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Development of Customized Diving Computer Based on Wearable Sensor for Marine Safety

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ABSTRACT The purpose of this paper is to develop a customized diving computer that is interlocked with a textile type sensor attached to a suit to enhance the safety factor of a diver and a monitoring system to help diver safety management. The development of this diving computer is largely divided into three stages. The first is to develop a function to check the status of the diver in conjunction with the textile type wearable sensor attached to the suit. Second, the development of a diving computer is based on Android OS based on the existing closed OS. The third is the development of actual diving computer hardware focusing on waterproof function. This course aims to focus on safety factors of the diver, to collect biometric information through a wearable sensor attached to the diver suit, to analyze it in the diving computer, and to provide a customized diving guide. The performance evaluation of the result was conducted through the usability evaluation of the diving computer, and the safety and efficiency were verified through the overall satisfaction and the functional evaluation of 92.7%. Future research will focus on the safety factors to ensure differentiation from the existing products, and we will carry out ongoing research.

INDEX TERMS Marine safety, diving computer, textile sensor, diving decompression, usage evaluation.

I. INTRODUCTION

Currently, scuba diving is so popular that about 200,000 people participate is scuba diving activities and there are approximately 1,000 scuba diving societies. In general, the sea not only causes fear but spirit of challenge to people. Therefore, people get to participate in marine activities with spirit of challenge which requires them to be more careful about safety. According to the survey, marine safety accidents increase at a certain rate every year [1]. In order to enhance the safety of marine leisure activities, developing safety products that can protect people from danger and keep them safe in case of various accidents such as inundation, distress and fire is necessary. Most of the underwater accidents depend on the psychological factors of the diver, and many factors are reflected according to the condition of the diver and the underwater situation. A technique to detect risks and inform the diver of them by sensing the bio - factors and environmental factors in the water is needed.

In the case of the diving computer market, the market is being formed with high-priced products of overseas operators [2]. In Korea, even companies with good production technology have not entered the market yet. Products manufactured by major foreign companies are mostly transacted and there are high barriers among companies. This paper aims to develop products based on the safety factors of diver in order to differentiate from products manufactured by overseas company and increase the chance of success in both domestic and foreign market. Safety factors have been added to existing overseas diving computer products but these items lack in direct linkage to biometric information and underwater information. In addition, as for the safety, a customized safety function is required that will judge the proportion of the customized element in the diving computer. Furthermore, it is common to use a closed operating system such as FreeRTOS for diving computer OS. Selecting a closed OS for commercialization and commercialization is reasonable, but in terms of long-term service, it may be desirable to develop products based on open OS such as iOS and Android. The diving computer developed through this paper is unprecedented one that is based on above mentioned safety factors and mobile open OS. The diving computer is equipped with diver's safety elements and customized elements through diver log management program at the back end to support the diving computer. [Figure 1] shows the

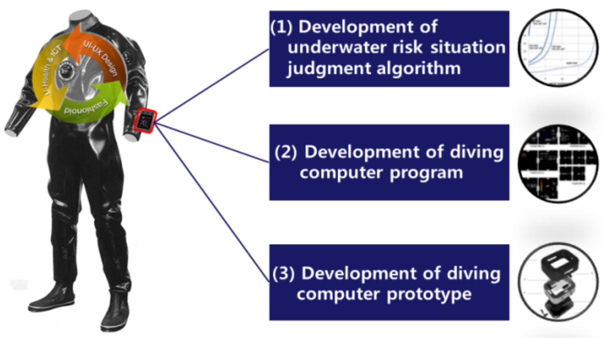

FIGURE 1. Overall concept of proposed product.

whole development concept proposed in this paper. Each of the development factors shows ① dangerous situation judgment algorithm, ② diving computer program, and ③ diving computer prototype development.

