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Database Design for IoT-based Greenhouse Systems*

Chunghan Kang·Seulgi Yu·Junghoon Moon

Abstract Since 2000s, proper utilization of IoT (Internet of Things) technology is a key factor for a firm to become more competitive, and this stream is not exceptional for the food and agriculture industry. Along with this stream, Korea government organization, for example MAFRA (Ministry of Agriculture, Food and Rural Affairs), elected to adopt IoT technology, such as USN and RFID technologies, in the food and agriculture industry. Based on the IoT technology, MAFARA launched six "IoT based farm" project in 2007. IoT based farm project includes IoT based greenhouse system project, and it shows drastic efficiency in terms of cost reduction. When it comes to the productivity, however, the effect of IoT based greenhouse system is still ambiguous. In this regard, this study conducted systems analysis and design for IoT based tomato greenhouse in order to help farmers' decision making related to the productivity by establishing standardized database structure and designing output form to analyze productivity indices. Proposed systems analysis and design can be utilized as a data analysis tools by farmers. Productivity data from the proposed systems is can be used by researchers to identify the relationship among environment, plant growth and productivity. Policy makers also can refer to the data and output forms to predict the quantity of fruit during certain period and to revise production guideline more precisely.

Key words IoT, Tomato greenhouse systems, System analysis

1 Introduction

Proper utilization of IoT (Internet of things) technology is a key factor for a firm to become more competitive(Porter, 2001). After 1995, IoT convergence industry has been expanded and this stream was more intensified in late 2000s (Kim, 2014). The food and agriculture industry cannot be free from this stream. Advanced countries in terms of agriculture, such as U.S., Japan, and Netherlands pull out all the stops to research and develop for agriculture IoT technology so as to protect agriculture industry and to increase their competitiveness(Lee, Hwang and Yoe. 2014). In the case of Korea, MAFRA (Ministry of Agriculture, Food and Rural Affairs) elected to adopt USN/RFID technologies in the food and agriculture industry. In this context, MAFRA also launched six "IoT based Farm" projects in 2007. This projects showed drastic efficiency in terms of cost reduction. For example, IoT based greenhouse system project shows 94% cost reduction and pigpen system project shows 5% cost reduction(see Figure 1).

C. Kang · S. Yu · J. Moon
College of Agriculture and Life Sciences
Seoul National University, South Korea

C. Kang
e-mail: ggulbbang@gmail.com

S. Yu
e-mail: akamiu@snu.ac.kr

J. Moon
e-mail: moonj@snu.ac.kr (✉)

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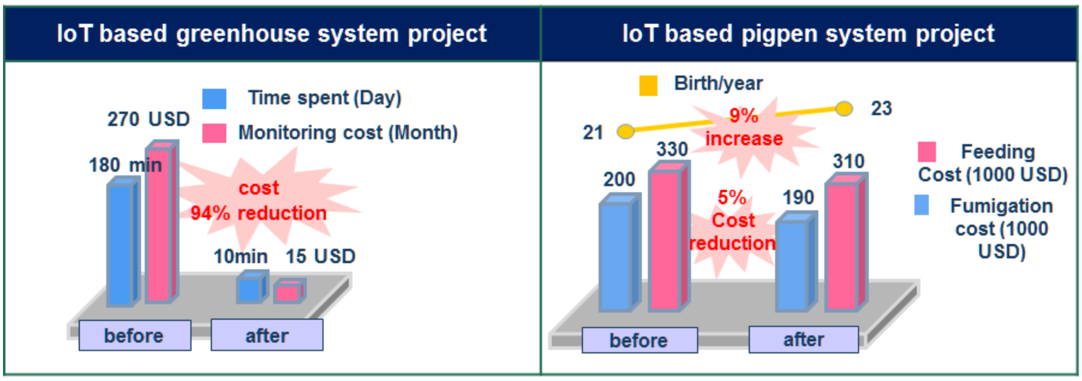


Source: Seoul National University Information Center for Agriculture and Life Science (2012)

Figure 1 The effect of cost reduction with greenhouse System project

IoT based greenhouse systems are efficient in terms of cost reduction, though its effects on the productivity is still in question. It may stems from the fact that present IoT based greenhouse systems only operate as an automatic controller of IoT devices such as, nutrition irrigator. Moreover, little work has been done to check indices related to the productivity in real time despite farmers' needs. The main reason of this problematic current situation is that establishing IoT based greenhouse systems have been only focused on the "applying latest technology to the agriculture industry" (Kim, 2015). Meanwhile, remote monitoring systems for managing the growth environment of the crop in real time developed with the connection the environment control equipment and IoT based greenhouse (Kim et al., 2011). The advance from these developments is needed to make the use of data of Iot based greenhouse and to combine different data systems of each IoT based greenhouse farms.

