DESIGN OF A SMARTPHONE-BASED DEVELOPMENT BOARD TO COLLECT UNDERWATER PHYSOLOGICAL DATA FROM DIVERS

(SUALTINDA DALGIÇLARDAN FİZYOLOJİK VERİLERİN TOPLANMASI İÇİN AKILLI TELEFON TABANLI GELİŞTİRME KİTİ TASARLANMASI)

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Abstract

Sensors are fundamental to all health monitoring systems. As technology advances in fields such as nanotechnology and MEMS (Microelectromechanical Systems), wearable sensors to be used in these systems are not bulky anymore. Since their quality increases, health monitoring systems are implemented in various scenarios. Underwater applications can be given as an example to these scenarios. When it comes to underwater electronic devices, one of the most frequently used equipment by divers is diving computer. This equipment provides conveniences to divers to protect them from decompression sickness which is one of the underwater threats. Basically, the purpose of the equipment is to calculate gas loads of tissues through mathematical models of tables; and to guide divers based on these calculations and to provide information for future diving activities. Another duty of diving computer is to keep log registry of diving activities of individual divers. As it is seen, diving computers vary based on basic duties as underwater equipment. They cannot be modified to collect physiological data from divers such as body temperature and muscle movement.

In this work, a development board to collect physiological data from divers that can be introduced to the users is designed. Underwater Development Board for Physiological Data Collection is developed for the purpose of contributing scientific projects and Research and Development works. This board aims to bring together all hardware and software required to monitor underwater physiological attributes of divers. It is aimed to prepare a kit ready to develop together with its all accessories, manuals and sample codes. This study includes developed kit’s design stages and its functions.

Résumé

Les capteurs sont essentiels pour tous les systèmes de surveillance de la santé. Comme la technologie progresse dans des domaines tels que les nanotechnologies et MEMS (systèmes micro-électromécaniques), capteurs portables à utiliser dans ces systèmes ne sont plus encombrants. Depuis l'augmentation de leur qualité, les systèmes de surveillance de la santé sont mises en œuvre dans différents scenarios. Applications sous-marines peuvent être données à titre d'exemple à ces scénarios. Quand il s'agit des appareils sous-marins, l'un des équipements le plus fréquemment utilisé par les plongeurs est l’ordinateur de plongée. Cet équipement fournit le confort des plongeurs pour les protéger de la maladie de décompression qui est l'une des menaces sous-marines. Fondamentalement, le but de l'équipement est de calculer les charges de gaz de tissus au moyen de modèles mathématiques de tables; et de guider les plongeurs sur la base de ces calculs et de fournir des informations pour les futures activités de plongée. Une autre fonction de l'ordinateur de plongée est de garder le registre des activités de plongée des plongeurs individuels. Comme on le voit, les ordinateurs de plongée, comme un équipement sous-marin, varient en fonction des misons de base. Ils ne peuvent pas être modifiés pour recueillir des données physiologiques de plongeurs tels que la température du corps et le mouvement des muscles.

Dans ce travail, une planche de développement, pour recueillir des données physiologiques de plongeurs qui peuvent être introduits aux utilisateurs est conçu. Planche de Développement Sous-Marin pour la Collection des Données Physiologiques est développé dans le but de contribuer des projets scientifiques et des travaux de Recherche et Développement. Cette planche vise à rassembler tout le matériel et les logiciels requis pour surveiller les attributs physiologiques sous-

marins des plongeurs. Il est destiné à préparer un équipement prêt à développer avec ses tous les accessoires, manuels et des exemples de codes. Cette étude comprend les étapes de la conception de l’équipement développée et ses fonctions.

Özet

Sensörler sağlık takip sistemlerinin yapıtaşlarıdır. Nanoteknoloji ve MEMS gibi alanlarda teknoloji ilerledikçe bu sistemlerde kullanılan giyilebilir sensörler giderek daha uygun olmaktadır. Kaliteleri arttıkça sağlık sistemleri bir çok senaryo için uygulanabilmektedir. Sualtı için geliştirilen uygulamalar bu senaryolara örnek olabilir. Sualtında çalışan elektronik cihaz dendiğinde dalgıçlarca en çok kullanılan ekipmanlardan birisi dalış bilgisayarıdır. Dalış bilgisayarları, bir sualtı elektronik ekipmanı olarak dalgıçların tehditlerinden biri olan dekompresyon hastalığından korunmaları için kolaylık sağlar. Temel olarak görevi tabloların matematiksel modellerini kullanarak dokuların gaz yüklerini hesaplamaktır. Bu hesaplara göre dalgıçları yönlendirmek ve sonraki dalışlar için dalgıca bildirim yapmaktır. Dalış bilgisayarlarının bir başka görevi dalgıçların yaptığı dalışların kaydını tutmaktır. Görüleceği üzere sualtı ekimpanı olarak dalış bilgisayarları temel görevler bakımından farklılıklar göstermemektedir. Dalgıcın vücüd ısısı, kas haraketi gibi fizyolojik verilerini toplamak için uygulamaya göre modifiye edilemezler.

Bu çalışmada, dalgıçlardan fizyolojik verileri toplamak için araştırmacıların hizmetine sunulabilecek bir geliştirme kartı tasarlanmıştır. Fizyolojik Veri Toplamak için Sualtı Geliştirme Kartı, sualtı teknolojileri konusunda yapılacak bilimsel araştırmalara, ArGe çalışmalarına, hobi amaçlı sualtı cihazı geliştiren dalgıçlara katkı sağlamak adına geliştirilmiştir. Bu kart, dalgıcın sualtı fizyolojisini izlemek için gerekli donanım ve yazılımları bir araya getirmeyi amaçlamıştır. Tüm aksesuarları, dökümanları, örnek kodlarıyla beraber geliştirme yapmaya hazır bir kit oluşturmak hedeflenmiştir. Bu bildiri, geliştirme kartının dizayn aşamasını, yapılan çalışmaları, tercihleri ve fonksiyonlarını içermektedir.

1. Introduction

Sensors are fundamental to all health monitoring systems. As technology advances in fields such as nanotechnology and MEMS (Microelectromechanical Systems), wearable sensors to be used in these systems are not bulky anymore. Since their quality increases, health monitoring systems are implemented in various scenarios such as detecting a heart attack, medical guidance for elderly (Peter & Valérie, 2008). Sensors used in these systems can be categorized as ambient sensors, kinetic sensors and physiological sensors (Ziyu et al., 2010). Ambient sensors can be listed as humidity, light, pressure and temperature whereas kinetics sensors can be exemplified as accelerometers, gyroscopes and magnetometers. Physiological sensors play role in measuring blood pressure, glucose and body temperature.

Health monitoring system applications has increased in recent years due to rapid growth of mobile technologies. There are a plenty number of health monitoring systems available for people to use in daily life with their iPhone, Samsung or any other mobile phones. Application store for mobile device users developed by Apple have effectively useable example of such applications one of which is iBGStar from Sanofi-Aventis. iBGStar has an external stick which tests user's sugar and can be connected as a glucose meter to the iPhone and iPod Touch and log the glucose history. Another example has been recently shown off is a smartphone application that uses camera of mobile device to analyze urine and check for a range of medical conditions presented at the February 2013 TED conference, Los Angeles Technology, Education and Design. Application which is called 'Uchek' tests for 25 different health issues and could help diagnose and treat diseases. Users do not need any external device. They only need to collect their urine and dip a standard test strip into it. Once the photo is taken application will be able to analyze and show the results.

When it comes to underwater electronic devices, one of the most frequently used equipment by divers is diving computer. In literature some implementations of physiological data collecting (Claudio et al., 2009) in controlled environments (Campbell et al., 1969), before/after diving (Marinovic et al., 2012) or via cabled data transmission (Moritz et al., 1972) can be found. But there are few studies on collecting data in real diving conditions. On the other hand, this equipment provides conveniences to divers to protect them from decompression sickness which is one of the underwater threats. For protection against decompression sickness, diving tables are used. However, these schemes are used based on the period between the time when the deepest point reached and the time when the surface left. There are no all depth and time combinations on tables. Diving depth and time are completed on one next level of depth available on the table. This causes serious amount of time waste. In shallow sports diving activities, a dive computer measures depth level continuously and monitors inert gas decomposed in tissues.

Basically, the purpose of the equipment is to calculate gas loads of tissues through mathematical models of tables; and to guide divers based on these calculations and to provide information for future diving activities. Another duty of diving computer is to keep log registry of diving activities of individual divers. As it is seen, diving computers vary based on basic duties as underwater equipment. They cannot be reprogrammed and modified to collect physiological data from divers such as body temperature and muscle movement. To make this kind of applications happen and develop new tools, a development board that can be introduced to the users was manufactured. Underwater Developing Board for

Physiological Data Collection is designed for the purpose of contributing scientific projects and Research and Development works. This board aims to bring together all hardware and software required to monitor underwater physiological attributes of divers. It is aimed to prepare a kit ready to develop together with its all accessories, manuals and sample codes.

In the commercial market, there is no equivalent product of this developing kit that is for sale. Products introduced as a developer kit by microprocessor makers are usually appropriate for developing surface applications. Therefore, a new and different developer kit was taken into focus of this study to allow development of electronic equipment which accommodates underwater conditions. In the design stage, proposed functions were paid attention and hardware designs were performed based on this.

In the hardware design, essential elements such as pressure sensor, potentiometer, monitor and battery are considered and their application was implemented. Firstly, for special underwater applications, pressure and temperature sensors are added. Additionally, to perform simulation of pressure and temperature sensors, two pieces potentiometer are added as well. Again, to provide superior application in the underwater conditions, piezo buttons are preferred. Finally, a circuit design that becomes activated when it contacts with water is implemented.

To allow microprocessor on the kit to be replaced in case of a malfunction and to make debug during development, Target Board MSP-TS430PM by Texas Instruments company are used in the design process. Furthermore, it is possible to make programming on these boards. To allow users to monitor certain outputs in the underwater environment, a TFT screen is added on the device. In the selection of this TFT screen, OLED technology is avoided since it provide clear view when there is sun ray reflections. As power supply, lithium-ion rechargeable batteries are preferred. To provide communication with microprocessor through serial connection, two UART entry were added. Wi-Fi and Bluetooth modules are added on these entries as application sample and accessory. By means of wireless modules, additional data such as ECG and pulse oximeter can be received from diver’s body so that different applications can be developed. Apart from wireless communication modules, a micro sd socket is added to provide opportunity to record physiological data underwater. An analogue-digital convertor section is added for various values such as oxygen and humidity which are required to be measured. By reaching all legs on the microprocessor, expansion of the kit is provided.

Finally, using the development board, a sample tool is developed to collect ECG parameters from divers. With the help of the underwater physiological monitoring development board and a smartphone, it is shown that it is relatively easy to develop such applications for people to use underwater.

1.1 Thesis Organization

Chapter 2, “Underwater Terminologies” gives background information about basic knowledge for diving and introducing the reader to underwater terminologies such as diving types, decompression sickness, decompression algorithms and dive computers.

Chapter 3, “DivePhone Dive Computer” gives background information about the DivePhone dive computer and lets the user understand the difference between dive computer and DivePhone system.

Chapter 4, “Design of a Development Board for Underwater Physiological Monitoring” introduces functions of the development board and gives information about the design process. Besides this, information about the parts of the board is listed.

Chapter 5, “Implementation of a Sample Application; Underwater ECG Monitoring” gives information about the design process of the sample application which is kind of a health monitoring system application applied on divers.

2. Underwater Terminologies

This section provides an overview of basic underwater terminology such as SCUBA diving, decompression sickness, dive computer and informs the reader on the dive tables and dive algorithms.

2.1 SCUBA Diving

Figure 2.1 SCUBA Diver

Scuba diving is a form of underwater diving that requires the use of scuba, a self-contained underwater breathing apparatus. The diver uses this apparatus to breathe underwater. Scuba diving is different than other forms of diving since the divers have to carry their own source of breathing gas. In other forms, the divers rely on breath-hold or on air supplied by the tools on the surface.

2.1.1 Types According to Breathing Apparatus

There are different types of scuba diving based on the breathing apparatus. These types are defined according to the equipment which is used by the divers. It is the self-contained underwater breathing apparatus. This equipment allows the diver to breathe while diving.

2.1.1.1 Open Circuit

Figure 2.2 Breathing apparatus installation

Open circuit scuba is one type of Scuba diving equipment. In this equipment, the breathing gas comes from a from a high-pressure diving cylinder through a scuba regulator. In open circuit Scuba diving, the diver does not inhale the same gas for the respiration. Rather the diver exhales the gas that is inhaled and beneath the surface of water bubbles rise to the surface.

2.1.1.2 Rebreather

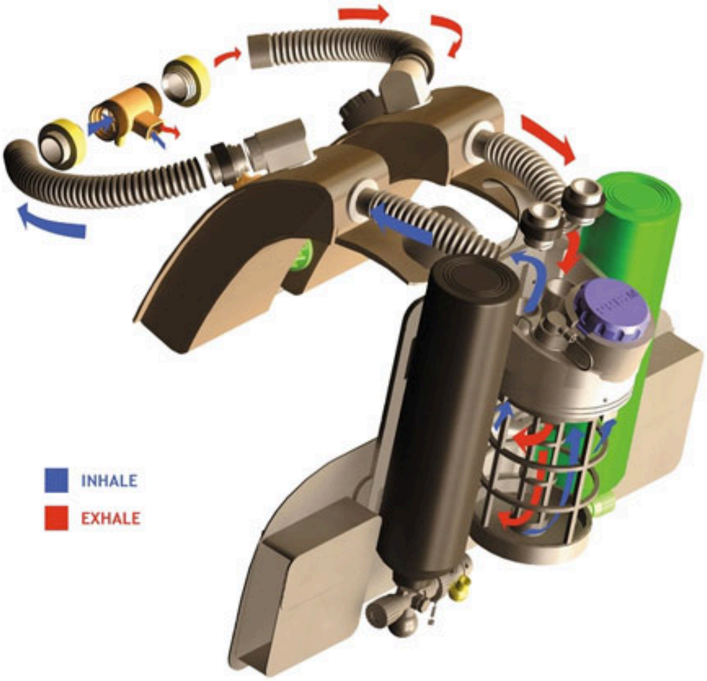


Figure 2.3 Rebreather

Another type which are used less commonly are closed circuit (CCR) and semi-closed (SCR) rebreathers. Unlike open-circuit sets, these types recycle all or part of exhaled gas. The mechanism in the apparatus removes the carbon dioxide and replaces the oxygen used by the diver. Since the inhaled gas is recycled, rebreathers release little or no gas bubbles into the water. Moreover, by the help of recycling the volume of consumed gas and stored gas is lower for an equivalent depth and time. Due to these utilities, rebreathers are used for research, military, photography, and other applications. There are several advantages of rebreathers. For instance, since they do not produce many bubbles, they do not disturb marine life. They are also very useful for underwater photography and covert work since it is easier for divers to hide themselves at the surface. However, rebreathers are more complex and more expensive than open-circuit scuba. Their prices may vary from 5000$ to 30000$. Their complexity can also lead to fatal accidents. Thus, for safety, they generally require special training and correct maintenance (Vann, 2004).