II. DEVELOPMENT OF DIVING COMPUTER BASED ON CUSTOMIZED SAFETY SYSTEM

The development of the diving computer proposed in this paper can be explained as the development of products to provide user-customized safety factors and ease of use. There are three major categories: a bio-based and underwater information-based risk assessment algorithm, an Android-based diving computer program, and a development of diving computer hardware equipped with the program, and a diver log management program linked to the diving computer is added to support the safety management of the final diver.

A. DEVELOPMENT OF UNDERWATER RISK SITUATION JUDGMENT ALGORITHM

Underwater risk situation diagnosis technology is one that judges with biometric information and underwater information as input values. Biometric information is the heartbeat, body temperature, and respiration information collected from the sensor in the diver suit, and represents the depth, water pressure, and water temperature information collected from the sensor in the diving computer. The sensing of biometric information is collected through a textile type [3] wearable sensor attached to the diving suit endothelium. The collected information is respiration and body temperature information, and the information is transmitted and received through the U-ART communication with the diving computer utilizing the wing end product which can measure the information. [Figure 2] shows the shape of the textile type sensor used to collect biometric information. Applicable sensor is an endothelium-type sensor that collects breathing information.

Factors that can determine panic and hypothermia in an underwater dangerous situation are biometric information (heart rate, respiration, body temperature) and underwater information (depth, water pressure, water temperature) information. In this study, the method of judging the underwater risk situation supports the determination of respiratory abnormality and hypothermia. In case of breathing, the respiration rate is usually an absolute reference base for one minute, and the user can adjust the normal reference value by reflecting the respiration information of the user at the time of initial acquisition. Also, in the case of body temperature, it is possible to judge the abnormality by adjusting the body temperature information before acquisition to the reference information as the beginning of hypothermia as below 37.C. For this, CART (Classification and Regression Trees) [4]–[11] algorithm has been applied. The CART algorithm is a non-parametric technique that produces classification or decision tree depending on whether the dependent variable is categorical or numerical. Decision trees using the CART algorithm. The tree learning method can be defined in the following several steps. Based on the above-mentioned biometric information, the learning data set for simulation is expressed as W1 body temperature, W2 heart rate, and W3 respiration. Z1 defines normal class, and Z2 class defines dangerous class. [Table 1] shows the learning data set values, and the relationship between the input variables and the classes is arbitrarily set to illustrate the CART algorithm, not empirical or simulation results.

FIGURE 2. Textile type sensors (for endothelium-type, respiratory sensing).

TABLE 1. Training data set (samples).

Dm	W1	W2	W3	Z
D1	32	55	13	Z2
D2	37	65	15	Z1
D3	38	70	20	Z1
D4	33	58	15	Z2
D5	32	59	16	Z2
D6	33	60	19	Z2
D7	36	85	22	Z1
D8	37	90	19	Z1

The CART algorithm repeats the partitioning procedure until it can no longer be partitioned because there is no stop rule. The result of applying the CART algorithm to the learning data set of [Table 1] can be represented by the process as shown in [Figure 3]. Based on the value of W, the structure of the final classification tree is shown by explaining the quarterly conditions of heartbeat, respiration, and body temperature.

