Improving depth awareness for divers in free ascend

Paul Kasteleyn

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Media Technology MSc program, Leiden University

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Thesis advisors: Peter van der Putten and Olivier van der Post

Abstract

One of the main hazards of diving is decompression sickness (DCS). The risk of DCS can be decreased by ascending slowly and taking stops at different depths. Maintaining a steady depth during these stops is difficult due to the unstable situation of a diver. Existing methods of determining depths are either not accurate enough, require environmental factors or constantly require a large amount of attention.

In this study a device was developed that indicates a deviation of stop depths using LEDs with different colors. Successful test dives with and without the device were made with 6 divers. After each dive the dive profile was analyzed, the diver's situational awareness was measured and each diver filled in a questionnaire about the use of the device.

No clear differences were found in dive profiles and situational awareness between the dives with and without device. However, most of the test divers seemed to be enthusiastic about the idea, scored the dive as less difficult and felt more secure while using the device.

Contents

1 Introduction

Diving is a relatively safe activity in which not many accidents happen. Divers Alert Network (DAN) has collected a large amount of diving profiles in a database. At the end of 2013 this database contained the data from 39944 dives by 2615 divers (most studies that led to today's theories about diving and decompression are based on a much smaller dataset that often consists of data from a very homogeneous population, for example US marines). Along with the collected profiles divers could declare problems they encountered during the dive. They reported problems related to equalization (1,24%), buoyancy (0,50%), ascent speed (0,47%) and out of air situations (0,45%). Actual numbers are estimated to be lower, since some of these reports were collected when divers came in for treatment. [1]

One of the main hazards of diving is decompression sickness (DCS). During or after a reduction in environmental pressure (decompression) bubbles will be formed in blood or tissue. Small quantities of bubbles form in practically every dive and can be effectively filtered by the pulmonary circulation. However, when they are too many and too large, they can lead to DCS. Symptoms of DCS in recreational divers typically consist of pain or numbness. The risk of DCS can be minimized by ascending slowly during the dive or by taking stops at different depths. These stops allow gases to be eliminated in dissolved form instead of bubbles. Yo-yoing will slow this process. [2] [3] In a study performed with 10 healthy military divers, a significant decrease in post-dive gas bubbles formation was found when performing a mild continuous exercise during the decompression stops. [4]

Most dives are no-decompression dives. During these recreational dives no stops are necessary besides a recommended safety stop. In general the skipping of such a safety stop should not lead to problems. During decompression dives however, there is a severe risk of DCS if stops are skipped or are poorly executed.

It is important to stay at a steady depth during decompression stops, because diving algorithms are based on that. Maintaining a steady depth is not easy, because a diver is in an unstable situation during these stops. Especially closer to the surface of the water, it will become more difficult to stabilize. A small change in depth leads to the compression or decompression of air in suits and equipment. This leads to an increase in descent or ascent rate. This is a self-reinforcing effect. To maintain a constant depth constant adjustments to the buoyancy are needed. This is only possible if a diver is aware of his depth.

Existing methods to determine your depth while diving are either not accurate enough, require environmental factors which are not always available or require constantly a large amount of attention which can lead to a decrease in focus to other aspects of the dive. Therefore we developed a device which can easily indicate the deviation from the desired depth during a stop without being dependent of environmental factors or the need to look constantly on a display. This is accomplished by mounting bright colored LEDs onto the diving mask that light up around set depths. To our knowledge this is the first study that uses LEDs on the diving mask to indicate depth. We hypothesize that such a device will make a dive easier and safer in an intuitive way. To test this we will perform test dives with a number of divers and analyze the dive profiles, measure the situational awareness and administer a short questionnaire.

This paper is structured as follows. In section 2 a background is given about the existing methods to determine depth while diving and situational awareness. Section 3 explains the materials and methods including the development of the device. Section 4 shows the results from the test dives and in section 5 the results will be discussed.

2 Background

A number of existing methods for determining depth is listed below.

2.1 Existing methods for determining depth

Bottom contact When the bottom is nearby, a diver can stay in contact with the bottom at one place to keep that depth.

For this method no instruments are needed. Since the depth at one place does not change, this is a very precise method. It is even possible to make physical contact with the bottom, in which case it is not even necessary to look. However this can only be used when the bottom is visible. A problem might be that flora and fauna might be disturbed by physical contact with the bottom.

Floating particles In most water there float tiny particles that stay approximately on the same depth. When staying at the same depth as those particles a diver can maintain it's depth by concentrating on it.

For this method no instruments are needed. This method is quite precise. However these particles are not always present and clearly visible and looking at the particles requires constant focus.

Water pressure When changing depth the pressure of the water on a diver's ears changes. Mainly an increase of pressure can be felt. This method is not very precise since only larger changes in depth in a short period of time are noticeable, however it can be used as a warning when descending very fast.

Depth of buddy Most dives are performed with a buddy. It is easy to stay on the same depth as the buddy, because it is a large object in your view. When the depth between a diver and his buddy changes, it might not be clear if he is changing depth or his buddy is. This method can only be used if it is agreed that one of them monitors the depth.

Line Holding or watching a fixed point on a line connected to a buoy or an anchor line can be used to stay on the same depth.

A line is easily available and it is very easy to maintain a fixed position on the line. If the line is steady this method is very precise. This method is unreliable if there are waves on the water, since these waves pull the buoy or boat and with it the line up and down. If the diver is connected to a fixed position on the line he will make this same movement and this can be dangerous.

Analogue or digital depth gauge and diving computer An analogue depth gauge measures the pressure of the water mechanically and shows on an analogue display the corresponding depth. A digital depth gauge and a diving computer measure the pressure of the water electronically and show the corresponding depth on a digital display. A digital depth gauge can show some extra variables on the display, like the dive time and temperature. A diving computer is even more advanced. It shows the ascend rate and has some algorithms to determine the time the diver can stay under water at the current depth to make a safe ascend without decompression stops. In case this time is exceeded, it shows the decompression stops to make.

These devices are very reliable and precise, but it is necessary to look at the display to know the depth. This requires constantly a large amount of attention to maintain a steady depth. When performing other tasks that make it hard to maintain a visual on the display, like using a compass or when in distress, the depth can change quickly. Only in case of a very fast ascend a diving computer gives an audible alarm.

Lightness Due the absorption of light by the water the amount of visible sunlight under water decreases with the depth. Also the color changes, as some color wavelengths pass the water more easily. In clear water the colors are more blue at greater depths. Some waters cause more yellow or red colors. Although the change in lightness strongly depends on the composition of the water it is often usable as a rough estimation of a change in depth.

For this method no instruments are needed. A change in lightness can get your attention while not monitoring your depth. However in troubled water there is no visible light at greater depths which makes this method unusable. Furthermore the lightness can be changed by other factors than the depth, for instance the shadow of clouds or a ship at the surface. Also the composition of the water might not be consistent over depth, which causes the amount of lightness not to decrease linearly.

Temperature As the depth increases the water temperature often decreases. The sun warms up the top layer of the water. This warm water stays on top because it is lighter than the colder water below. In some cases there exists a thermocline, which is a layer where the water below and above don't mix and have a large difference in temperature.

For this method no instruments are needed. A change in temperature can get your attention while not monitoring your depth. However, the temperature of the water is mostly very constant and changes often only a degree every few meters. Only when passing a thermocline a diver can really feel the difference in temperature in a short difference of depth.

Underwater flora and fauna Largely due to the change in lightness and temperature, the underwater flora and fauna changes with the depth. When the bottom is visible this can be an indication of the depth. At shallower areas there are often more plants.

For this method no instruments are needed. This method is not very reliable and precise, since a change in flora and fauna is not only based on depth, but also other factors, like the composition of the bottom.

Summary Existing methods to determine your depth while diving are either not accurate enough, require environmental factors which are not always available or require constantly a large amount of attention. Table 1 provides an overview of all above methods and their disadvantages.

Table 1: Disadvantages of existing methods of determining depth

	Not accurate enough	Requires environmental factors	Requires constant attention
Bottom contact		✓	
Particles		✓	✓
Water pressure	✓		
Depth of buddy	✓		
Line		✓	
Instruments			✓
Lightness	✓	✓	
Temperature	✓	✓	

2.2 Situation awareness

During diving a wrong action and, since diving is an unstable situation, also a lack of action can lead to a dangerous situation in which the risk of decompression sickness increases or a diver can drown. A constant awareness of the situation is essential to prevent wrong or no actions from taking place.

Situation awareness is a person's "perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [5]. A better SA will lead to better decisions and less mistakes.

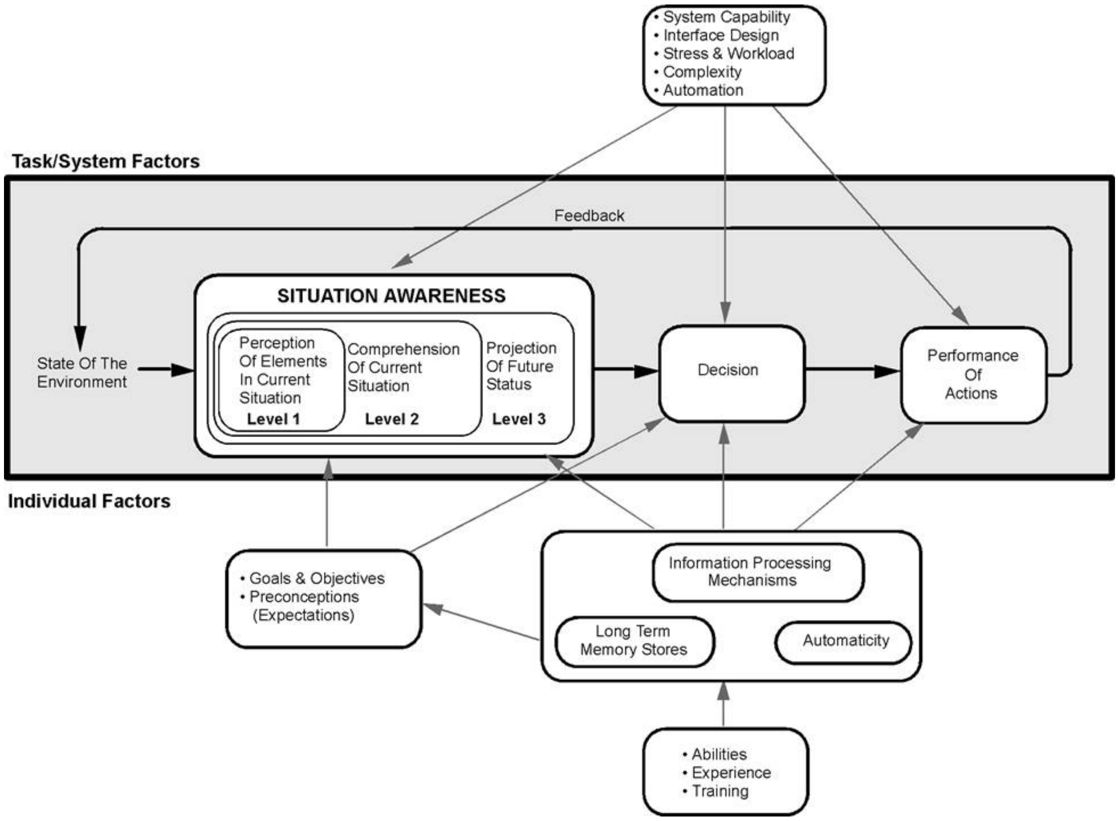
During the first world war the concept of situation awareness was identified. A better SA than the enemy could lead the way to victory. Since the late 1980's SA received more attention in the technical and academic literature. In the beginning it was mostly used in the aviation industry for pilots and air traffic controllers. Over the years the use has spread to researchers and practitioners in the field of medicine, ground transportation, energy production, energy distribution and process control. [6]

In figure 1 the different levels of situation awareness are shown. In the following paragraphs these levels are explained in the context of diving.