In this regard, this study aims to establish standardized database structure and to design output form in order to analyze productivity data to help farmers' decision making. To accomplish the aims of study, this study conducted systems analysis and design for IoT based greenhouse in order to fill the gap between farmers' needs and present IoT based greenhouse systems.

Among various kinds of IoT based greenhouse systems, IoT based tomato greenhouse was selected based on the following reasons. First of all, IoT based tomato greenhouse farmers' needs for checking and analyzing productivity indices are higher than any other farmers' needs. Also, different firms offering IoT based greenhouse systems for tomato greenhouse use different database structure, it is hard to compare productivity indices across the various kinds of tomato IoT based greenhouse systems in direct manner.

2 IoT-based Greenhouse

2.1 Process of Cultivation in Greenhouse

The research about process of cultivation in IoT based tomato greenhouse was conducted for the purpose of understanding the flow of process in IoT greenhouse and deducting the main information item for the system development. There are three main process in IoT based tomato greenhouse, such as sowing, cultivating, harvesting.

The first step of cultivating tomato is sowing the seeds to gain the seedlings for transplantation. The seedlings are transplanted to the nutrient solution culture facilities. The nutrient solution culture is the cultivation method by planting plants into the culture medium that is adjusted to the appropriate concentration in order to be able to properly absorb the nutrients necessary for growth. The nourishment supply of nutrient solution culture is made by nutrient solution. Once farmer prepare the nutrient solution, it is provided through dripper to nutrient irrigator. The key indicators related to nutrient solution are the amount of nutrient solution, EC(Electrical Conductivity), and pH, which have a decisive effect on the growth of tomato (Rural Development Administration, 2014).

The cultivating step relates in several indicators such as temperature, humidity, insolation, carbon dioxide(CO_2), and crop management. The indicators are controlled and recorded by greenhouse system and sensors in real time. The crop management is for the growth and development of tomato by thinning fruits and leaves (Rural Development Administration, 2015).

In the harvesting step, tomato trees usually set four or five tomatoes per flower cluster. Farmers record indicators in person such as average fruit weight, number of harvested fruit, and total weight of harvested fruit in this step. These three crop data is important to analyze the productivity of IoT based tomato greenhouse, and work the main item for the next step of system analysis and design.

2.2 Prototype of IoT Based Greenhouse

The propotype of IoT based greenhouse systems is illustarted in <Figure 2>. As shown in <Figure 2>, the prototype of IoT based greenhouse systems include environment sensor and environment controller. With the environmnet sensor, various environment data (e.g. Co2 density, temperature, humidity) are gathered into the database server. Managers of IoT based greenhouse can monitor the gathered environment data using personal computer. Managers also can control the environment of greenhouse, such as Co2 density, temperature, and humidity with the environment controller using their personal computer.

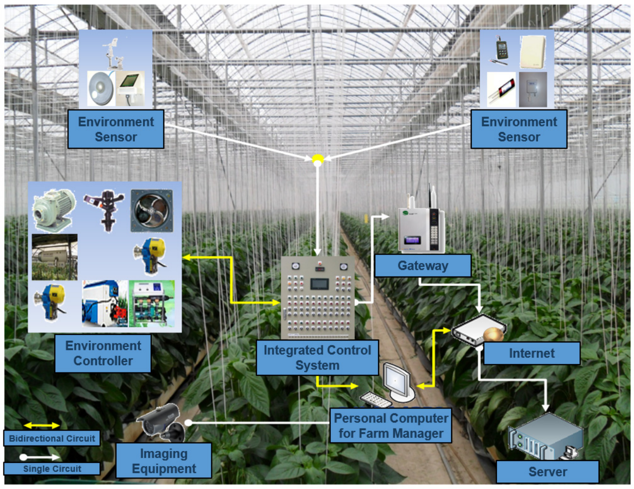


Figure 2 Prototype of IoT based greenhouse

Moreover, managers can screen current situation of greenhouse with imaging equipment installed in the greenhouse.

