Real-time monitoring of water level : a review of existing applications, and advancements in mini-telemetry system for agricultural planning.

Pongnathee Maneekul [1*] , Chanwit Suwannapong [2]

[1] Division of Civil Engineering, Faculty of Engineering, Nakhon Phanom University, Nittayo Road, Nong-Yart sub-district, Muang District, Nakhon Phanom Province, Thailand 48000

[2] Division of Computer Engineering, Faculty of Engineering, Nakhon Phanom University, Nittayo Road, Nong-Yart sub-district, Muang District, Nakhon Phanom Province, Thailand 48000
* Corresponding author. E-mail address: psm_york@hotmail.com

Abstract Recent advances in sensor technology have advantage in agricultural and water management. This paper presents an application of a small telemetry system to real-time water level management. The system has been developed by using a wireless sensor network, which automatically record the level of water to minicomputer(Raspberry Pi). The water level data collected at the end of a rainy season over six months period were converted to water volume. The water volume was then used as a model constraint for the agricultural acreage at Nam-Kam irrigation basin, Nam-Kam Sub-district, That-Phanom District, Nakhon Phanom Province, Thailand. The Differential Evolution algorithm (DE) was employed to modeling optimal water management. The results showed the suitable planting portion plan over the considered period for second rice: cassava: yam bean : tobacco were 83.76, 7.94, 8.02 and 0.27 percent, respectively.

Keyword : Small telemetry, Planting crop, Differential Evolution, Optimized solution

1. Introduction

At the present, water management system of reservoirs is very important in agricultural production around the reservoirs because individual reservoir has different cost in management. Water quantity required for the agriculture production depends on the type of plants in the farms so if the farmers around the reservoirs have knowledge and understand in cost of water for their own farms and can balance the quantity of water, this will be more efficiency to plan the schedule of the plants. Hence, efficiently water management of individual reservoirs is necessary for agricultural production especially for very important plants.

Thailand currently has more than 28 million hectares of irrigated area (Royal Irrigation Department, 2012), most of the water providing by gravitation. A system of irrigation canals could help to transmit and distribute water from the canal which could not go to the farmer's acreage. Information Management System of the water was considered as paramount importance in the management of the agricultural sector because indifferent area cost of water usage is various management as well. The information by the demand for water in the agriculture sector will depend on the type of plants used in cultivation. If there is a database or storage water level data in the canal, it is particularly useful for planning water management services to assist in the planting crop in the appropriate time period.

In the past, the water level in the canal used taking notes method by outsourcing as a scorer which consumes the cost of labor to keep the water level every day or every hour. Nowadays, the technology could measure in a various way for the water level measuring such as telemetry that measures the water level. There are many forms of wireless sensor networks to measure the water level. The application of technology transfer data wirelessly to a method of measuring the water level. This will facilitate the measurement, collection and storage of water. The wireless sensor network is featured with mini size of device, resistant to damage, the effectively power, real-time information and making note of the information from the sensors immediately (Prasansri & Khunboa, 2013, pp. 231-234). In the research, the researcher has selected the device module Xbee-Pro 900HP (Digi International, 2014) which made the device transfer data and supports standard wireless sensor network (IEEE 802.15.4) with the frequencies for transmitting data at 900 megahertz (MHz) and the rate of send less than or equal to 200 kilobits per second (kbps).

Now, the efficiency of the wireless sensor network technology, the researchers see benefit in their application for developing telemetering system for a small irrigation canal and can reducing the labor of collecting data and also collect data about the storage water level in the canal. This information support in term of data uses for the management of water in the canal more efficient.

2. Historical background

Nam-Kam irrigation basin is sub-irrigation basin of Mae Kong River that has important irrigation basins such as Nhong-han irrigation basin and Nam-Kam irrigation basin. Both of the irrigation basins are started from Nhong-han, Muang District, Sakon Nakhon Province which flow through south-east area of the province to Mae Kong river at Nam-Kam Sub-district, That Phanom District, Nakhon Phanom Province. The total distance of the irrigation basin is 123 km and the watershed area is 3,440 km^2 which can receive the amount of rainfall about 1,400 million m^3. Almost area along the irrigation basin-side are agricultural farm and rural community. The people living around the irrigation basin always encounter both flood and drought every year. In particularly in the raining season, the water level of Mae Kong River is very high, the agricultural farm will be flood. However, in the summer season, the water level of Mae Kong River is very low then the Nam-Kam irrigation basin will flow down to the Mae Kong River as a result the people along the irrigation basin will lack of water for utilization.

