IEEE 802.11b/g wireless LAN module, and a battery. These devices are controlled by Linux OS (Debian) installed to the CPU board. By utilizing the “AODV-uu”, Ad-Hoc networks can be constructed on the WSN. Table 3 shows the specification of the SN. The CPU board is “Armadillo-300” (@techno Inc.) in which Linux OS is implemented (Fig. 7 (a)). In RSSI value measurement, we used “wlanconfig” command included in the Linux wireless tools.

The throughput was measured by using “utest” provided by NTTPC Communications, Inc. The “utest” is a tool measuring throughput by transferring 10000 times of the packet of 1500 [byte] to communication partner. The throughput is calculated by received data per unit time. The crawler-type mobile robot, “S-90LWX” (TOPY INDUSTRIES, LIMITED) equipped with a SN deployment mechanism shown in Fig. 7 (b), is used as the mobile robot in this experiment.

The mobile robot constructed a WSN by utilizing our proposed SN deployment strategy prior to the evaluation. Each SN were deployed at SN1: 0 [m], SN2: 80 [m], SN3: 128 [m], SN4: 136 [m], and SN5: 196 [m]. After that, we measured 10 times of RSSI value and throughput between 1-hop connections in each 4 [m] interval in two situations of the linear routing network and the proposed routing method while the mobile robot (SN5) moved from the point of 196 [m] to the point of 0 [m]. The operator controlled the mobile robot as SN5 connected to SN1 via the WSN. The WSN provided communication infrastructure to the operator for wireless teleoperation of the mobile robot in this experiment.

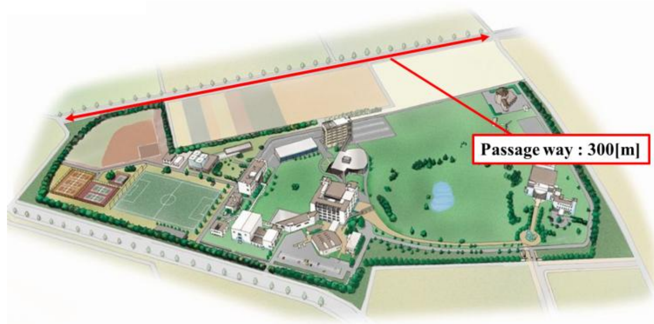
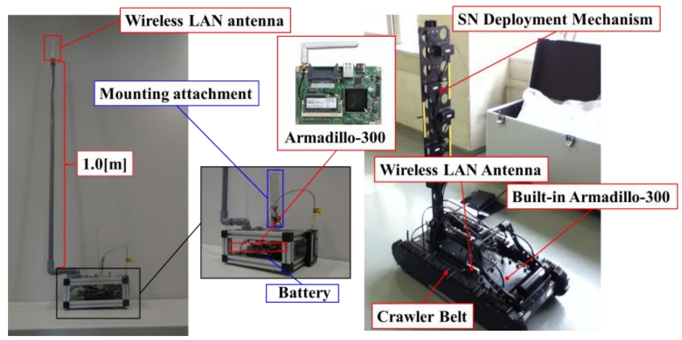


Fig. 6. Experimental environment

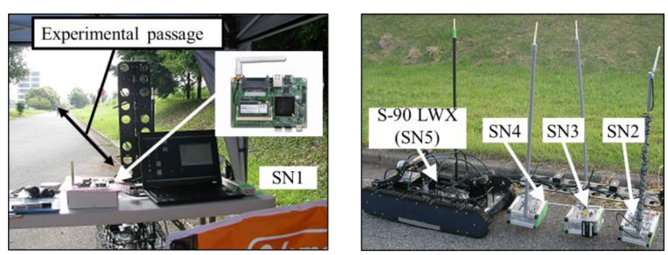


(a) Sensor Node (b) S-90LWX

Fig. 7. Configuration devices on WSN

TABLE III. SPECIFICATION OF WIRELESS SENSOR NODE

Sensor Node	
Operating system	Linux Kernel 2.6 (Debian)
CPU board	Armadillo-300 (ARM 200[MHz])
Weight	1.5 [kg]
Height×Width×Length	225 [mm] × 180 [mm] × 380 [mm]
Battery No. 1	Output : 5 [V], 1.8 [A]
Battery No. 2	Output : 12 [V], 2.1 [A]
Operating time	3 [hour]



(a) Experimental place (b) S-90LWX with SN

Fig. 8. Overview of experimental environment

B. Experimental Results

Figure 9 and 10 show experimental results that are the mean value of RSSI and throughput in fixed linear routing network. Figure 11 and 12 show the values in proposed routing network. In fixed linear routing network, measurement intervals of RSSI and throughput were between SN4 and SN5.

In the proposed routing network, SN4 connects SN5 between 196 [m] and 136 [m], SN3 connects SN5 between 132 [m] and 128 [m], SN2 connects SN5 between 124 [m] and 80 [m], and SN1 connects SN5 between 76 [m] and 0 [m] (Fig. 11 and 12). Thus measurement intervals of RSSI and throughput were above intervals in proposed routing network.

We confirmed that the mobile robot as SN5 was able to connect to WSN in all measurement intervals of the fixed linear routing network and the proposed routing network. Then the operator could control the mobile robot by connecting WSN in both routing network without communication failures such as network disconnection, multipath fading of radio wave, various environmental noise and so on.