2.1.1.3 Gas Mixtures

Figure 2.4 Nitrox gas tank

Given the competency of the diver, it is also possible to use gas mixtures other than normal atmospheric air can be used for some diving. The most commonly used mixture is nitrox. It is also known as Enriched Air Nitrox (EAN). Nitrox is air with extra oxygen, often with 32% or 36% oxygen, and thus less nitrogen. The benefits of using nitrox can be given as reduced risk of decompression sickness or longer exposure to the same pressure for equal risk. Moreover, since the nitrogen level is reduced, this may allow for no stops or shorter decompression stop times or a shorter surface interval between dives.

2.1.2 Hazards of SCUBA Diving

Given the complexities, there are many risks associated with Scuba diving. Several studies expose these risks. For instance, a study done in 1970s showed that diving was (on a man-hours based criteria) 96 times more dangerous than driving an automobile. (Hedge, 2009). A more recent study reveals that every hour of recreational diving is 36 to 62 times riskier than automobile driving (Piantadosi et al., 1979). Given these statistics, the following section focuses on some of the major problems that can occur as a result of Scuba diving.

2.1.2.1 Decompression Sickness

Breathing gases which are usually nitrogen underwater conditions results in increased amounts of non-metabolic gases dissolving in the bloodstream. Gases passes through the alveolar capillaries and carried to the other tissues of the body. They accumulate on these areas until the tissues are saturated. While the diver is ascending, the pressure is reduced. Therefore, the amount of dissolved inert gas in the tissues is reduced. This process is described by Henry's Law. The dissolved gas is diffused back from the bloodstream to the gas in the lungs and reducing the loading of the tissues. The diver eventually may reduce the gas loading by diffusion and stabilises at the current saturation pressure. There occurs problem when the diver ascends fast and the pressure is reduced more quickly. The problem is that the gas will not be able to be removed by the mechanism. At this point, bubbles may appear and grow in the tissues. These bubbles may block blood vessels which leads shutting off blood supply. This may result in hypoxia of those related tissues. This effect is called decompression sickness. This sickness must be avoided by ascending slowly and allowing the inert gases dissolved in the tissues. This process is called as off-gassing.

2.1.2.2 Nitrogen Narcosis

Nitrogen Narcosis is a problem of reversible alteration in consciousness that occurs to divers in deep waters. It is a result of the anesthetic effect of certain gases at high pressure. Narcosis is seen as a similar to alcohol intoxication, or nitrous oxide inhalation. The effect of narcosis increase dramatically as the diver goes in to greater depth. It is not generally noticeable at depths less than 30 meters (100 ft) and almost noticeable by every diver around 40 meters (132 feet). At these depths, the signs for nitrogen narcosis are euphoria, anxiety, loss of coordination and lack of concentration.

2.1.2.3 Oxygen Toxicity

Oxygen toxicity is a problem that affects central nervous system and causes seizures in extreme cases. This is a major issue that can lead to the diver spitting out their regulator and drowning. Oxygen toxicity occurs as a result of the harmful effects of breathing molecular oxygen when the oxygen in the body exceeds a safe partial pressure (PPO2).

2.2 Decompression Sickness Prevention

These problems listed above lead to many serious risks for the divers. However, there are some precautions that can be taken to decrease these risks associated with diving. For instance there are decompression practices to prevent from decompression sickness. These involve the planning and monitoring of the profile indicated by the algorithms or tables of the chosen decompression model.

2.2.1 Basic Knowledge

All dives and hyperbaric exposures involve basic knowledge of three common features: The descent, ascent and bottom time.

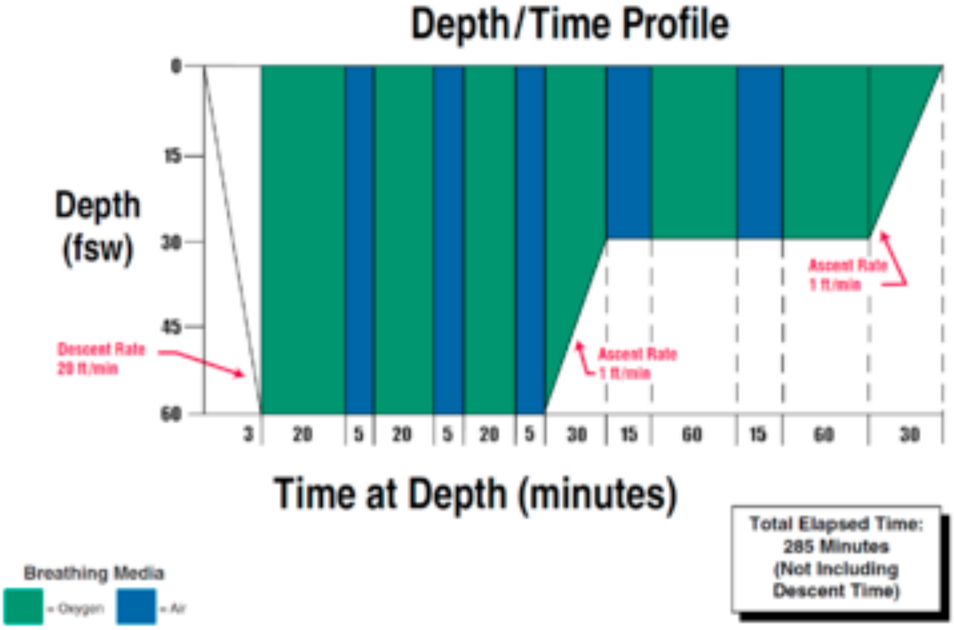


Figure 2.5 Depth time profile

2.2.1.1 Descent Rate

By the use of the tables that specify the maximum descent rate for any diving, one can calculate a descent rate allowed for in decompression planning. There are no serious problems associated with descending slower than nominal rate other than reducing useful bottom time.

2.2.1.2 Ascent Rate

The ascent is basically the time when reduction of ambient pressure occurs and is very critical part of the decompression process. The diver should have an ascent rate compatible with safe elimination of inert gas from the diver's tissues in order to prevent any serious problem and enable safe decompression. Given the limits, it is critical to maintain a safe ascent rate to prevent supersaturation of tissues. This would help the diver not to experience any unacceptable bubble development.

2.2.1.3 Bottom Time

Bottom time is the term used to define the time spent at depth before the diver begins the final ascent from the bottom. This time excludes ascent and decompression time. This may be different than the bottom time used for decompression planning.

2.2.2 No Decompression Dive

No decompression dive is a dive with no stop during the ascent. In this dive, the no decompression limit (NDL) refers to the interval that a diver may theoretically spend at a given depth without having to perform decompression stops. The NDL is very practical for the diver since he or she can plan dives accordingly and stay at a given depth and ascent without stopping. They also avoid unacceptable risk of decompression sickness.

2.2.3 Decompression Dive

Unlike no decompression dive, decompression dive requires one or more decompression stops. In this type of dive, the diver spends a relatively shallow constant depth during ascent in order to avoid the dangers of decompression. The stops enable safe elimination of absorbed inert gases from the body tissues. This practice that involves decompression stops is called staged decompression. Diver sets the for decompression stops with the help of decompression tables or software planning tools. He or She also can use a dive computer for this issue and see the depth and duration when needed. The process involves several steps. The diver ascends at the recommended rate until reaching the planned depth for the first stop. The diver stays in the specified depth for the specified period and then ascends to the next planned depth level. The same process is followed again as long as it is planned or required for the decompression to be completed. The process ends when the diver reaches the surface.

2.2.4 Repetitive Dive

In repetitive diving, the diver returns to the surface for a short surface interval in between two dives. During this time, the diver has not completely desaturated from the first dive. Thus, it is necessary to take into account the he or she has gas loading from the first dive. This amount should be considered in calculation no stop times and decompression requirements for the second dive. Depending on the time spent on the surface, the absorbed inert gases from the first dive are eliminated. If enough time is spent on the surface, the diver's body returns to those normal levels.

2.3 Equipment for Decompression Sickness Prevention

There are some equipment for divers to deal with decompression sickness such as decompression tables, decompression algorithms and dive computers.

2.3.1 Decompression Tables

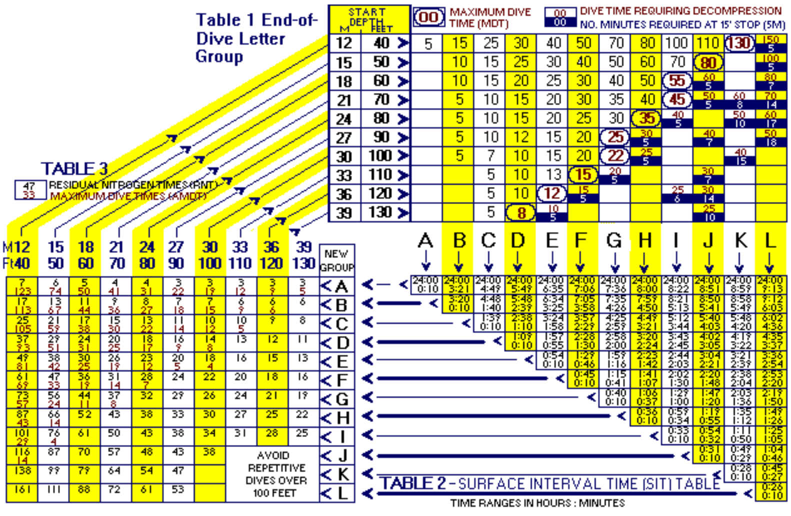


Table 1 End-of-Dive Letter Group

00 MAXIMUM DIVE TIME (MDT)

00 / 00 DIVE TIME REQUIRING DECOMPRESSION / NO. MINUTES REQUIRED AT 15' STOP (5M)

START DEPTH M	START DEPTH FEET	A	B	C	D	E	F	G	H	I	J	K	L
12	40	5	15	25	30	40	50	70	80	100	110	130	150 5
15	50		10	15	25	30	40	50	60	70	80		100 5
18	60		10	15	20	25	30	40	50	55	60 5		80 7
21	70		5	10	15	20	30	35	40	45	50 5	60 8	70 14
24	80		5	10	15	20	25	30	35	40 5		50 10	60 17
27	90		5	10	12	15	20	25	30 5		40 7		50 18
30	100		5	7	10	15	20	22	25 5			40 15	
33	110			5	10	13	15	20 5			30 7		
36	120			5	10	12	15 5			25 6	30 14		
39	130			5	8	10 5					25 10		

TABLE 3

47 / 33 RESIDUAL NITROGEN TIMES (RNT) / MAXIMUM DIVE TIMES (AMDT)

M 12 Ft 40	15 50	18 60	21 70	24 80	27 90	30 100	33 110	36 120	39 130	NEW GROUP
7 123	6 74	5 50	4 41	4 31	3 22	3 19	3 12	3 9	3 5	A
17 113	13 67	11 44	9 36	8 27	7 18	7 15	6 9	6 6	6	B
25 105	21 59	17 38	15 30	13 22	11 14	10 12	10 5	9	8	C
37 93	29 51	24 31	20 25	18 17	16 9	14 8	13	12	11	D
49 81	38 42	30 25	26 19	23 12	20 5	18 4	16	15	13	E
61 69	47 33	36 19	31 14	28 7	24	22	20	18	16	F
73 57	56 24	44 11	37 8	32	29	26	24	21	19	G
87 43	66 14	52	43	38	33	30	27	25	22	H
101 29	76 4	61	50	43	38	34	31	28	25	I
116 14	87	70	57	48	43	38	AVOID REPETITIVE DIVES OVER 100 FEET			J
138	99	79	64	54	47					K
161	111	88	72	61	53					L

TABLE 2 - SURFACE INTERVAL TIME (SIT) TABLE

TIME RANGES IN HOURS : MINUTES

	A	B	C	D	E	F	G	H	I	J	K	L
A	24:00 0:10	24:00 3:21	24:00 4:49	24:00 5:49	24:00 6:35	24:00 7:06	24:00 7:36	24:00 8:00	24:00 8:22	24:00 8:51	24:00 8:59	24:00 9:13
B		3:20 0:10	4:48 1:40	5:48 2:39	6:34 3:25	7:05 3:58	7:35 4:26	7:59 4:50	8:21 5:13	8:50 5:41	8:58 5:49	9:12 6:03
C			1:39 0:10	2:38 1:10	3:24 1:58	3:57 2:29	4:25 2:59	4:49 3:21	5:12 3:44	5:40 4:03	5:48 4:20	6:02 4:36
D				1:09 0:10	1:57 0:55	2:28 1:30	2:58 2:00	3:20 2:24	3:43 2:45	4:02 3:05	4:19 3:22	4:35 3:37
E					0:54 0:10	1:29 0:46	1:59 1:16	2:23 1:42	2:44 2:03	3:04 2:21	3:21 2:39	3:36 2:54
F						0:45 0:10	1:15 0:41	1:41 1:07	2:02 1:30	2:20 1:48	2:38 2:04	2:53 2:20
G							0:40 0:10	1:06 0:37	1:29 1:00	1:47 1:20	2:03 1:36	2:19 1:50
H								0:36 0:10	0:59 0:34	1:19 0:55	1:35 1:12	1:49 1:26
I									0:33 0:10	0:54 0:32	1:11 0:50	1:25 1:05
J										0:31 0:10	0:49 0:29	1:04 0:46
K											0:28 0:10	0:45 0:27
L												0:26 0:10

Figure 2.6 Decompression table

In order to determine a decompression schedule for a particular dive profile and breathing gas divers can use dive tables or decompression tables. These tables can be in the form of printed cards or booklets. With dive tables, the divers descend to maximum depth allowed immediately and stay at the same depth until resurfacing given the time allowed. This type of dive profile is assumed to be a square dive. Since its profile is a square dive, it is not calculated in real times. It is assumed that in a every seconds of a dive, the depth used for the decompression calculation is considered to be the maximum depth of the dive.