Level 1, the perception of elements in current situation Elements to be perceived include technical data like depth, tank pressure, dive time and heading, knowledge of the environment like visibility, flora and fauna, artificial objects under water, like fishing nets or ship wrecks, but also the status of the divers buddy.

Level 2, the comprehension of current situation The data gathered in level 1 can be combined with knowledge about diving in general and the dive plan of the current dive. This leads to an understanding of the situation.

Figure 1: Situation awareness in the process of dynamic decision making. [7]



Level 3, the projection of future status With the knowledge of level 2, the implications of the data from level 1 can be combined with possible actions and for each action the possible future status can be derived.

Situation Awareness Rating Technique (SART) The Situation Awareness Rating Technique (SART) [8] is one of the first widely used techniques for situation awareness rating. SART is originally developed for military aviation. The requirements to SA for aviation are much the same as they are for diving. And since the SART is administered after completing the task, it is suitable for our test dives. It is a subjective technique that lets the divers rate their own SA.

A disadvantage of this technique is that the rating might be influenced by the performance on the task at hand [9]. If the task is easier because of some other factors than an improved SA, the subject will often give a higher rating to the SA. Furthermore, since the ratings are given after the task, subjects might have forgotten some moments during the dive and generalize their SA. Therefore the ratings only give possibly reliable information about the divers' idea of their global SA.

The SART form consists of 10 questions that need to be answered on a 7 point scale. The questions are divided in three main dimensions:

1. Demand: a combination of instability, complexity and variability of the situation
2. Supply: a combination of arousal of the situation, concentration, division of attention and spare mental capacity
3. Understanding: a combination of information quantity, information quality and familiarity with the situation.

These dimensions with their corresponding questions are shown in table 2.

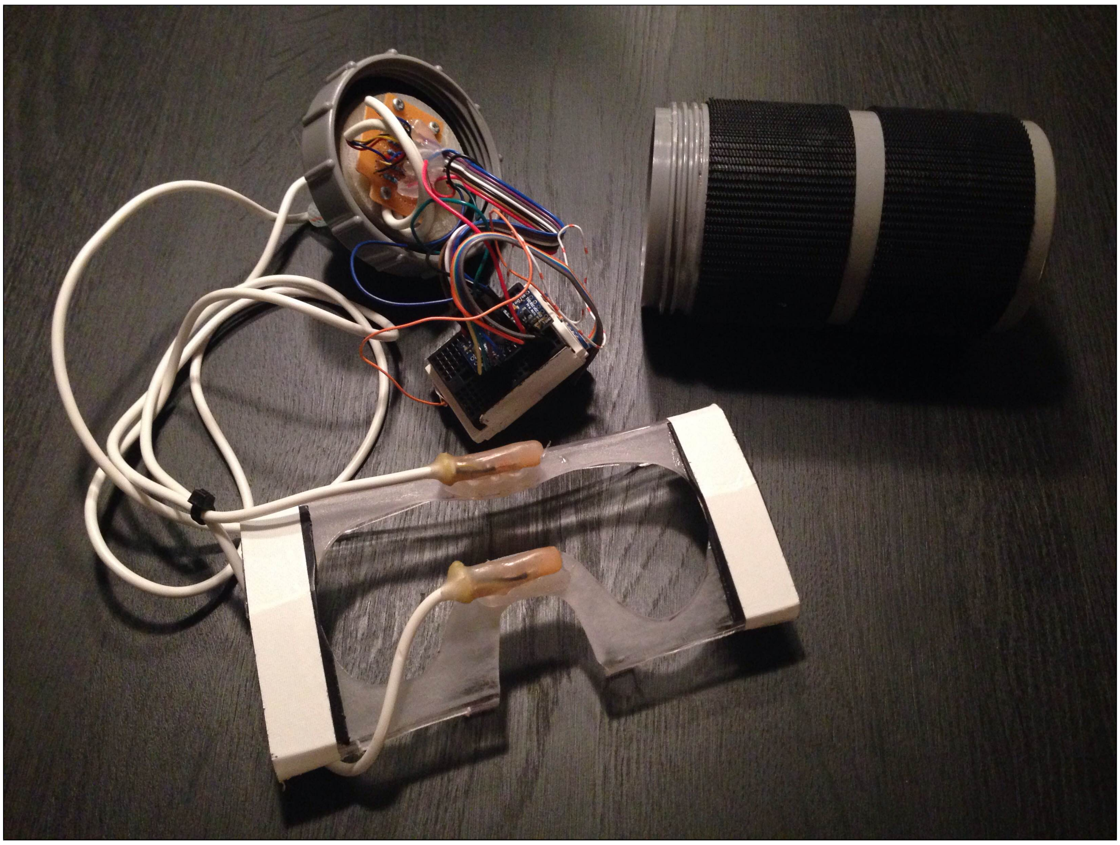
Table 2: The questions of SART form divided in the three dimensions. Answers on a 7 point scale.

Demand	**Instability of the situation** How changeable is the situation? Is the situation highly unstable and likely to change suddenly (high) or is it very stable and straightforward (low)? **Complexity of situation** How complicated is the situation? Is it complex with many interrelated components (high) or is it simple and straightforward (low)? **Variability of situation** How many variables are changing within the situation? Are there a large number of factors varying (high) or are there few variables changing (low)?
Supply	**Arousal** How aroused are you in the situation? Are you alert and ready for activity (high) or do yo have a low degree of alertness (low)? **Concentration of attention** How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)? **Division of attention** How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)? **Spare mental capacity** How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (high) or nothing to spare at all (low)?
Understanding	**Information quantity** How much information have you gained about the situation? Have you received and understood a great deal of knowledge (high) or very little (low)? **Information quality** What was the quality of the information gained in the situation? Was the information accurate (high) or inaccurate (low)? **Familiarity with the situation** How familiar are you with the situation? Do you have a great deal of relevant experience (high) or is it a new situation (low)?

3 Materials & methods

To test our hypothesis we developed a system that indicates the deviation from the stop depth using LEDs that are mounted on the diving mask. The software runs on an Arduino development board, which is connected to a pressure sensor, an SD-card writer and the LEDs on the diving mask. The Arduino with the pressure sensor and SD-card writer is mounted in a waterproof protective case that can be mounted on the divers equipment. It is connected to the LEDs with cables. A picture of the device is shown in figure 2. During the development several dives were made to test the system. Details of these dives can be found in appendix A.1.

Figure 2



3.1 Case

Requirements The case had to be large enough to hold the necessary hardware. The first prototype contained an Arduino board with a length of 7,5 cm, a width of 5,5 cm and a height of 2 cm. The finished circuit board had a length of 8 cm, a width of 5 cm and a height of 0,5 cm. Furthermore space was needed for a 9V PP3 battery and some wires. In the final prototype is a lot of empty space, because it contains a smaller Arduino and battery and the circuit board is also much smaller, since the pressure sensor is now digital and there is no need for extra components to change the output of the pressure sensor into a format that the Arduino can read.

There had to be some holes to feed cables through and a small hole for the pressure sensor.

To be able to use the case under water it has to be completely watertight and be able to withstand a pressure of at least 5 bar to allow the use in water depths up to 40 meters, which is the recreational diving depth limit.

Design The case is made of PVC plumbing materials. It consists of a PVC pipe with on one end an end cap glued on. On the other end a thread for a screw cap is glued with a generous amount of PVC glue. The screw-on cap has a rubber ring to make a watertight seal. The case has a height of 13,5 cm and a diameter of 7 cm. This is plenty of room for all the components. Because the largest surface is cylindrical shaped, it should be able to withstand some pressure. On the inside of the screw-on cap a 5 mm thick piece of plastic was glued to allow the cap to be screwed in without penetrating the whole cap as this might create leaks.

In the screw-on cap two holes were made for the cables to the LEDs. On the inside the cables were secured by screwing on a small plate that holds the cables in place. This prevents movement of the cables that might create leaks. On the outside the holes are a little flushed and after the cables are fed through the holes, a large amount of hot glue is applied to create a watertight seal.

For the sensor of the first prototype a small hole is drilled. The long port of the sensor sticks through the hole and is sealed with a small rubber ring. A small plate is screwed over the back of the sensor to push it firmly onto the cap and let the rubber ring make a good seal.

The pressure sensor of the final prototype did not have a long port to stick through the hole and a rubber ring was placed between the top of the sensor and the case. This was not waterproof and so the whole sensor was placed on the outside of the case, completely glued in, with only the top of the sensor sticking out of the glue. To protect the sensor and make it possible to connect a pump to the sensor to apply pressure on shore, a small cap was glued over the sensor with a small tube that connects to the pump.

The outside of the case is covered with Velcro to securely mount the case to a part of the diving equipment. This could for example be the jacket or the tank.

3.2 Input/Output

Pressure sensor There are 3 types of digital pressure sensors: absolute, gauge and differential. The absolute pressure sensor measures the pressure relative to vacuum. The gauge pressure sensor measures the pressure against the atmosphere. The differential pressure sensor has two pressure ports to measure the pressure difference between those two. For this project an absolute pressure sensor is needed, because atmospheric pressure is not available under water.