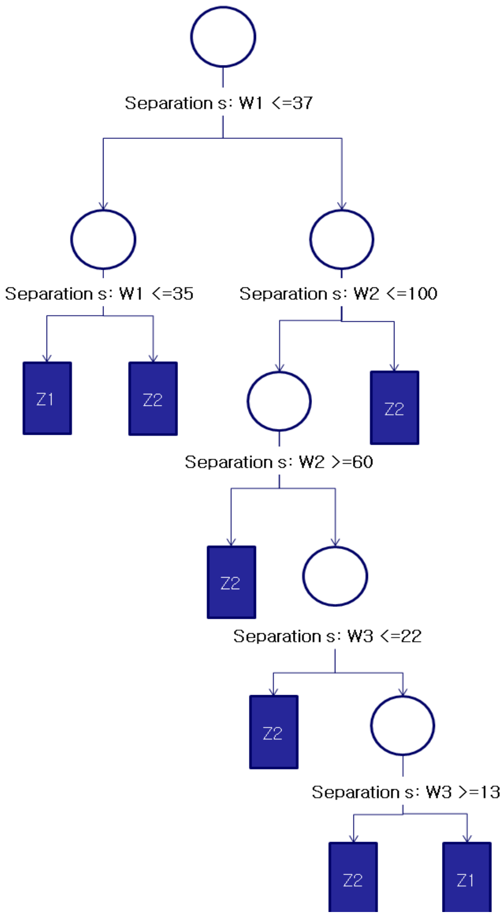

FIGURE 3. Final decision tree.

B. DEVELOPMENT OF ANDROID BASED DIVING COMPUTER PROGRAM

Various programs such as diving mode and log management have been developed supporting diving decompression algorithm applying Buehlmann [12] algorithm in case of decompression algorithm to develop a program based on Android (version 4.4, kitcat) embedded in a diving computer. Configuration and connection of developed controller are as shown in [Figure 4]. As schematic diagram of diving computer program, in general state, clock screen is displayed. The diving computer program consists of a menu of the dive plan, logs, settings, and diving information in the dive mode.

Four physical buttons were operated. The menu screen is designed to move according to the up and down buttons of the diving computer, and when there is no user input for a certain time, the clock is displayed. Source reusability was improved by using Model-View-Presenter method to enhance development efficiency. Reactive extension library [13]–[16] was used to reduce dependence between sources and quickly react to user input. UI that can maximize readability in the water has been developed so that a user can dive more safely. Driving computer program is designed to display various diving information at once on the display screen. Up and down NAVIGATION key and ESC / ENTER key are

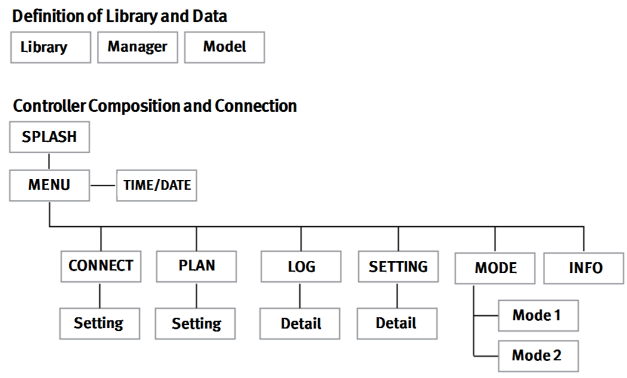

FIGURE 4. Final decision tree.

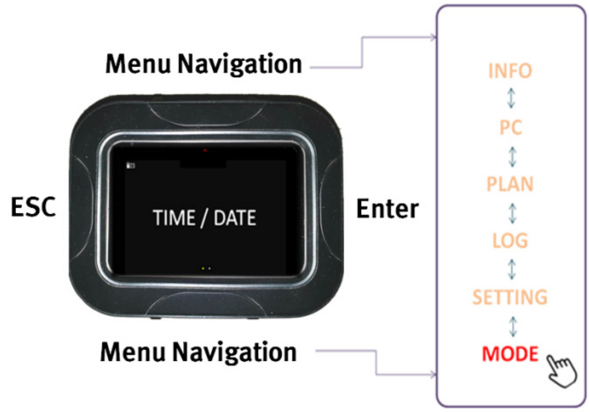

FIGURE 5. Diving computer navigation type.