2.3.2 Decompression Algorithms

One of the ways of reducing the risks of decompression sickness at the end of a dive is using a decompression algorithm. These algorithms help divers to calculate the decompression stops needed and to generate decompression schedules for a particular dive profile. Actual behavior of gases in specific issues is not generally known. However, mathematical models are developed to approximate the real situation. These models predict bubble formation for a given dive profile and applied on decompression algorithms.

2.3.3 Dive Computers

Another useful equipment to help the divers is the dive computer. These are small computers to be worn by the divers. They generally involve a pressure sensor and an electronic timer mounted in a waterproof and pressure resistant housing. They are also programmed to model the inert gas loading of the diver's tissues. Unlike the decompression tables, dive computers calculate the gas loading in real time during a dive.

Figure 2.7 Dive computers

With a display monitor, the diver can monitor critical data during the dive such as the maximum allowed and current depth, duration of the dive, and decompression data including the remaining no decompression limit calculated in real time for the diver throughout the dive. Some devices may also include data on water temperature and air time remaining. By providing this crucial information, the dive computer is very advantageous during the actual dive. It enables the diver to have dynamic calculations about the pressure exposure in real time. The amount of residual gas loading for each tissue used in the algorithm are calculated at least in every second. Therefore, it does not have to be rely on square profile as it is the case for planned dive.

3. DivePhone Dive Computer

Divephone Dive Computer is a combination of diving decompression management application designed for personal digital assistants (PDAs), enclosed in housing and the external module, for use by scuba divers using compressed air or mixed gas (Nitrox) for breathing. It is patented product with the number 2009-G-55062 given by Türk Patent Enstitüsü. The Divephone Sport consists of three components one of which is the application running on the Windows Mobile Operations System, iPhone/iPad and Android based mobile devices. Secondly, the housing covering the mobile device with an external module component attached. Finally, the external module with pressure and temperature sensors, and a wireless communication device to transmit data to the mobile device. DivePhone works as a dive computer and it is for single-level, multi-level and repetitive diving by recreational divers, for use by divers using Air or mixed gas (Nitrox) with oxygen concentrations (FO2) of 21% to 99% as a breathing gas, capable of using different decompression models which are named “B-GFx” based on Bühlmann ZHL 16 with fixed GF, “Table” based on US Navy Table, “NeOX” based on a number of M values including Suunto and Continuous decompression model. Finally, it is capable of decompression management at sea level and at altitude diving.

3.1 The Idea

DivePhone is a patented, groundbreaking alternative to dive computers. It turns mobile devices into a dive computer. The external module wirelessly sends dive data to the smartphone, and Depth Monitor application uses the data to make the smartphone function as the world's first programmable dive computer with an operating system and all the advantages.

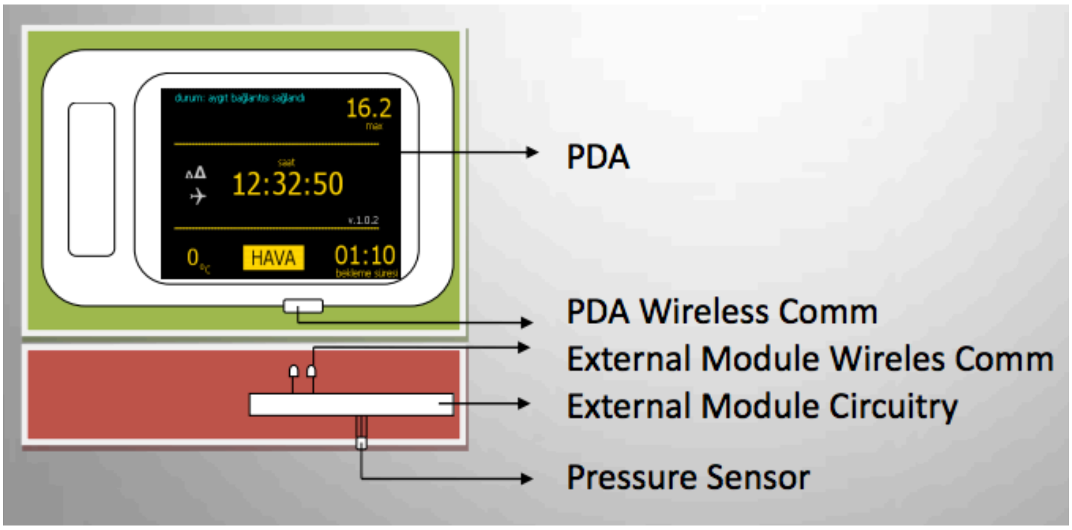


Figure 3.1 DivePhone idea

3.2 Underwater Wireless Communication

Wi-Fi is a wireless communication protocol, based on the 2.4GHz or 5GHz frequencies. It uses 802.11 networking standards, which is split in different flavors:

- 802.11a: transmits at 5GHz frequency, up to 54MB/s (Mega Byte per second) transfer speed.

- 802.11b: transmits at 2.4GHz frequency, up to 11MB/S transfer speed.

- 802.11g: transmits at 2.4GHz and up to 54MB/s

- 802.11n: transmits in both the frequencies and is up to 300MB/s

Many different other standards are available, but these ones are the most common. However, the effectiveness of high frequency RF signals changes underwater.

3.2.1 The Behavior of RF Energy Underwater

High frequency RF communication is defined with regard to propagation characteristics in air whereas underwater this definition is not valid. Propagation under the water does not related to the ionosphere conditions. RF signals are attenuated underwater. Therefore, the effectiveness of the signals are diminished. The following equation shows the changes of this attenuation;

$$\alpha = 0.0173 \sqrt{(f\sigma)}^{I} \tag{3.1}$$

The equation where α is attenuation in dB/meter, f is frequency in hertz, shows that attenuation increases as frequency rises and finally σ is conductivity in mhos/meter. This shows that low frequency transmission should be used for the underwater applications.

3.2.2 Practical Approach

In order to deal with this frequency problems, two PDA devices are used to test the operation of short range high frequency RF transmission underwater. Two devices are put into the sealed boxes and file transfer over Bluetooth between two devices tried to be established. One of the devices is set as the sender whereas the other one is set as the receiver. First, two devices are located by 1 meter distance to each other. It is observed that no transfer could be established. When the distance set to 10 cm, the transfer could be established.

Figure 3.2 Experiments undertaken

Based on the results of the tests, it seems that reasonable to conclude that high frequency RF transmission underwater over a short distance is possible.

3.3 Components

Divephone as a dive computer, consists of a rugged housing for the mobile device (smartphone, palmtop computer, Personal Digital Assistant-PDA), an external module collecting the ambient dive-related data and the exclusive Depth Monitor application installed on the mobile device.

3.3.1 Housing

Figure 3.3 DivePhone housing and mobile device

The housing is used to protect the mobile device from water under pressure and to carry the external module beside the mobile device. It has

- Rectangular shape with 118x61 mm internal dimensions
- The housing internal size is determined with respect to the Iphone 3GS; thickness +5 mm, height +2.5 mm which is 16 mm. The selection of internal dimensions is documented in table.
- A transparent window topside of the dry compartment enabling the user to see the screen of the mobile device clearly
- A double lock cover system uniting the external module with the mobile device compartment
- A soft laying preventing the mobile device from being sketched and getting loose into the housing
- A ring (or a hole) to attach the Divephone device to the diver’s gear
- Slots for strap enabling the diver to put the Divephone on this arm
- Rated to 75 m (tested to 117.5 m)

The housing's window for mobile device's screen is to be made by polycarbonate. It is mounted to the housing by multiple screws. The polycarbonate is demountable to be changed by a new one. The user is able to see the mobile device's screen easily when the temperature measured between 0°C (32°F) and 60°C (140°F). The PDA compartment of the housing is sealed with o-ring and lock system. The closing system includes a secondary locking mechanism.

3.3.2 External Module

The main aim of the external module is to send dive data to the mobile devie wirelessly. There are two types of modules one of which is Wi-Fi to be used with iOS based mobile devices such as iPhone, iPod touch. The other one is Bluetooth to be used with Android based mobile devices. The external module has,

- an independent housing/compartment rated to 75 m (tested to 117.5 m), such that if it is flooded the housing of the mobile device will not be affected.
- 3x5 cm dimensions
- battery compartment with cover to allow the user the user for replacement of the battery

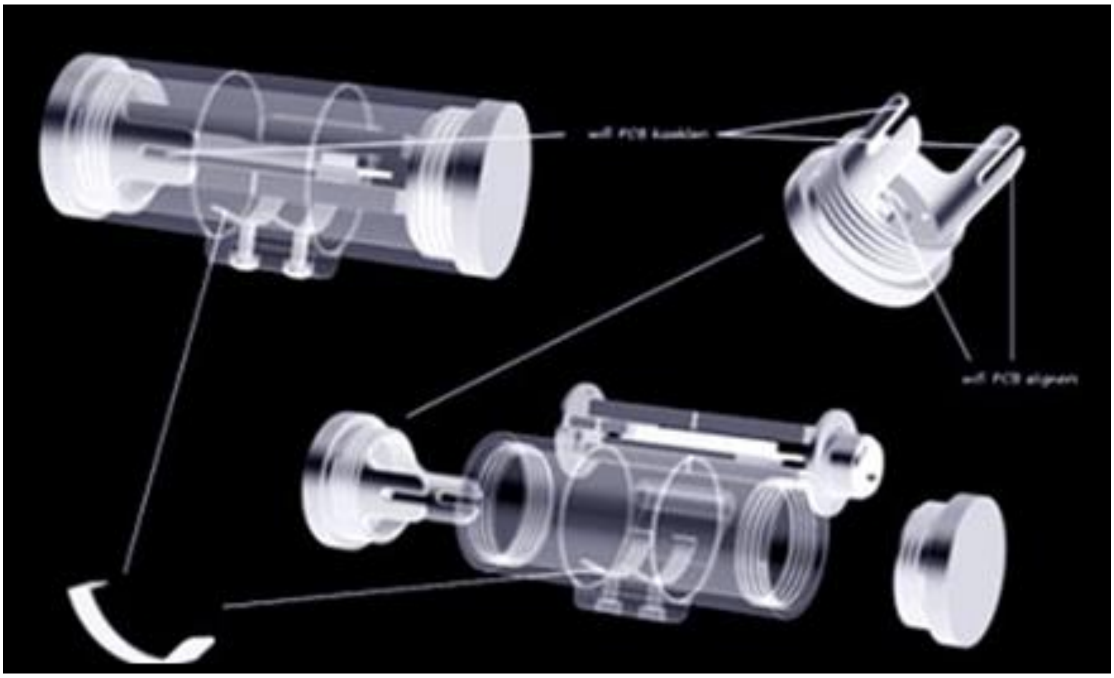


Figure 3.4 External module drawings

On the PCB side which is electronic board development part, the module has following components,

- A microprocessor
- An oscillator
- Wi-Fi module (IEEE 802.1x protocol) or Bluetooth
- Resistors
- Capacitors

In addition to the mechanical and electronically parts, the following component are the parts soldered separately,

- An integrated pressure and temperature sensor
- wet contacts
- battery

The external module compartment is placed adjacent to the PDA's compartment. The impermeability is provided by two successive o-rings. A double lock system is used to prevent the external module and the PDA's compartment from breaking apart underwater. The lock system is designed not to get cause entanglement. The external module checks for the wet contact every 180 seconds. If the contact is cut, it returns to sleep mode after the next check. Upon wakeup, the external module shall begin to sense the pressure (depth), temperature and send the data by IEEE 802.1x protocol to the mobile device.

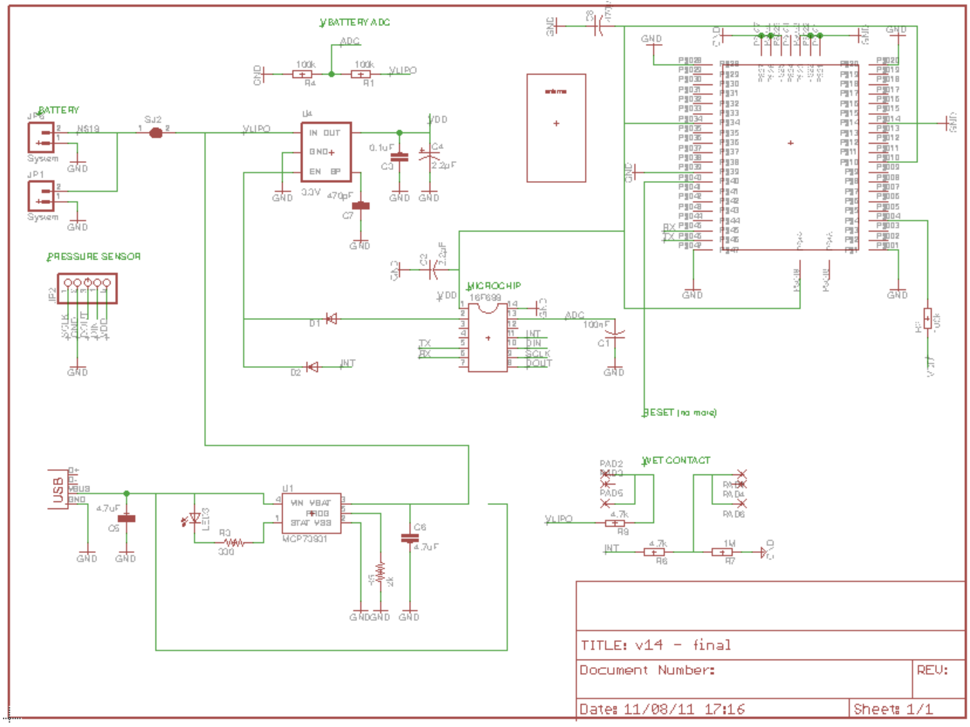


Figure 3.5 External module circuit design

The battery compartment of the external module has no opening to the mobile device compartment so that the mobile device compartment is not affected in case of leaking. In addition to this, each module has a Serial Number, buried inside the cover of its housing.

