Technische Universität München
Heinz-Nixdorf-Lehrstuhl für Medizinische Elektronik
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# Bachelor Thesis

## Conception of a system for the assessment of physical performance

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# Contents

# Chapter 1

# Introduction

## 1.1 Project Description

For the last few years one's personal fitness and an overall healthier way of living gained more and more importance, mainly due to the popularity of a vast varietey of fitness trackers, which are available on the market today. Medical devices which may be used at home are a common thing by now for the average consumer and said fitness trackers try to be accepted as such medical products. Those devices are precise in distinguishing different types of activities, such as cycling, running or walking and usually present a value of consumed calories for the user. But here, all fitness trackers share the same disadvantage: the measured calorie consumption is always just an estimation based on the kind of activity or parameters like the heart rate during the activity. Those devices are not able to directly measure the calorie consumption and thus can - for most cases - not be used as a medical device, because one has no information about his own metabolism.

To truly measure the metabolic rate of an individual, physicians use ergospirometric devices. Those devices are rather big setups consisting of an ergometer for defined physical activity and a mask and gas analysis system to measure oxygen update and carbon dioxide release during exercise. Due to their high complexity, these systems do not qualify for the average person and are mainly used by sports therapists and professional athletes.

The team under the lead of Alexander Scholz at the Technical University of Munich develops an easy to use, mobile spiroergometry device which will focus on average sportsmen and fitness enthusiasts rather than professional athletes. The device can be used to optimize one's individual workout plan to his or her specific needs by measuring the aerobic threshold which is a key parameter in physical performance assessment. Therefore the device will try to combine the advantages of both ergospirometry - by measuring ventilation an the level of carbon dioxide in exhaled air - and fitness trackers - by presenting the measurements with a smartphone application and thus provide an easy to understand and easy to use system.

## 1.2 State-of-the-art

For several years, breathing has been measured in order to evaluate human metabolism as well as lung function. That information can be used for many purposes such as diagnosing and monitoring illness or sports applications.

In 1749 Daniel Bernouili developed a theory to measure respiratory volume. Later, in 1813 Edward Kentish invented the pulsometer. Finally, in 1846 John Hutchinson developed the first spirometer. It was a calibrated bell, inverted in water, which was used to capture the volume of air exhaled by a person. However, the measurements were limited to the evaluation of "vital capacity", which is now called expiratory vital capacity [1].

The first exercise tests were performed by bicycle at the beginning of the 20th century by Wilbur Olin Atwater. During these tests the behavior of the lungs was tracked while the subject expended different levels of effort. Initially, they were developed to evaluate the abilities of long distance runners, cross-country skiers and cyclists.

Not until the beginning of the 21st century, were exercise tests available in common gyms with the goal of keeping athletes informed of their performance.

In the following years these devices have been improved. The exercise tests have become more focused on medicine, and provide a wide range of useful and accurate parameters. The rise of smartphones has lead to increasing popularity of mobile activity trackers among amateur athletes.

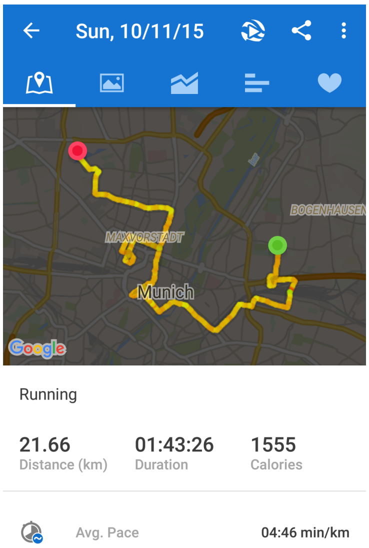
Most measurement apparatus can be found as watches or fitness applications for the smartphone. While fitness applications are more popular due to ubiquity of smartphone ownership, they are less precise than the watches.

Then two measuring devices are presented. They can be included in the activity trackers field. Subsequently, ergospirometry will be discussed in further detail.

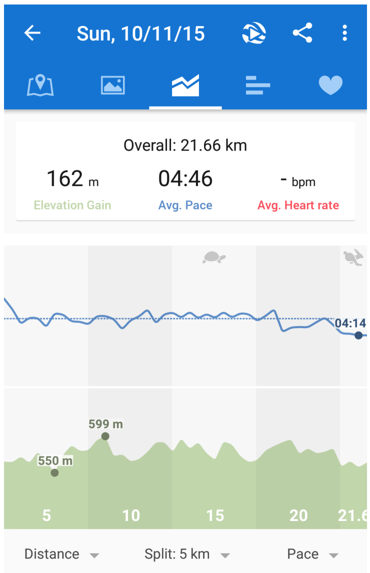
**Runtastic**

Runtastic is one of the most popular fitness applications for smartphones. Other smartphone applications have similar functions [2].

Runtastic tracks the activity of the user. Making use of the GPS, it traces the route covered on a map and calculates the average speed every certain period of time. It estimates as well calories burnt and dehydration and monitors the heart beating during the activity (additional heart rate belt is needed).




(a) Route map and main parameters.




(b) Elevation profile combined with pace.

Figure 1.1: Runtastic activity results example. It shows mainly the route run and the pace with the elevation and the heart rate (in case the heart rate belt is used). These parameters give to the athlete a good overview of the activity according to its difficulty.

This application has become popular because it draws attention to the social aspects. All the activities done can be seen by other known users either on the Runtastic web page or on the social networks. That allows the community to observe others' progresses.

However, although the parameters provided by the application are useful, for a senior athlete it becomes difficult to increase training efficiency without monitoring breath.

### Polar Fitness Test

The next product is a watch application. Polar produces watches dedicated to improve the sport experience [3].

The Polar Fitness Test consist of a test that measures one's aerobic fitness at rest in five minutes. It estimates the $VO_2$max (explained in Main Parameters, Theoretical Basis section) and punctuates the result obtained in a scale developed by the brand. The test is based on heart rate variability at rest and personal information.

The main features of these watches are:

- Manual target zone – bpm/%: enables to define the target zone suitable for the training. The target zone can be set for the training as beats per minute (bpm), as a percentage of the maximum heart rate, or as a percentage of the heart rate reserve (HRR%).
- Calorie expenditure with fat percentage: calculates the number of kilocalories expended during training.
- Speed/Pace current, average and maximum.
- Polar STAR Training Program: guides the user through the training. It is based on personal information and the goals of the athlete.

The information obtained after the activities is similar than in Runtastic. Nevertheless, here the user also receives a feedback clarifying what the results mean. Then, a mentoring program is provided to indicate how to react to such results.

One parameter not mentioned above that these watches can calculate is the $VO_2$max. However, it is only well estimated at a rest state of the athlete. While practising sport, 95% of the samples presents error between 24% and 53% [4]. Therefore, these devices can not be used with medical purposes.

Hereinafter are discussed some of the latest researches and scientific articles about ergospirometry.

According to Eduardo Rivas and Norka Gómez [5], the cardiopulmonary exercise testing allows one to know the overall efficiency of transport systems and the use of oxygen in the human body. Through the analysis of exhaled respiratory gases during application of physiological stress such as physical exercise, it is possible to analyze the subject's functional capacity, detect a possible pathology or design a rigorous program of physical exercises which are effective and free of risk.

The role of physical exercise is becoming more and more relevant due to its effects on cardiovascular prevention and rehabilitation (it has a very strong influence on the heart functioning, blood volume, muscular capillary density, etc.). Therefore, it can be considered a powerful tool for preventing diseases by improving body efficiency.

In contrast, balnk et al. believe ergospirometry can be useful outside of athletics [6]. Rather, they claim that the knowledge of peak oxygen uptake, is useful for predicting mortality in patients with coronary heart disease. Above all, they maintain that the most recognized utility of cardiopulmonary stress test is to evaluate patients with chronic cardiac failure.

Thereupon are described two ergospirometers. Both of them are using the latest existent technology in this field.

### Oxycon™Mobile Device

This apparatus is more sophisticated than the previous ones. It is included in the ergospirometry field.

Oxycon Mobile perform stress tests. It consists of a little bag attached either to the chest or the back and connected to a mask with a volume sensor. The device sends the measurements taken to a telemetry unit, which processes them. The results are displayed on a computer on the spot [7].

Oxycon differentiates two parts of the whole stress test performance: the test itself and the evaluation.

During the test, the program provides an overview after each breath. This overview includes a dynamic Flow-Volume Loop, the nine-panel graph by Wasserman (15 breath variables placed onto 9 graphs and showing all the relevant results), a combined graph of CPX (analysis of gas exchange at rest) and ECG (electrocardiogram).

After the test, it is possible to visualize the evaluation. Here the anaerobic threshold is determined according to different methods (such as RER, Vslope, lactate, etc.). Moreover, the Indirect Calorimetry program determines the Basal Metabolic

Rate and exercise-dependent Energy Expenditure (EE) including a differentiation between carbohydrates, fats and proteins.