When the problem of the water management passing to HM the King Bhumibol Adulyadej of Thailand, he gave the concept to solve this problem through Royal Irrigation Department for establishing the development plan of Nam-Kam irrigation basin. The project has started from November, 1992 by drawing the map for the irrigation basin development. The irrigation basin development composed of the head which is Nhong-han irrigation basin, a large natural irrigation basin, the backbone which is Nam-Kam irrigation basin, similar to vertebra – the segment using for control and drain the water along the irrigation basin, and the tail which is Mae Kong River. With this concept, it should be guidance for solving the flood and drought for the people along the Nam-Kam irrigation basin.

Until 22nd November, 1999, HM the King Bhumibol Adulyadej added the new concept by assigning the Royal Irrigation Department launching the construction of control building in down-stream of Nam-Kam irrigation basin. This was for collecting small amount of water due to the land price was very high. So, when the government can expropriation in appropriate price, the Royal Irrigation Department launched a new construction water gate which was higher efficiency for collecting the water. The king gave the name of this water gate as Thoranisanalumit which means the water gate that the king given name as shown in Fig. 1

The operation of 7 water gates can collect the water at the top of the gates. By constructing the pumping station and transfer the water through irrigation canal to irrigation area along the Nam-Kam irrigation basin. At the present, the operation can deliver the water from the water gate to the irrigation area around 67 km^2 from the target area 264 km^2.

Fig. 1 Thoranisanalumit Water Gate

Thoranisanalumit water gate located at the down-stream of Nam-Kam irrigation basin, Baan Non Sang, Nam-Kam Sub-district, That Phanom District, Nakhon Phanom Province. This water gate was constructed by reinforce concrete size about 10.00 x 9.00 m. There are 4 gates installing with reverse pumping systems. The water storage capacity for this water gate is about 16.4 million m^3 at highest water level +137.5 meters and at the lowest level +136.5 meters can collected water more than 8.4 million m^3 which can serve the agricultural area of 31 km^2 of Nam-Kam Sub-district.

In this report, the important of database for collecting the water level of Nam-Kam irrigation basin for water management of people who utilize water is studied. The concept of this study are as follow:

1) Establishing mini-telemetry system for collecting water level.

2) Developing the graphical data to show real-time of the water level via website or android system in every 5 minutes.

3) Collecting the water level data for 6 months by using mini-telemetry.

4) Using the collecting data as a constraint for water management to investigate a cultivation plan of the next season by differential evolution algorithm.

3. The small telemetry system

3.1 Wireless sensor network

Wireless Sensor Network [1] is a node sensor network comprising of a large number of node sensor devices that work automatically, whereby the node sensors inside the network functioning for detecting and storing data including environmental properties that they are interested in, for example, light, humidity, vibration, temperature, pressure, movement, and pollution. After the node sensor devices receive the data, they will send it back to the upstream node which needs the mentioned data via the adjacent node sensors. The node sensor devices will send the data consecutively in order to process and create new knowledge relating to the environment. As described in Fig 2.

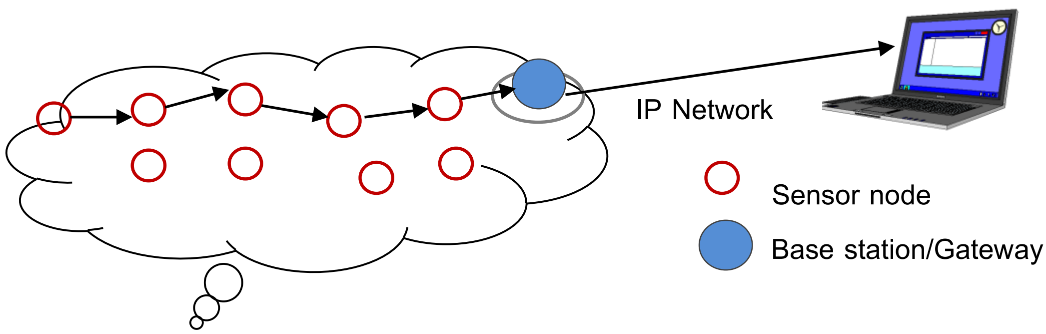

Fig. 2 Wireless sensor network module

motivation in development of the wireless sensor system starts from utilizing this system in soldier's project. Then, the concept above was applied continuously to other work systems such as medical system, intelligent system in home, traffic control, agricultural system and location tracking system for animals.

3.2 Pressure sensor

There are various types of pressure sensors which can be divided by the measured water height and the type of water to be measured, i.e. standing water or running water. The objective of this research is to provide a sensor which is able to measure the water's height approximately at 5 m. in an irrigation canal. From the study and research of various sensors, the selected sensor should have specific properties as described below.

The sensor [2] must be a transducer which gives an output in a range of 0-5 Volt and capable of measuring water at 5 meters. Every changing of the depth, that sensor must give electric pressure value (Volt) in millivolt, whereby a signal emitted from the sensor must be an analog sensor.

