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A Study on Real-Time Slope Monitoring System using 3-axis Acceleration

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Abstract

The researcher set up multiple sensor units on the road slope such as national highway and highway where there is a possibility of loss, and using the acceleration sensor built into the sensor unit the researcher will sense whether the inclination of the road slope occur in real time, and Based on the sensed data, the researcher tries to implement a system that detects collapse of road slope and dangerous situation. In the experiment of measuring the error between the actual measurement time and the judgment time of the monitoring system when judging the warning of the sensor and falling rock detection by using the acceleration sensor, the error between measurement time and the judgment time at the sensor warning was 0.34 seconds on average, and an error between measurement time and judgment time at falling rock detection was 0.21 seconds on average. The error is relatively small, the accuracy is high, and thus the change of the slope can be clearly judged.

Keywords: Slope, Real-Time, Monitoring System, 3-axis Acceleration, Sensor Network

1. Introduction

South Korea has a high proportion of production areas, and many of the land development is done close to the production area, and there are inevitable slopes at the time of construction of roads and railroads. Disasters that can take place in the production area are very diverse, including landslides, falling rocks, and floods, but due to the effects of climate change caused by global warming, maintenance of highway suffers from continuous damages caused by heavy rainfall, strong winds, heavy snow etc.[1]. Recently, due to the influence of No. 18 Typhoon "CHABA", traffics were blocked by landslides and debris flows, resulting in a sudden increase in social problems and interests in such issues due to human life and property damage.

As of May 2014, highways and national highway slopes managed from the country due to the risk of collapse reached 38,090 in total, with 8,240 expressways and 29,850 national highways. In recent years, more than 100 highway slope failures occur each year, traffic volume is large, maintenance and management such as checking is difficult in actual circumstances, the national road slope collapse occurred in less than 80 cases per year[2].

Such landslides and slope failures are frequent natural disasters. It is a disaster, and it corresponds to a field that must be systematically and continuously managed through real-time monitoring[3]. To prevent this, prevention through periodic continuous measurement and prediction over a long period of time is necessary[4].

In this paper, the researcher set up multiple sensor units on the road slope such as national highway and highway where there is a possibility of loss, and using the acceleration sensor built into the sensor unit the researcher will sense whether the inclination of the road slope occur in real time, and Based on the sensed data, the researcher tries to implement a system that detects collapse of road slope and dangerous situation.

2. System Configuration and Design

A sensor network based real-time slope failure monitoring system to be implemented in this paper consists of a sensor unit capable of detecting the state of the road slope, a control unit that can control thus, and a solar light unit for power supply. Fig. 1 shows the proposed system configuration.

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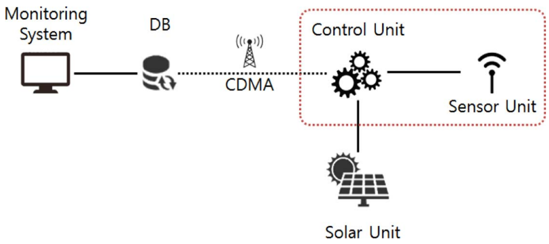

Fig. 1. System configuration.