Except for above mentioned basic IoT devices –environment sensor, environment controller and imaging equipment- nutrient irrigators are also can be added to the prototype of IoT based greenhouse system. If the IoT based nutrient irrigators are equipped, managers also can control the supply quantity of nutrient and it is also possible to control it automatically.

Following system analysis and output form design includes nutrient irrigators because the aim of this study is to establish standardized database structure that can be generally applied.

3 Database Design

3.1 Defining Table of Process in Greenhouse

Prior to system development for utilizing the data, defining tables of process in greenhouse is needed as the basic step of Integrating the recording of information on the process and equipment. Table 1 is the result of defining table based on process of cultivation in greenhouse and prototype of IoT based greenhouse.

Basic data are for giving an ID for each of the facilities of the farm, and for recording the main information on the farm. The information is recorded in Farm information such as farm ID, region, area of farm, area of greenhouse, and number of greenhouse Farm Information. Greenhouse Information includes farm ID, greenhouse ID, type of greenhouse, area of greenhouse, height of greenhouse, width of greenhouse, length of greenhouse, and cultivation

Table 1 Data definition item of IoT based greenhouse

Type of data	Data table	Contents	Recording method
Basic data	1)Farm Information 2)Greenhouse Information 3)Facilities Information	Data for a given basic information of the record information and IoT equipment	Manual input for the first time
Greenhouse environment data	4)Nutrient Irrigator Data 5)Sensor Record Data	Data measured by the sensor and actuator corresponding to the time-specific environmental status of the facility	automatic input per second
Actuator data	6)Actuator Data	Data recorded by operating status of actuator	automatic input per second
Growth data	7)Basic Growth Information 8)Growth Information 9)Detailed Growth Information	Data recorded based on the growth recording paper	Manual input per week
Guideline data	10)Growing environment Guideline 11)Growth Guideline 12)Data of Other Farms	Data for analyzing the productivity of greenhouse	Manual input

area. Facilities Information is the information of actuator, sensor, and nutrient irrigator. Actuator information includes actuator table and actuator allocation table, and sensor information consists of sensor table and sensor allocation table. Nutrient irrigator table includes irrigator ID, type of irrigator, and allocation. These basic data are absolute value for each facility, so the data are put manually for the first time.

Greenhouse environment data is the growing environment measured by sensors and nutrient irrigators. There are environment sensors which sensing the important growing condition such as temperature, humidity, insolation, and carbon dioxide. The sensing data are recorded automatically to sensor record table in real time. Nutrient irrigation data like EC are also recorded by automatic system.

Actuator data are related to the actuating status of environment controller such as window, screen, carbon dioxide generator, fan, and fog system. The data include whether each environment controller is on or off, and are recorded to actuator data table.

Growth data include three data tables such as basic growth information, growth information, detailed growth information. Basic growth information consists of cultivation start date, cultivation end date, species, cultivation method, number of crop, of sow date. Growth information and detailed growth information include the measured values such as height to the first leaf, number of leaf, and leaf area. These data are recorded based on the growth recording paper farmers write in person after measuring. Especially, growth data are important to analyzing productivity of IoT based greenhouse, as the data include average fruit weight, number of harvested fruit, and total weight of harvested fruit.

Guideline data is recorded based on the cultivating information from Rural Development Administration or other farming information.