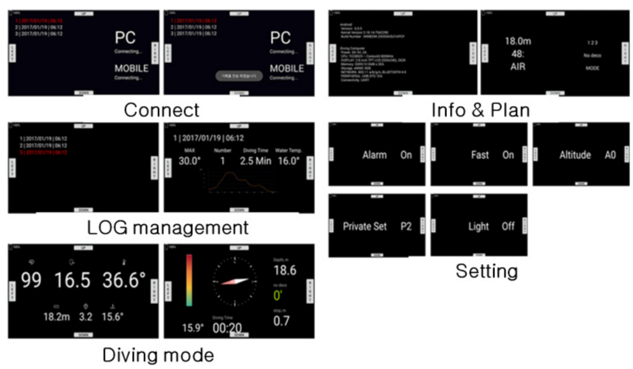

FIGURE 6. Android-based dive program implementation results.

configured to control entry and operation of each mode of computer. [Figure 5] explains such navigation type. [Table 2] and [Figure 6] show the actual functions and implementation screens of these diving computers.

C. DEVELOPMENT OF DIVING COMPUTER PROTOTYPE

This is to develop a diving computer with the diving program developed earlier. Diving computer prototype is designed with sensors that can measure water pressure and water temperature embedded. MS5803-14BA

TABLE 2. Process of the diving computer CPU (TCC8925).

Steps	Contents
1	Communication speed setting and I2C setting initialization
2	Reset sensor module and check device
3	Read PROM: Read and save the coefficients
4	Hydraulic Data Conversion (ADC)
5	Water temperature data conversion (ADC)
6	Read ADC data
7	Compensation calculation
8	Output Value

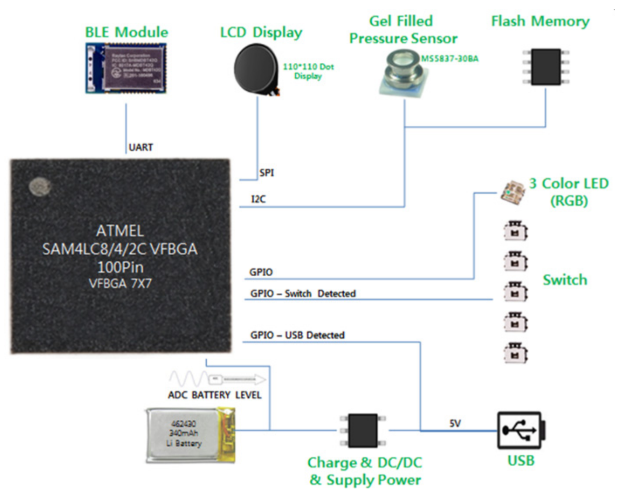

FIGURE 7. Diving computer process block diagram.

(Measurement Specialties) was used as hydraulic and water temperature measurement sensor module. Values are output through a total of 8 steps of processing, centering on CPU (TCC8925) processing. [Table 2] and [Figure 7] below show the CPU process and overall process block diagram of the diving computer.

According to the main specifications of the product shown in [Table 3], the MAIN circuit is configured as shown in [Figure 8] below. UART port enables to receive biometric information (heartbeat, respiration, body temperature) of suit sensor and designed as POGO pin for waterproof design. The USB port enables charging and data transmission, and diving computer prototype is designed to ensure sufficient transmission speed. [Figure 9] shows the prototype that was developed based on the applicable design. As shown in the figure, the results of porting the previously developed Android-based diving program to actual equipment, showing the operation of each menu step by step.

TABLE 3. Process of the diving computer CPU (TCC8925).

Category	Specifications	
	Item	Detail
CPU	TCC8925	Cortex A5 800MHz
Display	TFT LCD	2.8inch, 320 x 240, 262K Color
Memory	DDR3	512MB x 2EA
Storage	eMMC	4GB
Network	Bluetooth4.0	Connected with mobile phone
Peripheral	USB OTG	Battery charging, internal data backup
Connectivity	UART	Coupled with suit sensor module
Battery	Li-Polymer	3.7V / 1,000mAh
OS	Android	Kikat

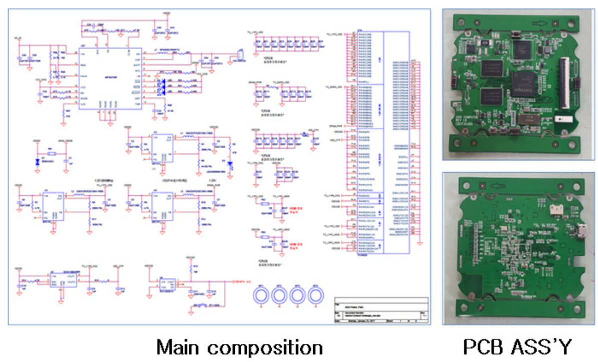

FIGURE 8. Diving computer main circuit schematic and PCB board.