3.3 The framework of a small telemetry system

This section discusses the various development stages. The study system and the function of the water level sensor which relate to transmission equipment, networks, wireless sensor Xbee-Pro 900HP of Digi by programming using C and connected via a mini computer Raspberry Pi (Raspberry Pi Foundation, 2015)[3], the USB cable signal processing and display information through a Web browser. This is a development stage, critical systems are three parts ; sending and receiving wireless sensor networks, the water level sensor and the recording and display section.

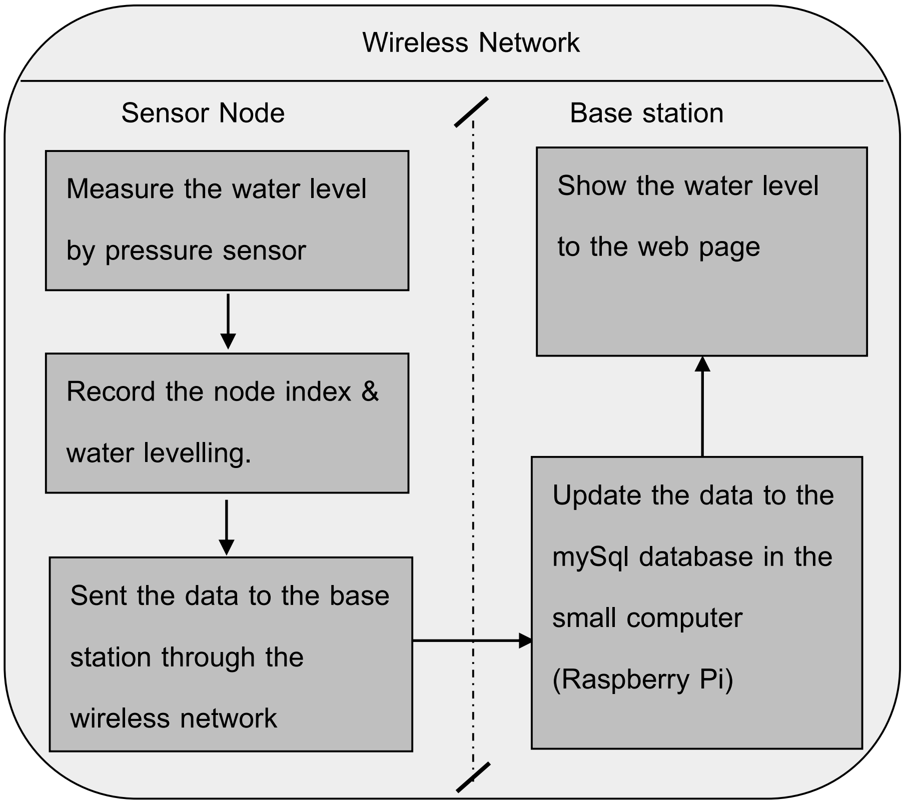

Fig. 3 The framework of a small telemetry system

3.4 Development of the transmission network of wireless sensors.

The researchers select module Xbee-Pro 900HP device to be used as a device for transferring data over wireless sensor networks (IEEE 802.15.4) at frequency 900 MHz with data rates ranging from 10 up to 200 Kbps. The signal can be sent it on the outside (Outdoor) of approximately 6 kilometers (km). In addition, the device also has the information from analog sensors and another four series which receive analog data and convert to digital (ADC) with a resolution of 10 bits of data of sensor readings is between 0-1023 by the characteristics of data transmission with wireless sensor networks.

3.5 Development of the water level sensor.

The device measures the water level in this research has selected Analog Devices by using measurements vary with depth. The depth of measurement is 0 to 5 meters (m) where each 1 centimeter (cm) depth is converted to a voltage output 9 millivolts (mV) according to the specification of the sensor level [4] , minimum 0.2 V and maximum 4.7 V (ElecSensor, 2015). However, by signal output connecting with a signaling device

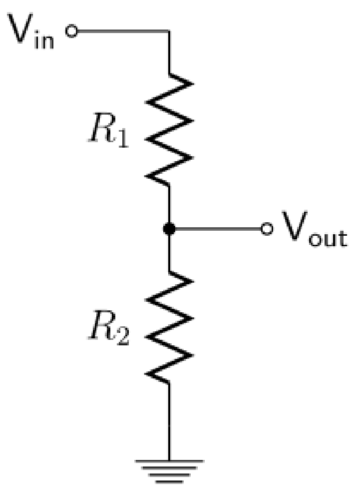

Fig. 4 The voltage divider.