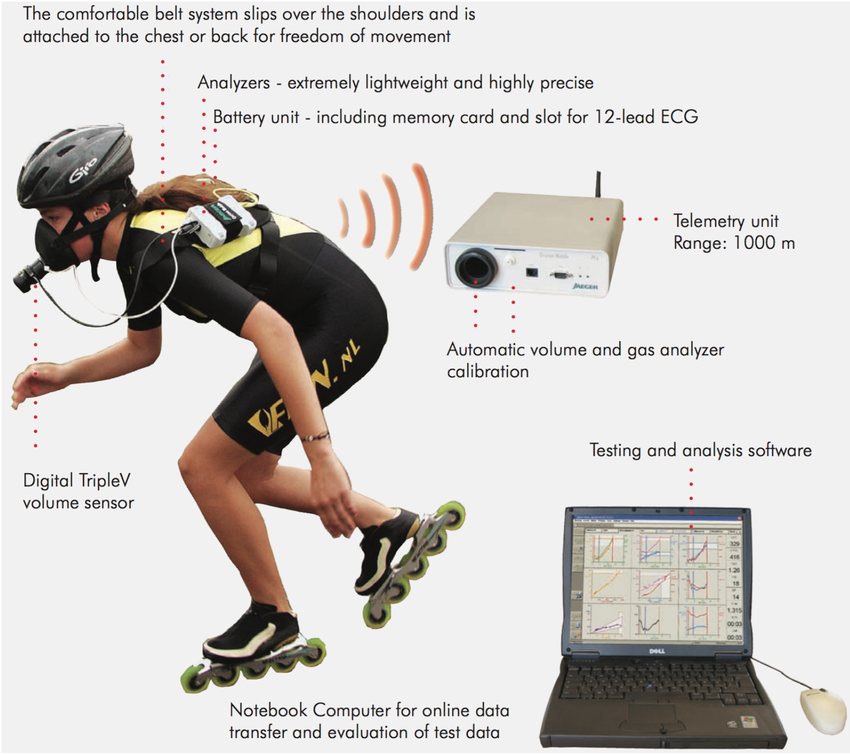



Figure 1.2: Oxycon Mobile Device System. The athlete can practice the sport freely only with the mask and the backpack. Nevertheless, the backpack can not be further than 1000 meters from the Telemetry Unit. The results are displayed on the computer.

As shown in the picture above, the backpack needs a telemetry unit closer than 1000 m. That restricts the usage area of the product to places where the telemetry unit can be established and connected.

### CASE ES Ergospirometry Testing System

This last apparatus is one of the most modern ergospirometry systems is the *CASE ES Ergospirometry Testing System*. This is useful for sports and medicine. It can also be used to increase the accuracy in diagnosing heart failure, assessing the patient's fitness for surgery or evaluating breathing disorders [8].

It provides all the spirometry and ergospirometry parameters in high accuracy and can be combined with multiple peripheral devices. It includes a double flatscreen system for simultaneous presentation of all cardiopulmonary parameters and graphs, a PowerCube-Ergo measurement system for metabolic stress testing and a gas bottle for gas analysis. A bike or a treadmill are also needed to perform the test.

The PowerCube-Ergo uses a micro-fuel cell for the $O_2$ analyzer. A micro fuel cell is a power source for electronic devices that converts chemical energy into electrical energy. Fuel cells operate by oxidizing combustible fuel, such as hydrogen or alcohol [9].

For the $CO_2$ analyzer ultrasounds are used. An ultrasound flowmeter can measure molar mass, the molecular or specific weight of the breathing gas, derived in real time from the sum of transit times. While ambient air is inhaled through the sensor, the molecular weight changes during expiration as oxygen content drops and carbon dioxide increases ($O_2$ has much lower density than $CO_2$). When molar mass is registered during expiration, its waveform resembles that of $CO_2$ [10].

Accuracy and safety distinguish the PowerCube-Ergo from other tests. As it is used for a lot of medical purposes, it is important to protect it against the risk of infections.

In conclusion, ergospirometry advances in both the fields of medicine and athletics.

## 1.3 Objectives of the research

The product being developed here can be cataloged between two different fields: ergospirometry and activity trackers.

The main problem with the activity trackers is that they can only estimate the parameters measured in ergospirometry. On the contrary, ergospirometry systems can provide accurate information, but they are not movable enough.

So far ergospirometry has been performed in closed-rooms. Just for a few sports it does not matter whether the tests are performed indoor or outdoor. However, for most of the outdoor sports, the conditions are not the same in a closed-room than outside with climate and land adversities. Hence, although performing ergospirometry in a closed-room is convenient, it does not approach real training or competition conditions.

On the other hand, ergospirometry is mostly performed in private clinics, which increases the costs. Besides, an expert is needed to interpret the test results and adjust the training according to them. Consequently, for a non-professional athlete, ergospirometry might not be worth the price.

All these problems led to the creation of the product described in the introduction. During its development, more obstacles arose.

- Since the mask is not finished, the smartphone application has not been started yet.
- Therefore, there is not any communication protocol between the mask and the smartphone.
- The relevant parameters to be displayed are unknown. Thus, the way the smartphone should show them has not been determined either.

Thereupon, the goals of this thesis were set according to enumerated problems.

The aim of the research is, in general terms, to build a mobile system for physical performance assessment. It is important to make clear that the objective is not to replace the current ergospirometry neither the fitness applications, but to create a new option between them.

Particularly, the main purposes of this project can be differentiated in two fields: hardware and software.

In the hardware field, as the face piece is not available yet, it is necessary to build up a system which emulates its behavior.

Then, in the software field, one of the main goals is to develop a smartphone application to communicate with the mask and display its measurements as well as their interpretation. On the other hand, it is necessary to know which parameters are useful for the athletes and can be measured or calculated by means of the mask.

Finally, for the communication between hardware and software, there must be a protocol that defines every step since the measurements are done until the results are displayed.

### Problem solution

Firstly, the problem of the unfinished mask was solved. A test device was found with the same communicative functions than the mask. Therefore, for the smartphone there is no difference between them.

Afterwards, in the software field, a research was done to find the most important parameters measured in ergospirometry. Moreover, the functions of the fitness applications were investigated as well to make the application as complete as possible.

Once known which information is relevant and how to obtain it, the next step was to find out how to display it in a useful and intuitive way.

Finally, a communication protocol based on Bluetooth Low Energy was defined for data transfer.

Over the next chapter all this process will be deeply explained.

# Chapter 2

# Main

In this chapter will be explained in detail the solution to the problems previously set out. Firstly, a theoretical basis about all the parameters and calculations done will be expounded. Subsequently, the materials used will be presented and finally the explanation of how them work together.

## 2.1 Theoretical Basis

In the first section the parameters will be explained and then the methods followed to calculate them.

### 2.1.1 Parameters

To know which parameters are relevant, the attention was drawn to the ones measured in ergospirometry; always taking into account the limitations of the mask.

#### $VO_2$max (maximum oxygen uptake)

It is the most important parameter. It means the the maximum rate of oxygen consumption as measured during incremental exercise.

The more oxygen one can uptake, the bigger effort one can do. If the lungs can provide the muscles with the oxygen that they need, the muscles will respond properly for a long period of time. As long as the lungs can uptake more oxygen, the body will be working in the aerobic zone. However, in case the limit is reached (maximal aerobic capacity), the anaerobic zone starts. After that point, the muscles require more oxygen than the lungs can uptake. Then, it becomes more difficult to stay in that zone.

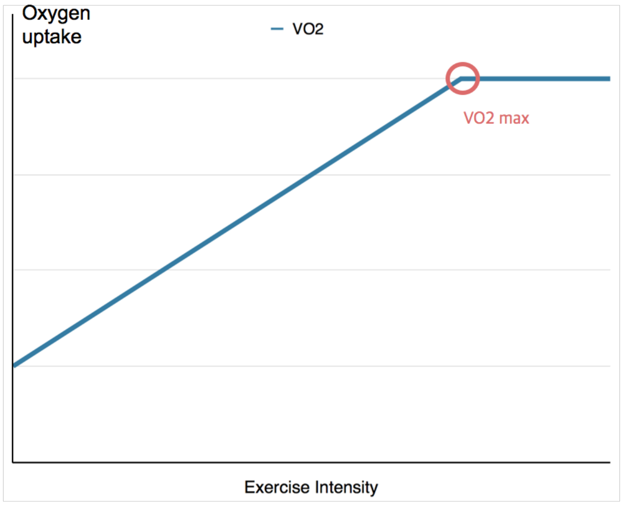



Figure 2.1: General example of VO2 consumption compared to the exercise intensity. It shows the aerobic zone (until the $VO_2$max) and the anaerobic zone (beyond the threshold).

In the previous figure there is the usual line that the oxygen uptake follows depending on the exercise intensity. As mentioned, when the oxygen uptake increases with the effort, it is the aerobic zone. When the lungs can not uptake more oxygen (aerobic threshold), it means that the maximum oxygen uptake point has been reached. In the following effort levels, it will involve the anaerobic zone.

This kind of chart is useful when plotted with older measurements. It allows to see the improvements on the maximum oxygen uptake point: the further it is in the intensity axis the bigger and longer effort the athlete will be able to do.