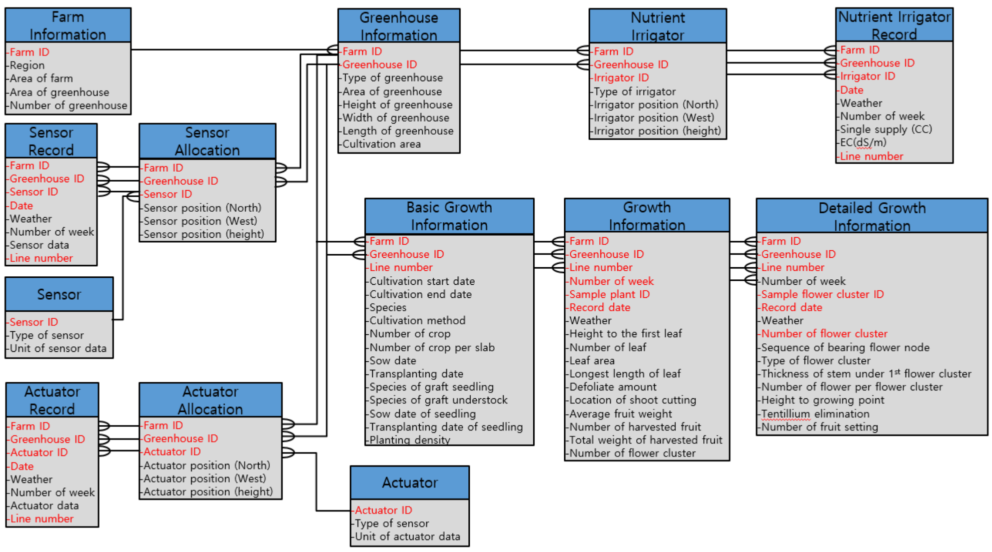
The next step is the modeling for developing the output based on defining table of process in greenhouse.

3.2 Development of Entity-Relationship (ER) Modeling

This study analyzed IoT based tomato greenhouse system and designed database based on the entity-relationship model. The entity-relationship model is popular model in terms of database design because entity-relationship model is based on simple graphical representations (Thalheim and Bernhard 2013). According to Thalheim and Bernhard (2013), entity-relationship modeling is widely applied method in databases, information systems, and software engineering.

As illustrated in <Figure 3> totally 13 number of entities are included in the entity-relationship model and the cardinality among the entities are also defined. The guideline data, listed in <Table 1>, was excluded from the entity-relationship model because guideline data has no relationship with other entities.

The proposed entity-relationship diagram (ERD) is for the prototype of IoT based tomato greenhouse systems and it can be easily extended adding other entities to the proposed ERD (Thalheim and Bernhard 2013).



* Identifiers of each entity are red colored

Figure 3 Result of Entity-Relationship Diagram (ERD)

4 Output Form Design

4.1 Greenhouse Productivity

Based on the proposed ER modeling, it is possible to develop output from for checking greenhouse productivity in real time. Specifically, following structured query language (SQL) was developed so as to design such an output form (see Table 2).

As shown in <Figure 4>, it is possible to print out various productivity indices and height of plants as a form of intuitive graph. In <Figure 4>, horizontal axis denotes time and vertical axis denotes the value of each index. Using this output form, it is possible for greenhouse manager to check each productivity index (average fruit weight, number of harvested fruit, total weight of harvested fruit) in real time, as well as to compare growth index (height in <Figure 4>) with productivity indices. Though in <Figure 4>, time window is week, it is possible to change time window to minute, hour, day or month. Furthermore, it is also possible to compare one greenhouse to another greenhouse, and thus greenhouse managers not only can identify high productivity greenhouse and low productivity greenhouse, but also figure out the reason for productivity gap.