The first prototype used a Honeywell S&C NBPDLNN060PAUNV pressure sensor [10]. It had a range of 0-60 PSI, which is a little more than 4 bars. This allows depth measurement up to ± 30 meters under water. It allows an overpressure of 120 PSI (± 8.3 bars) which allows diving up to ± 70 meters. The sensor has an input voltage of 1.8 to 12V and an analogue output of a couple of mV, based on the input voltage and the pressure.

When preparing for the second day of test dives, the system malfunctioned. Above the water it stated a depth of -11 meters. When changing the pressure this did not change. After measuring the output of the pressure sensor without anything else connected it became clear the pressure sensor was broken. This was strange, since it worked flawlessly during the last dive and nothing had changed since then. After reading the specifications of the sensor more meticulous it became clear that this specific sensor was only build to measure the pressure of gases, not liquids. The exposure to water had probably damaged the sensor.

Since this pressure sensor also did not have the desired accuracy, this moment was used to find a new waterproof pressure sensor with a higher accuracy and a digital output to overcome the limitations of the 10 bit Arduino ADC. This was found in the MS5803-14BA from Measurement Specialties [11]. This sensor is a bit more expensive, but meets our requirements. It is also used in other projects to measure the depth of ROVs [12]. This sensor has a gel protection that allows the use of it under water. It has a operating range from 0 to 14 bar, enough for dives up to ± 130 meters, way more than the depth limit for recreational diving. It can even withstand a pressure of 30 bar (± 290 meters) so it is no problem to dive deeper with it, but it can't determine the depth below ± 130 meters. The accuracy between 0 and 40°C is between -20 and +20 mbar. Using an oversampling rate of 4096 the resolution is 0,2 mbar. This corresponds to a depth resolution smaller than 1 cm. An extra feature on this sensor is its integrated temperature sensor.

LEDs on diving mask There are two arrays of three bright LEDs. Each array has one green, one yellow and one red LED. These colors were chosen since they are used for safety and warning indication for centuries. The color red has been used to indicate emergency and alarms, the color green to indicate safety or normal conditions and the color yellow in between. We don't have reason to deviate from this. [13] The LEDs are glued on a plastic frame that can be mounted on the diving mask. One array is positioned at the center of the top of the glass of the mask, the other one at the center of the bottom, to make it possible to distinguish between being above or below the desired depth.

SD card interface In a later stage a SD card interface was added to the SPI bus of the Arduino to log the temperature and depth during the dives.

3.3 Logic

Arduino The first prototype is based on a simple serial Arduino development board. 6 output pins are used to power the LED's and 1 analog input pin for the pressure sensor. In later versions the serial Arduino is replaced with an Arduino Pro Mini 3.3V. 6 output pins are used to power the LED's and analog pin 4 and 5 are used for the I2C interface with the sensor.

Power For the first prototype a simple 9V PP3 battery was used. Later this was replaced with a rechargeable 3,8V phone battery.

Op-amp In the first prototype an INA125P op-amp was used to boost the mV signal from the sensor to 0-5V for the Arduino analog input port. In later versions the sensor was replaced with one that has a digital output which is connected to the I2C ports of the Arduino, so the op-amp is not necessary anymore.

LEDs The LEDs require a voltage that is lower than the output voltage of the Arduino. In table 3 it is shown what resistors are needed to lower the Arduino voltage to the LED voltage.

Table 3: LED specifications and required resistors

Arduino voltage (V)	LED color	LED voltage (V)	LED current (mA)	Resistor (Ω)
5	green	3.1	20	100
5	yellow	2.1	20	150
5	red	2.1	20	150
3.3	green	3.1	20	10
3.3	yellow	2.1	20	68
3.3	red	2.1	20	68

3.4 Software

The source code of the software for the Arduino can be found in appendix C.

Conversion of pressure to water depth For reading out the pressure sensor, the SparkFun_MS5803_I2C library [14] is used. This gives the temperature and the water pressure. The depth can be calculated using the formula

$$\text{depth} = (\text{pressure} - \text{atmospheric pressure})/(\text{water density} * \text{gravity})$$

The pressure and atmospheric pressure are in Pascal, so the pressure in bar should be multiplied by 100.000.

The atmospheric pressure is set from the first pressure measurement once the device is turned on.

The water density is different for different kinds of water. For instance salt seawater has a higher density than freshwater. Also the temperature has some influence on the density. In this project we are not interested in the absolute depth, but in the change in depth over time. The fluctuation in water density during a decompression stop is minimal. Therefore the water density is estimated at $1000kg/m^3$ for all dives.

Due to the inconsistent composition of the earth and the difference in centrifugal force the gravity is not exactly the same for every place on earth. In the Netherlands the gravity is approximately $9,81m/s^2$. Again, since we are not interested in the exact absolute depth, we can fix this parameter.

$$\text{depth} = (\text{pressure} - \text{atmospheric pressure})/(1000 * 9,81)$$

$$\text{depth} = (\text{pressure} - \text{atmospheric pressure})/9810$$

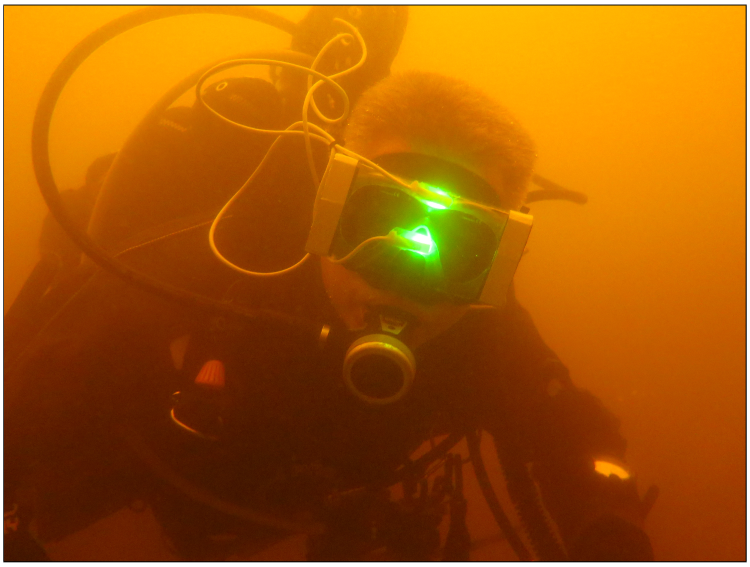
Stop depths and margins Most algorithms for decompression stops implement stops at depths of 12, 9, 6 and 3 meters. The time for each stop is calculated by the algorithm. When the software detects that the diver is within a range of 1 meter of such a stop depth, it turns on and shows the distance to that depth. When the diver is exactly at the stop depth, for example 6,00 meters, the green LEDs both on the top and on the bottom of the diving mask light up. A small deviation of 25 centimeters of this depth is allowed, because it is impossible to stay at exactly that depth and to allow small measurement errors. 25 centimeters should be enough for these small fluctuations. The green lights shown at a depth of the stop depth ±25 cm (for example 5,75m - 6,25m) indicate that the diver is within good range of the stop depth.

If this 25 centimeters is exceeded, the green lights will turn off and a yellow light will turn on. If the diver is more than 25 cm beneath the stop depth, the yellow LED on the bottom of the mask will turn on, indicating the diver is a little too deep. If the diver is more than 25 cm above the depth stop the yellow LED on top of the mask will turn on, indicating the diver is a little too shallow. These yellow lights will stay on until the stop depth (±25cm) is reached, or the diver deviates even more from the stop depth.

From 50 centimeters to 1 meter away from the stop depth a red light will turn on. If the diver is more than 50 cm beneath the stop depth, the red LED on the bottom of the mask will turn on, indicating the diver is way too deep. If the diver is more than 50 cm above the depth stop the red LED on top of the mask will turn on, indicating the diver is way too shallow. These red lights will stay on until he is within 50 centimeters of the stop depth, in which case the yellow light will take over, or the diver deviates even more from the stop depth. At a distance of more than 1 meter from the stop depth all LED's turn off until the diver gets into the range of a stop depth again.

These margins should provide the diver with a precise indication of the depth, while allowing small errors.

Figure 3: The device in use under water



Logging For debugging, the depth and temperature is logged during the dive. This is written to an SD card every 300ms.

3.5 Testing

To test the system a series of test dives was executed with 11 divers with different levels of experience. Since we have the availability to a limited number of subjects and we want to keep the differences in other variables than the use of our system to a minimum we use a within-subject design. [15] As far as possible we made two dives with every subject of which one was with the system and the other one without. This leads to the problem that there might be carryover effects in which the second dive is influenced by the first dive. A diver might for instance learn from the first dive, or become more fatigued. To compensate for this half of the subjects dived first with the system and the other half first without, in random order.

The first idea was to make a set of simulated decompression stops at depths of 12, 9, 6 and 3 meters. (see table 4). The first 10 minutes is used to become comfortable in the water. After that 6 minute stops were made of which the objective of the first half was to maintain the stop depth and the objective of the second half to swim on the same depth a certain course using a compass. This would distract the diver from maintaining his depth.

During the first test dives it soon became clear that the dive plan was too difficult for most subjects. Some divers were unable to maintain a steady depth during all stops and some of them were so exhausted they could not execute the second dive. Therefore the dive plan was simplified as shown in table 5.

Table 4: Dive plan 1

Time (minutes)	Duration (minutes)	Objective
0 min	10 min	Descent to 15 meters
10 min	1 min	Ascent to 12 meters
11 min	3 min	Stop at 12 meters
14 min	3 min	Swimming during stop at 12 meters
17 min	1 min	Ascent to 9 meters
18 min	3 min	Stop at 9 meters
21 min	3 min	Swimming during stop at 9 meters
24 min	1 min	Ascent to 6 meters
25 min	3 min	Stop at 6 meters
38 min	3 min	Swimming during stop at 6 meters
31 min	1 min	Ascent to 3 meters
32 min	3 min	Stop at 3 meters
35 min	3 min	Swimming during stop at 3 meters
38 min	1 min	Ascent to surface

Table 5: Dive plan 2

Duration (minutes)	Objective
$\pm$ 8 min	Descent to 12 meters and then follow the bottom at that depth
$\pm$ 6 min	Ascent to 9 meters and swim using a compass while maintaining depth
$\pm$ 6 min	Ascent to 6 meters and swim using a compass while maintaining depth
$\pm$ 1 min	Ascent to surface

Location The location for all test dives from dive #6 is Vlietland in Leidschendam. At this location the water reaches a depth of approximately 22 meters. There is no thermocline and the temperature during the tests is at all depths between 18°C and 22°C. The visibility is low (not more than 3 meters). Therefore it is difficult to maintain a steady depth without a constant focus on a depth meter.