In Fig. 4 shows the voltage divider. To find out, we can find from the equation.

$$V_{out} = V_{in} \cdot \frac{R_1}{R_1+R_2} \qquad \textbf{(1)}$$

when

V_{out} = The output voltage (V).
V_{in} = The incoming voltage (V).
R_1 = the resistance (kΩ).
R_2 = the resistance (kΩ).

For example, in equation (1), the voltage output (V_{out}) must be equal to 3.3 V when the voltage input (V_{in}) is 4.7 V. The resistor R_1 is 1 kilo-ohm (kΩ) and a variable resistor, R_2. which is used to adjust the results in line with requirements which could find the resistor R_2 is equal to 2,357.14 Ω or equal to 2.357 kΩ. Figure 5 shows the calculated voltage output, which shows that when the sensor voltage output of up to 4.7 V parts of the voltage divider

which can receive voltages up to 3.3 V for the need of voltage divider (El-Sherif, 2016)[5] to lateral ratio of the voltage sensor in the range of the transmitter can be received. The voltage divider is shown in Fig 4.

will be adjusted. The value does not exceed the device's signal received which is equal to 3.3 Volt.

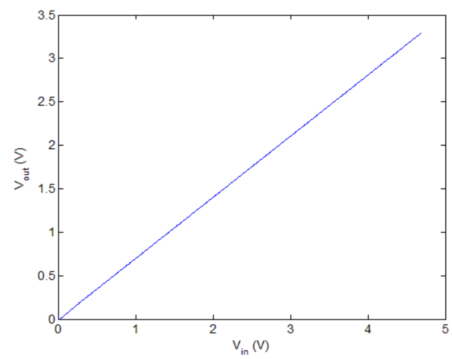

Fig. 5 Value of V_{out} was calculated by pressure dividing.

After adjusting the voltage output of the sensor in certain area, we could compare the output voltage of the sensor on the depth of water. As mentioned above, when the water level changes 1 cm depth, the sensor provides voltage output to 9 mV as shown in Fig 6.

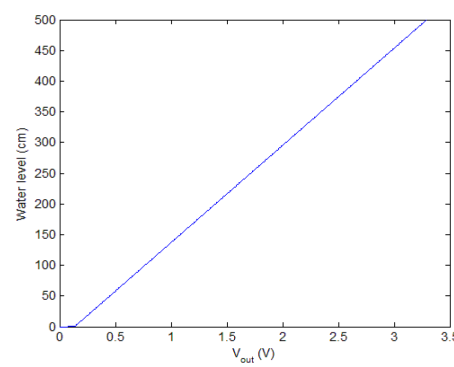

Fig. 6 The depth of water compared to the voltage output from sensor.

When the sensor voltage ratio based on the depth of water, transmission equipment wireless sensor networks will convert analog data into digital data which has value from 0 to 1023 and will be recorded in the database. See the Fig 7.

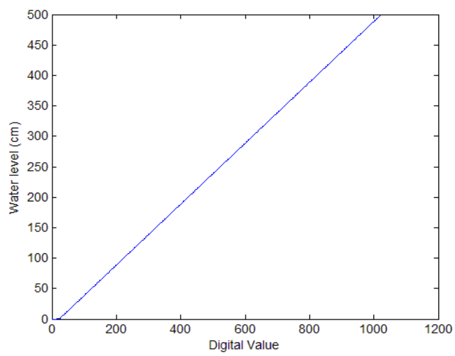

Fig. 7 The digital data and the depth of the water.

3.6 Development of the recording and display

To collect all data and display the results from the sensor level, the researchers have selected a mini computer Raspberry Pi which is inexpensive and can be installed with operating system (Linux OS) which is convenient to record and display data. The researchers install the

mySql database to collect the data received from the information and install a Web server so that users can browse easily. The data is the latest show automatically. As shown in Fig. 8.

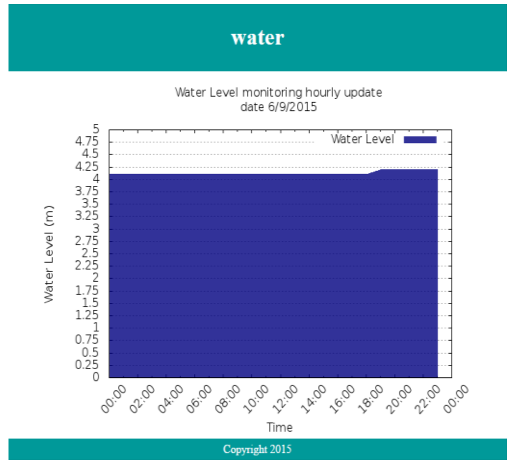

Fig. 8 The proportion of water result.

4. Water management for agricultural planning

This paper proposed the optimization of planting crop versus the water storage of Nam-Kam irrigation Project, Nam-Kam Sub-district, That-Phanom District, Nakhon Phanom Province, Thailand, by using Differential Evolution algorithms as follow.