3.3.3 Software

The application receives the following data in an encrypted way from the external module:

- Pressure data
- Temperature data
- Battery Condition

and convert it into relevant information displayed on the depth monitor application's screen. The Depth Monitor Application is supported by any kind of mobile device that runs on Android or iOS (iPhone Operating System). This enables nearly any smartphone device to be used with DivePhone (including many PDAs, iPod Touch, iPhone, or any kind of smartphone using above operating systems).

The application is started by the user in iPhone, iPod touch or Android based mobile devices, touching the application icon. After touching the icon, applications appears. When the application is being loaded, a welcoming screen with “INNOVASUB” logo is displayed and the main screen of the application appears. The external module is activated with the wet contact. The external module is to be provided with 2 contacts that causes the unit to wake-up immediately when the space between contacts is bridged by a conductive material (e.g., water contact).

All the settings is made using the menus and sub-menus of the application by the touch screen of the mobile device. The main menu is reached touching the Surface Mode screen that appears after the welcome screen. The main menu items are;

- Settings
- Dive Planner
- Logbook
- Dive Site Maps

The last option of the main menu is Exit Program which is available for Android based mobile devices that ends the application when it is clicked. The application asks the user if he/she is sure, he/she wants to exit application.

Figure 3.6 DivePhone underwater

The Divephone enters surface mode after the application startup checks are accomplished. It can be identified as the main screen of the application. When returning from the sub-menus of the application, the last (top) screen of the application is the surface mode screen. The user is able to return to surface mode directly (by one click) from any level of the sub-menus. In every screen of the application there are two icons, one for returning directly to the surface mode (main screen), and the other for returning to previous screen. Finally, dive mode is entered either, if the depth is deeper than 0.9 m. By that time, application starts recording the dive and showing the required information on the mobile device screen. The Information is to include;

- Wireless Communication information The communication status is displayed by an icon. As long as there is communication between the authenticated external module and the PDA, the icon shall be animated. Otherwise a red cross on the icon shall be displayed.

- Battery icon and battery levels as percentages for both the PDA and the external module.

- Altitude level icon

- Current Time
- Profile
- Warning Icons (Maximum three, First In first Out)
- Temperature
- Current Depth
- Maximum Depth
- Ascent or descent rate in m/mn or ft/min
- Elapsed Dive Time
- Deco Model(s) by their corresponding short names
- No Deco Dive Time (according to the deco model(s) used)
- Mode (AIR-NITROX)
- EANxx xx showing the O2 percentage in NITROX Mode
- % CNS TOX(in nitrox mode)
- Dive profile

3.4 Communication Protocol

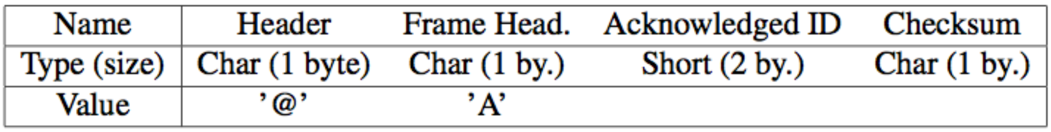
The purpose of the communication protocol between the external module and the cell- phone is to transmits the measures of the module to the mobile device with the best speed, reliability and safety of communication. The external module collects data from its sensors and peripherals and put them together into a so called frame. This frame is transmitted to the mobile device using wireless communication (WiFi or Bluetooth) and analyzed by the mobile device when received. A frame is made up with data collected by the module and some additional data in order to help the mobile device application to read the frame. In order to ensure that every data (frame) sent by the module will be properly received and read by the mobile device, the mobile device must send an acknowledge. An acknowledge is a frame sent by the mobile device to inform the module a frame was properly received. If the module doesn’t received any acknowledge, it keeps sending the same frame to make sure the mobile device will receive it. Meanwhile, it stores the new frame to be sent into its flash memory (buffer) to send them later.

3.4.1 Frames

It would be wise to describe all the frames. Frame structure is the base idea of the mobile device based sensor development board. New frames can be specified and included into the monitoring system.

3.4.1.1 Acknowledge Frame

The Acknowledge is used to inform that a frame was properly received.

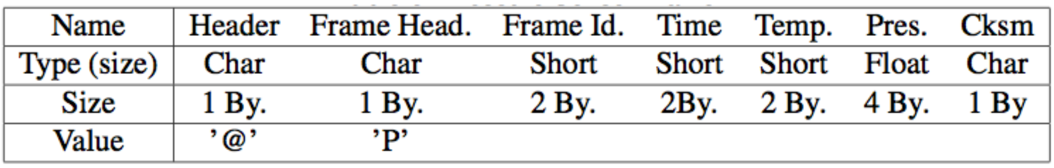


Name	Header	Frame Head.	Acknowledged ID	Checksum
Type (size)	Char (1 byte)	Char (1 by.)	Short (2 by.)	Char (1 by.)
Value	'@'	'A'		

Figure 3.7 Diagram of acknowledge frame

3.4.1.2 Pressure Sensor Frame

The pressure sensor frame contains the measures of the pressure sensor. Namely the pressure value (mbar) and the temperature. Time is the time the frame was generated by the module, in second. Time is an unsigned short that starts from 0 at the start-up of the module and counts the seconds. The maximum count of Time is 65535. Temperature is coded as a signed Integer on two bytes (short). Its unit is 0.01◦C. Its range is from -327.68◦C to 327.67◦C.



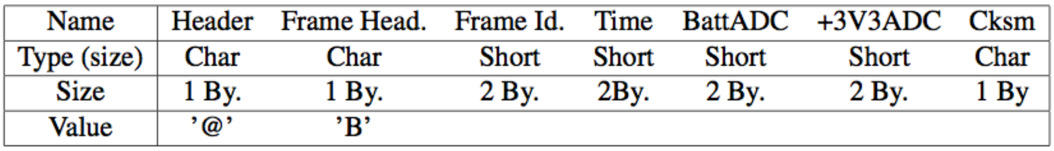
Name	Header	Frame Head.	Frame Id.	Time	Temp.	Pres.	Cksm
Type (size)	Char	Char	Short	Short	Short	Float	Char
Size	1 By.	1 By.	2 By.	2By.	2 By.	4 By.	1 By
Value	'@'	'P'					

Figure 3.8 Diagram of pressure sensor frame

Pressure is coded as a float (four bytes). Its unit is 1bar and its precision is 0.00001bar = 0.01mbar = 10μbar. Its range is infinity. For instance, if the HEX value received is: "40 08 93 9F", then its decimal float value is 2.13401 which makes 2.13401bar.

3.4.1.3 Battery Frame

The battery frame contains the ADC values of the Battery level acquisition and the of the +3V3 Line level acquisition. Time is the time the frame was generated by the module, in second. Time is an unsigned short that starts from 0 at the start-up of the module and counts the seconds. The maximum count of Time is 65535.



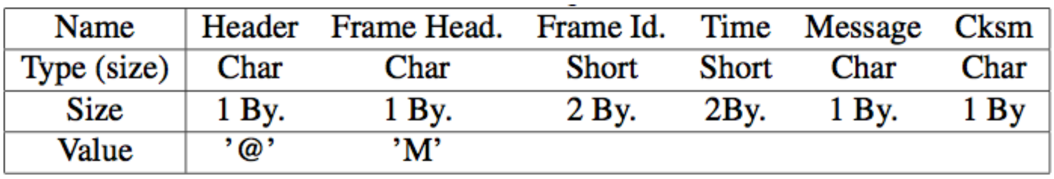
Name	Header	Frame Head.	Frame Id.	Time	BattADC	+3V3ADC	Cksm
Type (size)	Char	Char	Short	Short	Short	Short	Char
Size	1 By.	1 By.	2 By.	2By.	2 By.	2 By.	1 By
Value	’@’	’B’					

Figure 3.9 Diagram of battery frame

BattADC is an unsigned short representing the ADC value of the acquisition of the battery level. +3V3ADC is an unsigned short representing the ADC value of the acquisition of the +3V3 Line level.

3.4.1.4 Message Frame

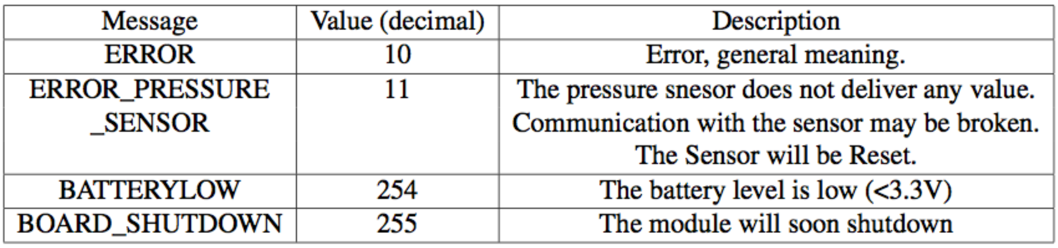
Time is the time the frame was generated by the module, in second. Time is an unsigned short that starts from 0 at the start-up of the module and counts the seconds.



Name	Header	Frame Head.	Frame Id.	Time	Message	Cksm
Type (size)	Char	Char	Short	Short	Char	Char
Size	1 By.	1 By.	2 By.	2By.	1 By.	1 By
Value	'@'	'M'				

Figure 3.10 Diagram of message frame

The maximum count of Time is 65535 which corresponds to 43 days of running. Message is a char (1 byte) having a meaning. There are 256 different possible messages. Their definition is given in Figure 3.8.

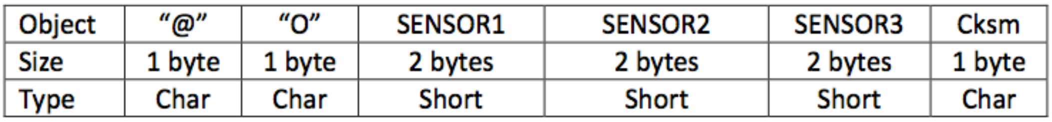


Message	Value (decimal)	Description
ERROR	10	Error, general meaning.
ERROR_PRESSURE _SENSOR	11	The pressure snesor does not deliver any value. Communication with the sensor may be broken. The Sensor will be Reset.
BATTERYLOW	254	The battery level is low (<3.3V)
BOARD_SHUTDOWN	255	The module will soon shutdown

Figure 3.11 Diagram of message definitions

3.4.1.5 Sensor Frame

The sensor frame contains the three sensors ADC values.



Object	"@"	"O"	SENSOR1	SENSOR2	SENSOR3	Cksm
Size	1 byte	1 byte	2 bytes	2 bytes	2 bytes	1 byte
Type	Char	Char	Short	Short	Short	Char

Figure 3.12 Diagram of sensor frame

For each sensor (1, 2 or 3), the value is an unsigned short which represents the ADC value of the oxygen sensor. Its value is from 0 to 4095 (12-bit ADC). When the value is 0, then it means the sensor is not connected or does not work properly.

4. Design of a Development Board for Underwater Physiological Monitoring

The Physiological Monitoring Development Board aims at helping research and development in diving technologies. It combines all the hardware and software required for monitoring the diver's physiology underwater. The board is designed for people, researcher, engineer which want to develop products similar to mobile phone based dive computer, DivePhone with additional features. They can create their own underwater application such as including an EMG, ECG sensor, a rebreather controller, O2 or Helium sensors and buttons (piezo-switches for example).

This part describes the hardware components of the development board as well as their design processes.

4.1 Board Overview

The Development Board is equipped with many features for underwater application: oxygen sensor, 3 x pressure sensors, up to 2 wireless communication modules, LCD display, MicroSD card and USB interface. Based on Texas Instruments' microcontroller MSP430F5529, development board combines the powerful functions for underwater physiological monitoring with low-power consumption for long battery life. It has features such as;

- Target Board MSP-TS430PN80USB & MSP430F5529. Processor replaceable. Target Board supports any other MSP430 in 80-pin LQFP package
- 32.768 KHz crystal oscillator for precise time measurements

- 1 x Oxygen sensor
- 2 x INNOVASUB Digital Pressure Sensors: connect the digital pressure sensor to your pneumatic system (up to 14 bars). 2 sensors connected to the board through UART port
- 1 x MS5541C Digital Pressure Sensor
- Up to 2 wireless communication modules in XBee footprint, if pressure sensors through UART not used. 1 module (Wi-Fi or Bluetooth) loaded with configuration to connect with Android or iOS included in package. Second module in option. Supports any XBee footprint module.
- 1 x Wired UART port accessible if Digital Pressure Sensor and XBee module not used
- LCD display
- SD Card: FAT32 supported via SPI interface
- USB
- Battery: Lithium-Ion, rechargeable, single-cell, 2000mAh, package 18650. Power supplied by wall charger with Mini-USB connection
- Battery and regulated 3.3V line voltages monitored through 12-bit ADC
- 2 x precision multi-turn potentiometers (12-bit ADC)
- 6 x additional 12-bit analog input connector (12-bit ADC)
- 2 x Piezo switches: piezo-electric switch can be used underwater
- 4 x Programmable LEDs
- Expansion of the 80 pins of the MSP430 into standard 2x10 2”-pitch connectors