3.5.1 Measurement

Performance measurement To measure the divers performance, an Uwatec Aladin Prime dive computer is mounted to the subjects diving equipment. It logs the depth during the dive every four seconds. This is an objective and non-intrusive measurement. A good performance would be a constant depth during the stops. To allow the test divers to have a little practice with the system we only analyzed the data from the last stop depth (6 meters). A paired T-test was used to test the significance.

Situation awareness measurement To test the situation awareness of the subjects during the dive the Situation Awareness Rating Technique (SART) was used. For more information about SART see section 2.2. Immediately after each dive the SART form was filled out by the test divers. This way we are able to compare the SART scores from the dives with and without the LEDs. A paired T-test was used to test the significance. The test divers were instructed to fill out the form about their situation awareness during the 6 meter stop. The SART form is shown in appendix B.

The total SART score can be calculated with the following formula:

$$\text{SART Score} = \text{Understanding} - (\text{Demand} - \text{Supply})$$

A higher total SART score corresponds to a better situational awareness.

Questionnaire A short questionnaire is administered after both dives have taken place. There are questions about some design decisions and the perception of the system by the subject. Care was taken to ask questions that lead to scalable answers and we tried to avoid leading questions. The values of the scale yield non-numeric data. The goal of this questionnaire is to determine if the used colors for the LEDs are a good choice, if the depth margins are well chosen and to which extend the lights are distracting. Furthermore it will show the difference in difficulty and the feeling of security between diving with and without the system after which a one-sample T-test was used to test the significance. Finally it should give an idea of the general thoughts about the system and possible improvements. The questionnaire can be found in appendix B.

4 Results

Test dives were performed with 11 divers. A summary of each test dive is reported in appendix A.2. Test results from 5 divers were incomplete because not both dives were completed according the dive plan. One subject was colorblind and over-sensitive to light. He was blinded by the brightness of the LEDs and could not see his diving computer to determine his depth. This led to a very unstable buoyancy and the dive was aborted. Other subjects had problems with their buoyancy due to inexperience and/or were too exhausted to perform a second dive. One subject had leaking water inside his diving mask after which the dive was aborted.

After each dive the subjects filled out the SART form and after having completed both dives the questionnaire was administered.

To check the accuracy of our device we compared the dive profiles for dive #11 as measured by our device and is written to the SD card and the dive profile as measured by the Uwatec Aladin Prime dive computer. This is shown in figure 4(a) Only when zoomed in a small difference in depth can be found as is shown in 4(b)

4.1 Performance measurement

Less experienced divers are unable to maintain a steady depth in the circumstances of the tests. An example of this can be seen in figure 5. Both dives where made without the LEDs, but it is also visible for the dives with the LEDs. The profile of the less experienced diver with 39 dives shows much fluctuation, where the profile of the diver with over 600 dives is quite steady and the stops are clearly visible.

A paired T-test shows that the average standard deviation during the 6 meter stop was not significantly different between the dives with and without the LEDs (0,37m vs 0,34m; p=0,362). The standard deviation during this stop for each diver is shown in figure 6. A lower deviation of depth contributes to a better stop.

All logged dive profiles of the test dives can be found in appendix A.2.

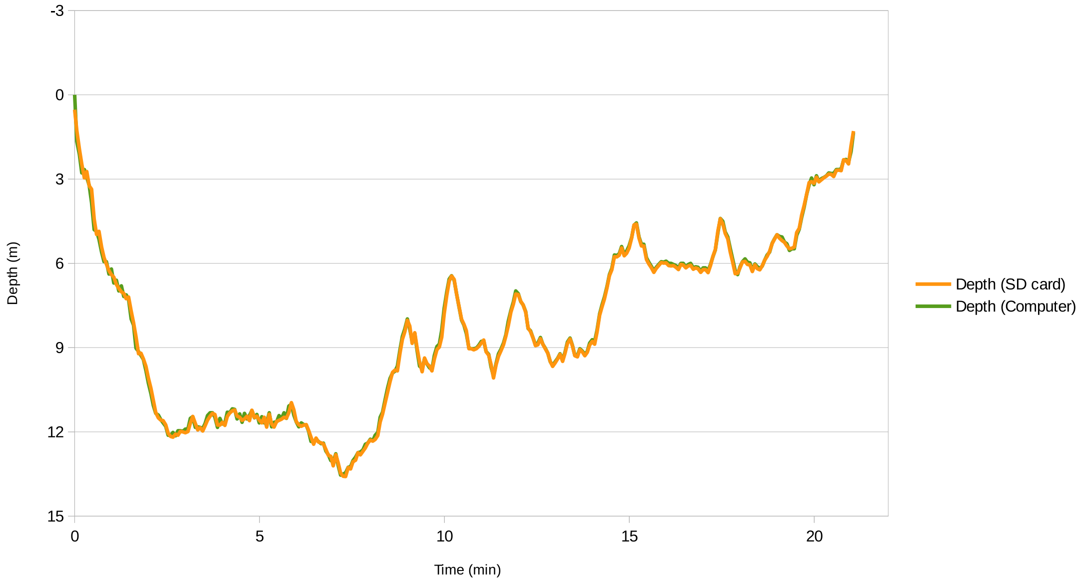
4.2 Situation awareness

The situational awareness during the stops was measured using SART. The total SART score for each test diver with and without the LEDs is shown in figure 7. The average total SART score for all divers is 18,7 without the LEDs and 19,5 with the LEDs. A paired T-test shows that this difference is not significant (p=0,625). One might think that a higher situational awareness leads to a better performance. However, for 5 of the 6 divers the standard deviation is higher (performance is lower) while the situation awareness is higher as can be clearly seen when comparing the charts for the standard deviation (figure 6) and the situation awareness (figure 7), which are almost the same.

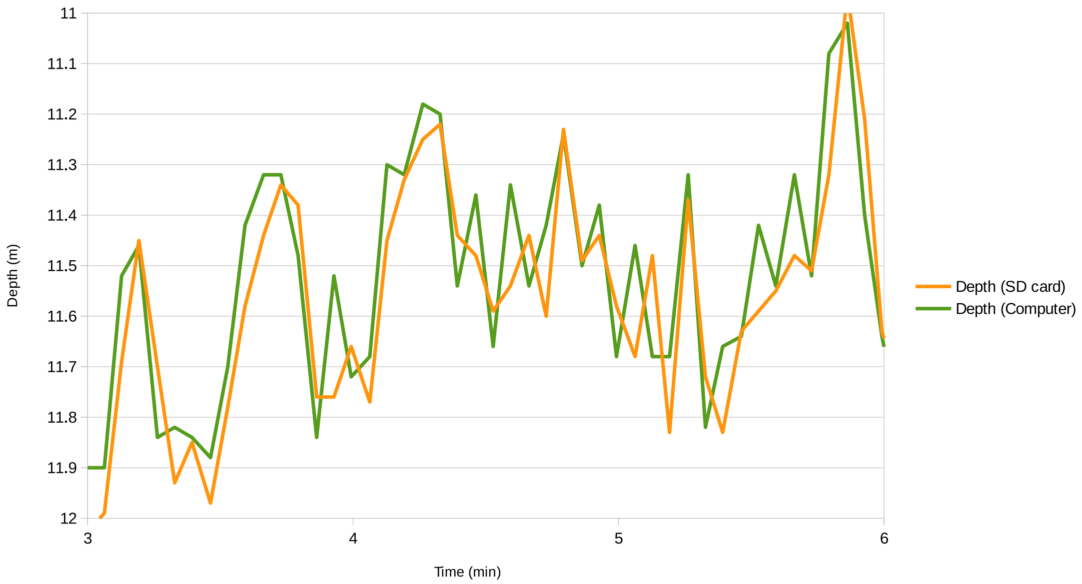
4.3 Questionnaire

After completing the two dives the subject filled out a questionnaire. The average answers to the Likert-scale answers are shown in figure 8. The color green is rated to be

Figure 4: Comparison of the depth profile read for dive number #11 from the SD card in our system to the depth profile from the Uwatec Aladin Prime diving computer.



(a) Overview



(b) Zoomed in

Figure 5: Dive profiles of divers with different levels of experience

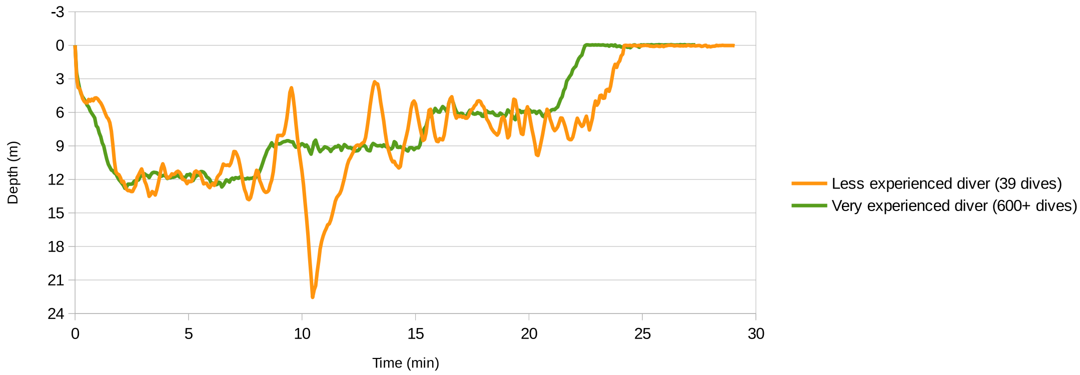


Figure 6: Standard deviation during the 6 meter stop for each test diver with and without the LEDs (lower is better)