It is usually expressed as an absolute rate in [L/m] or as a relative rate in [mL/(kg·min)] (milliliters of oxygen per kg of the body mass). Due to the relative rate is more specific for every individual, it will be the one used in this project.

This parameter must be obtained with a mask for a proper result. Nonetheless, it can be estimated with other methods like the 2.4 km test, the balke test or the multistage fitness test [11].

#### VE (pulmonary ventilation)

It is the amount of air moved in and out of the lungs per minute. It is dependent on the depth of each breath (the tidal volume) and the number of breaths taken per minute (breathing frequency). VE increases linearly with the VO2 and workload until about 60% maximum [12].

#### FEO2 (fraction of air expired that is oxygen)

The air breathed in is 20.93% $O_2$, and from that is typically extracted 3.6% of the air that is $O_2$. Thus, the air exhaled is usually 15.18% $O_2$. Low values for $FEO_2$ suggests that the subject is extracting $CO_2$ and that means that gas exchange in the alveoli is good [13].

#### VE/VCO2 (ventilatory equivalent ratio for O2 and CO2)

At the "anaerobic threshold", when a significant amount of energy is coming from anaerobic metabolism, there is an increase in lactic acid in the blood (lactic acid is by product of anaerobic metabolism). In order to keep the blood from becoming too acidic, ventilation increases and helps the body to blow off excess $CO_2$. At this point VE increases at a higher rate than $O_2$. If the subject's lungs are very efficient at gas exchange, the subject will not need a very high VE for the given $VO_2$ [13].

#### RER (respiratory exchange ratio)

Is the ratio between the amount of $O_2$ and $CO_2$ produced in one breath. A RER of 0.7 indicates that fat is the predominant fuel source, RER of 0.85 suggests a mix of fat and carbohydrates, and a value of 1.00 or above is indicative of carbohydrate being the predominant fuel source [13].

According to a research of different institutes and universities in Mexico [14], the RER indirectly shows the muscle's oxidative capacity to get energy. Endurance trained men presented higher O2 uptake, lower blood lactate concentrations and lower RER values than those in untrained men at the three similar relative workloads.

#### kcal (energy expenditure)

Physically talking, one calorie (Cal) is the energy needed to increase 1 kg of water by 1°C at a pressure of 1 atmosphere [15].

In sports, they are used to measure the energy consumed over one activity. That way, it is possible regulate the energy intake before the exercise according to the purposes of the athlete.

The energy expenditure can be split in fat and carbohydrates. Realize that the CHO consumption increases proportionally with the kcal, which means a major usage of energy. This, when doing a big effort is completely normal. Nevertheless, it is good that the energy consumption is as less as possible in a rest state of the body. That will allow the athlete to reach higher efforts with less energy.

This is related also with the kind of energy that the carbohydrates and fat provide. When fat is consumed (concerning good fat: unsaturated), it is slowly absorbed and kept for a long time, so it can be used whenever it is needed. However, fat cannot provide high levels of energy, it is only useful under sub-maximum exercise (sports that require stamina but not power, such as marathons).

On the other hand, CHO is a fuel that will supply fast energy and also in a large amount, which is good for big concentrated efforts. Nevertheless, when the carbohydrates are not consumed once they have been absorbed, they are kept as glycogen and then turned into bad fat.

In the scenario of a marathon, if the runner knows when his body starts consuming carbohydrates instead of fat, he can decrease the pace in order to keep using the proper fuel. Besides, he can also know in which point of the race will he need to eat something and the quantity.

Summarizing, even though the muscles are ready for some kind of effort, if they are not provided with the right fuel before doing it, they will not respond properly. Therefore, the fraction of fat and CHO consumed are essential for an athlete to become his training and diet more efficient. Furthermore, it can also prevent from diseases like diabetes.

### HR (heart rate)

Despite the heart rate is not a pulmonary measurement, it is fundamental in some aspects. In athletics, the most important information that this parameter can provide is the training zones [16].

These training zones are based in the maximum and the resting HR of the individual. They are the following ones:

- **Energy Efficient or Recovery Zone - 60% to 70%.** This zone is perfect to work endurance. The body here keeps burning fat all the time and bringing glycogen to the muscles, accelerating then their recovery.
- **Aerobic Zone - 70% to 80%.** When training in this zone, the cardiovascular system improves. The body becomes more capable of transporting bigger amounts of oxygen to the muscles and taking away the carbon dioxide. This improves of course the $VO_2max$.
- **The Red Line Zone - 90% to 100%.** Training in this zone can be dangerous

for non-experienced people. For each and every second that is spent at this red-line zone, the capacity of the oxygen, fuel and the skeletal and heart muscles would be taxing to their respective limits.

Consequently, knowing the HR is possible to know in which zones is more convenient to train depending on the aim and also it is possible to check the fitness level of the athlete.

### 2.1.2 Calculations

With all the parameters known, now the methods followed to attain them will be explained (excluding the HR, which can not be measured with the mask).

According to Dr. Robert Robergs [17], the respiratory parameters can be calculated just by knowing the volume of expired air and the fraction of that volume which is oxygen and which is carbon dioxide. This method is called *Indirect Calorimetry.*

On the basis that the mask can measure the breathing flow as well as the fraction of carbon dioxide and oxygen expired, the only parameter missing would be the volume expired. Nevertheless, it can be obtained by means of the air flow.

First the flow is integrated to get the total volume, and then, as only the volume expired is needed, it is measured subtracting the volume in the point that the flow becomes positive to the volume in the previous point when the flow became negative.

Since the mask processor is not powerful enough, it would make no sense to try to do all the maths that follows in the device. Then, as for the smartphone it does not suppose any effort, the mask is in charge only to take the measurements, not to operate with them.

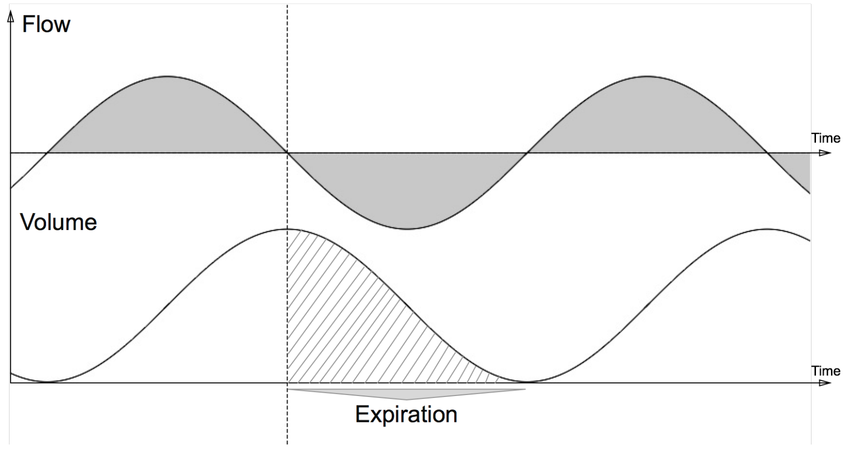



Figure 2.2: Graph showing an example of air flow and volume. The volume of the striped area would be the expiration volume. It can be calculated integrating the flow.

Once measured these three parameters (ventilation and the fraction of carbon dioxide and oxygen expired), the rest can be calculated by maths.

Notice that the ventilation can be continuously sent to the smartphone. However, with the $CO_2$ it is different. As the $CO_2$ inspired is the same for everyone (it does not depend on the person but on the atmosphere), it is useless to calculate it. Therefore, it must be calculated during the expiration. As a consequence, the mask can not send $CO_2$ values all the time, only in a moment during the following inspiration. Otherwise, the values would be mixed up.

In the next figure there is the range when the $CO_2$ expired should be calculated.

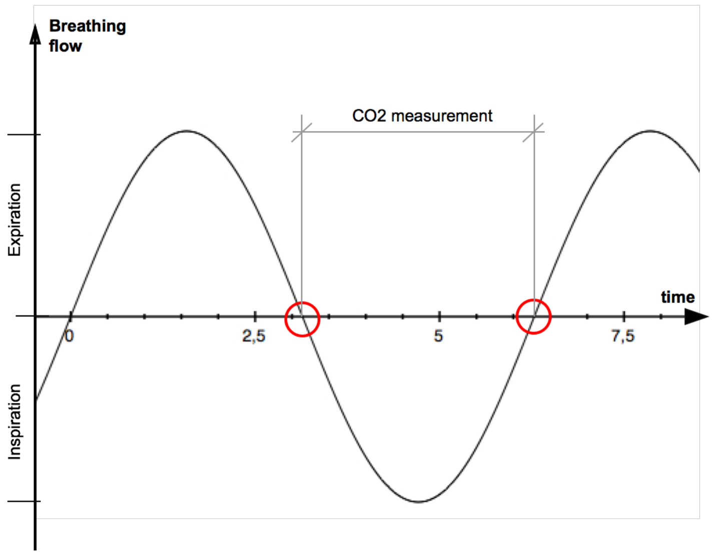



Figure 2.3: Period of time within the mask has to calculate the $CO_2$ expired. Notice that it must be after one expiration and before the following one starts.