D. DEVELOPMENT OF DIVER LOG MANAGEMENT PROGRAM

A file transfer protocol that is interoperable with mobile app based on IoT was developed by using Bluetooth diver log information.

Even if the Bluetooth is disconnected, file transfer protocol is designed to operate after reconnection, and the integrity of the file is verified using md5. In addition, to provide optimized screen for mobile, UI support through graph, and time information of log including log information are provided. Applicable information is finally stored in the server and the log information is sequentially output through the user history function. [Figure 10] below shows the results of the program implementation for diver log management.

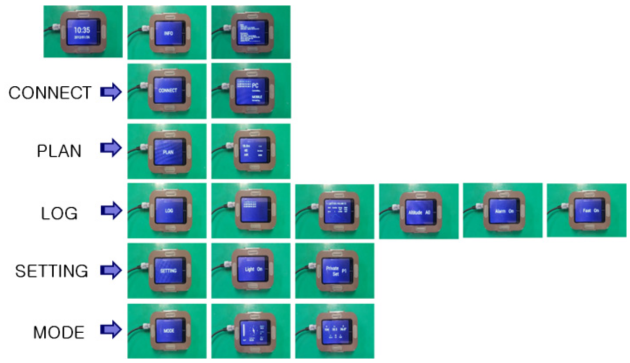

FIGURE 9. Actual implemented diving computer prototype (menu operation).

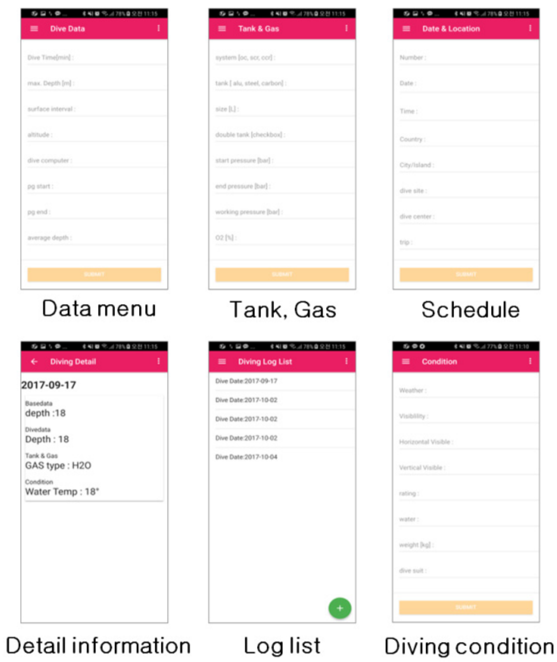

FIGURE 10. Diver log management program (app).

TABLE 4. Analysis results (objective items).

Expert	Usefulness	Satisfaction.	Ease	Dialicity
A	38	52	20	33
B	34	45	18	31
C	37	51	19	33
D	27	41	16	21
E	32	47	19	28
F	31	41	19	21
Average(150) / %	33.2(40) / 82.9	46.2(55) / 83.9	18.5(20) / 92.5	27.8(35) / 79.5

III. DIVING COMPUTER PERFORMANCE EVALUATION

In order to evaluate the performance of the diving computer based on the customized safety system proposed in this paper, the usability evaluation, the decompression algorithm, and the performance evaluation of the safety function were performed for evaluation of underwater titration design.