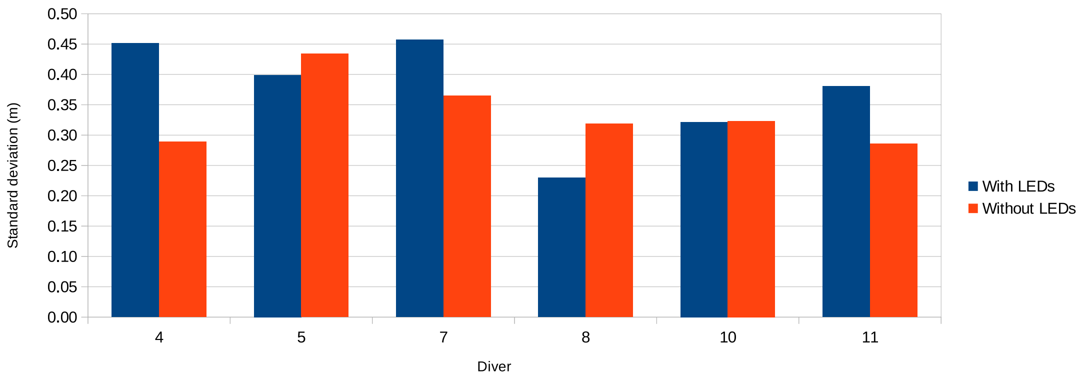


Figure 7: Total SART score for each test diver with and without the LEDs (higher is better)

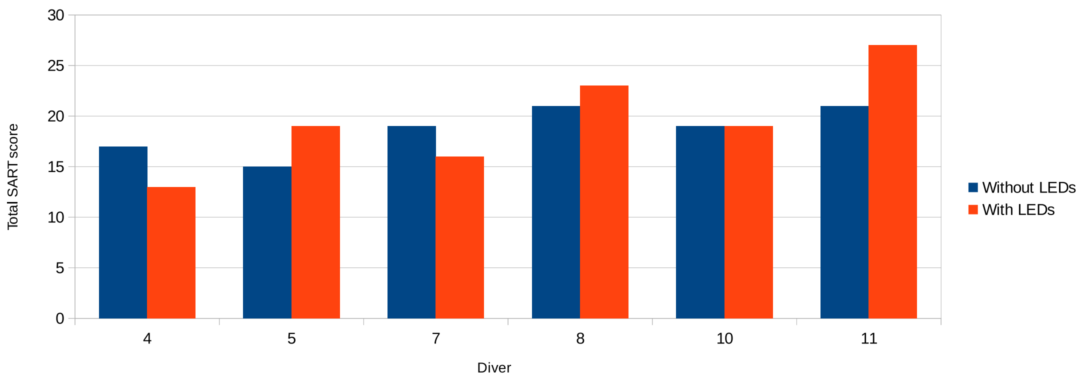
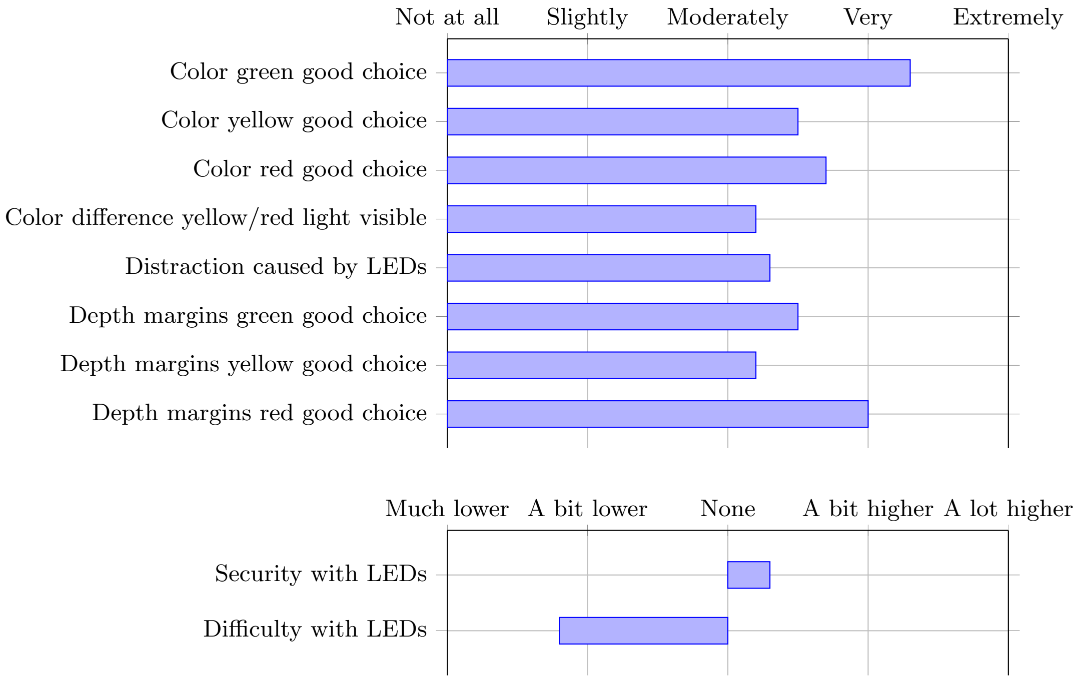


Figure 8: Average answers to Likers-scale questions from the questionnaire



a very good choice for the safe stop depth. The colors red and mostly yellow are worse and for most divers it is hard to see the difference between them. The LEDs cause some distraction to the diver. The depth margin for red is very well liked, the margins for green and yellow are a bit less good.

On average the test divers experience a minor, but not significant increase in the feeling of security (p=0,530) and a larger drop in difficulty maintaining a steady depth during the stops which is significant (p=0,013).

The answers to the open questions are shown in table 6 and 7. Most test divers like the idea well, but see room for improvement and need more time to get familiar with it to fully benefit from it. Most heard feature requests are an on/off switch and dimmable lights.

Table 6: Questionnaire: What are your general thoughts about the system?

Welcome feature.
It is a good system which allows you to focus on other things during your stops.
Needs getting used to (confidence in the system needs to grow). I used it as an extra sensor whereas it should be instead of the depth meter.
A bit distracting during non-stops. LEDs in the center blocks the view a slightly.
Good potential. Could be of added value. Potential for improvement.
Good, but needs getting familiar with.

Table 7: Questionnaire: What would you change?

Welcome feature.
Skip yellow LED, change lower limit LED color to blue.
The lights can be a bit distracting during the moments you don't really need them. A way to switch them off during your dive and on during your stops would be nice.
Change the location of the indicators in the field of view. Try other ways to indicate adequate depth.
Move LEDs. maybe increase the margins a bit (50cm yellow, 1m red).
Ability to switch off during most of the dive. Up & down hard to distinguish due to reflections.

5 Discussion & conclusion

In this study we developed a device which can be used to monitor the depth during stops while diving. We found no clear differences in dive profiles or situational awareness during the use of this device. However, the test divers seemed to be enthusiastic and most of them thought this could be a good addition to the methods used at the moment. Furthermore, they scored a lower on difficulty and a little bit higher on feeling of security during the dive while using the device.

Our device can be used to gain information about the depth without the need to look at a display. In this way you will be easily notified of changes in depth while enjoying your dive.

Since this is the first prototype of this device, there are some limitations. As indicated by most of the test divers, the LEDs can be distracting and might increase stress. The test dives were performed in dark water with low visibility. Because of the darkness the LEDs were too bright. However, in direct sunlight the LEDs are barely visible. An LDR can be used to measure the brightness of the environment. This value can be used to adapt the brightness of the LEDs to the brightness of the environment. This will provide the diver with a similar experience under all circumstances. In a new prototype another function can be added which makes it possible to turn off the lights during the dive and turn them on while starting your decompression stops.

Another limitation is the construction of the device. The LEDs on the diving mask are connected to the control unit with cables. When the control unit with positive buoyancy is lost, or the cables get stuck on something, the diving mask might be pulled from the head. The device could be made much smaller. If everything is integrated on a single circuit board and smaller components are used, the device could be small enough to be directly fitted onto the diving mask. This removes the need for cables.

Furthermore, we had some problems with one of the test divers who is colorblind. The system in its current state has limited use for people that cannot distinguish colors. It can be used to indicate a certain depth, but not a detailed indication of the deviation from that depth. This problem might be reduced by changing the colors of the lights or by using blinking lights instead of colors.

The reason that we did not find clear differences in dive profiles and situation awareness between the dives with and without the device might be due to the fact that none of the divers were used to maintain their depth based on LEDs. The device might not be as intuitive as we had hoped. When using the device more frequently a diver might become more handy with it and learns to trust it. The number of test divers and the number of dives with each test diver needs to be increased to get a better idea of the usefulness of this device.

In conclusion, in this study we developed a first prototype of a device for divers which indicates the deviation of the desired depth during decompression stops. Although there were no clear differences in dive profiles or situational awareness while using this device, test divers score the dive with device as less difficult and feel more secure. Therefore it might be a useful tool in the maintaining of depth and the safety of the dive. However, more dives are needed to get used to the system and some improvements need to be made in a next prototype.

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A Test dives

A.1 Test dives during development

Diving statistics as reported by a Suunto Gekko diving computer.

A.1.1 Dive #1

Date: 05-06-2015
Time: 12:21
Maximum depth: 11,3 meters
Dive time: 6 minutes
Location: Klinkenbergerplas, Oegstgeest

While descending during the first dive, as expected some of the lights lit temporarily up while passing the different programmed depths. This was ignored to first become fully stable in the water. After descending to 11 meters the casing was checked for leaks by seeing if any air was escaping from it. No leaks were identified. After that a slow ascend was made to the first shallower depth level of 9 meters. Unfortunately the lights did not lit up. While slowly ascending to the the surface none of the lights lit up anymore. A malfunction of the system was suspected and it was taken to shore.

Back on shore the casing was dried with a towel and opened. Inside was a small amount of water found. This was probably the cause of the malfunction. It seemed to be too much water to have entered the case from the thread when opening the case so a small leak was suspected. However the position of the leak could not be determined. There was no water found on the inside of the feed-troughs for the cables and the depth sensor. Maybe something was stuck under the rubber ring to prevent a good seal.

A.1.2 Dive #2

Date: 05-06-2015
Time: 12:51
Maximum depth: 8,2 meters
Dive time: 13 minutes
Location: Klinkenbergerplas, Oegstgeest

After the first dive extra care was taken to prevent any more leaks. The rubber sealing ring was cleaned and it was made sure there were no wires touching the rubber ring while closing the case. Unfortunately one of the heel straps of the diving fins broke, so the dive was made without fins.

During the descent the case was constantly looked at to see if any air escaped, that would indicate a leak. Because some air was trapped in the thread a small amount of air would be normal. After this was all gone, no new air escaped, so it seemed like there were no leaks.