The initials that are going to be used below mean:

- $\mathbf{V}_I$ = Volume inhaled.
- $\mathbf{V}_E$ = Volume exhaled.
- $\mathbf{F}_I\mathbf{O}_2$ = Fraction of oxygen inspired in air (=0.2095).
- $\mathbf{F}_E\mathbf{O}_2$ = Fraction of oxygen expired in air (variable).
- $\mathbf{F}_I\mathbf{N}_2$ = Fraction of inspired nitrogen (=0.7809).
- $\mathbf{F}_E\mathbf{N}_2$ = Fraction of expired nitrogen (variable).

First of all, the $VO_2$ must be determined.

$$VO_2 = V_I O_2 - V_E O_2 \tag{2.1}$$

As the gas volume is equals to the volume of air multiplied by the gas fraction, we have that:

$$VO_2 = V_I F_I O_2 - V_E F_E O_2 \tag{2.2}$$

There are three unknown variables so far. Nonetheless, it is possible to avoid measuring both inspired and expired volumes with the Haldane Transformation. This transformation assumes that nitrogen is physiologically inert. Therefore, the F$_I N_2$ must equal the F$_I N_2$.

$$V_I F_I N2 = V_E F_E N_2 \tag{2.3}$$

$$V_I = V_E \frac{F_E N_2}{F_I N_2} \tag{2.4}$$

The F$_I N_2$ can be measured in the atmosphere assuming that is what the individual will breath in.

But still, the F$_E N_2$ is unknown and not measured. However, given that air exhaled consist a 99.063% of oxygen, nitrogen and carbon dioxide; getting the fraction of nitrogen expired is so straightforward.

$$F_E N_2 = 0.99063 - (F_E O_2 + F_E CO_2) \tag{2.5}$$

Thus,

$$V_I = V_E \frac{0.99063 - (F_E O_2 + F_E CO_2)}{0.7808} \tag{2.6}$$

So finally, here is the volume of oxygen uptake:

$$VO_2 = V_E \frac{0.99063 - (F_E O_2 + F_E CO_2)}{0.7808} F_I O_2 - (V_E F_E O_2) \tag{2.7}$$

Notice that that now, in the equation 2.7, $VO_2$ only depends on expired air, which can be measured by the mask. The fraction of oxygen expired usually varies from 0.15 and 0.18, and the fraction of carbon dioxide between 0.020 and 0.035.

Having this, it is also easy to calculate the carbon dioxide consumption.

$$VCO_2 = V_E F_I CO_2 - V_I F_I CO_2 \tag{2.8}$$

Getting afterwards the RER (Respiratory Exchange Ratio).

$$RER = \frac{VCO_2}{VO_2} \tag{2.9}$$

And, finally, the kilocalories.

$$kcal = VO_2[L/min] \times RERcaloricequivalent \times time[min] \tag{2.10}$$

Where the RER caloric equivalent is equals to 3.815 + 1.232*RER.

Besides, knowing now the RER caloric equivalent and the RER, it is possible to estimate which fuel (carbohydrate or fat) is being metabolized to supply the body with energy.

In the following chart is shown the relation between these parameters.

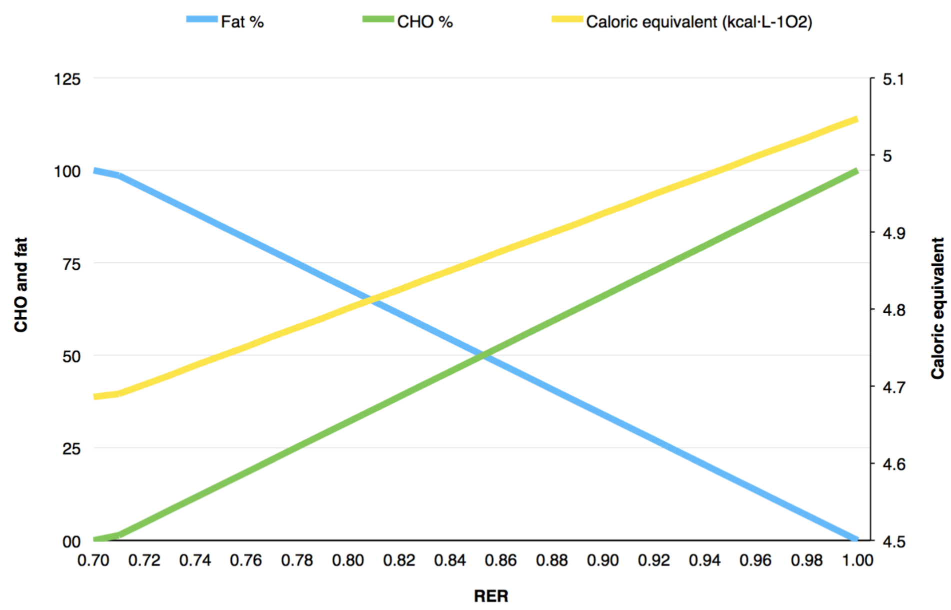



Figure 2.4: Role of CHO and fat and calories used depending on the respiratory exchange ratio (which is strictly related with the level of effort). Fat provide low but long-lasting energy. Carbohydrates provide fast and high energy. In every sport there is an optimal point where the athlete should be to reach the maximum efficiency.

Once mask and the application are able to calculate all the important parameters (excluding HR), the next step would be thinking about how to display them on the smartphone. However, firstly all the materials used will be explained in order to clarify later the processes from the measurements until the results.

## 2.2 Material

Here there is a sketch of the whole environment.

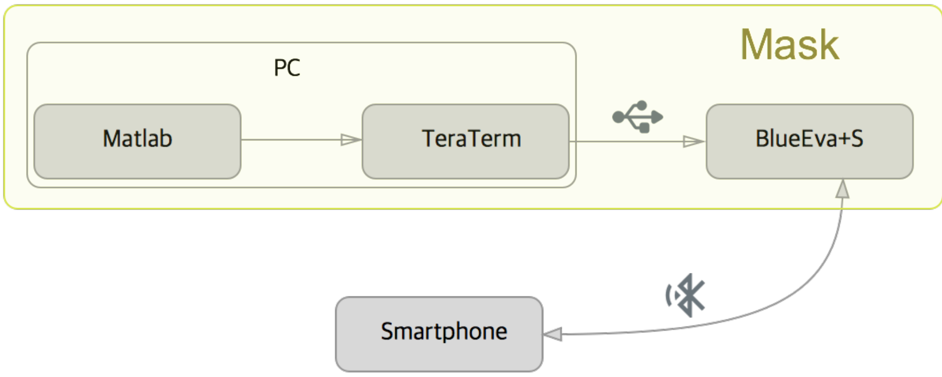



Figure 2.5: Communication environment. Matlab receives data from a measuring device and convert it into a TeraTerm script. TeraTerm is a terminal emulator software used to execute the scripts on the BluEva+S device. The device connects with the smartphone vie Bluetooth LE in a bidirectional way and both send information.

As observed, the PC with the BluEva+S play the role of the mask, so the smartphone can not distinguish whether it is establishing connection with the mask or the test device. Below these four components of the system and the mask will be described.

### 2.2.1 Mask

The mask will consist of three core parts: an anemometric sensor, a carbon dioxide sensor and a valve. The anemometric sensor will measure the flow of inhaled air. By measuring the flow velocity of gas during inhalation and integrating it over time, the mask will calculate the overall inhaled volume. During exhalation, a fraction of the exhaled air has to be seperated from the main stream by the valve and guided into a sperate chamber where the carbon dioxide sensor is placed. Due to the measurement principle of the carbon dioxide sensor, it is necessary to place it in a seperate chamber where convection is reduced. The level of carbon dioxide will then be measured during the following inspiratory phase and deliver the value before the next expiratory phase starts. This fact, that the carbon dioxide measurement is not available at any times, had to be taken into account when designen the emulation system for the mask which will be explained in more detail in the following sections.

### 2.2.2 BlueEva+S and TeraTerm

Since the mask is not completely developed yet, it was necessary to find a way to imitate its operation. The *Bluetooth Low Energy Module* of Stollmann was what better fitted to replicate the mask's behavior. Besides, the mask will use exactly this same chip.

For that reason, the *BlueEva+S Development Kit* was acquired and used to emulate the mask. This is an evaluation kit. The device is capable of sending data previously loaded on it via Bluetooth Low Energy. It is connected to a computer with USB. The data is loaded to it by means of a terminal emulator software called TeraTerm.

The evaluation kit also included the code of an application called *Stollmann* to communicate with the device via Bluetooth. That application had already developed the whole communication system and it could receive and send strings to the microcontroller. Thus, it was an excellent basis to start with.

### 2.2.3 Matlab

Since there was no real signal coming from the mask, it was necessary to generate it with Matlab. Matlab is a powerful software that can be used to generate all kind of signals. As the flow has the figure of a distorted sine, Matlab has been used to generate sines of different duration, frequencies and amplitudes simulating various sort of breathing measurements.

After all the data is generated, the next step is to transform it to make it understandable by TeraTerm and also by the smartphone.