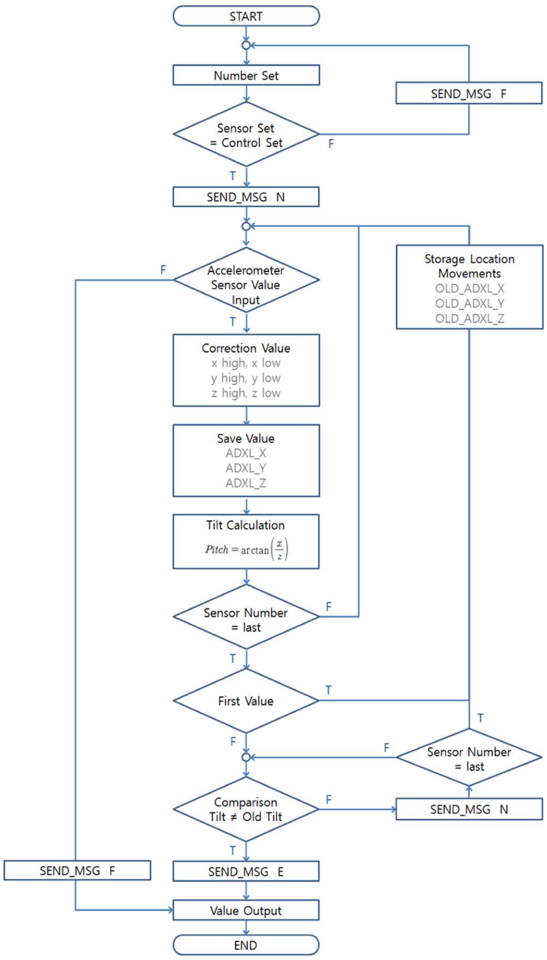

Fig. 2. Flowchart of the proposed system.

The data collected by the sensor unit are the acceleration values o f the X axis, the Y axis, and the Z axis of the acceleration sensor and transmitted to the monitoring system for analysis. The data transferred to the surveillance system was applied to the proposed algorithm and designed to find if slope occurred. Fig. 2 is a flowchart of the proposed system.

Since six sensor units are used to detect the state of the slope, set so that the numbers of switches on each sensor unit do not overlap. The switch of the control unit sets the number of sensor units to be used. When the number of sensor units and the value set in the control unit are set to the same, a normal message (N) is transmitted, and When setting switch number of sensor unit by omitting duplicate setting or number, send initial disconnection error message (F).

When it operates normally, it receives the value of the sensor. If the value of the sensor is not received, a disconnection error message (F) is transmitted. Then it receives the values o f x, y, z high / low, a total of 6 sensors and processes and corrects x, y, z values a nd saves them in ADXL_X, ADXL_Y, ADXL_Z respectively. The corrected measured value is converted into an angle and used. Repeat until sensor values f or all sensor units are received.

If the value of the received sensor is the initial value, it will be saved in ADXL_X, ADXL_Y, ADXL_Z and it will repeat and accept the new sensor value. When the value of the newly received sensor comes in, the values o f the sensors stored in the existing ADXL_X, ADXL_Y, ADXL_Z are saved in OLD_ADXL_X, OLD_ADXL_Y, OLD_ADXL_Z, and the newly received sensor values a re stored in ADXL_X, ADXL_Y, ADXL_Z.

The inclination of the newly measured and saved ADXL_X, ADXL_Y, ADXL_Z is compared with the slope of OLD_ADXL_X, OLD_ADXL_Y, OLD_ADXL_Z previously measured and stored, and when an inclination occurs, an error message (E) is transmitted, and if no slope occurs, a normal message (N) is transmitted and the values c urrently stored in ADXL_X, ADXL_Y, ADXL_Z are stored in OLD_ADXL_X, OLD_ADXL_Y, OLD_ADXL_Z, and then repeat this process until the end of comparison process of the slope of the sensor value of the last sensor unit set. Upon completion of the last slope comparison, new sensor value is received.

With these vectors of x, y, z, the value of the slope of the x axis as Roll, the value of the slope of the y axis as Pitch, and the value of the slope of the z axis as Yaw Euler angle can be measured. However, since the rotation of the z axis coincident with the direction of the gravitational acceleration cannot be detected with only the triaxial acceleration sensor, the Yaw value is excluded. A vector value of y and z to tan is applied in order to measure the angle made by tilting the 3-axis acceleration sensor about the x axis and the floor. By using Arctan, delta value can be easily obtained. Applying these principles, the researcher can show the relational expression as follows. In this thesis, the inclination angle was measured using the values o f Roll and Pitch[5].

2.1. Correction of Measured Value

In order to calculate the slope using the value received from the sensor, six measurement data (x high, x low, y high, y low, z high, z low) are required in a fixed state. Measurement data is obtained with the high and low directions aligned for each axis.

A gravity acceleration vector corresponding to a vector of six measurement data in a stopped state is made to correspond to 1:1 and an expression of a least squares method is established. Obtain the values o f 12 parameters and process the raw data measured using that parameter to obtain the corrected measured values A DXL_X, ADXL_Y, ADXL_Z. The corrected measurement value can be converted into an angle and used.

2.2. Sensor Unit

The sensor unit includes a sensor for collecting data, a processor for processing sensed data, and a communication module for transmitting the collected data. Fig. 4 shows a PCB and a sensor unit that were designed and fabricated optimally.