Because the dive was made without fins, since one of the heel straps was broken, it was hard to maintain a good buoyancy. Therefor it was decided to find a place at the bottom around 7 meters to do some testing. While sitting at the bottom the case, which had a positive buoyancy, because of the trapped air, was floating around six meters, while it's depth was controlled by pulling and releasing the cables connecting it to the diving mask. Immediately it was clear that the lights were mounted in the wrong way. The lights that were supposed to be on top of the mask were placed on it's bottom and the lights that were supposed to be on the bottom were placed on top of the mask. This was very confusing.

Furthermore the accuracy was not as good as expected. It seemed to be that the position in which the lights turned on was not always the same. Another small annoyance was the fact that on a switching point the lights start to flicker between two colors. The visibility of the lights was not very good, especially in brighter conditions. On the bright sight, the case did not leak this time and the system kept working.

A.1.3 Dive #3

Date: 03-07-2015
Time: 15:19
Maximum depth: 4,6 meters
Dive time: 2 minutes
Location: Klinkenbergerplas, Oegstgeest

After the second test dive the pressure sensor stopped working. It turned out the sensor itself wasn't water resistant. This is the first dive with a new water resistant sensor.

Quickly after descending the system stopped functioning. Back on the surface it turned out there was a lot of water in the case. Back to the drawing board.

A.1.4 Dive #4

Date: 12-07-2015
Time: 13:02
Maximum depth: 17,7 meters
Dive time: 10 minutes
Location: 't Joppe, Warmond

After some failures this test dive was made from a boat. This brought the ability to bring repair tools for the device onto the boat, to quickly repair problems. Fortunately, during this test dive the system worked very well. Two stops were made, one at 6 meters and one at 3 meters.

A.1.5 Dive #5

Date: 12-07-2015
Time: 15:27

Maximum depth: 6,4 meters
Dive time: 12 minutes
Location: 't Joppe, Warmond

This was the first test dive with someone else. Unfortunately the led frame did not fit on the subjects mask. Therefor the subject had to dive with a mask that did not fit the subjects head well. This lead to the bottom LEDs shining directly into the subjects eyes. Besides this the system performed well and the subject was enthusiastic about the possibilities. The subject reported that the green LEDs gave a secure feeling while staying on the right depth.

A.1.6 Dive #6

Date: 16-08-2015
Time: 15:49
Maximum depth: 16,2 meters
Dive time: 35 minutes
Location: Vlietland, Leidschendam

This was the first time that a large part of the original dive plan was executed with another diver. This is a very experienced diver and should have no problems staying on a fixed depth. Stops were made at 12, 9, 6 and 3 meters. After the stop at 3 meters the dive was finished by following a compass course to the shore at that depth of 3 meters. The dive was executed flawlessly and the system worked perfect. The subject had difficulties with distinguishing between the yellow and led light and between the bottom and top lights. He used the green light to know he was on the right depth. When the light turned yellow or even red he checked his dive computer to see if he was too shallow or too deep and corrected it. When using the compass he found the green indicator very usable. A downside was that the lights were quite bright and made it more difficult to see the environment.

A.2 Test dives with test divers

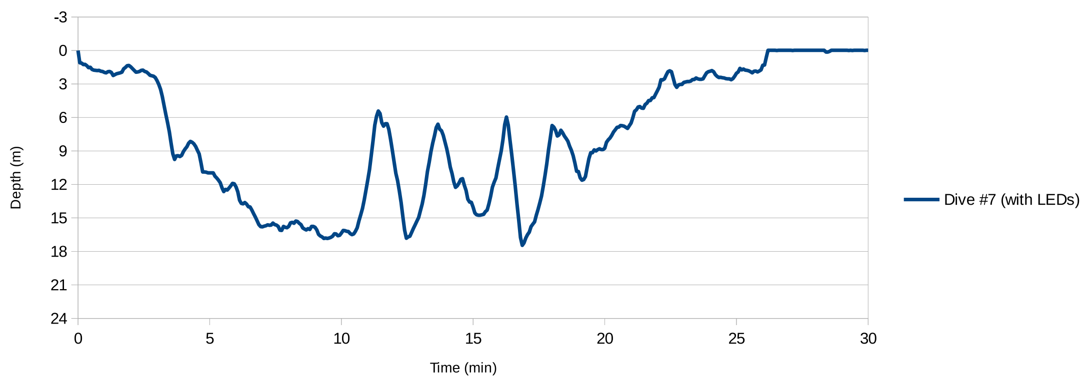
All dives were made at Vlietland, Leidschendam. Water temperature was always around 20°C. Diving statistics as reported by an Uwatec Aladin Prime diving computer.

A.2.1 Test diver #1

Dive training level: NOB/CMAS 2*
Total number of dives: 167

Dive: #7
Date: 19-08-2015
Time: 13:30
Maximum depth: 17,6 meters
Dive time: 28 minutes
With LEDs: yes
Included: no

While explaining the system prior to the dive, the subject indicated to be color blind. This was something that was not foreseen, but it was decided to dive anyway. The dive went problematic. The subject could not determine the right depth from the colored lights and also had an increased sensitivity to light and was unable to read the depth from his computer. This lead to a dive where the subject bounced four times between 6 and 16 meters. After this it was decided to abort the dive for safety.



A.2.2 Test diver #2

Dive training level: NOB/CMAS 2*
Total number of dives: ±60

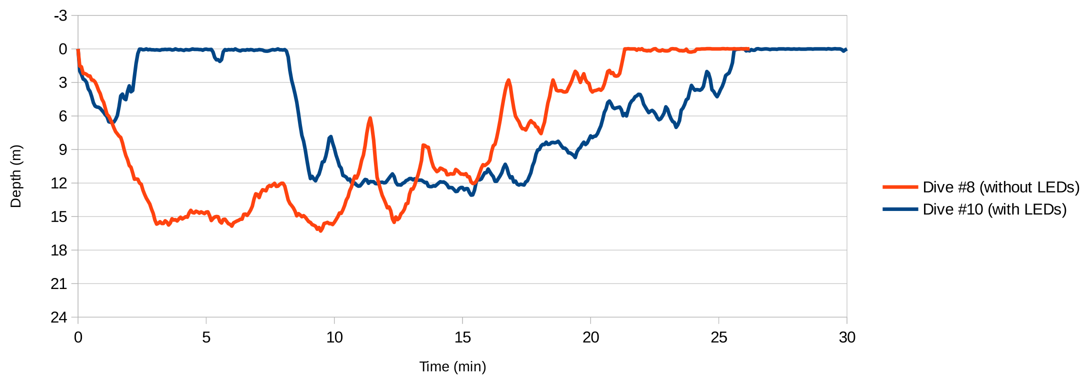
Dive: #8
Date: 19-08-2015
Time: 19:45

Maximum depth: 16,3 meters
Dive time: 21 minutes
With LEDs: no
Included: no

Prior to the dive it became clear that the subject only had an air supply of 80 bar in a 15 liter tank. This would not be enough. Still it was decided to proceed to gain some more experience with the experiment. At 50 bar, during the 9 meter stop, the exercise was aborted for safety. The subject had problems staying on the stop depths, probably due to inexperience.

Dive: #10
Date: 20-08-2015
Time: 16:41
Maximum depth: 13,1 meters
Dive time: 22 minutes
With LEDs: yes
Included: no

Although the subject thought the mask would fit well, he experienced leakage under water and we had to abort the dive. After this the design of the frame was adapted so it would fit more diving masks and people could dive with their own mask.



A.2.3 Test diver #3

Dive training level: NOB/CMAS 2*
Total number of dives: ?

Dive training level: 2*
Total number of dives: ±60
Dive: #9
Date: 19-08-2015

Time: 20:28
With LEDs: no
Included: no

Again the system was not used. The dive plan was followed precisely and was well executed. After the dive the subject indicated that he was exhausted by this dive and could not go for a second dive with the system. Unfortunately we have no diving profile of this dive.

A.2.4 Test diver #4

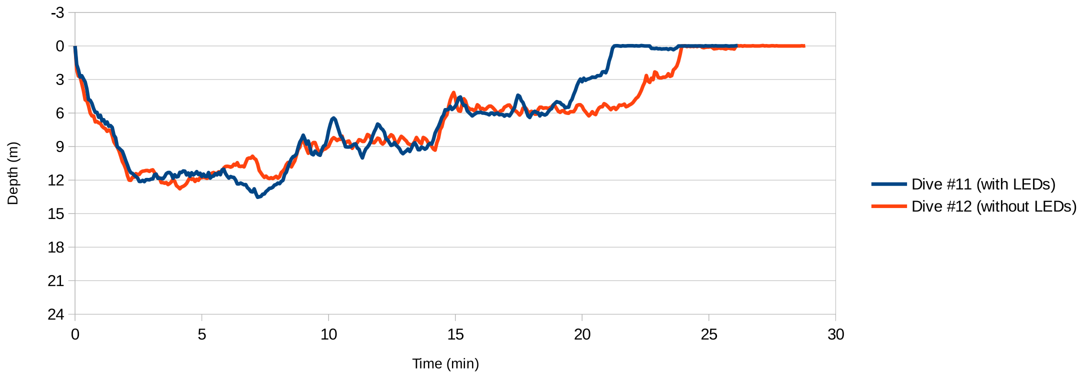
Dive training level: PADI Advanced Open Water
Total number of dives: ±200

Dive: #11
Date: 21-08-2015
Time: 11:06
Maximum depth: 13,6 meters
Dive time: 22 minutes
With LEDs: yes
Included: yes

Everything went as planned. He was very enthusiastic about the system.

Dive: #12
Date: 21-08-2015
Time: 11:48
Maximum depth: 12,8 meters
Dive time: 24 minutes
With LEDs: no
Included: yes

Everything went according plan.