Therefore, Matlab can generate signals, adapt them according to the communication protocol and generate then TeraTerm scripts ready to be executed in the test device and sent.

### 2.2.4 Smartphone

As mentioned, the smartphone is in charge of receiving the information and interpret it. For this purpose, an Android and iOS application have been developed (both based on the *Stollmann* one). The program used to develop in Android is *Android Studio*, from Google. In this software Java is used to program the logic and XML for the interface.

The first thing to do is to determine the application program interface (API) version. API [18] is a set of routines, protocols, and tools for building software applications. The API specifies how software components should interact and APIs are used when programming graphical user interface (GUI) components.

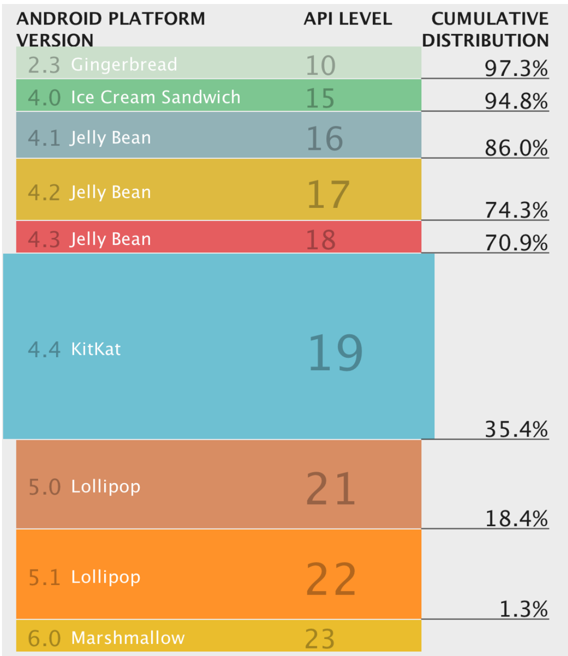



Figure 2.6: API users among all the existing Android versions. A 35.4% can use the application so far. However, due to the fast advances in Android every year, this percentage increases approximately monthly.

Currently in Android the application is working from the API 19 onward. There is a trade-off between the possible users that can be reached and the functionality of the application. The more advanced is the API, the more programming possibilities it offers.

In this project the API 19 was selected. This is due to for previous versions, the smartphones with an API higher than the 19th version could not detect the Bluetooth module. Although for the moment there are more people using lower versions than the 19th, it would make no sense to deprive the users with newer versions knowing that this will change in the near future.

## 2.3 Protocol

Hereinafter it is explained the procedure followed until the last version of the application. Also, it is explained how the data is processed from the measurements until it is displayed.

In the first place, Lufttacho takes the breathing measurements of the user: ventilation and level of $CO_2$ in expired air. Then, these data is loaded into Matlab. In case it is more interesting to generate new data with determined frequencies or amplitudes, this software is also used for that purpose.

Making use of a created function called "Sine.m", it is possible to generate sines indicating the frequency, length and amplitude. The sines can be mixed to create different harmonics with testing purposes.

The first thing to modify once the data gathering is done is the data format. Due to the device can not send infinite data at a time, it was interesting to find out the best format to send data as fast as possible. The Stollmann device can send a maximum of 20 bytes at once. Given that the only kind of data needed are numbers, it would be a waste of space to send information as strings (1 byte each digit). In spite of that, data is converted into bytes. Two bytes for each value are reserved. With two bytes it is possible to reach the number 65535. Bigger values will not be used.

Matlab is in charge of performing the conversion. The measurements taken by the mask have one decimal precision. Therefore, to avoid having to manage this in byte format, all the values are multiplied by ten and then transformed.

Here is an example of one value. Notice the importance of the line $num = num + (num > 0) * 2^{16}$. In case the number is negative, the most significant bit is turned into '1' in order to recognize that is negative in hexadecimal.

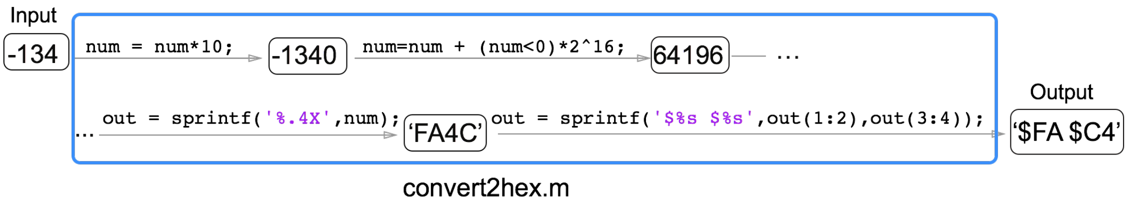



Figure 2.7: Example of decimal measured value converted by Matlab into hexadecimal. First they are multiplied by ten to avoid decimals. Then, the two's complement is done in case the number is negative and finally it is turned into hexadecimal and adapted for the TeraTerm script.

After the conversion is done, it is time to generate the complete TeraTerm script. However, before it is necessary to explain how the order and the meaning of the packages delivered to the smartphone.

The smartphone is the first sending information. It sends a basic command to the mask indicating which kind of data wants to receive (sport activity, stress test, state of the battery, state of the memory, etc.) and then the mask answers according to the structure explained below.

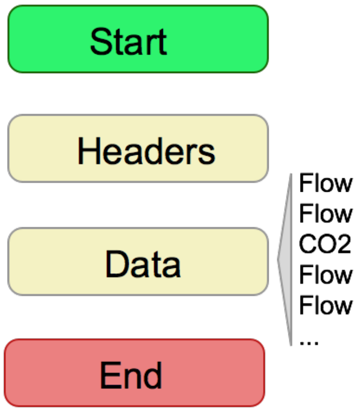



Figure 2.8: Structure of packages sent to the smartphone. First there is a start line indicating the beginning of the transmission. The headers indicates the kind of information being transferred. Afterwards, the values are sent and finally an End line denoting the end of the transmission.

As shown, the first set sent from the device indicates that the transmission is going to start. Then, the headers come. They give to the smartphone important information about the transmission, like the time when the measurements were kept on the mask, the duration of the test, the number of packages that are going to be sent, etc.

Later comes the data. All the packages with measured values have two bytes reserved at the beginning. They indicate first if they are part of an activity or a test and also which sort of data is being sent (flow, CO2, O2, and so on). Notice that it is impossible to glimpse in which positions will the CO2 values be received; the mask can only measure them once the exhalation is over (further explanation later).

Finally, the smartphone receives one "End" package indicating that all the values have been already transmitted. Thank to this line it is possible to know whether there have been looses during the transmission. Since the number of packages to be sent are indicated in one of the headers, it is possible to keep the count of all the packages received and then compare that counter with the header value. In the unlikely case there have been too many looses, it would be possible to restart the transmission.

Here there is a snippet of a TeraTerm script containing some values. As one might observe, the first two bytes indicate that the information is an activity ($21) and belongs to flow data ($00).

```
send $21 $00 $FB $5A $FB $1C $FB $1C $FB $73 $FB $5F $FB $65 $FB $BE $FB $DE $00 $43
 mpause 1
send $21 $00 $FB $E2 $FB $C5 $FB $BC $FB $7C $FB $7A $FB $78 $FB $7A $FB $BE $00 $43
 mpause 1
send $21 $00 $FB $B0 $FB $D9 $FC $36 $FC $3C $FC $27 $FC $4E $FC $50 $FC $60 $00 $43
 mpause 1
```

Figure 2.9: Snippet of TeraTerm script. First two bytes show the kind of values in that line. The following eight are the measured values and the last two bytes are kept to implement a counter of the number of lines sent.

First of all, the values are preceded by a dollar symbol. This is to indicate that they are hexadecimal values. There are also two different commands. The command "send" is used to send a string of data. After every line of data there is a "mpause" followed by a number. This is the time in milliseconds that the microcontroller must wait after sending a package.

The point of these pauses is that, if they are not previously established, the device will send the information in an unknown rate. This way, having always packages of 20 bytes and the pause in between determined, the communications are better controlled.

As mentioned, every line contains 20 bytes, which is the maximum size available. The sets must be always this size because otherwise the microcontroller joins different packages to reach the maximum size before sending them. In case that happens there is no way to differentiate between packages, not even the parts of one.

The following example has been generated by Matlab. Now it will be explained all the process followed by Matlab to produce TeraTerm scripts.

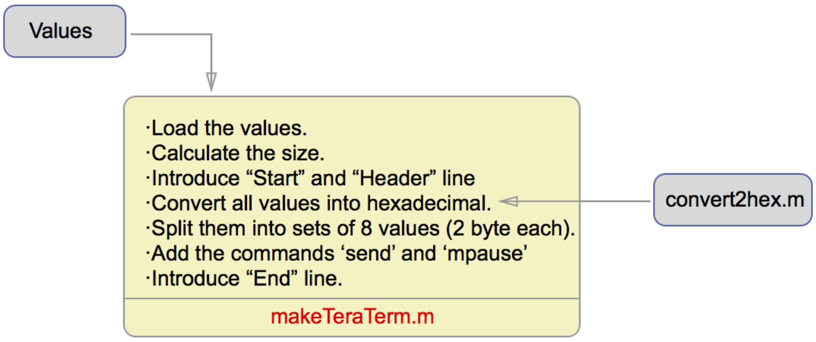



Figure 2.10: Matlab functions.