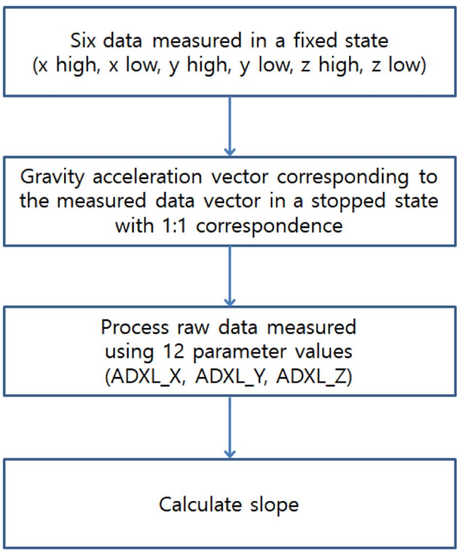

Fig. 3. Correction of value of acceleration sensor.

It has a built-in 3-axis acceleration sensor and is designed to be applicable to sensor network system, and since the system proposed in this paper is exposed to the exterior, it made it possible to communicate by wired connection instead of wireless.

1.3. Control Unit

The gateway that collects and processes the measurement data of the sensor node and sends the processed data to the final server consists of an RS-485 base station that receives data of the sensor unit, and Host PC which stores and processes data via RS-485 communication with the base station and sends it to the final server. Fig. 5 shows the PCB and the control unit, which were designed and fabricated optimally.

For the proposed system in this paper, a single control unit and a large number of sensor units are connected by 485 communication, and wired communication made possible up to 10 km long distance at a rate of 10Mbit/s via RS485 communication.

2.4. Solar Unit

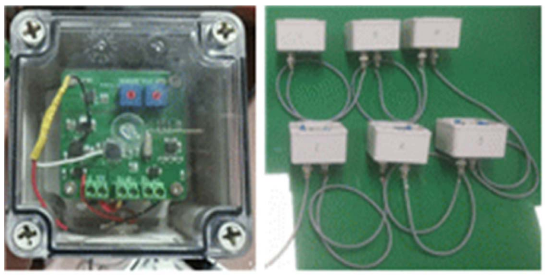

Fig. 4. Correction of value of acceleration sensor.

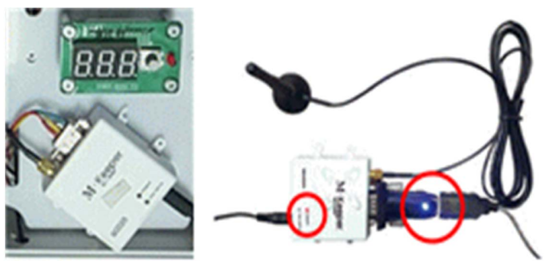

Fig. 5. Control unit.

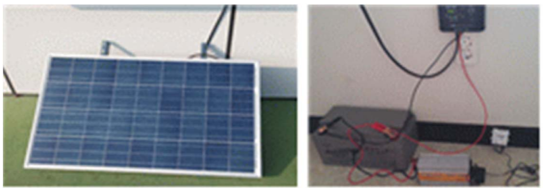

Fig. 6. Solar unit.

Since the sensor unit operates with a battery, there is a limitation that it cannot be used permanently. In addition, the sunlight unit is designed considering the difficulty of supplying power to the road slope.

2.5. Monitoring System

When the control unit and the sensor unit operate properly, it will receive the value of the acceleration sensor from the sensor unit. The upper 8 bits and the lower 8 bits of the x high, x low, y high, y low, z high, z low values r eceived in the array are corrected and saved in ADXL_X, ADXL_Y, ADXL_Z. The saved value is transmitted to the control unit at a constant cycle. Fig. 7 is the code for comparing slope values.