A. DIVING COMPUTER USABILITY EVALUATION (UI / UX)

This section conducted UI / UX usability evaluation of diving computer to evaluate UI intuitiveness and convenience of product usability. This is to evaluate whether diving computer was designed properly for use in the water. Expert group for UI evaluation consisted of 6 experts(4 experts in the field of UI / UX engineering, 2 dive instructors) and UI / UX evaluation was conducted from various perspectives. Representative UI/UX evaluation model [17] based on multi metrics was applied to evaluation. Evaluation items were established for UI evaluation by using Jacob Nielsen's model. UI / UX evaluation of the diving computer developed through the preparation of checklist and the evaluation and investigation of the expert group was conducted. The post test evaluation metric method was used. Each questionnaire consisted of 40 positive sentences in terms of usability, satisfaction, ease of use, and ease of use. A 5-point Likert scale was used to assess the level of consent of the expert group. The results were analyzed by adding a score from 1 to 5, adding averages, and converting them to percentage according to each category. [Table 5] shows the objective item results of such usability evaluation.

In case of analysis results of the engineering experts, contents of the menu, importance, and difficulty account for great part in subjective analysis. There were many comments on the UI design factors such as the size of the font and the color that can be seen in the distance with importance of frequently used menu. Field experts who conducted analysis recommended that steps entering detailed menu should be shortened and setting functions that deem to be unnecessary and dangerous (for example, rising speed warning alarm function) should be removed. Diving plan and log management function were rated UI/UX functions which are differentiated from existing products. Diving computer usability got overall average evaluation of 84.7%. [Figure 11] below shows a comprehensive evaluation result of usability, usability, ease, and satisfaction.

B. DIVING COMPUTER FUNCTIONALITY EVALUATION

Functions of the diving computer's underwater risk situation judgment algorithm and basic diving program functions (safety stop, no decompression time limit, decompression algorithm) are checked as second performance evaluation of diving computer based on customized safety elements proposed in this paper. First, the evaluation of the underwater risk situation judgment algorithm is to simulate the implementation result of the CART algorithm mentioned above.

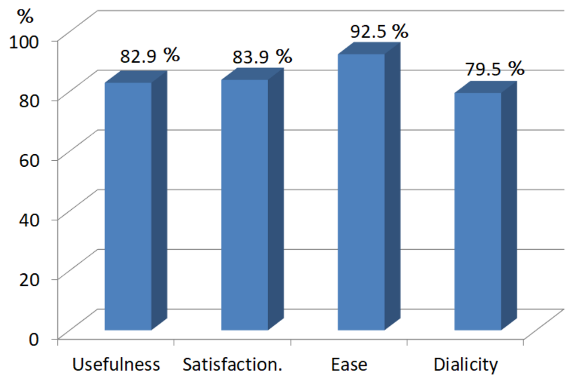

FIGURE 11. Diver log management program (app).

TABLE 5. Analysis of error matrix.

Confusion matrix	Proposed method
True Positive	43
False Positive	2
True Negative	44
False Negative	1

TABLE 6. Functional evaluation of a diving computer.

Evaluation	Proposed product	Major product A	Major product B
① Safety stop	10min	10min	5min
② No decompression time limit (Conservative grade)	Middle	High	Middle-low
③ Decompression-based dive time (Average time)	22min	20min	25min

FIGURE 12. Waterproof test instrument used for functional evaluation.

Values for normal and abnormal ranges of respiration and body temperature are entered at random and the underwater environment is adjusted based on water pressure and water temperature information. In such simulation, the input values were processed at random in the diving computer, and the underwater environment was conducted in the same environment as the actual underwater environment using the waterproof tester. [Table 5] below shows the results of the error matrix analysis of the underwater risk situation determination algorithm that was actually tested.