4.1 Water storage during the pilot project study

The volume of water storage of Nam-Kam irrigation basin Project during November, 2015 to April, 2016 was calculated by the product of water level and cross sectional area of the canal through the length of canal in this project are shown in Fig 9.

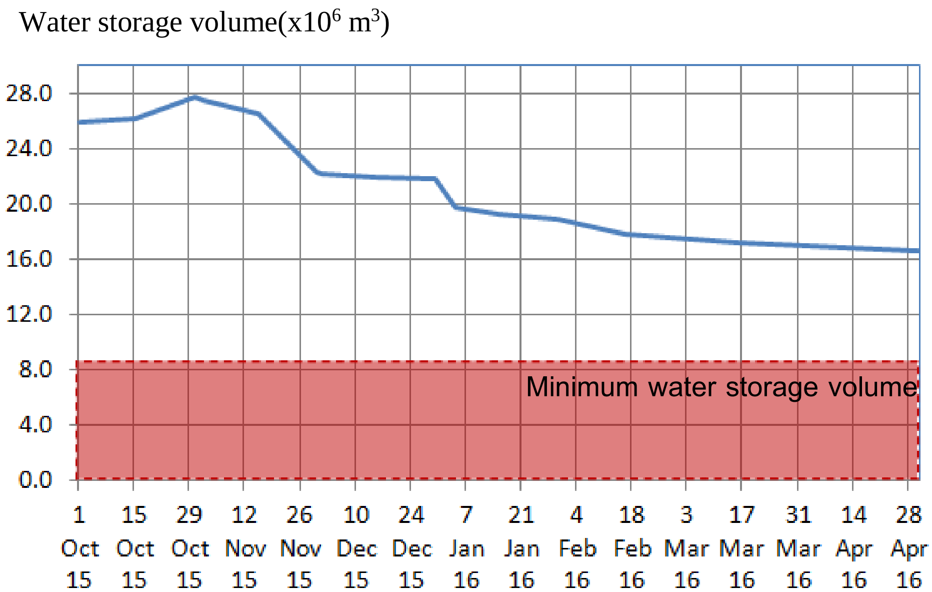

Fig. 9 The volume of water storage in Nam-Kam river basin project.

4.2 Differential Evolution Algorithm

The Differential Evolution (DE) is a population-based stochastic search algorithm that firstly proposed by Storn and Price (1997) [5] was proven to be one of the new optimization algorithm for global search methods. This algorithm was widely used to solve optimization problems in many fields such as minimized weight of truss structures [6], In the year 2010, Adeyemo, J., and Otieno, F. use a differential evolution algorithm for solving multi-objective crop planning model to find an optimal cultivation planning. [7]

General problem formulation is:

For an objective function $f: X \subseteq \mathbb{R}^D \to \mathbb{R}$ where the feasible region $X \neq \emptyset$, the minimization or maximization problem is to find

$$x^* \in X \text{ such that } f(x^*) \leq or \geq f(x) \forall x \in X \quad \textbf{(2)}$$

where:

$$f(x^*) \neq -\infty \quad \textbf{(3)}$$

DE is an evolutionary algorithm and this class also includes Genetic Algorithms, Evolutionary Strategies and Evolution Programming. The algorithm that works through four main phases as shown in fig. 10

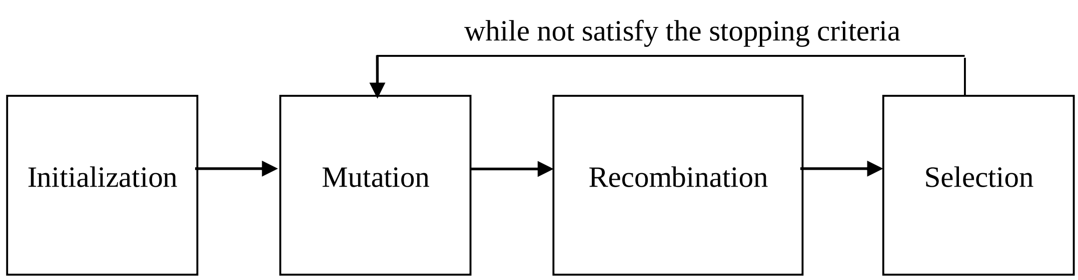

Fig. 10 General Evolutionary Algorithm Procedure

Suppose the optimization problem has a function with D real parameters we must select the size of the population *NP* (≥4) the parameter vectors have the form :

$$x_{i,G} = [x_{1,i,G}, x_{2,i,G}, \dots, x_{D,i,G}], i = 1,2,3, \dots, NP \quad \textbf{(4)}$$

When G is generation number.