Table 2 SQL for designing productivity indices output from

```
SELECT [12Growth Information].[Number of week], [12Growth Information].[Average fruit weight],
[12Growth Information].[Number of harvested fruit], [12Growth Information].[Total weight of harvested fruit],
[12Growth Information].[Height], [12Growth Information].[Number of flower cluster], [12Growth Information].[Greenhouse ID],
[12Growth Information].[Height]-[14Guideline].[Expected height] AS Difference
FROM [12Growth Information] INNER JOIN [14Guideline] ON ([12Growth Information].[Number of week] =
[14Guideline].[Number of week]) AND ([12Growth Information].Weather = [14Guideline].Weather)
WHERE ((([12Growth Information].SampleID)="SAM01") AND (([12Growth Information].FarmID)="ID00001"));
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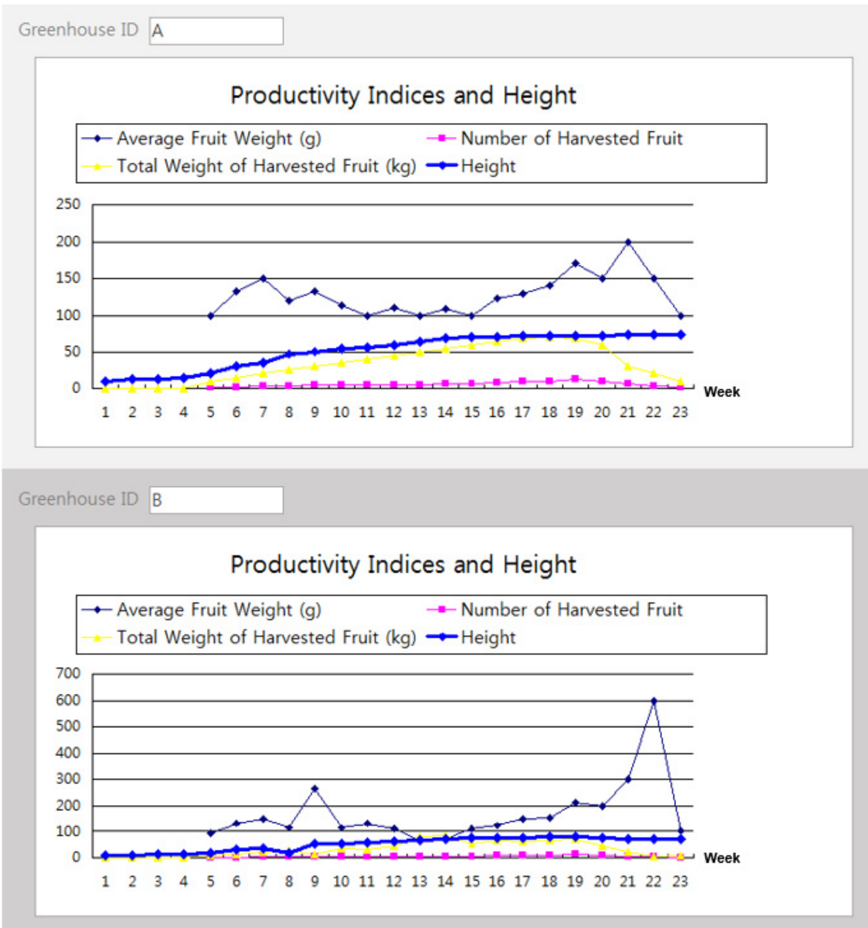

Figure 4 Output form design: greenhouse productivity

Therefore, the proposed output form also enable greenhouse managers to utilize IoT based greenhouse systems as a IoT device controller and to analyze productivity indices of each greenhouse. Through this process, patterns of environment data (e.g. temperature, humidity, and density of CO_2 ect.) of high productivity greenhouse can be captured and this patterns can contribute to increase productivity of farm.

4.2 Productivity Gap Analysis

Another output form was also designed to print out relationship between productivity and height difference from growth guideline. To develop such an form, following structured query language (SQL) was developed (see Table 3).

In <Figure 5> horizontal axis denotes time and vertical axis denotes the value of each index. Using this output form, it is possible for greenhouse manager to check each productivity index (average fruit weight, number of harvested fruit, total weight of harvested fruit) in real time, as well as to compare disparity between growth index (height in <Figure 5>) and the value of growth guideline with productivity indices. Though in <Figure 5>, time window is week, it is possible to change time window to minute, hour, day or month. The greenhouse managers cannot directly follow the growth guideline until now because growth guideline is still in infant stage, and used nutrient is also different from each farms or greenhouses. The proposed output form, however, enables the greenhouse managers to check relationship between growth gap (between current plants in greenhouse and guideline) and productivity indices. Thus, it is possible to optimize growth levels of plants to maximize productivity indices. For example, graph in <Figure 5> shows that productivity indices(average fruit weight, number of harvested fruit, total weight of harvested fruit) can be maximized when height of plants in greenhouse is 55cm higher than the recommendation of growth guideline. Therefore, in such a case, greenhouse managers can maximize the productivity indices by controlling environment factors affecting to the height of the plants.

The proposed output form is also helpful to the policy makers who are responsible to develop growth guideline. First of all, they can analyze data gathered in database of greenhouse farmers who are using IoT based greenhouse system and it enable policy makers to analyze environment data affecting to the plants growth in more detailed manner. Secondly, it is also possible to predict production quantity more precisely by analyzing gathered environment and growth data. Precise production quantity pre-

Table 3 SQL for designing productivity gap analysis from