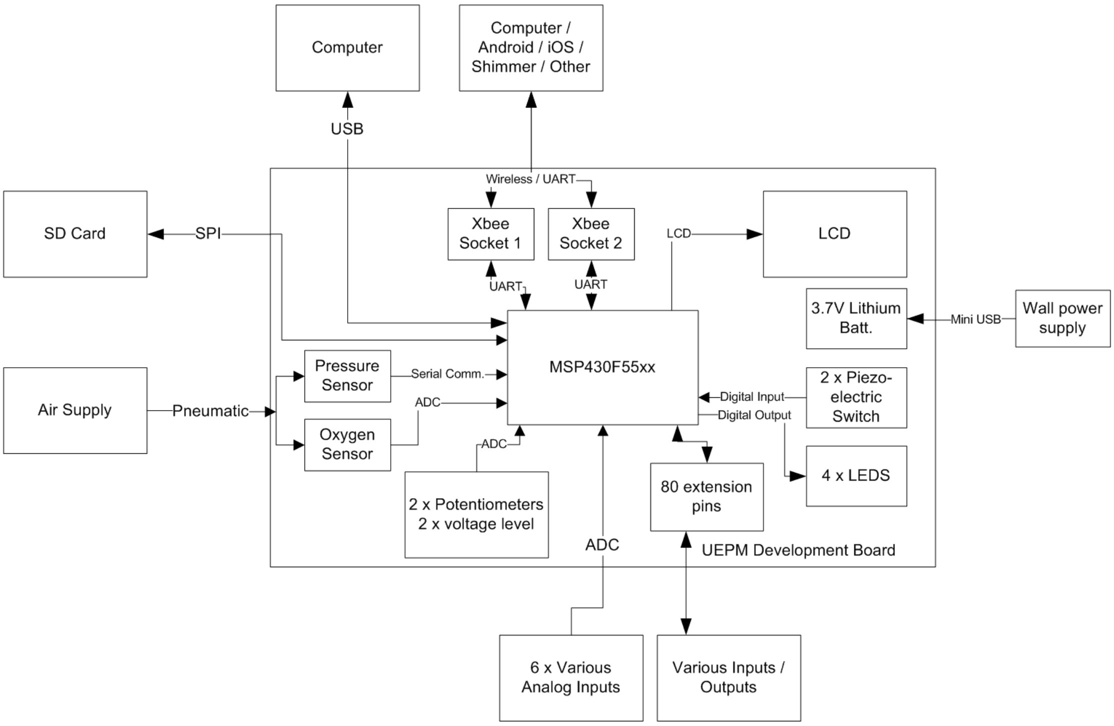


Figure 4.1 Board overview

The Development Board supports the use of multiple wireless modules to connect both Android (Bluetooth) and iOS (Wi-Fi) devices. In addition, the Bluetooth module lets developer receive data from cardiac activity sensor (ECG & EMG) by Shimmer Research Company. Shimmer unit is a wearable wireless sensor module by which you can capture and communicate sensed data. These modules let user to measure activities such as cardiac and muscle. The physical activity of divers causes the inconsistency of data. Shimmer modules have accelerometer sensors to deal with this inconsistency. In addition, the modules have their own operating systems and can be programmed to meet your specific application with configurable sensitivity and sampling rate. Besides, it is possible to implement filter techniques such as high-pass or moving average on the module.

4.2 Design

The PCB for the development board has a limited size of 30cm x 30cm. The PCB is designed 2 sided. The PCB is mounted on spacers so that the PCB is fixed and stable and the components may not be damaged when the board is set down. Each connector, jumper and connector is labeled to make each function very clear the user/developer using the development board.

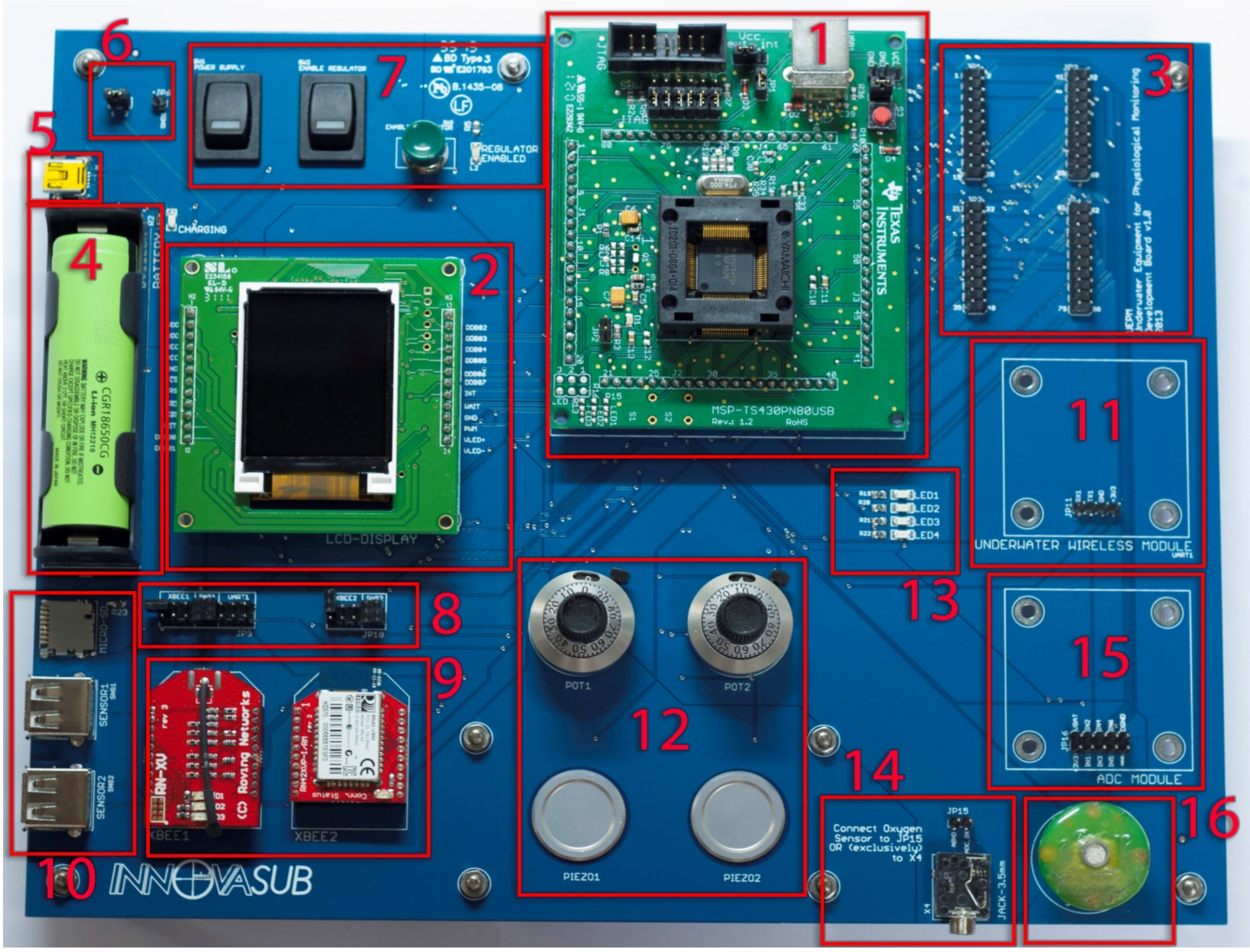


Figure 4.2 Board design

1 MSP-TS430PN80USB. Target Board for Texas Instruments 80-PN package MSP430 microcontrollers. Equipped with JTAG for on-board programming and debugging, and USB. Specific datasheet available on the CD provided with the UEPM Development Board.

2 INT018ATFT LCD display. 1.8” TFT, 160x128 RGB integrated driver. Specific datasheet available on the CD provided with the UEPM Development Board.

3 Extension of the MSP430’s 80 pins. 0.1” pitch connectors.

4 CGR18650CG. Lithium-Ion Rechargeable battery.

5 Mini-USB connector. Power supply to recharge the battery. NOT USB COMPLIANT. Connect only a power supply with 5V and at least 1A capacity.

6 Reference pin (GND) and pins to control current through the battery.

7 Switches controlling power supply to the MSP430 and peripheral components.

8 Jumpers to select the devices to be connected to the two UART ports of the MSP430. For each port (UART1 and UART2) can be connected an XBEE port, a pressure sensor or (only on UART1) the Underwater Wireless Module.

9 XBEE1 and XBEE2 ports. 2 x Ports compatible with XBee footprint modules.

10 2 x USB Female A connectors for connection with Innovasub Pressure sensor. Connectors NOT USB COMPLIANT. Do not connect any USB device to these connectors.

1 x Micro-SD socket. Connected to the SPI port of the MSP430.

11 Underwater Wireless Module, connected to the UART1 port (USCI0) of the MSP430.

12 2 x High precision, 10-turn potentiometer. Connected to 12-bit ADC of the MSP430.

2 x Piezo-electric switches. Connected to digital, interruptible input of the MSP430.

13 4 x General purpose LEDs. Connected to digital output of the MSP430.

14 Port for connection with Oxygen Sensor. Jack 3.5mm or standard 0.1” connectors available. DO NOT USE BOTH CONNECTORS AT THE SAME TIME as they are connected to the same 12-bit ADC input.

15 General purpose 12-bit ADC acquisition. Connection for custom board.

6 x ADC inputs, power from battery and regulated 3.3V, Digital and Analog grounds.

16 MS5541C pressure sensor mounted on INNOVASUB PCB.

4.2.1 MSP430 and Target Board with Programmer

The board supposed to be based on a micro-controller of the family MSP430 since the mobile phone based dive computer DivePhone is already developed with Texas Instrument MSP430 family. The MSP package used is 64-pin QFP (PM). The socket allows the user to change the micro-controller for any other 64-pin PM package micro-controller. The board should integrates the target board MSP-TS430PM by Texas-Instrument. This target board is designed for the microcontrollers: MSP430F13x, MSP430F14x, MSP430F14x1, MSP430F15x, MSP430F16x(1), MSP430F23x, MSP430F24x, MSP430F24xx, MSP430F261x, MSP430F41x, MSP430F42x(A), MSP430FE42x(A), MSP430FE42x2, and MSP430FW42x devices in 64-pin PM packages.

The target board is chosen because it integrates the socket for 64-pin-PM-package MSPs and JTAG connector for programming and debugging. The target board also contains a 32.768 kHz crystal oscillator.

The package MSP-FET430U64 is used from Texas Instrument since it integrates:

- One READ ME FIRST document
- One MSP-FET430UIF USB interface module. This is the unit that has a USB B-connector on one end of the case, and a 2×7-pin male connector on the other end of the case.
- One USB cable
- One 32.768-kHz crystal from Micro Crystal (except MSP-FET430U24)
- A 2×7-pin male JTAG connector is also present on the PCB
- One 14-Pin JTAG conductor cable
- One small box containing two MSP430 device samples
- One MSP-TS430PM target board

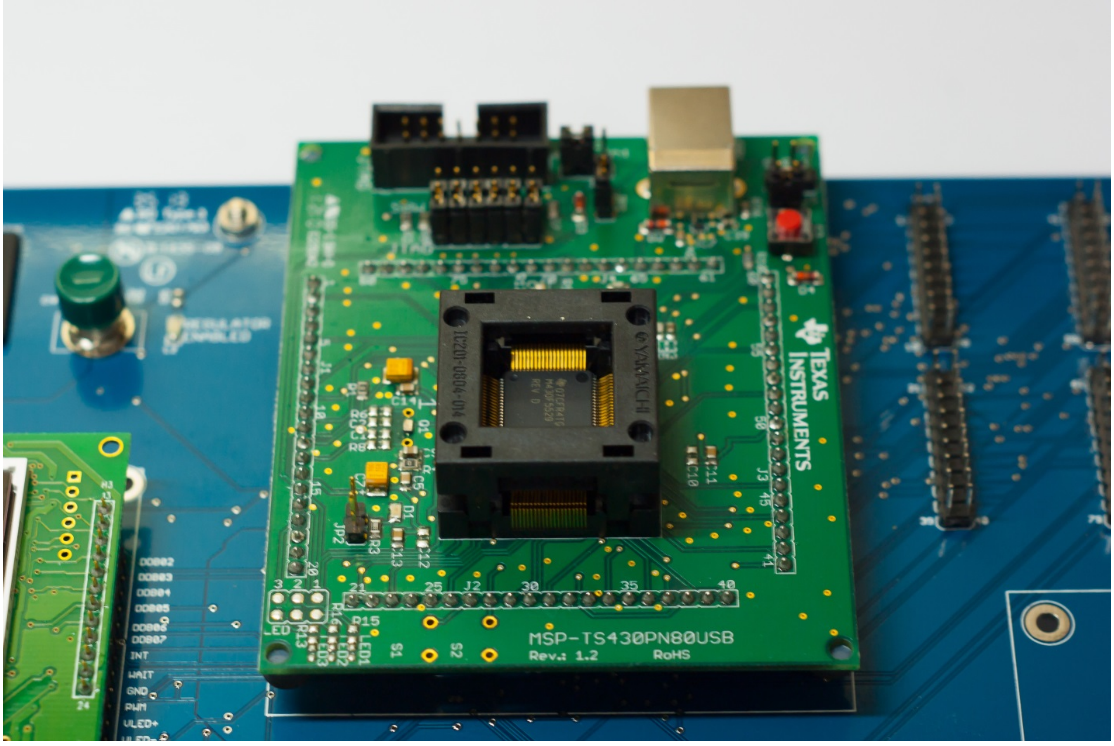


Figure 4.3 MSP430 Target board

Hence the full equipment required to program MSP430 in 64-pin PM package. However, the board is specifically designed and optimized for the MSP430F5529.

4.2.2 Battery and Charging Circuit

The evaluation board should be supplied by:

- A USB connection (providing only power, but not USB data) -
- or a single cell Lithium-Polymer or Lithium-Ion battery

The battery should be allowed to be plugged and unplugged to the board. A battery holder should be used to keep the battery in position.

According to these concerns the battery used on the board is CGR18650CG. It is a Rechargeable, single-cell Lithium-Ion battery, with a capacity of 2000 mAh. Its nominal voltage is 3.7V but it can vary between 4.2V and 2.7V depending on its state-of-charge. Its package is the standard 18650. The board is equipped with a charging circuit to manage the charge of the battery using a Constant Current – Constant Voltage method. The maximum current provided to the battery is 500mA and the maximum voltage is 4.2V. When charging, the led charging is bright red.

In order to properly proceed to the charge of the battery, use a power supply of 5V and a minimum capacity of 1000mA.