4.2.1 Initialization

Firstly of algorithm is to define upper and lower bounds for each parameter:

$$x_j^L \leq x_{j,i,1} \leq x_j^U \quad \textbf{(5)}$$

Then the algorithm randomly select the initial parameter values uniformly on the intervals $[x_j^L, x_j^U]$

4.2.2 Mutation

Each of the *NP* parameter vectors undergoes mutation, recombination and selection. For this phase the mutation will expands the search space by randomly select three vectors $x_{r1,G}, x_{r2,G}$ and $x_{r3,G}$ such that the indices *i, r1, r2* and *r3* are distinct. Add the weighted difference of two of the vectors to the third.

$$v_{i,G+1} = x_{r1,G} + F(x_{r2,G} - x_{r3,G}) \quad \textbf{(6)}$$

Where the mutation factor F is constant range from [0,2] and $v_{i,G+1}$ is called the donor vector

4.2.3 Recombination

Recombination incorporates successful solutions from the previous generation of feasible solution. The trial vector $u_{i,G+1}$ is developed from the elements of the target vector, $x_{i,G}$ and the elements of the donor vector, $v_{i,G+1}$ are show in the equation (7)

$$u_{j,i,G+1} = \begin{cases} v_{j,i,G+1} & if\ \text{rand}_{j,i} \leq CR\ or\ j = \text{I}_{\text{rand}} \\ x_{j,i,G} & if\ \text{rand}_{j,i} > CR\ and\ j \neq \text{I}_{\text{rand}} \end{cases} \quad \textbf{(7)}$$

Where $i = 1,2,\dots,NP$; $j = 1,2,\dots,D$ and $\text{rand}_{j,i} \sim U[0,1]$, I_{rand} is a random integer from $[1,2,\dots,D]$ and I_{rand} ensures that $v_{i,G+1} \neq x_{i,G}$, Elements of the donor vector enter the trial vector with probability crossover rate (CR) and D is the dimension of decision variables.

4.2.4 Selection

The last phase of algorithm is compared the target vector $x_{i,G}$ with the trial vector $v_{i,G}$ which one that satisfy the optimization problem.

$$x_{i,G+1} = \begin{cases} u_{i,G+1} & \text{if } f(u_{i,G+1}) \text{better than } f(x_{i,G}) \\ x_{i,G} & otherwise \end{cases} \quad \textbf{(8)}$$

The algorithm will stop when the stopping criterion were reached.

4.3 Planning of appropriate planting.

The following mathematical model is proposed allocation model to take advantage of the farmland to the appropriate amount of water stored in the canal during drought intensity. Use 4 types of economic plants in this study which included second rice, cassava, yam bean and tobacco, with the objective function to maximize the profits receive from the revenue generated from sailing products minus production costs. The considered a production costs were including with the cost of cultivation, opportunity cost of agricultural products sales and the cost of irrigation water tariff Under the restriction of the amount of water storage in the period of November 2015 to April 2016. Finding solution of the problem by using an differential evolution algorithm. The details as follows. [8]

<u>Indices</u>

i Type of plant, i = 1 is rice, i=2 iscassava, i=3 is yam bean and i=4 is tobacco

j Cultivated field number(CF#), j = 1,2,3 (As shown in Fig.11)

Decision Variables

x_{ij} = Percentage of the crop number i in the cultivated field number j

Parameters

a_{ij} = Crop yield of plant number i in the cultivated fields number j (Ton/Rai)

b_{ij} = Area of crop planning of plant number i in the cultivated fields number j (Rai)

c_i = Cost of cultivation plant number i (Baht/Rai)

d_i = Market demand of agricultural product number i (Ton)

g_i = Opportunity cost of plant number i (Baht/Ton)

p_i = Price of agricultural product number i (Baht/Ton)

u_i = The demand of water for the plant number i (m^3/Rai)

w_j = Water consumption of the dominant plants in cultivated fields number j (m^3)

y_j = Unit cost of irrigation water to the cultivated fields number j (Baht/ m^3)

z_i = Production volume was less than the market demand of plant number i

Objective function

To find the proportion of cultivated plants in the watershed in study area will figure out the most profitable place by use total income from sales minus the four list of costs that consisted of cot of crops in the area, cost of irrigation water tariff, cost of changing the kinds of crops and opportunity cost of some production is not sufficient to meet market demand. The objective function is defined as in Eq. (9)

$$\text{Maximize profit} = \sum_{i=1}^{n}\sum_{j=1}^{m} p_i b_{ij} a_{ij} x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} c_i b_{ij} x_{ij} - \sum_{j=1}^{3} w_j y_j - \sum_{i=1}^{n}\sum_{j=1}^{m} g_i z_i \quad \textbf{(9)}$$