In order to evaluate risk diagnosis technique proposed in this study, 50 random test data sets were constructed and the error matrix of the simulated values were calculated. Calculation of error matrix found that TP and TN were high while FP and FN representing inaccuracy were low. This is the case where inaccuracy is confirmed. When the depth of the water is deepened, the weighted value of the risk is applied conservatively rather than the existing standard. Except this, high accuracy was obtained within 30 meters. Secondly, to evaluate the function of the basic diving computer program, three critical functions of the diving computer, safety stop, no -decompression limit time and decompression algorithm, were performed 30 times based on depth of water of 30m which are three key functions of diving computer to obtain the average results. The criteria for the evaluation were selected by comparing two existing major products and the results with those of the corresponding product group. A final evaluation was made by reflecting the opinion of the dive instructor as an absolute standard. [Table 6] shows the overall evaluation results of the three functions. The waterproof test instrument used for the experiment is shown in [Figure 12].

The experimental results are shown in the table above. It was found that a product developed in this paper has similar performance to that of the existing major products in three functions. In case of safety stop, it was found that the time required to stay at depth of 5m was slightly different among products but there was no significant difference as it usually took between 5 and 10 minutes. In the case of no decompression time limit, the authors of this paper tried to confirm the degree of decrease in time as the depth of water increases. The same function as the existing product was derived, and there was no significant difference in the overall time difference when there was no difference in the degree of time control of the decompression limit time (maintenance degree). Finally, it was judged that it was not appropriate to evaluate one factor for evaluation of decompression algorithm, and compared with existing products by calculating the minimum dive time for specific depth with the basic diving program. As a result of comparison, Major A product provided a relatively conservative pressure guide, and a more flexible pressure guide than Major B. It is confirmed that this product is able to provide a medium pressure guide between the two products. In the case of the pressure reducing function, it is considered that there is no problem in the safety part between the maintenance and the flexible guide. These results were performed under basic verification of dive instructors and it was confirmed that there was no problem in functional parts with the existing products.

IV. CONCLUSION

According to the marine accident investigation, marine safety accidents increase at a certain rate every year. In order to enhance the safety of marine leisure activities, it is necessary to develop safety products that can protect people from danger and keep them safe in case of various accidents such as inundation, distress and fire. In the case of scuba diving among marine leisure activities, accidents occur frequently due to the underwater environment, the diver's psychology, and the condition. The purpose of this paper is to develop a personalized diving computer that is interlocked with a textile type sensor attached to a suit to enhance the safety factor of a diver. The development of this diving computer is largely divided into three stages. The first is the development of a function to check the status of the diver in conjunction with the textile type wearable sensor attached to the suit. Second, development of diving computer is based on open-type mobile OS based on existing closed OS. Third, the development of real-diving computer prototypes focused on waterproofing can be configured. The bio information obtained from the textile type sensor can be used to determine the status of the diver by using CART algorithm decision method using information of respiration, body temperature information, water depth, and water depth. In the case of the CART algorithm, the accuracy of the error matrix is relatively high. However, it is necessary to compensate the accuracy of the algorithm at a deeper water depth within 30m. The dive management program was developed as an open OS based on Android and was selected considering future expansion and consumer participation. In addition, IoT-based log management program can be further developed to monitor the actual diver's dive records. It is expected that log information will be able to analyze diverse behaviors such as anomalous signs by analyzing diver's diving pattern by combining research with big data base in the future. The diving computer was developed as prototype and two usability evaluation and functional evaluation for performance evaluation were conducted. The usability evaluation was evaluated to find out whether diving computer was designed properly for use in the water and an excellent result was obtained with an average evaluation of 84.7%. Functional evaluation was also able to confirm performance that did not lag behind existing major products. As a result, the diving computer added safety factor to differentiate it from existing products, and this part has a distinct difference from the products of existing major companies. As a procedure for commercialization of diving computer developed through this research and development in the future, it is necessary to emphasize the safety factor that is based on the customization that is proposed to enter the domestic and foreign market. In this part, the authors of this paper will develop customized safety guiding system based on various learning data, and we will carry out further research and development on the safety factor and conduct continuous product verification.

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Authors' photographs and biographies not available at the time of publication.