```
SELECT [12Growth Information].[Number of week], [12Growth Information].[Average fruit weight],
[12Growth Information].[Number of harvested fruit], [12Growth Information].[Total weight of harvested fruit],
[12Growth Information].[Height], [12Growth Information].[Number of flower cluster], [12Growth Information].[Greenhouse ID],
[12Growth Information].[Height]-[14Guideline].[Expected height] AS Difference
FROM [12Growth Information] INNER JOIN [14Guideline] ON ([12Growth Information].[Number of week] =
[14Guideline].[Number of week]) AND ([12Growth Information].Weather = [14Guideline].Weather)
WHERE ((([12Growth Information].SampleID)="SAM01") AND (([12Growth Information].FarmID)="ID00001"));
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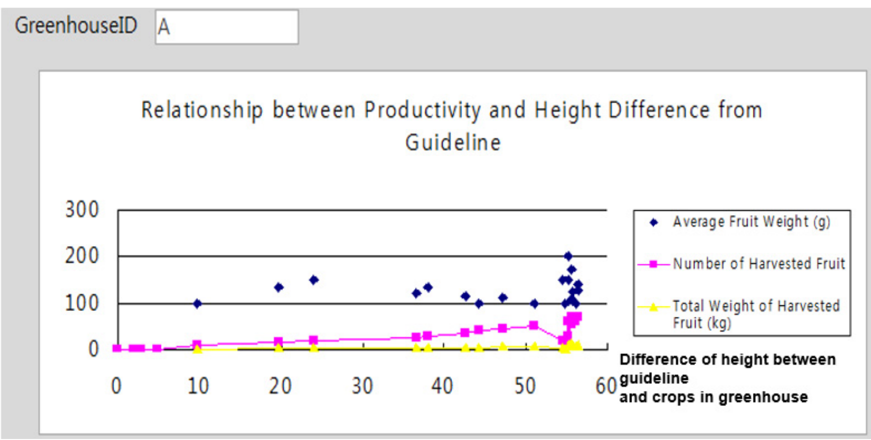

Figure 5 Output form design: productivity gap analysis

diction is helpful to establish price stabilization programs for agro-products.

5 Conclusion & Contributions

Using proposed systems analysis and design, IoT based greenhouse systems which are helpful to the productivity can be established. At First, farmers can utilize IoT based greenhouse systems as an automatic controller of IoT devices as well as data analysis tool for increasing productivity. Specifically, it is possible to set and manage the target value of growth index per week because proposed systems analysis and output forms enable greenhouse managers not only to check productivity indices in real time, but also to compare productivity indices with growth indices. Especially, by analyzing environment data related to the growth indices of plants, such as temperature, humidity, and density of CO_2, it is possible to control IoT based environment controllers for the sake of optimized productivity. Therefore, greenhouse managers actually can control the IoT based environment controllers for the direction of maximizing productivity beyond the current "just automatic" controlling.

Policy makers also refer to the data and output forms of the IoT based greenhouse systems to predict the quantity of fruit during certain period. Because the unstability of agro-products' price is basically stems from imbalance of supply and demand, production quantity prediction using proposed systems analysis and design can be important method to deal with the price unstability problems of agro-products. Moreover, growth guideline is also be continuously revised by gathering and analyzing data of farms using IoT based greenhouse system.

Researchers can utilize data from the IoT based greenhouse systems in order to identify the relationship among environment, plant growth and productivity.

The proposed systems analysis and design, however, did not contain statistical analysis algorithm to analyze gathered data in elaborated manner. In this vein, proposed systems analysis and design shows the effect of environment data on growth data intuitively rather than elaborately analyze it. it is possible, however, to generate statistical analysis tools by linking with programming languages, such as R because proposed systems analysis and design is generalizable and easy to extend (Thalheim and Bernhard 2013). Proposed systems analysis and design are part of ongoing government-funded research project to support efficient decision making for IoT based greenhouse farmers and consultants, and thus advanced data analysis tool will be developed in near future.

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