When comparing the values a nd accepting other values, the researcher uses the equations (1) and (2) having the values s tored in ADXL_X, ADXL_Y, ADXL_Z to calculate the slope value of Roll and the value Pitch of the inclination of the y axis. Since the value of the slope of the z axis cannot be measured, Yaw is excluded. Fig. 8 is the program code to calculate the slope.

$$Roll = \arctan\left(\frac{y}{z}\right) \quad (1)$$

$$Pitch = \arctan\left(\frac{x}{z}\right) \quad (2)$$

```
ADC_F = UARTO_RXD_BUFF[26];
if (START == 0)
{
    OLD_ADXL[RUN_CNT][0] = ADXL_X;
    OLD_ADXL[RUN_CNT][1] = ADXL_Y;
    OLD_ADXL[RUN_CNT][2] = ADXL_Z;
    //OLD_ADXLX=ADXL_X;
    //OLD_ADXLY=ADXL_Y;
    //OLD_ADXLZ=ADXL_Z;
}
else
{
    if (((OLD_ADXL[RUN_CNT][0] + 15)<ADXL_X || (OLD_ADXL[RUN_CNT][0] - 15)>ADXL_X)
        || ((OLD_ADXL[RUN_CNT][1] + 15)<ADXL_Y || (OLD_ADXL[RUN_CNT][1] - 15)>ADXL_Y)
        || ((OLD_ADXL[RUN_CNT][2] + 50)<ADXL_Z || (OLD_ADXL[RUN_CNT][2] - 50)>ADXL_Z))
    }
```

Fig. 7. Tilt comparison code.

```
buf[0] = ADXL_X / 0x1000;
buf[1] = ADXL_Y / 0x1000;
buf[2] = ADXL_Z / 0x1000;
x = 0x0FFF & ADXL_X;
y = 0x0FFF & ADXL_Y;
z = 0x0FFF & ADXL_Z;
if (buf[0] == 15)
{
    x = 4096 - x;
}
if (buf[1] == 15)
{
    y = 4096 - y;
}
if (buf[2] == 15)
{
    z = 4096 - z;
}
ax = (double)x;
ay = (double)y;
az = (double)z;
pitchl = atan(ax / az);
pitchv = (unsigned int)pitchl;
pitchv = pitchv + 100;
Uart_Put((pitchv / 1000) + '0');
Uart_Put((pitchv % 1000 / 100) + '0');
Uart_Put((pitchv % 100 / 10) + '0');
Uart_Put((pitchv % 10) + '0');
rolll = atan(ay / az);
rollv = (unsigned int)rolll;
rollv = rollv + 100;
Uart_Put((rollv / 1000) + '0');
Uart_Put((rollv % 1000 / 100) + '0');
Uart_Put((rollv % 100 / 10) + '0');
Uart_Put((rollv % 10) + '0');
```

Fig. 8. Tilt calculation code.

Sensor warnings are generated in the monitoring system when gradients of about 5 degrees or more gradually occur or sustained vibrations occur in the sensor unit for 5 seconds or longer. When a tilt of about 5 degrees or more occurred rapidly due to a strong impact, it was detected by the impact of the upper rock fall, and a falling stone detection warning is to be generated in the monitoring system. Fig. 9 shows the implementation result of the slope collapse monitoring system interface.

When an error is detected in the sensor unit and an

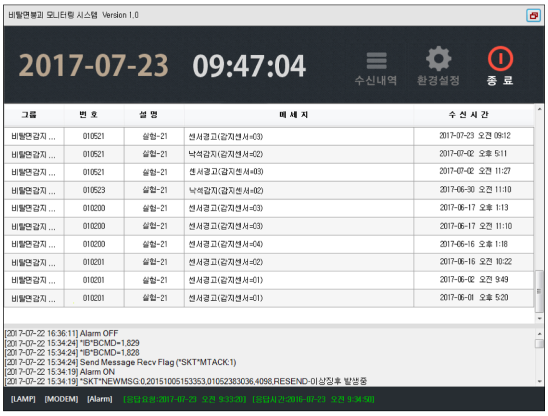

Fig. 9. Slope collapse monitoring system interface.

Fig. 10. Pop-up window when detecting beyond slopes.

alarm message is received, a popup window like the one shown in Fig. 10 is displayed. The reception time and message are used to display the time when the alarm sets off and information beyond the slope. If the detected sensor units are different, the alarm windows are continuously displayed. In the case of the same sensor unit, a list is additionally displayed in the same window.