As observed in the picture, first Matlab load all the values, which will be in decimal format. Thereupon, in the *makeTeraTerm* function, it opens a file and introduces the first lines The dollar symbols and the TeraTerm commands “send” and “mpause” are included here. Then it divides the values into sets of eight (two bytes each value). This is because two bytes in the beginning and two bytes in the end are kept to inform about the kind of values in that specific line. The TeraTerm commands are included here as well in every line.

Finally, when all the values have been processed, it includes the ”End” line and save the file created in TeraTerm format.

### Smartphone

The smartphone is the last stage of the protocol. Firstly, it scans nearby devices and shows them (*ManagerActivity*). The user can choose one and the application connects automatically with it, all using Bluetooth Low Energy. Once both devices are paired, the smartphone can ask for information to the mask by sending a command. The mask will interpret it and answer following the structure shown in the figure 2.8 (*PeripheralActivity*).

As explained before, the application will synchronize all the data from the mask before showing the results. At the same time the data is being downloaded, it is also being kept and processed through the *SpiroMeasurement* class.

Every time a new package of values come, it is split into the command bytes and the values and then passed to the *Spiromeasurement* function. There, every value is processed and the volume calculated. Afterwards, the whole set of flow, volume and time is kept.

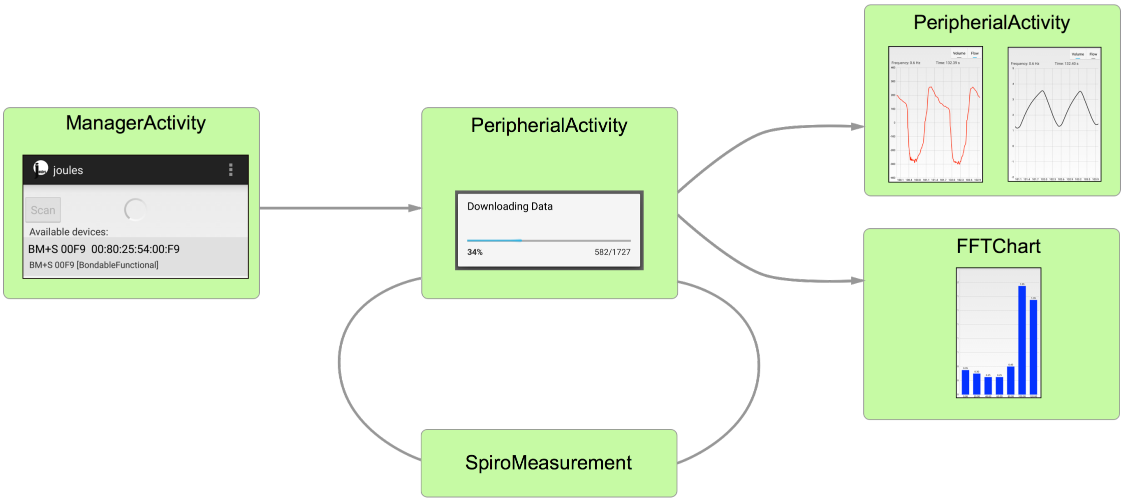



Figure 2.11: Sketch of the application main activities. First the smartphone scans nearby devices and connect with one. Then it collects data from the device and make calculations on the fly. Finally, it displays the results.

Thereupon, the smartphone will show the data received and processed.

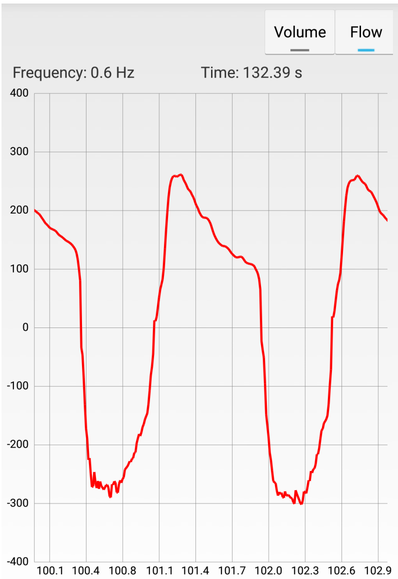
The most intuitive way to display the data is in graphs. With that purpose, *MPAndroidChart* [19] was the best option. It is a library that provides a large range of different sorts of charts that can be easily implemented.

To pick one kind of chart, it is necessary to know which type of information is going to be drawn on it. In the first place, given that the mask can measure the breathing flow and the $CO_2$, the flow will be shown in one chart. However, the $CO_2$ will not be drawn because of its lack of relevance as a chart. It will be rather used for the calorie consumption calculations.

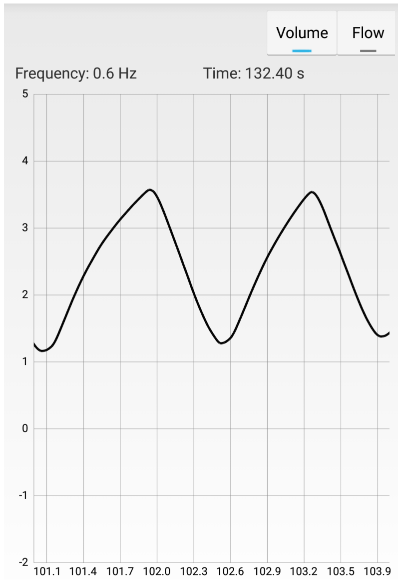
On the other hand, as the flow-volume loop is one of the most valuable graphs in ergospirometry, there was an attempt to draw it. Unfortunately, the *MPAndroid-Chart* works with indexes in the X Axis, and they can only go upwards. Therefore, there is no way to draw a loop. The other option then was to make a chart for the flow and another one for the volume so that the user can switch between them on the same screen (buttons up on the right side of the screen in the figures bellow).

In order to show two different charts in one same screen a listener was implemented. Hence, the smartphone is aware all the time of which of the buttons is pressed. In case the graph changes, it loads all the data from the new graph selected overwriting the current one.

The information was performed in a line chart because it was the most representative. Besides, the window size is only big enough to show a few seconds (at least one period). It is possible to scroll the chart to the left or to the right to see the rest of the data. It has been done this way because in case a whole activity is shown in a window it would be impossible to differentiate the values.




(a) Flow.




(b) Volume.

Figure 2.12: Screenshots of the application showing a few seconds of a breathing measurement. The flow is just displayed without any calculation. The volume is calculated by means of the flow and then shown. Notice that on the screen also appear the duration of the activity received and the average breathing frequency.

Finally one last chart was implemented in the *FFTChart* class. This one is about the breathing frequency. Given that this one is a bar chart, it could not be shown with the two others. Then, it has to be accessed through a button down on the screen.

In this new chart, the Fast Fourier Transform (FFT) of the flow values is calculated. However, the bars represent only the greatest value calculated every 20 seconds. In this case, the window size will increase to five minutes.

This graph is interesting to check in which time intervals the breathing frequency has been higher or lower. Then, it is possible to know exactly how intensive is one determined exercise for a specific athlete.

For that task, the library *JTransforms* was used [20]. It provides several functions for Fourier Transforms performing. In this case, only the *realForward* one was used. It calculates the FFT of an array and overwrite the results on it.

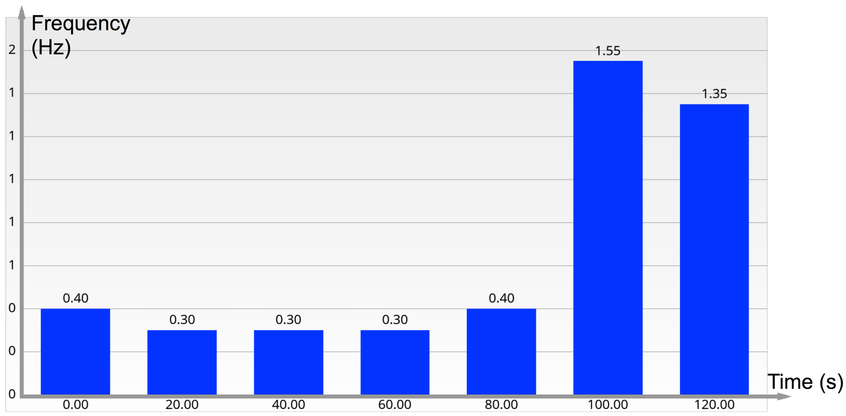



Figure 2.13: Fast Fourier Transform. In this graph are displayed the maximum breathing frequencies of the activity received every 20 seconds. It is interesting to check the intensity of the exercise.

### Transmission channel

One problem faced too was to decide whether to display the results on the fly or wait until the end of the activity to synchronize the smartphone with the mask.

For debugging purposes, at the beginning the application was developed to show results on the spot. Nonetheless, *MPAndroidChart* charts are not meant to display data in life, so that entailed many problems when refreshing the screen or changing from one graph to another.