5. Result and discussion.

5.1 Basic information of the pilot project study area.

The area of pilot project study is Nam-Kam sub district ,That Phanom district, Nakhon Phanom province, Thailand. Total area is approximately 39,960 Rai. Agricultural land is approximately 19,545 Rai and divided into three zones of cultivation fields away from the canal. The cultivation field number1, 2 and 3 there are planted area about 7818 Rai, 6840 Rai and 4887 Rai, respectively as shown in Fig. 11

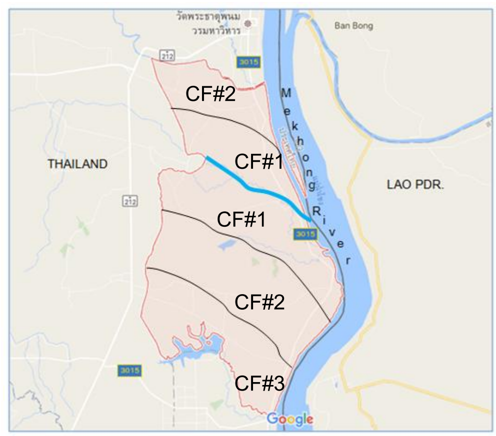

Fig. 11 Pilot study project area. (http://www.google.co.th)

From the agricultural production report of the year 2015 by the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives reported in the area of agricultural water district bundle which consists of four main crops. It consisted of 13,076 Rai for rice area, 665 Rai of cassava area, 647 Rai of yam bean area and 23 Rai of tobacco area were use to be the maximum market demand in this report. The basics information of four agricultural plants shown in Table 1.

Table 1 Agriculture basic information

Plant	Age (Days)	Water usage (m^3/Rai)	Yield (Ton/Rai)	Production Cost (Baht/Rai)	Market Price (Baht/Ton)	Market Demand (Ton)
1. Second rice	110	1,730	0.469	4,967	13,003	6,746
2. Cassava	360	640	1.245	1,649	1,730	910
3. Yam bean	210	1,350	4.250	12,500	3,520	3,109
4. Tobacco	120	589	0.253	10,566	37,520	6.40

Remark Market demand calculated by forecast from the last year product added 10 percent.

To grow cassava for maximum productivity must be planted during the rainy season. It must be start from March to April. The water used in the first two months of growth is came from rainfall runoff and a full five months during the drought season from November until March. Harvest at the age of 12 months, so in this report was calculate the amount of water used for a cassava only in five months of the drought season.

5.2 Optimal cultivation plan

This research used Visual Basic programming to find a solution of the allocation model to take advantage of the farmland to the appropriate amount of excess of irrigation storage water by the differential evolution algorithm method as described in section 4.3. The constant of DE algorithm in this research were used where NP = 4, CR = 0.9 and F = 0.5. The calculation process stop when the results remain constant more than 50 times, as illustrated in Fig. 12. After ninth trials, the statistical information for area management for planting 4 economic crops were obtained as shown in Table 2.