3. Assessment of Implement and Performance

3.1. Experiment Model

In order to experiment the system proposed in this paper, the researcher constructed an experimental model as shown in Fig. 11 below. The slope of the experimental model used decomposed granite, not considering commonly known soil inhomogeneity and repair conductivity, but only the homogeneous slope examined by the experimental conditions. The height of the slope is 70cm from the tip of the slope, and the width of the slope was made constant at 100cm. The inclination angle of the slope is 35°, which is known to represent the slope of the natural soil slope where destruction occurs on a relatively low slope, thus it was applied to experimental conditions[6].

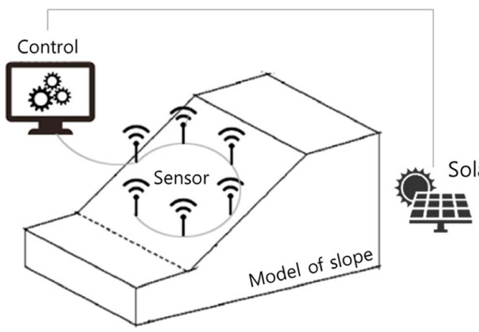

Fig. 11. Experimental model configuration.

Fig. 12. Control-Sensor unit used in experiments.

In order to use six sensor units, set the switches of each sensor unit so that they do not overlap sequentially from No. 1 to No. 6. The switch of the control unit sets the number 6 of sensor units to be used. After setting the number, connect to the 485 communication line in order as shown in Fig. 12.

After fixing the sensor unit connected by wire to the experimental model slope at a depth of 20cm, the experiment was constructed by a method of affecting the sensor unit in various directions of motion.

3.2. Experimental Results

This paper evaluated the performance of the monitoring system implemented in this thesis, when giving any influence of the sensor unit, the sensor alarm falling rocket alarm is distinguished and transmitted to the monitoring system.

Since the system proposed in this paper aims at early detection of loss of road slope and reduction of damage, it is assumed that the slope of the x-axis and the y-axis exceeds 30 degrees with a strong landslide and earthquake had occurred severely. In this experiment, the inclination in the case where the vibration continuously occurred for 5 seconds or more or when the inclination of about 5 degrees or more occurred was measured within 30 degrees, and any further inclination measurement was excluded. Also, since the experiment was carried out while being fixed on the slope, the rotation of the z axis coincident with the direction of the gravitational acceleration can not be detected, so the output value of the z-axis is fixed to 0.

First, for the sensor alarm experiment, the researcher gradually applied an impact to one sensor unit, gradually generated an inclination of 5 degrees or more,

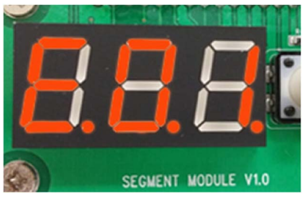

Fig. 13. Control unit 7-segment when the tilt occurring.

Fig. 14. Sensor alarm pop-up window when the tilt occurring.

applied shock to the two sensor units, and applied vibration more than 5 seconds. As a result of the experiment, when a slope of about 5 degrees or more in one sensor unit occurred, the first syllable E of Error and the sensor unit number 01 where the inclination is occurring in the segment of the control unit are displayed as shown in Fig. 13, and the monitoring system displayed a sensor alarm popup, as shown in Fig. 14. In the pop-up window, the time when the tilt occurred, the sensor warning message, and the sensor number 01 which detected the tilt were displayed. As a gradient occurred continuously from the same sensor unit, a tilt occurred in the same window a list was additionally displayed.

When shock is applied to two sensor units and vibration of 5 seconds or more is generated, E02 is displayed on the segment of the control unit as shown in Fig. 15, and a sensor alarm pop-up is displaced on the monitoring system as shown in Fig. 16.

As a result of repeating the experiment 60 times, it is possible to know that a sustained vibration occurred for 5 seconds or more, or a gradient of about 5 degrees or more gradually generated a sensor warning.

For the rock fall detection alarm experiment, the

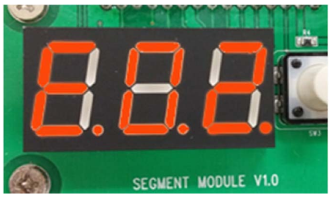

Fig. 15. Control unit 7-segment when detection of vibration.

Fig. 16. Sensor alarm pop-up window when detection of vibration.