Despite the difficulties, it finally worked. However, thinking already about the final purpose of the application, it made sense to develop a second version where data is synchronized after the activity. This whole product is supposed to be completely functional without any help or supervision. Hence, there is no need to be showing the results all the time on the smartphone. Besides, it implies a considerable save of energy if both the mask and the smartphone are not connected transmitting data over the activity.

The only issues to take into account when transmitting data after the activity are that the user must wait while the data is being transmitted and also that the mask has to keep the data in its memory before it is sent. In the *Discussion and conclusion* section both issues will be covered.

In this second version, the smartphone scans all the close devices in the same way as the first one. once connected to one of them, it waits for all the information (a loading toast appears on the screen showing the progress of the transfer).

For the transmission channel Bluetooth was chosen. It is the only one that allows data transmission on the spot without the need of other devices like a router. Moreover, it can be connected for a long time and the devices paired can be a few meters separated.

However, the conventional Bluetooth is not used for this project. Due to the arising of new devices that can be connected between them and to smartphones during long periods of time, it was meaningful to develop a new manner to transmit data with the lowest possible consumption. Thus, as many devices just need to transfer little amounts of data, *Bluetooth Low Energy* (BLE) was developed mainly for smart homes, health and fitness sectors.

Even though they use the same radio frequency (2.4 GHz), this kind of Bluetooth is not compatible with the “Classic” Bluetooth protocol. The major difference between them are shown in the following table [21].

| **Technical specification** | **Classic** | **BLE** |
|---|---|---|
| Range (theoretical maximum) | 100 m | > 100 m |
| Over the air data rate | 1-3 Mbit/s | 1 Mbit/s |
| Latency (from a non-connected state) | Typically 100 ms | 6 ms |
| Min. total time to send data (determines battery life) | 100 ms | 3 ms |
| Power consumption | 1 W as the reference | 0.01-0.5 W (depending on the use) |
| Peak current consumption | <30 mA | <15 mA |
| Primary use cases | Mobile phones, gaming, headsets, audiostreaming, smart homes, wearables, automotive, PCs, healthcare, sports, etc. | Mobile phones, gaming, smart homes, wearables, automotive, PCs, security, proximity, healthcare, sports, Industrial, etc. |

Table 2.1: Comparative table classic Bluetooth Technology VS Bluetooth Low Energy.

As one might observe, the Bluetooth Low Energy fits perfectly with the communication protocol previously developed.

# Chapter 3

# Conclusions

## 3.1 Results and analysis

In this section the objectives achieved are exposed.

The first goal was to find a device that could emulate the behavior of the mask. That has been attained with a system consisting of the *BluEva+S* test device, TeraTerm and Matlab.

Then, the most important parameters to be displayed have been defined, as well as the way to calculate them. Afterwards, the smartphone application has been developed in two versions: one for debugging purposes and the other meant for the user.

Finally, a protocol has been developed as well for the communication between the microcontroller and the smartphone. It specifies, as mentioned before, the path to be followed by the data since it is measured until it is displayed on the smartphone.

Regarding the emulation environment, it now fulfils the goal of allowing the development of a smartphone application. Therefore, now it is possible to work in both parts of the project in parallel.

The debugging smartphone application has been completely developed. It allows to:

- Check whether there are losses during the data transmission.
- In case there are losses, identify where they are.
- A faster improvement of the communication protocol given that it is not necessary to wait until all the values are transmitted.
- Check the maximum sending frequency by varying it on the spot while watching the results.

Concerning the final application version, only the basis has been developed. The smartphone establishes connection automatically with the device. Both of them can send data mutually and the results displayed are already useful for the user. Nonetheless, not all the expected parameters can be shown yet because of a lack of time. In the next section are suggested the steps to complete the user version of the application.

The communication though, is not working as expected. When synchronizing the data after one activity, it takes longer than it should. However, it is probably only a matter of reprogramming the test device.

There is also another lost end about the heart rate monitoring. So far it can not be measured. Nevertheless, there are lots of possibilities to handle this problem. They will be mentioned in the last section of this thesis.

Here there is an example of the air flow measured during two minutes with the Lufttacho. In the first graph the data have been plotted with Matlab straightaway from the measuring device. In the second graph, it has already been sent to the smartphone, processed and shown.

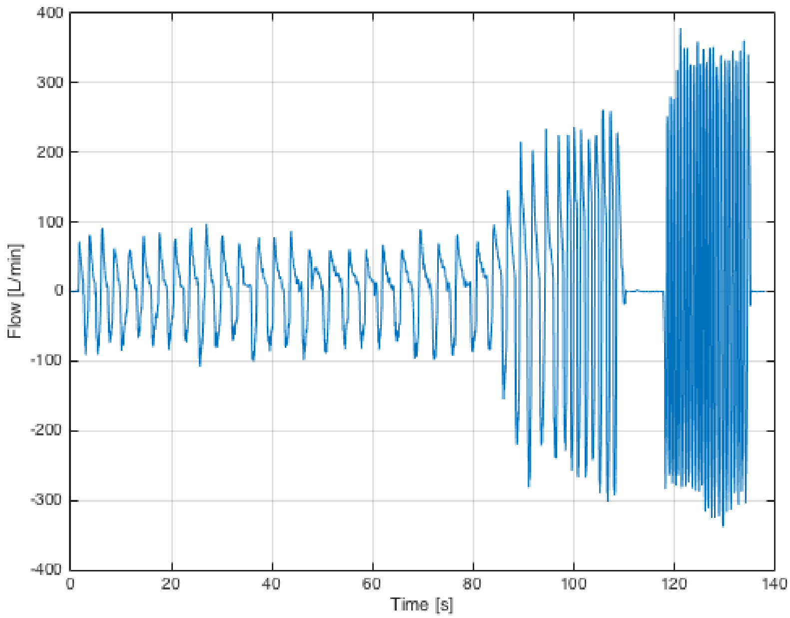



Figure 3.1: Flow graph with Matlab.

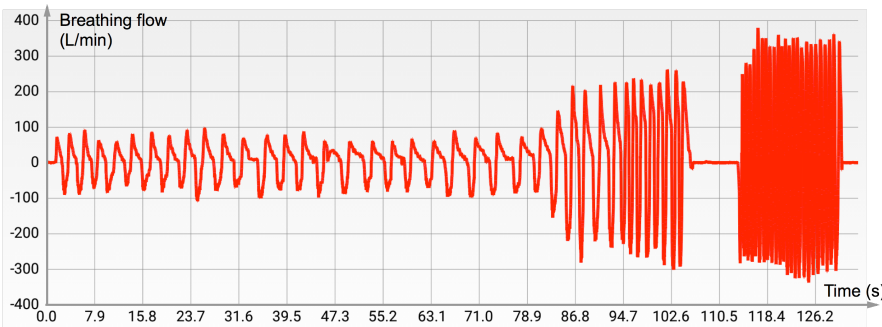



Figure 3.2: Flow graph with the smartphone.

As one might observe, there are no differences between them. Thus, this demonstrates that the emulation system for the mask is working and the basis of the application as well.

All things considered, despite the parts not working yet or not completely developed, the most important goals have been achieved.

## 3.2 Discussion and conclusion

After all, the question about whether it is truly possible to build the mask continuously arises. As one might observe over the previous sections, the bases of the product are already established. However, it must be clear how to continue from the current state of development of the product until its final completion.

Here are exposed the possible next steps for the further development of the project.

### Possible improvements

The first one would be introducing a **heart rate monitor** in the system. The most common device to measure heart rate in athletics consists of a belt turning around the body, just under the chest. This could be an option due to its low price and the fact that it works with Bluetooth.

Another option would be a watch with a sensor integrated. For example, The Garmin Forerunner®. It includes also a GPS. It synchronizes with the smartphone via Bluetooth in the same way as the mask does. That is an advantage because it would not be necessary to take the smartphone while performing the activity. Moreover, the route tracking and the speed measurements would be more precise in case they are calculated by the watch instead of by the smartphone.

A third choice would be heart rate monitoring headphones. Most of them work with Bluetooth as well. Besides, they could be useful in order to give instructions to the athlete while performing a stress test. The problem with both, the headphones and the watch, is that they cost around one hundred euros more than the belt.

On the other hand, after synchronizing the mask and the HR monitor with the smartphone, it would be necessary to merge the data of both devices. This problem though, can be solved aligning the time indexes before displaying the results.

In the scenario that the HR monitor is already available, below a sketch of a possible final version of the smartphone application is detailed.

Firstly, the application would keep register of all the users including their mail, name, age, weight and high. This is useful for social purposes and also to be able to calculate some parameters. After that, the user has two options: synchronize with the mask to get data or check the history of previous activities.