Figure 4.4 Battery

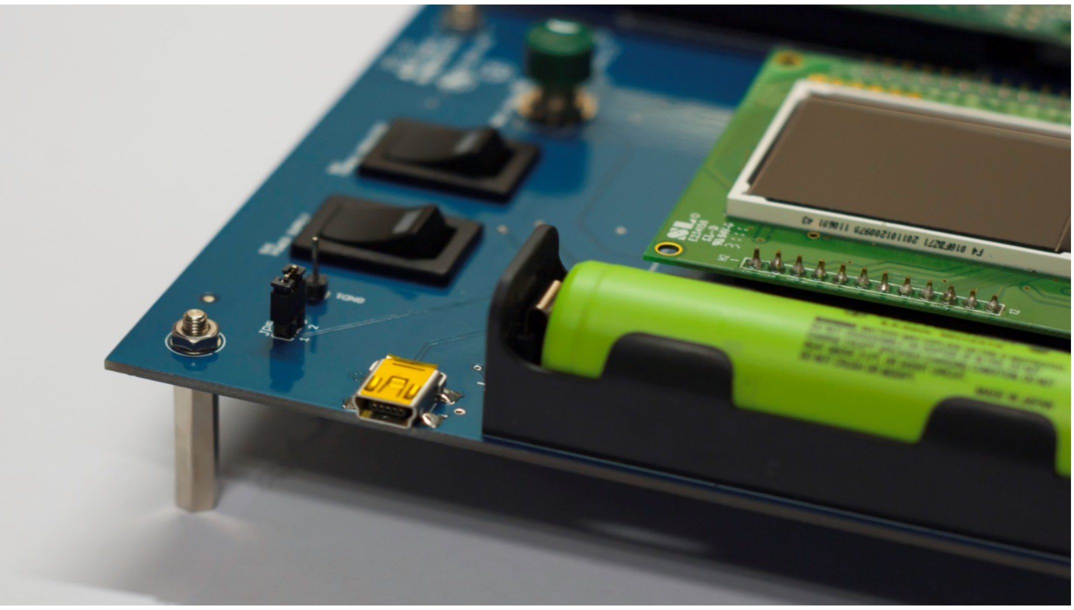


Figure 4.5 Mini-USB connector for charging the battery

The connector used for the power supply is a Mini-USB female connector. Since it is not USB compliant, it should not be connected to any USB device. It should only be plugged to a power supply.

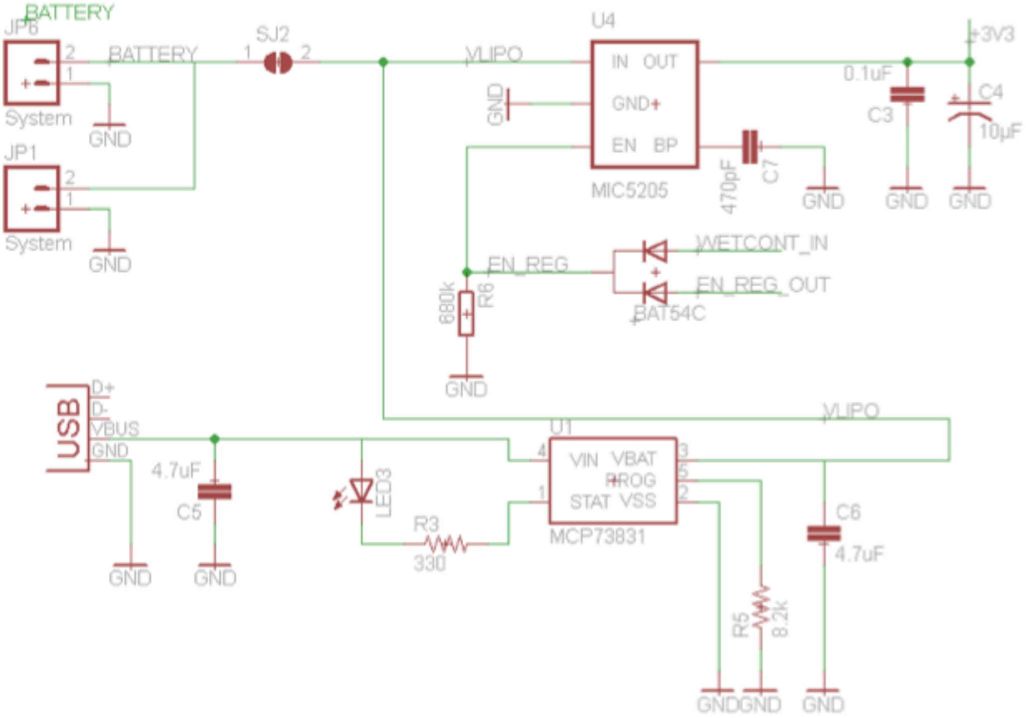


Figure 4.6 Schematic design for the battery management

The power supply circuit for the development board is designed by adding a pull-down resistor (R6) to the diodes to prevent from a floating input when WETCONT_IN and EN_REG_OUT are low. WETCONT_IN is a pin used for the wet contact activation. A small package with common cathode diodes was chosen for the diodes. The circuit Figure 4.7 is to reduce the noise on Analog-to-Digital Conversion (ADC) acquisition, according to the datasheet for MSP430F233.

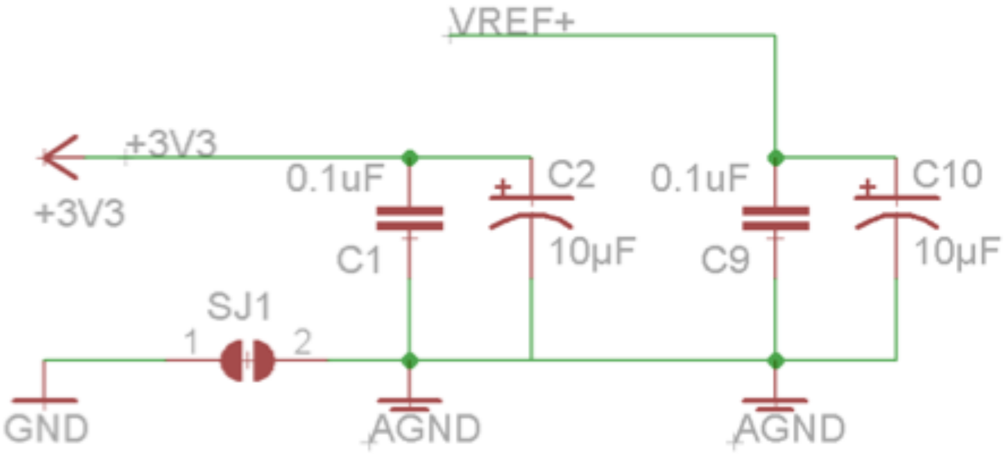


Figure 4.7 Schematic design for voltage referencing

4.2.3 LCD Display

The INT018ATFT is selected for the board display since 1.8” TFT display of 160 x 128. It uses 8 data pins for optimum display time.

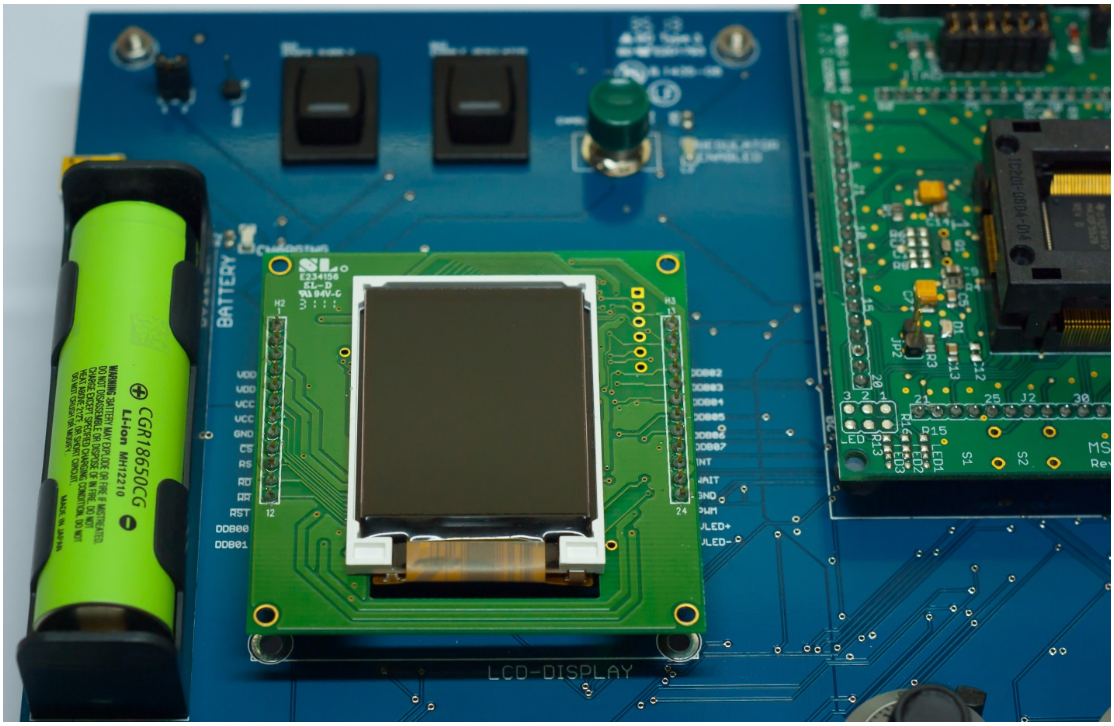


Figure 4.8 LCD display placement

4.2.4 Control Pins

The control pins can be used to control the voltage on the board and to control the current flowing through the battery. The pin GND1 (JP6) is a reference for the ground level on the Development Board. The connector JP5 is connected in series with the battery in order to control the current flowing through it, with the help of an amperemeter. If not in use, a jumper can be placed on JP5.

Figure 4.9 Control pins

4.2.5 Switches

The Development Board is equipped with three switches:

- SW1: main switch. It connects the battery to the input of the regulator. SW1 is bright red when closed.
- SW2 and SW3: enabling switches. They enable the regulator to let the current flow to power the UEPM Development Board when closed. SW2 and SW3 are in parallel. SW2 is SPST ON-OFF. SW3 is a momentary SPDT ON-OFF. SW2 is bright green when SW2 or SW3 is closed.

When the voltage regulator of the UEPM Development Board is powered and enabled (SW1 & (SW2+SW3)) the LED L2 is bright green. Moreover, the digital output EN_REG2 of the MSP430 is connected to the enable pin of the voltage regulator. Hence, after a short impulse on SW3 to allow current flowing through the voltage regulator and power the MSP430, the latter can set its output EN_REG2 high to always enable the regulator. Only clearing EN_REG2 programmatically or switching off SW1 will shut down the board. The advantage of this configuration is that the program of the MSP430 can control when it needs to totally shut down.

Figure 4.10 Switches SW1 and SW2

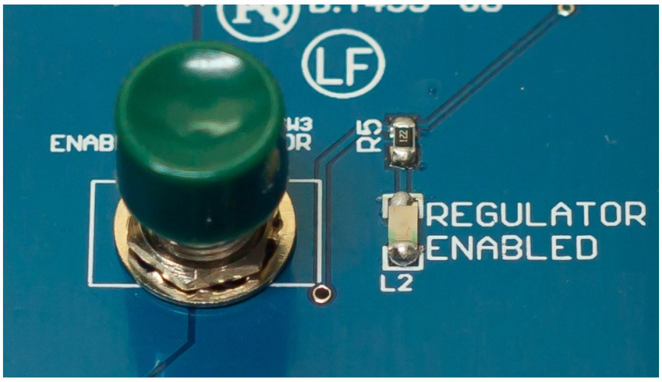


Figure 4.11 Switches SW3

4.2.6 Serial Communication

The Development Board uses two UART ports of the MSP430 and one SPI port. The two UART ports of the MSP430 are USCI0 and USCI1 and are respectively called on the UEPM Development Board UART1 and UART2. The SPI port is directly connected to the micro-SD Slot. An additional interruptible input SD_CD is used to detect when a micro-SD card is inserted into the slot.

The UART1 can be used with any XBee footprint compatible module, an external pressure sensor or an underwater communication module which can be developed. However, only 1 device can be used at the same time. The Jumper JP9 is used to select which device is to be used with UART1. To use XBEE1 with UART1, the jumpers need to be removed from the positions UART1 and SNS1, and finally placed three jumpers on XBEE1 on JP9. In order to use the external pressure sensor 1, first all the jumpers need to be removed from JP9 and placed two jumpers on the position SNS1. In order to use the underwater communication module, all the jumpers need to be removed from JP9 and placed three jumpers on the position UART1. When using XBEE1, CTS and RTS pins are directly wired to the MSP430 if high baud rates needed. When using XBEE2, its CTS and RTS pins are directly wired to the MSP430 in case high baud rates needed.