A.2.5 Test diver #5

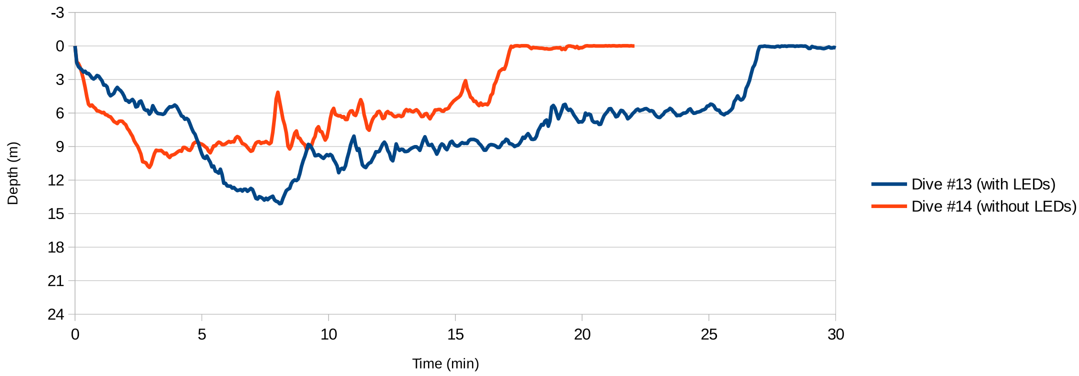
Dive training level: NOB/CMAS 1*
Total number of dives: 16

Dive: #13
Date: 21-08-2015
Time: 19:18
Maximum depth: 14,1 meters
Dive time: 27 minutes
With LEDs: yes
Include: yes

Since the subject did not have much diving experience and hadn't dived for some time so it took some more time to become comfortable in the water. After that the dive plan was more or less successfully executed.

Dive #: 14
Date: 21-08-2015
Time: 20:11
Maximum depth: 11,0 meters
Dive time: 18 minutes
With LEDs: no
Included: yes

Due to limited time we decided to shorten the dive and skip the 8 minutes at 12 meters. The rest of the dive was quite unstable. The subject indicated to miss the LEDs.

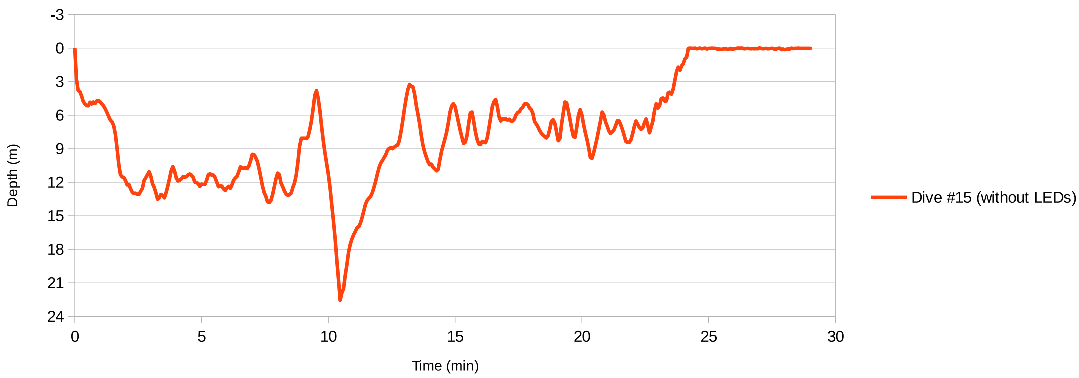


A.2.6 Test diver #6

Dive training level: NOB/CMAS 2*
Total number of dives: 39

Dive #: 15
Date: 21-08-2015
Time: 20:46
Maximum depth: 23,0 meters
Dive time: 25 minutes
Included: yes

Due to limited experience it was not possible to maintain the depths from the dive plan. The subject bounced a lot and it was decided to postpone the second dive.



A.2.7 Test diver #7

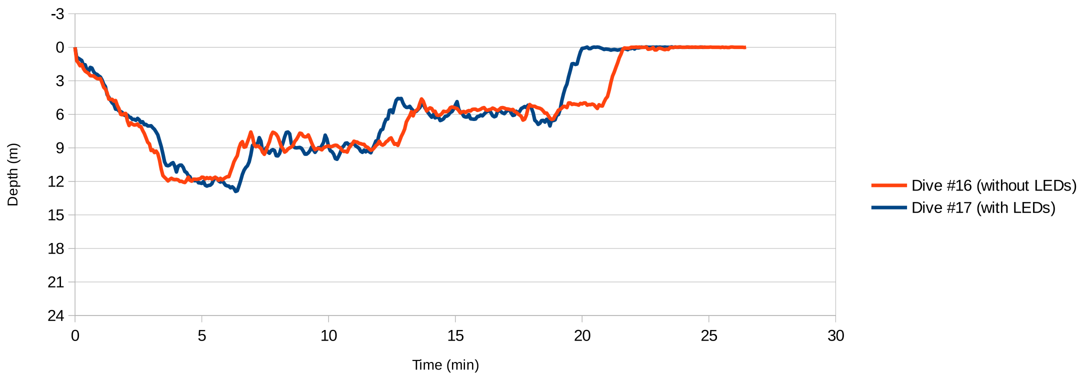
Dive training level: NOB/CMAS 3*
Total number of dives: 160

Dive #: 16
Date: 22-08-2015
Time: 8:46
Maximum depth: 12,1 meters
Dive time: 22 minutes
With LEDs: no
Included: yes

The dive went as planned.

Dive #: 17
Date: 22-08-2015
Time: 9:37
Maximum depth: 13,0 meters
Dive time: 20 minutes
With LEDs: yes
Included: yes

The subject experienced more difficulty during the dive with the LEDs than without. He did not trust the system and looked often on his diving computer to check if the LEDs were working as they should.



A.2.8 Test diver #8

Dive training level: NOB/CMAS 2*I
Total number of dives: ±600

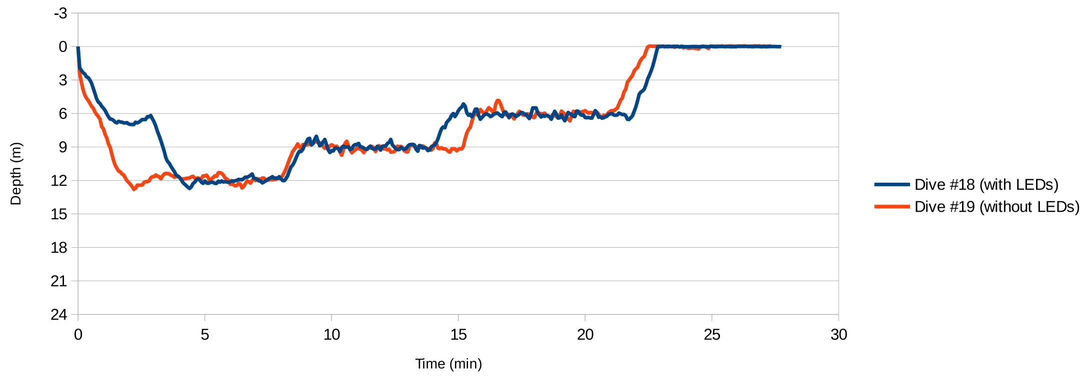
Dive #: 18
Date: 22-08-2015
Time: 10:36
Maximum depth: 12,7 meters
Dive time: 23 minutes

Location: Vlietland, Leidschendam
With LEDs: yes
Included: yes

This very experienced diver had no problem using the system and the dive was made as planned.

Dive #: 19
Date: 22-08-2015
Time: 11:18
Maximum depth: 12,8 meters
Dive time: 23 minutes
With LEDs: no
Included: yes

The dive went as planned.

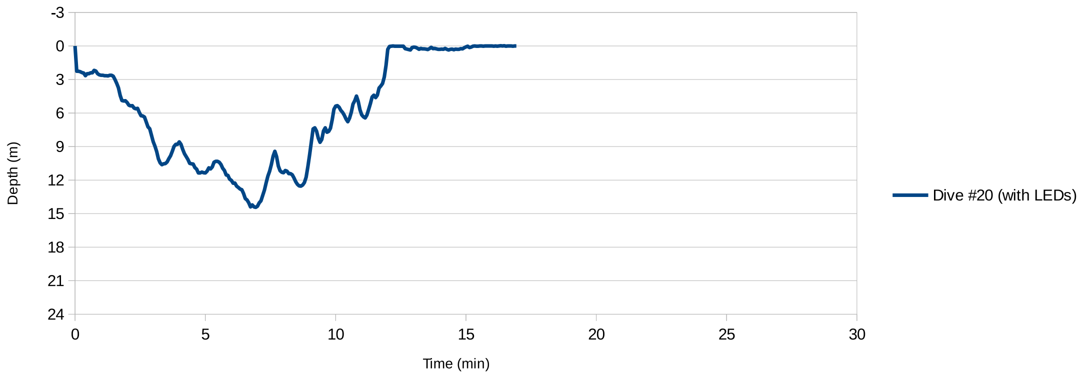


A.2.9 Test diver #9

Dive training level: 2*
Total number of dives: 60

Dive #: 20
Date: 23-08-2015
Time: 10:11
Maximum depth: 14,5 meters
Dive time: 12 minutes
With LEDs: yes
Included: no

After a few minutes the system stopped functioning because of water leakage.



A.2.10 Test diver #10

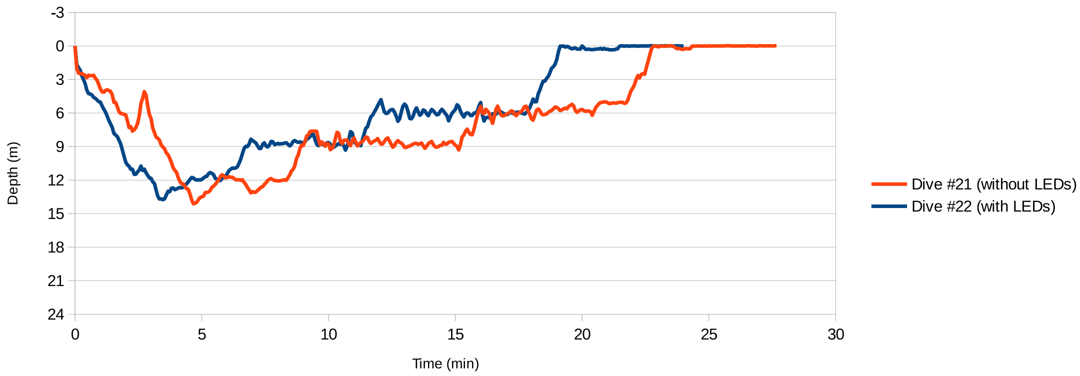
Dive training level: NOB/CMAS 2*
Total number of dives: 54

Dive #: 21
Date: 23-08-2015
Time: 11:42
Maximum depth: 14,2 meters
Dive time: 23 minutes
With LEDs: no
Included: yes

The dive went as planned.