V. Discussion

In the case of using the fixed linear routing network in the performance evaluation, the throughput between End-to-End communications was lower than 1.0 [Mbps] at the point of 80 [m] (Fig. 9). It shows maintaining the throughput of 6.0 [Mbps] between SN4 and SN5 was difficult with the decrease of RSSI because the distance between SN4 and SN5 was expanded (Fig. 10). Also, the throughput between SN4 and SN5 was unstable from the point of over 80 [m] where the upper limit value of the throughput was adjusted frequently. Then, the operability of the mobile robot might decrease.

Against that, the case of using our proposed routing method, the throughput between End-to-End communication increased from 1.4 [Mbps] to 7.0 [Mbps] because the number of hops between SN1 and SN5 decreased (Fig. 11). Therefore, we confirmed that the throughput of 1.0 [Mbps] between End-to-End communications and 7.0 [Mbps] between the mobile robot and the SN connected by 1-hop were maintained at all SN deployed positions (Fig. 12). These results show the availability of our proposed method in this field test.

VI. Conclusion

This paper proposed the WSN management method of changing routing path considering communication disconnection by the effect of multi path fading. The proposed method maintained communication conditions that throughput

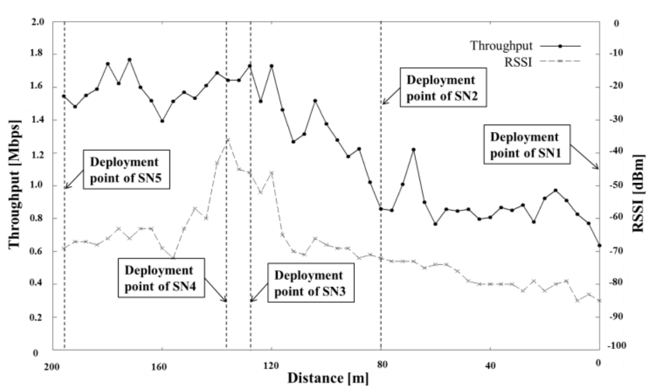


Fig. 9. Experimental result of RSSI and End-to-End throughput in fixed linear routing network

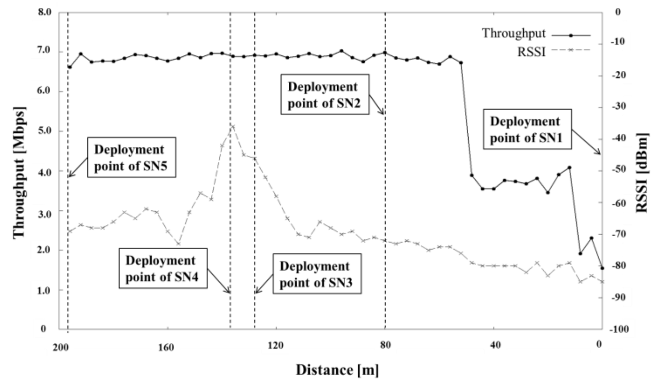


Fig. 10. Experimental result of RSSI and 1-hop throughput in fixed linear routing network

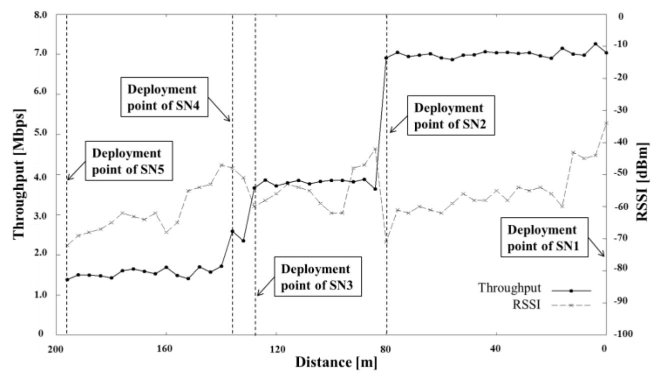


Fig. 11. Experimental result of RSSI and End-to-End throughput utilizing our proposed routing network

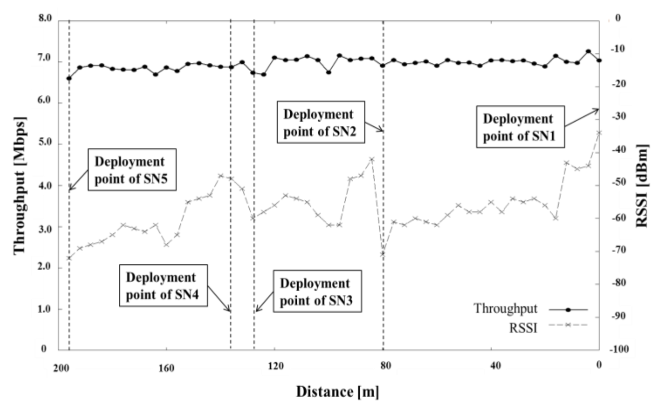


Fig. 12. Experimental result of RSSI and 1-hop throughput utilizing our proposed routing network

between End-to-End communications in the WSN enables smooth teleoperation of the mobile robot in a post-disaster underground space. Experimental results showed the effectiveness of the proposed method that enables to manage the WSN in the field test. The rapid implementation of actions to reduce secondary disasters in disaster areas requires the stable referral of disaster information. Therefore, this WSN managing method that maintains the throughput stable by utilizing the mobile robot is effective for gathering disaster area information in actual disaster scenarios.

In future work, we should consider the communication disconnection on WSN due to SN failure. In the underground space, the SN may break down by the effect of secondary disasters. It means that information gathering by the RWSN becomes impossible. We will consider the improved SN re-deployment method to repair the communication disconnection by integrating our proposed routing path decision methods.

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