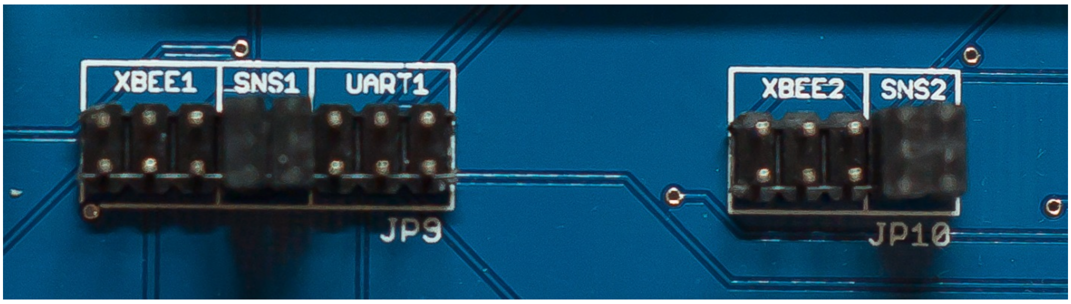


Figure 4.12 Jumper JP9 in position SNS1 and JP10 in position SNS2

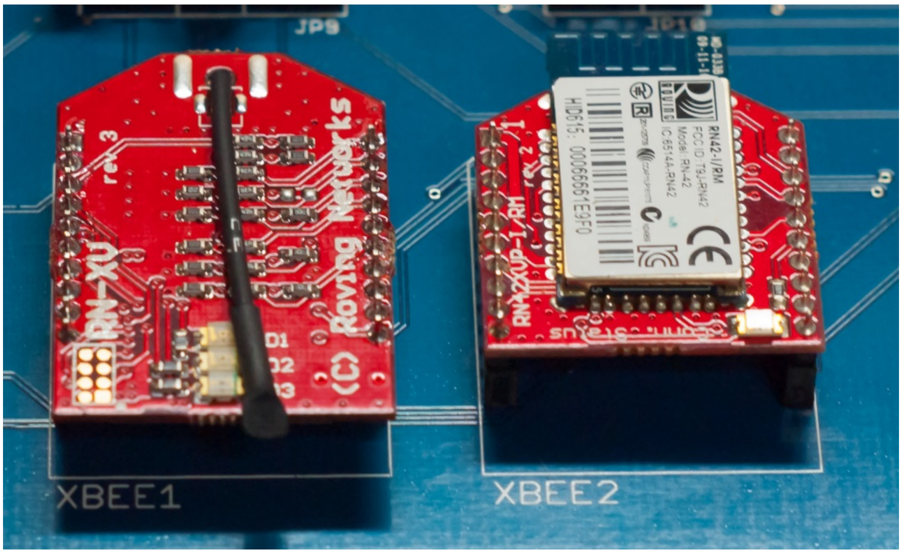


Figure 4.13 XBEE1 as RN-171XV connected and XBEE2 as RN-42XV connected

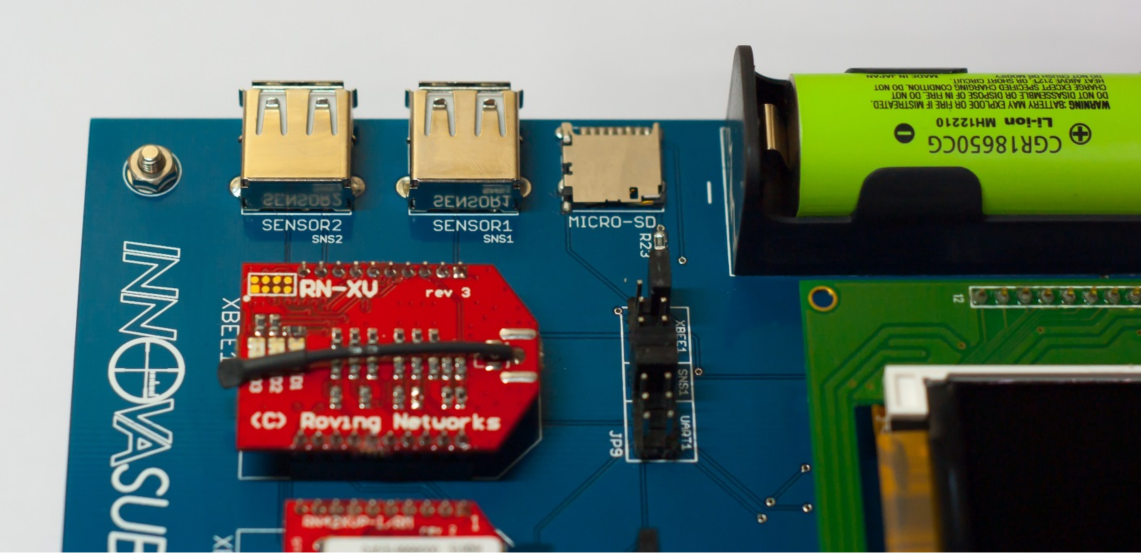


Figure 4.14 SENSOR1, SENSOR2 and MicoSD slot for memory space

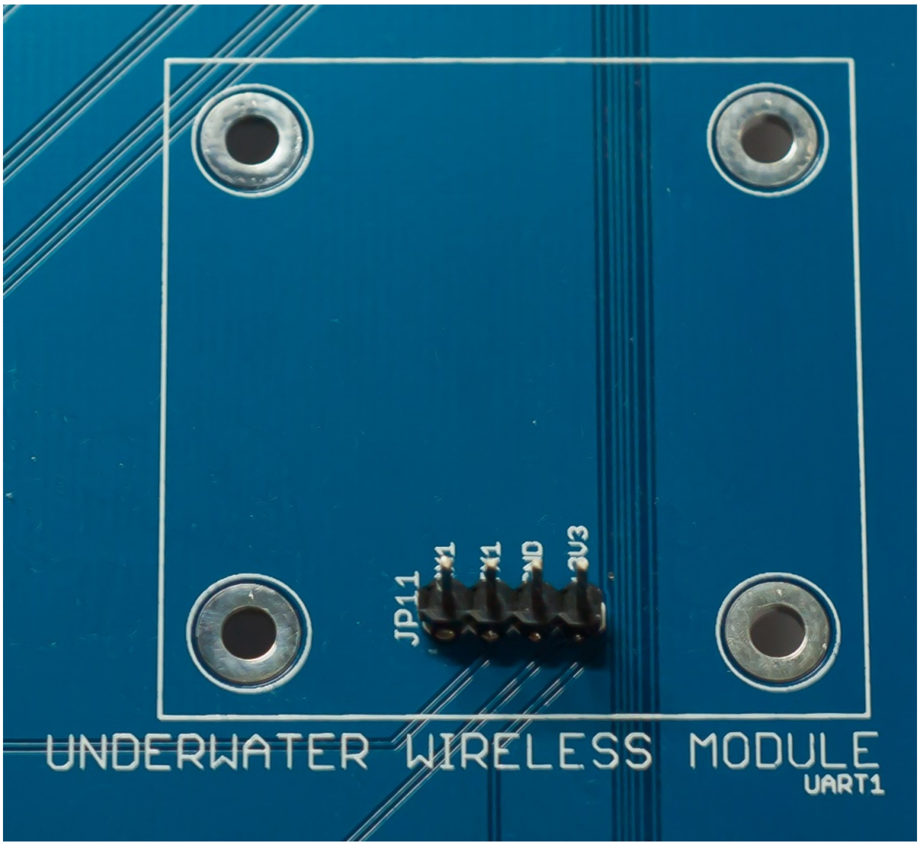


Figure 4.15 Underwater Wireless Module Connector

4.2.7 External Pressure Sensor

The external pressure sensor is a high precision pressure sensor to monitor the divers' depths. Based on the MS5541C, its resolution is 1.2 mbar and its range is up to 14 bar. The external pressure sensor easily plugs to the existing systems using the T-pipes.

Figure 4.16 INNOVASUB Pressure sensors with USB cable

4.2.8 Piezo Switches

Piezo-Switches are often used on dive computers and other underwater electronic devices that require switches as they are completely water proof and they easily work underwater. A small impulse of the piezo-electric switch will close the circuit for a short period of time which can be detected by the MSP430’s input. PIEZO1 is wired to the input P2.2 and PIEZO2 is wired to the input P2.3.

Figure 4.17 Piezo switches PIEZO1 and PIEZO2

4.2.9 Potentiometers

Figure 4.18 Potentiometers POT1 and POT2

POT1 and POT2 are high precision, 10-turn potentiometers with knob. They are respectively wired to the A2 and A3 12-bit ADC inputs of the MSP430. The signals of the potentiometers are inverted. The position 0.0 corresponds to the highest signal in ADC acquisition and 10.0 to the smallest value.

4.2.10 LEDs

Four general purpose LEDs are available on the development board. They can be used to display basic information. They are called LED1, LED2, LED3 and LED4 and their signals are of the same names on the circuit's schematics. They are directly connected to the MSP430 digital outputs and they use 220 Ohm resistors to limit current.

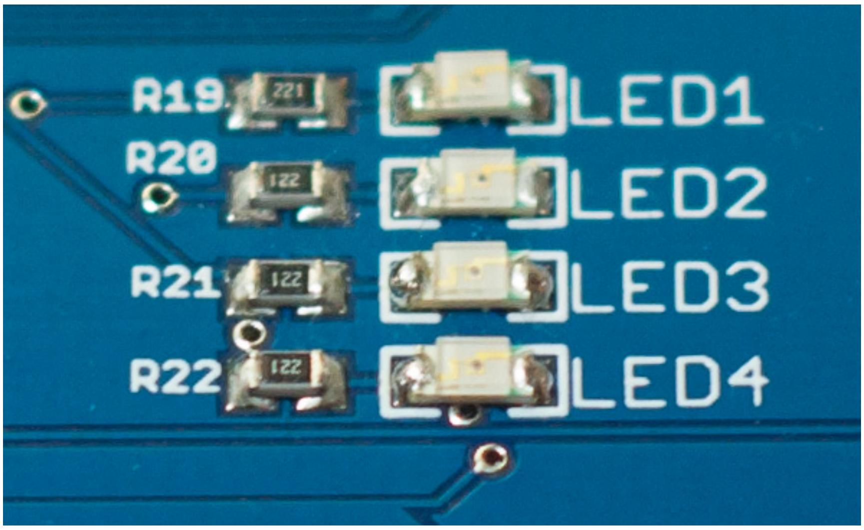


Figure 4.19 LED1, LED2, LED3 and LED4

4.2.11 Oxygen Sensor

The connector X4 (jack 3.5mm) and JP15 (0.1” pitch standard) are designed to be connected to an analog oxygen sensor. They are connected to the 12-bit ADC input A4. X4 and JP15 should not be connected to an oxygen sensor at the same time since they are wired to the same input and may result to damage the two sensors.

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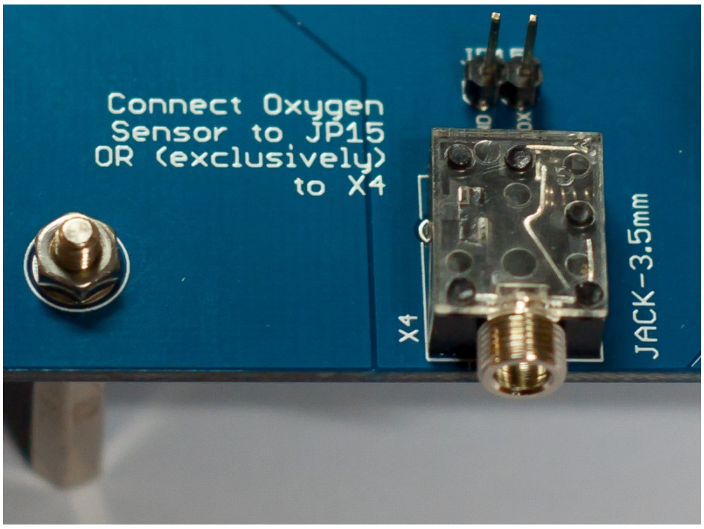

Figure 4.20 Connectors for oxygen sensor X4 and JP15

4.2.12 General Purpose ADC Inputs

The connector JP16 offers to connect a custom general purpose board for up to 6 12-bit Analog-To-Digital inputs. It also provides the battery lines, the regulated 3.3V, the analog ground (AGND) and digital ground (DGND) for a high quality signal.

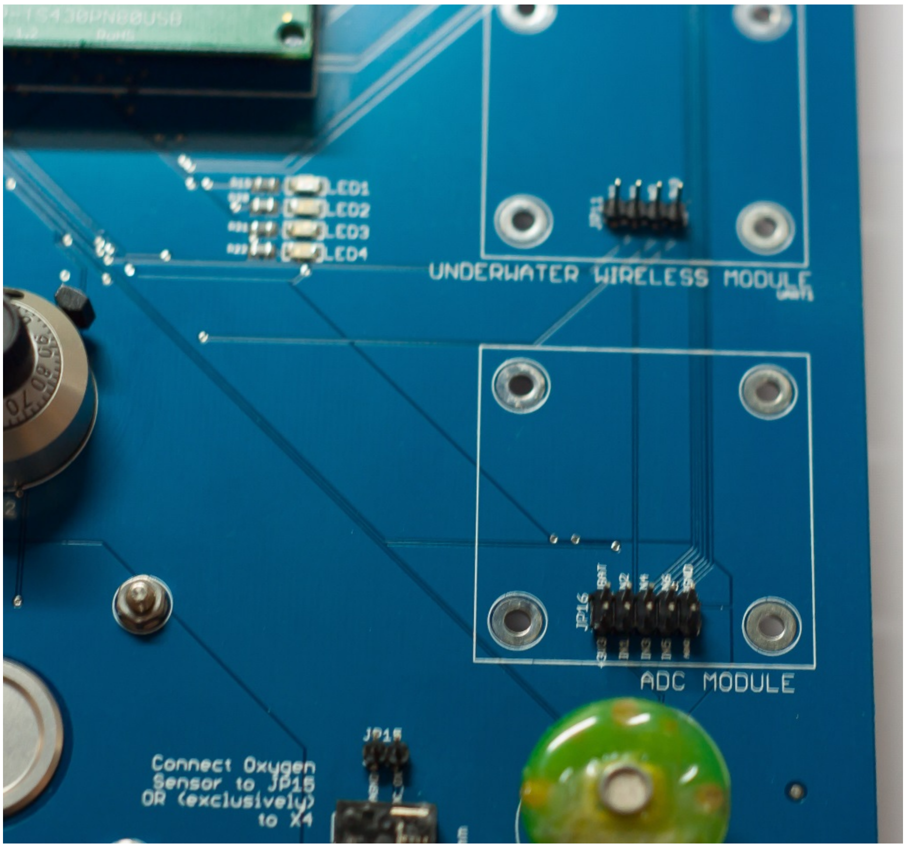

Figure 4.21 ADC inputs JP16 connector

4.2.13 MS5541C Pressure Sensor

The MS5541C is mounted on an another PCB for easy experimenting and development of the communication protocol with the pressure sensor. The connection is made with 5 pins only. The sensor's connection should not be inverted while plugging it to the development board. It may result damaging it. User needs to follow the PCB's drawing to plug it in the correct direction.