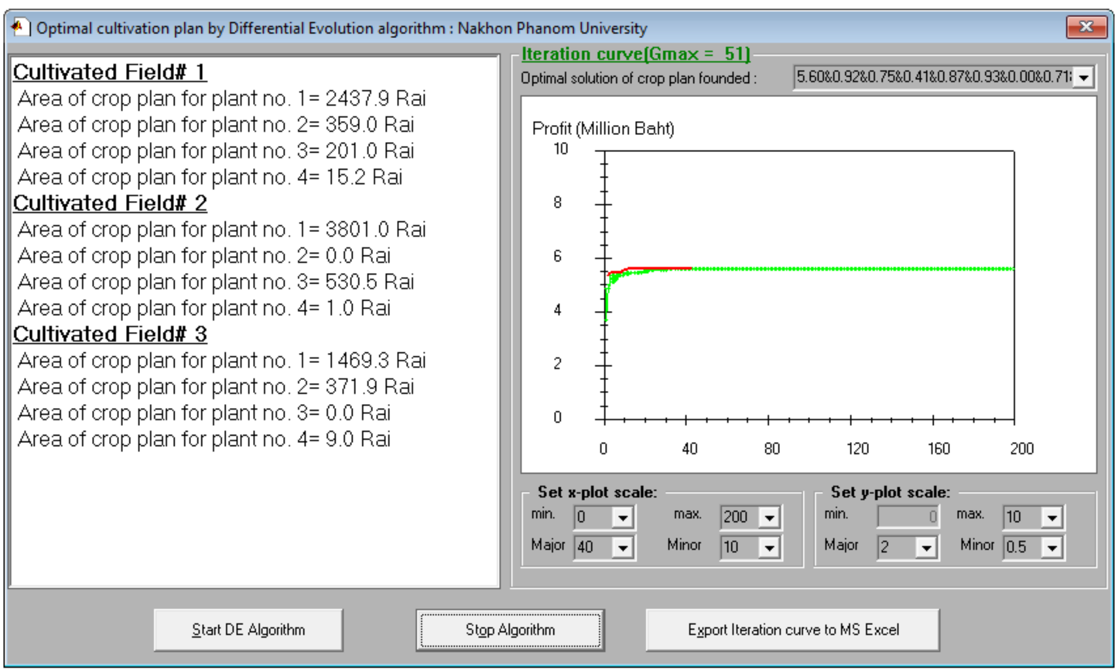

Fig. 12 Optimal cultivation plan result.

In Fig. 12 the horizontal axis represents the repetition of the algorithm, while the vertical axis represents the profit gained by managing planting areas. The algorithm perform well with fast converged results at the iteration of around 20^{th}.

Table 2 Percentage of managed area managed for planting crops in the Nam-Kam irrigation area.

Data No.	Demand from markets	Profits (MB)	Percentage of managed area for planting crops (%)			
			Second rice	Cassava	Yam bean	Tobacco
1	30% increase	5.11	88.05	5.84	5.91	0.20
2	20% decrease	5.28	86.57	6.57	6.64	0.23
3	10% increase	5.45	85.14	7.27	7.34	0.25
4	No change	5.62	83.76	7.94	8.02	0.27
5	10% increase	5.79	82.37	8.59	8.77	0.30
6	20% increase	5.95	81.12	9.23	9.33	0.32
7	30% increase	6.28	79.95	9.81	9.91	0.34
		Average	83.76	7.94	8.02	0.27
		S.D.	2.93	1.43	1.45	0.05

The results showed that the percentages of the managed area were affected by the demand from the market. Table 2 presents the suitable cropping areas for four different crops: second rice, cassava, yam bean and tobacco in the Nam-Kam irrigation area, which are 83.76%, 7.94%, 8.02%, and 0.27% respectively. In addition, the cropping area for second rice will be decreased when the demand from the market increase, whenever the demand for the other crops increase. This is because the returns from cropping second rice is less than those of others.

Water management for allocate the use of agricultural land to be reasonable under the circumstances is essential to maximize the benefits of the economic growth of the country as well as the lives and well-being for the betterment of farmers. The Crop change could be considered as the cause of the instability that has changed dramatically. Due to key factors such as price fluctuations of agricultural crops, market demand, promoting public policies, etc. These factors will contribute to changing the way farmers to produce crops that make better returns. However, each plant would be suitable to be planted in different areas. Resulting in yield per hectare of each crop in each area as well. The limitation of the amount of water stored in the irrigation system in the drought season, distance of water delivery for irrigation systems, etc. Therefore, the water management to allocate the use of agricultural land to the right (Land use optimization) is absolutely essential to use as a tool in water management of each basin.

6. Conclusion

This research investigates an application of a small telemetry system for real-time water level recording. The system has been developed by using a wireless sensor network, which automatically record the level of water to minicomputer(Raspberry Pi). The water level data collected at the end of a rainy season over a six months period were converted to a water volume. The water volume was then used as a model constraint for the agricultural acreage at Nam-Kam irrigation basin, Nam-Kam Sub-district, That-Phanom District, Nakhon Phanom Province, Thailand.. The differential evolution algorithm (DE) was employed to modeling optimal water management. The results showed the suitable planting portion plan over the considered period for second rice: cassava:

yam bean : tobacco were 83.76 , 7.94, 8.02 and 0.27 percent, respectively.

The managed area obtained by the propose model may not applied for larger irrigation area. This is because there could be more factors that are not included in this study. For instance, the cost for planting a similar crop may vary from place to place, particularly when the area is large. The Meta-heuristics Method is still recommended to solve more complex problems. The appropriate algorithm constant will help improve calculation time and the quality of results.

7. Acknowledgement

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Biography

Pongnathee Maneekul He received his B.Eng. in Civil Engineering from King Mongkut University of Technology Thonburi (KMUTT), Thailand, in 1994 and M.Eng degrees in Civil Engineering from Khon kaen University (KKU), Thailand, in 2010. Currently, he is a lecturer at the Division of Civil Engineering, Nakhon Phanom University (NPU). His research interests include the structural design and optimization techniques.

Chanwit Suwannapong. He received his B.Eng. and M.Eng degrees in Computer Engineering from Khon kaen University (KKU), Thailand, in 2011 and 2013. Currently, he is a lecturer at the Division of Computer Engineering, Nakhon Phanom University (NPU). His research interests include ad hoc networks, sensor networks and telecommunications systems.