Dive #: 22
Date: 23-08-2015
Time: 12:48
Maximum depth: 13,8 meters
Dive time: 20 minutes
With LEDs: yes
Included: yes

The dive went as planned.



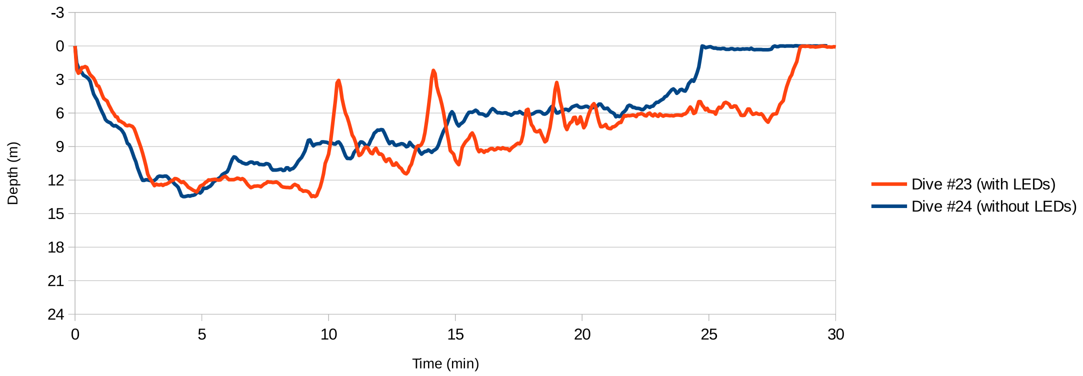
A.2.11 Test diver #11

Dive training level: NOB/CMAS 3*
Total number of dives: 166

Dive #: 23
Date: 24-08-2015
Time: 10:59
Maximum depth: 13,5 meters
Dive time: 29 minutes
With LEDs: yes
Included: yes

During the first stop and the beginning of the second stop the subject had some difficulties maintaining depth. This was partly caused by his diving equipment that he was not used. He also said that during the yo-yoing he was unaware at which depths he was when the LEDs turned on. After the test dive plan, we stayed at 6 meters to make some pictures and film.
Dive #: 24
Date: 24-08-2015
Time: 12:00
Maximum depth: 13,5 meters
Dive time: 25 minutes
With LEDs: no
Included: yes

The dive went as planned.


Depth (m)
-3
0
3
6
9
12
15
18
21
24
0
5
10
15
20
25
30
Time (min)
Dive #23 (with LEDs)
Dive #24 (without LEDs)

B Forms

Date and time
Name
Diving training level
Total number of dives

	Not at all	Slightly	Moderately	Very	Extremely
To which extent is the color green fitting to indicate the desired depth?	☐	☐	☐	☐	☐
To which extent is the color yellow fitting to indicate a small deviation from the desired depth?	☐	☐	☐	☐	☐
To which extent is the color red fitting to indicate a small deviation from the the desired depth?	☐	☐	☐	☐	☐
How visible was the difference between the yellow and red lights?	☐	☐	☐	☐	☐
To which extent were you distracted by the lights?	☐	☐	☐	☐	☐
To which extent is the depth at which the green lights light up (stop depth $\pm$0-25 cm) a good choice?	☐	☐	☐	☐	☐
To which extent is the depth at which the yellow lights light up (stop depth $\pm$25-50 cm) a good choice?	☐	☐	☐	☐	☐
To which extent is the depth at which the red lights light up (stop depth $\pm$50-100 cm) a good choice?	☐	☐	☐	☐	☐

	Much lower	A bit lower	None	A bit higher	A lot higher
What was the difficulty to maintain the desired depth during the stops with the system in comparison to the stops without the system?	☐	☐	☐	☐	☐
What was the feeling of security during the stops with the system in comparison to the stops without the system?	☐	☐	☐	☐	☐

What are your general thoughts about the system?
What would you change?

Date and time							
Name							
Diving training level							
Total number of dives							
Dive with LEDs?	☐ yes			☐ no			
	1	2	3	4	5	6	7
Instability of the situation How changeable is the situation? Is the situation highly unstable and likely to change suddenly (high) or is it very stable and straightforward (low)?	☐	☐	☐	☐	☐	☐	☐
Complexity of situation How complicated is the situation? Is it complex with many interrelated components (high) or is it simple and straightforward (low)?	☐	☐	☐	☐	☐	☐	☐
Variability of situation How many variables are changing within the situation? Are there a large number of factors varying (high) or are there few variables changing (low)?	☐	☐	☐	☐	☐	☐	☐
Arousal How aroused are you in the situation? Are you alert and ready for activity (high) or do yo have a low degree of alertness (low)?	☐	☐	☐	☐	☐	☐	☐
Concentration of attention How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)?	☐	☐	☐	☐	☐	☐	☐
Division of attention How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)?	☐	☐	☐	☐	☐	☐	☐
Spare mental capacity How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (high) or nothing to spare at all (low)?	☐	☐	☐	☐	☐	☐	☐
Information quantity How much information have you gained about the situation? Have you received and understood a great deal of knowledge (high) or very little (low)?	☐	☐	☐	☐	☐	☐	☐
Information quality What was the quality of the information gained in the situation? Was the information accurate (high) or inaccurate (low)?	☐	☐	☐	☐	☐	☐	☐
Familiarity with the situation How familiar are you with the situation? Do you have a great deal of relevant experience (high) or is it a new situation (low)?	☐	☐	☐	☐	☐	☐	☐

C Arduino source code

```
/* Source code for graduation project
 * 'Improving depth awareness for divers in free ascend'
 * Master programme Media Technology, Leiden University
 * Author:        Paul Kasteleyn
 * Last updated: 23-08-2015
*/

// Load libraries for communicating with SD card and pressure sensor.
#include <SD.h>
#include <SparkFun_MS5803_I2C.h>
#include <Wire.h>

// Rate at which the system refreshes
#define FREQ 300

// Arduino pins to which the LEDs are connected
#define BOTTOMRED 3
#define BOTTOMYELLOW 4
#define BOTTOMGREEN 5
#define TOPRED 6
#define TOPYELLOW 7
#define TOPGREEN 8

// Construct sensor at high address (address adjustable on sensor)
MS5803 sensor(ADDRESS_HIGH);

bool system_enabled = false;
double pressure_baseline, pressure_abs, depth, temp;
long ticks, tcnv;
const int chipSelect = 10;
char depthString[8], tempString[6];
const String sep = ",";
char filename[8];

void setup() {
  // Initialize serial communication:
  Serial.begin(9600);

  // Initialize output pins for LEDs
  pinMode(BOTTOMRED, OUTPUT);
  pinMode(BOTTOMYELLOW, OUTPUT);
  pinMode(BOTTOMGREEN, OUTPUT);
  pinMode(TOPRED, OUTPUT);
  pinMode(TOPYELLOW, OUTPUT);
  pinMode(TOPGREEN, OUTPUT);

  // Initialize SD card writer
  pinMode(10, OUTPUT);
  if (!SD.begin(chipSelect)) {
    Serial.println("SD card failed, or not present");
    blink(TOPRED);
  }
  else Serial.println("SD card initialized");

  // Initialize pressure sensor
  sensor.reset();
  sensor.begin();

  // Set pressure baseline in bar
```

```
  pressure_baseline = sensor.getPressure(ADC_4096) / 1000;

  blink(TOPYELLOW);
}

void loop() {
  ticks = millis();

  // Get pressure and temperature from sensor
  pressure_abs = sensor.getPressure(ADC_4096) / 1000;
  temp = sensor.getTemperature(CELSIUS, ADC_512);

  // Calculate depth from pressure
  depth = ((pressure_abs - pressure_baseline) * 100000) / 9810;

  dtostrf(depth,1,2,depthString);
  dtostrf(temp,1,1,tempString);

  // Disable system if depth is less than 0.5 meters
  if (depth < 0.5 && system_enabled) {
    system_enabled = false;
    blink(TOPYELLOW);
  }

  // Enable system if depth is more than 0.5 meters
  else if (depth > 0.5 && !system_enabled) {
    // Create new numbered file on SD card to log the next dive
    int i = 0;
    sprintf(filename, "%d", i);
    while(SD.exists(filename)) {
      i++;
      sprintf(filename, "%d", i);
    }
    // Enable system
    system_enabled = true;
    blink(TOPGREEN);
  }

  // Create string from time, depth and temperature to write to serial port for
  // debugging and to the SD card if the system is enabled
  String dataString = ticks + sep + depthString + sep + tempString;
  Serial.println(dataString);

  if(system_enabled) {
    File dataFile = SD.open(filename, FILE_WRITE);
    if (dataFile) {
      dataFile.println(dataString);
      dataFile.close();
    }
  }

  // Turn all LEDs off
  digitalWrite(BOTTOMRED, LOW);
  digitalWrite(BOTTOMYELLOW, LOW);
  digitalWrite(BOTTOMGREEN, LOW);
  digitalWrite(TOPRED, LOW);
  digitalWrite(TOPYELLOW, LOW);
  digitalWrite(TOPGREEN, LOW);

  // Only act if depth is between 2 and 13 meters, for stops
  if(depth > 2 && depth < 13) {
    // Normalize to calculate with depth around 3 meters
```

```
    while(depth > 4) depth-=3;

    // Depth is good
    if(depth > 2.75 && depth < 3.25) {
      digitalWrite(TOPGREEN, HIGH);
      digitalWrite(BOTTOMGREEN, HIGH);
    }

    // Too deep
    else if(depth >= 3.25 && depth < 3.5) digitalWrite(BOTTOMYELLOW, HIGH);
    else if(depth >= 3.5 && depth < 4) digitalWrite(BOTTOMRED, HIGH);

    // Too shallow
    else if(depth <= 2.75 && depth > 2.5) digitalWrite(TOPYELLOW, HIGH);
    else if(depth <= 2.5 && depth > 2) digitalWrite(TOPRED, HIGH);

  }

  // Calculate time since last pass and delay till next refresh rate
  tcnv = millis() - ticks;
  if(FREQ > tcnv) delay(FREQ - tcnv);
}

// Blink a LED 3 times
void blink(int led) {
  digitalWrite(led, HIGH); delay(200);
  digitalWrite(led, LOW); delay(200);
  digitalWrite(led, HIGH); delay(200);
  digitalWrite(led, LOW); delay(200);
  digitalWrite(led, HIGH); delay(200);
  digitalWrite(led, LOW);
}
```