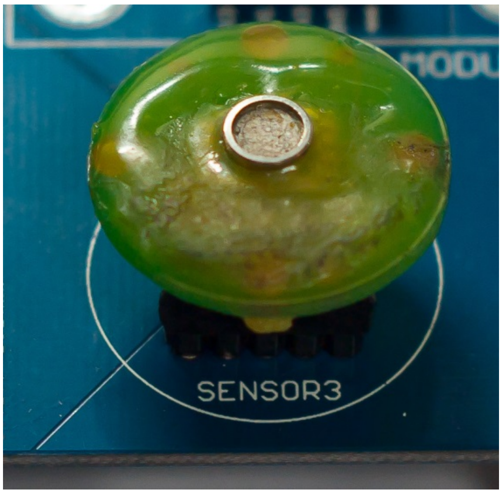

Figure 4.22 MS5541C pressure sensor connector

5. Implementation of a Sample Application; Underwater ECG Monitoring

Health monitoring system applications has increased in recent years due to rapid growth of mobile technologies. There are a plenty number of health monitoring systems available for people to use in daily life with their iPhone, Samsung or any other mobile phones. In recent studies, custom designed tools (Arne et al., 2009) for measuring blood pressure (Arne et al., 2008) and electrocardiography (ECG) (Arne et al., 2008) (Marabotti et al., 2008) can be observed (Toni et al., 2011). Galileo dive computer produced by Johnson Outdoors Diving LLC/Scubapro has the capacity of monitoring the heart rate during dive and (Benjamin et al., 2010) developed a custom designed apnea dive computer for continuous monitoring of oxygen saturation and heart rate. With the help of the underwater physiological monitoring development board and DivePhone system, it is relatively easy to develop such applications for people to use underwater.

5.1 Overview

An ECG data collection tool is designed as a sample application using the development board and the DivePhone system. Before the design of the tool, some tests are achieved for system efficiency.

Figure 5.1 Experiment setup

Shimmer ready to use ECG monitoring device is placed on the diver's chest. DivePhone's external module is included to the system. Finally, mobile device captured the ECG data over Bluetooth and pressure data over WiFi and visualized on an excel document.

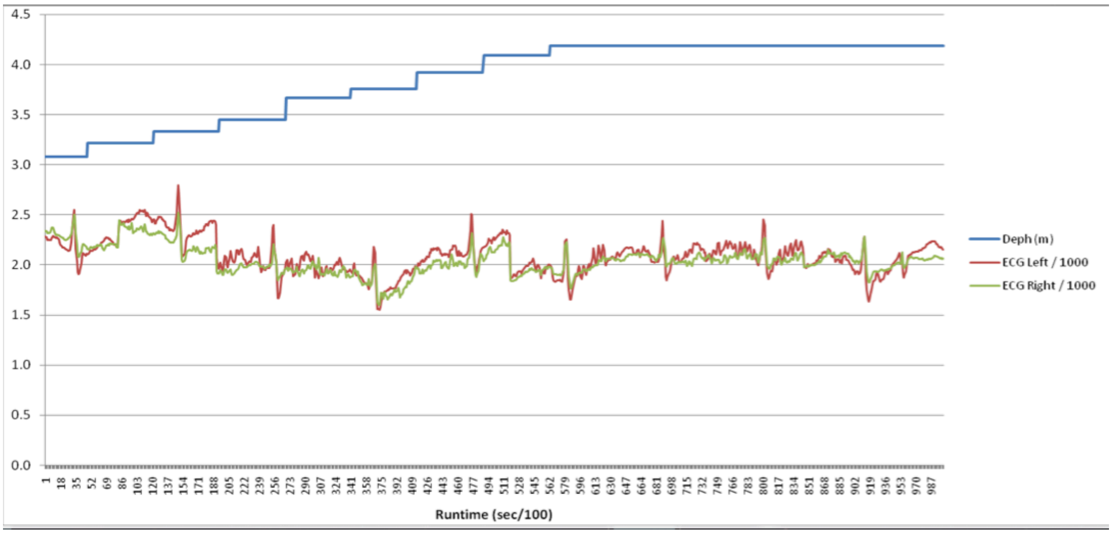

Figure 5.2 ECG inputs with pressure information

5.2 Design

The tests taken underwater show that it is possible to process and record the ECG data underwater with a special device that can be designed. In order to develop this device, underwater physiological monitoring development board can be used. The development board has the feature to combine the shimmer ECG module with a wireless module to transfer measured data to the mobile device.

5.2.1 Whisperer Module

First step to design ECG monitoring application is building an extra module that functions as a bridge between the shimmer ECG unit and mobile devices. This module is called as Whisperer Module. It receives data from the shimmer unit and sends it over WiFi to iPhone, iPod touch mobile devices.

The shimmer unit is compatible with mobile devices underwater. The range of the shimmer signal is limited to 15-20 cm underwater, so the mobile devices can not grab data from the shimmer unit. Therefore, the Whisperer Module is located on the diver's wrist. This module behaves as a connection between the shimmer unit and the mobile device.

5.2.2 Shimmer ECG Unit

Shimmer ECG module developed by Intel Digital Health Advanced Technology Group is used in a dry suit in order to prevent ECG electrodes get into the water. It would not be wise to design a complete new ECG module because noise reduction in ECG measurement with wearable systems would cost relatively too much time and effort. Although Shimmer ECG module is used in the system, ECG measurement variability arises from physical activity. In order to handle this variability there exists some code development on the software side of the unit such as taking accelerometer information into account while measuring the ECG data on the unit.

Shimmer unit has a firmware to transmit the ECG data over Bluetooth. This firmware is updated so that the unit transmits the ECG data not over Bluetooth but over UART port of the unit. UART port of the unit is connected to Whisperer Module. Thus, the ECG data is transmitted over WiFi.

5.2.3 Mobile Device

On the mobile device side a new software is developed to log the ECG data. DivePhone has already a software developed. This software is modified to interact with the Whisperer Module. The first step of this interaction is the connection establishment. In order to establish the connection, new user interface is implemented on the Depth Monitor application of the DivePhone system.

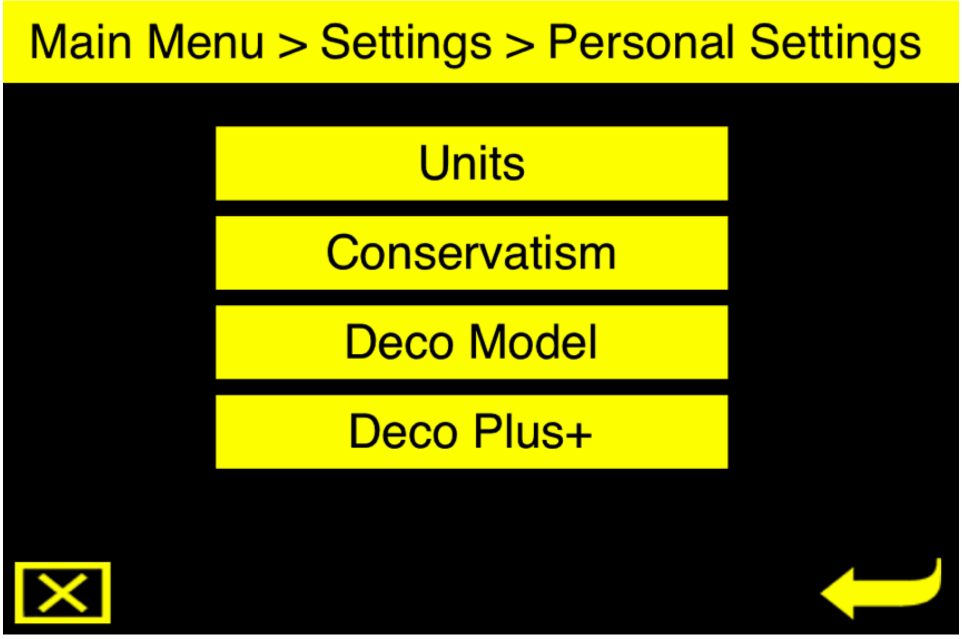

Figure 5.3 Deco Plus+ menu navigation

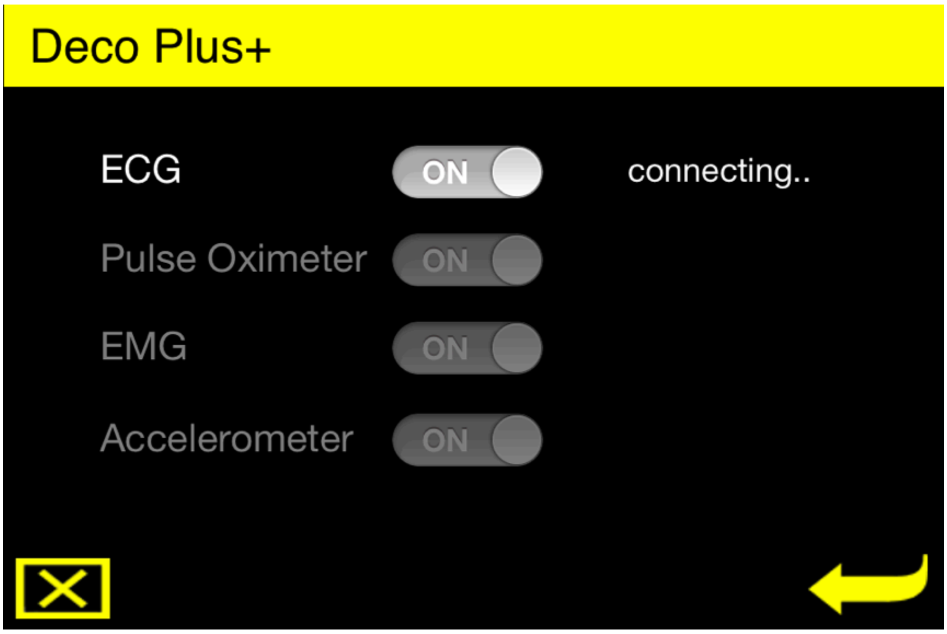

Figure 5.4 Deco Plus+ setup screen

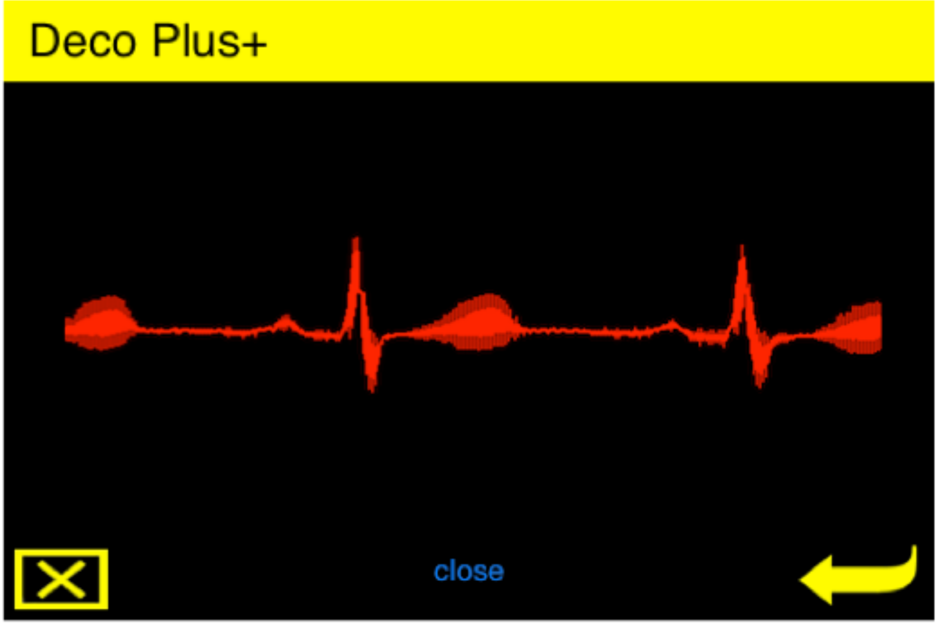

Figure 5.5 ECG monitoring on the iPhone application

5.2.4 Diver Net

Figure 5.6 Combination of Diver Net system and mobile device

After ECG data is measured by shimmer ECG modules, there occurs a problem which is how to manage transmitting measurement to the mobile device which is located on the wrist of the diver. A cable is included to the system to deal with this problem. The basic cabled network system is named as ‘Diver Net’. ECG values are distributed across the suit with the help of this network. All signal levels are nominally 3.3 volts (+/- 10%) logic high. In order to prevent loss of received data, high-performance ribbon cables are used in the design of the cable network. The combination of DiverNet system and mobile device implement underwater ECG measurement system. Benefit of the cable network on which DiverNet implemented is that it can be used for the first step in development wearable computer suit for divers by adding extra sensors such as pulse oximeter.

In addition to the network cable, it is advised that diver wears a suit. Because of unstable contact of an electrode with diver’s skin, the motion of the diver can generate noise in the ECG signal. When diver wears this dive suit, it can make the electrodes stuck between the diver’s skin and the suit. Merging the cable network with the dive suit, it may be a innovative idea to build the dive suit with the cable network, whisperer module and having all the parts in one suit.

6. Conclusion

The main task of this work was design of a development board named Underwater Developing Board for Physiological Data Collection. It is designed for the purpose of contributing scientific projects and Research and Development works. This board aims to bring together all hardware and software required to monitor underwater physiological attributes of divers. It is aimed to prepare a kit ready to develop together with its all accessories, manuals and sample codes.

To allow this idea to be developed, microprocessor on the kit to be replaced in case of a malfunction and to make debug during development, a TFT screen is added, to provide communication with microprocessor through serial connection, two UART entry were added, by means of wireless modules, in order to make additional data such as ECG and pulse oximeter received from diver's body Wi-Fi and Bluetooth modules are added, apart from wireless communication modules, a micro sd socket is added and finally an analogue-digital convertor section is added for various values such as oxygen and humidity which are required to be measured on the development board.

Finally, using the development board, a sample tool is developed to collect ECG parameters from divers. With the help of the underwater physiological monitoring development board and a smartphone, it is shown that it is relatively easy to develop such applications for people to use underwater.

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Biographical Sketch

The author of this thesis was born in 1982 in Denizli, Turkey. He has studied in TEV Anatolian High School between 1994 and 2000, and started his undergraduate education in the Computer Science and Engineering Department of the Engineering and Natural Sciences Faculty of Sabancı University in 2001-2006 terms. Consequent to the graduation from the undergraduate degree, in 2010 he has enrolled to the Computer Engineering Master’s Degree in Galatasaray University Institute of Sciences. Since 2008 he has been working at Innavasub as an R&D engineer in underwater technologies.

Paper titled "ECG and AMG Measurements During Dive Using a PDA Based Dive Computer: First Step into the Wearable Dive Computer" of this thesis has been presented in 37th Scientific Annual Meeting of the European Underwater & Baromedical Society (EUBS 2011).