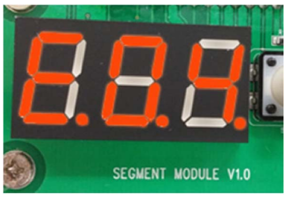

Fig. 17. Control unit segment when falling rock detection.

Fig. 18. Sensor alarm pop-up window when falling rock detection.

researcher applied strong shock to the four sensor units and tried to generate the inclination more than 5 degrees. As a result of the experiment, when a slope of about 4 degrees or more is generated in No. 4 sensor unit, E04 is displayed on the segment of the control unit as shown in Fig. 17, and the monitoring system displays the falling rock detection pop-up window as shown in Fig. 18 It was done. In the pop-up window, the time when the tilt occurred, the sensor warning message, and the sensor number 04 which detected the tilt were displayed.

As a result of repeating the experiment 60 times, when a gradient of about 5 degrees or more occurred rapidly with a strong impact, a falling rock detection warning was generated.

Finally, in order to evaluate the performance of the system implemented in this paper, the sensor unit when the inclination of the sensor unit occurred was tested on the actual measured time and the error when judged by the monitoring system. The experiment was carried out by applying a weak impact (sensor warning) and a strong impact (falling rock detection) to the sensor unit for 3 seconds each. Table 1 shows the actual measured time and the time error judged by the monitoring system using the data obtained by performing the experiment 60 times.

Since it was designed to neglect vibrations of less than 5 seconds and inclinations of less than 5 degrees with a weak shock at sensor warning, an error of measurement time and judgment time averaging 0.2 seconds occurred. At the time of falling rock detection, an error of measurement time and judgment time averaged 0.1 seconds occurred when an inclination of 5 degrees or more suddenly occurred with a strong impact.

When judging sensor warning and falling rock detection using acceleration sensor, the error between actual measurement time and monitoring system judgment time is below 0.25 seconds on average, and thus it seems that the accuracy is high and it is possible to clearly judge the change of the slope.

Table 1. System judgment time via sensor warning and rogue detection

	Measurement time (sec)	Judgment time (sec)	Error (sec)
Sensor warning	3.0	3.34	0.34
Rogue detection	3.0	3.21	0.21

4. Conclusions

The road slope real-time sensing system implemented in this paper is a system that uses acceleration sensor to sense real-time conditions of road slope in areas such as national highway and highway and dangerous situation, and based on the sensed data, it minimizes the damage by detecting the situation inclination sites and dangerous situations.

A sensor unit that can optimally design and detect the state of the road slope and a control unit that can control the slope are manufactured by using an acceleration sensor, and solar light unit was designed considering the difficulty of power supply. Where there is a possibility of loss, install a sensor unit and control unit and monitor whether the sensor unit changes.

In order to evaluate the performance of the system implemented in this paper, after fixing the sensor unit connected to the RS-485 communication line to the experimental model slope, the researcher applied shock to the sensor unit in various directions of motion. It was possible to obtain the values o f Roll and Pitch by using the values o f the x, y, and z axes connected to the sensor unit and measured via the acceleration sensor, and since if the only force applied is the gravity sensor, the measurement result of the accelerometer shows the angle of the correct direction, and thus it was possible to measure the occurrence of the loss of the road slope through the inclination. As a result of the experiment, a warning (Error) message of the sensor was displayed on the control unit when a sustained vibration occurred for more than 5 seconds, or when an inclination of about 5 degrees or more occurred.

The most important aspect of the system implemented in this paper is to immediately transmit the information to the monitoring system when slope loss occurs. Therefore, rapidity and accuracy are required among the sensor unit, the control unit and the monitoring system. In the experiment of measuring the error between the actual measurement time and the judgment time of the monitoring system when judging the warning of the sensor and falling rock detection by using the acceleration sensor, the error between measurement time and the judgment time at the sensor warning was 0.34 seconds on average, and an error between measurement time and judgment time at falling rock detection was 0.21 seconds on average. The error is relatively small, the accuracy is high, and thus the change of the slope can be clearly judged.

The road slope real time sensing system using the acceleration sensor through the contents experimented in this paper can quickly judge the presence or absence of loss by clear and quick judgment, and ultimately be utilized to minimize life loss, road damage, and material damage.

Acknowledgments

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