In case the synchronization is done, the coming data can be from a normal activity or a test (it would be indicated in the header lines). If it is an activity, a new screen will appear with the possibility of choosing two kind of charts. The first one with the pace (min/km) and the HR on the Y axes. The second one would show the CHO and the fat burnt. Both graphs with the distance run in the X axis. Depending on the chart chosen, one of the following tables would be shown below it.

| **Distance** (km) | **Pace** (min/km) | **Elevation gained** (m) | **Elevation lost** (m) | **Heart Rate** (bpm) |
|---|---|---|---|---|
| 3 | 4:39 | 8 | 23 | 100 |
| 4 | 4:55 | 32 | 5 | 110 |
| 5 | 5:08 | 20 | 0 | 96 |
| 6 | 4:31 | 3 | 16 | 111 |

Figure 3.3: Example of pace/HR table. All these parameters together can give a good overview to the athlete about his performance depending on the difficulty.

The pace is an important factor to be considered depending on the kind of training. For example, when training for long distance races, it is interesting that the pace remains the same in every kilometer because speed variations mean a waste of energy. The elevation gained and lost is also important for mountain activities. In the mountain scenario, the pace should change depending on the elevation in order to reach the highest possible efficiency.

| **Time (h:mm:ss)** | **Distance** (m) | **CHO** (g/h) | **FAT** (g/h) | **Heart Rate** (bpm) |
|---|---|---|---|---|
| 1:00:00 | 7.0 | 64 | 27 | 85 |
| 1:00:30 | 7.1 | 67 | 29 | 110 |
| 1:01:00 | 7.3 | 84 | 25 | 100 |
| 1:01:30 | 7.6 | 92 | 24 | 120 |

Figure 3.4: Example of CHO/fat table. This table is situated below the graph showing these same parameters. It has already been explained why are them important in the *Theoretical basis* section.

In case that the information received from the device is from a test, the results displayed on the smartphone will not be the same than for a normal training. There will be one table showing the main ergospirometry parameters ($VO_2$, VE, $FEO_2$, $VE/VCO_2$, HR, CHO and fat) over the time. Besides, in another screen there will be one chart showing the $O_2$ consumption on the Y axis and the speed on the X axis. In this chart it would be possible to add curves from past tests. That way, it would be possible to compare the $VO_2$max point. As explained before, that comparison is useful to check the improvements done.

To that graph corresponds the following table:

| | AEROBIC THRESHOLD | ANAEROBIC THRESHOLD | VO2 MAX |
|---|---|---|---|
| HEART RATE (bpm) | 150 | 182 | 190 |
| SPEED (km/h) | 10 | 15 | 17 |

Figure 3.5: Example of $VO_2$ thresholds table. It denotes the aerobic threshold of the athlete according to the $VO_2$max.

These screens described would form the main structure of the application. All the activities and tests would be saved in a server and in the smartphone if desired. Then, it will be possible to check them from every computer and smartphone just logging in with the user created before.

### Discussion

In this section will be considered possible future problems when developing the application described above.

As mentioned, the mask must have enough memory to save one whole activity before sending it to the smartphone. Besides, there is the possibility that the smartphone keeps the activities in its memory as well as in the server. Therefore, it makes sense to calculate **how much memory would need one whole activity**. With this purpose, activities with different lengths have been simulated with Matlab.

The first simulation lasts ten minutes, which would be the duration of a test approximately. The data size for this length is 64 kB.

Given that a normal activity lasts around 30 minutes, the second simulation lasted one hour in order to ensure it will not take more memory than that. The size then happened to be 373,6 kB.

If only one activity is saved it will not suppose a problem neither for the smartphone nor for the mask. However, the smartphone could have to save all the activities during a year or even more time. Considering that one activity is saved per week, at the end of the year the whole would take up around 20 MB. Taking into account that an average smartphone has 8 GB or more, saving 20 MB is good enough.

Taking advantage of these simulations, it was also measured **how long it took to synchronize longer activities**.

In the testing version of the application where the data is shown on the fly, the synchronization takes as long as the activity lasts. In the other version is different though. Due to the limitations of Bluetooth Low Energy, the data is not received immediately or as fast as it would do via Wi-Fi.

Following the same method as before, time measurements have been taken for ten minutes and one hour. For the ten minutes activity, the synchronization lasts 2 minutes approximately. On the other hand, for the one hour one it lasts 13 minutes.

| | BlueEva+S | |
|---|---|---|
| | Transmit [kbit/s] | Receive [kbit/s] |
| iPhone 6 (iOS 9.1) | 47 | 37 |
| Nexus 5 (Android 5.1.1) | 41 | 36 |

Figure 3.6: Transmission rate between the device and an Android and iOS smartphone. With these values it is possible to check whether the transmission speed is the proper one or, in contrast, there is something wrong with it that delays the communication.

According to the table provided by Stollmann, the receiving rate is 36 kbit/s. Therefore, for the Android smartphone and one hour activity:

$$\frac{373,6kbyte * 8kbit/kbyte}{36kbit/s} = 83seconds$$

Thus, knowing that the values are transmitted in byte format, there is no way to increase the sending speed using the smartphone. Therefore the problem is probably on the Stollmann device programming, as suggested in the previous section.

On the other hand, it was also tested if the sending speed changed with the distance between the device and the smartphone. The result was that until they were about to reach the limit distance where the connection is lost, the speed remained the same.

It has been demonstrated then that it would be possible to save many activities. Also, although it can be improved, the synchronization time so far is already acceptable.

Staying in the transmission field, another issue to consider is whether **all the transmitted values to the smartphone are properly received**.

With the purpose of checking whether there are losses during the transmission, four bytes in the header line (at the beginning of the transmission) have been kept to indicate to the smartphone how many packages should be received. After the headers, the smartphone starts calculating the bytes received until the "Finish" line arrives.

Then there are two options to check if there are packages missing. The first option is to compare the number of lines received with the number indicated on the header. It must be done once the transmission is over. The second one is checking whether the counter increases one by one in the packages received. Besides, in this option it is also possible to find out which package is missing in case there are losses.

The result was that approximately a 3% of packages are lost. This is not critical for making the calculations for the graphs and tables displayed. However, it is possible to get a 0% of looses if needed increasing the synchronization time.

Trying to solve this little problem without decreasing the transmission speed, an acknowledge system was established. When the test device sent one set to the smartphone, it had to wait until a ”GO” signal from the smartphone to send the next one. That way none of the packages was lost. Nonetheless, it took double the time to finish the synchronization, so it was not considered as an option.

Once answered the most important questions about the software, the following ones will be addressed to the hardware.

The main question in this field is whether **the mask would still be useful without the smartphone**.

The principal task of the smartphone in the project is to display the results. It allows to see them immediately after the measures are taken and in any place without the external need of a computer.

Apart from that, with the smartphone it is also possible to keep track of the speed and route during the activities. Given that having the route traced on a map is not necessary to provide the parameters defined in the protocol, this is not considered a reason to keep the smartphone. However, the speed measurements are actually necessary.

When using a smartphone, the speed measurement is carried out by the GPS. Nevertheless, the speed can be obtained with an accelerometer as well. Currently they are small enough to be integrated into the mask with the microcontroller. Then it is explained the procedure to calculate the speed making use of the accelerometer.

As their name indicates, they provide the acceleration. It is a matter of integrating it to attain the velocity.

$$v(t) = \int_0^t a \cdot dt$$

Usually, the accelerometer give the information as acceleration in the x, y and z axis.

Therefore, to calculate the speed it could work like follows (in case the intervals are regular):

$$v_x += \frac{a_x + a_{x0}}{2}(t - t_0)$$

$$v_y += \frac{a_y + a_{y0}}{2}(t - t_0)$$

$$v_z += \frac{a_z + a_{z0}}{2}(t - t_0)$$

And then, once obtained all the values:

$$|v| = \sqrt{v_x + v_y + v_z}$$

Nevertheless, these are simple approximations of an integral. The Simpson method [22] could be used to get a more accurate result of the integration.

Considering all the options, the smartphone would not be necessary to obtain the parameters needed. Therefore, the tests could be performed only with the mask. The smartphone application would still be useful though for checking the results when desired without the need of a computer.

Changing topic now, it has been mentioned before that a heart rate monitor provide relevant information for the athletes. Nonetheless, **would the mask still be useful without a heart rate monitor?**

Monitoring the heart rate is a function that has not been implemented yet in the mask, and this one can not be performed by the smartphone either. However, it is one important parameter when comparing it with the speed and the $VO_2$. So, what is set out here is whether the knowledge of heartbeat is a fundamental factor for this product.

It could seem that the HR monitoring can be avoided by knowing its relationship with the $VO_2$. However, it has been demonstrated that they are not proportional [23]. Their relationship rather vary depending on the activity.

As explained in the Background section, the heart rate allows the athlete to know in every moment in which zone is he training being performed. Then, the athlete can modify the intensity in case is not the proper one. Meanwhile, the $VO_2$ determines aerobic and anaerobic threshold. Although the mask can still offer valuable information without measuring the HR, it is a lot more complete if the HR is included.

**Conclusion**

As a general conclusion, for the moment there is not any trouble that impede the development of the product. Despite many things can be improved, it has already been set out how to do it.

My personal opinion about this project is that it is really innovative and it can be finished with the expected results. A product like the explained in the thesis would help the professional athletes to improve their efficiency with the possibility of performing ergospirometry in real conditions. On the other hand, it would also encourage the non-professional athletes to keep practicing sports and reach more ambitious goals.

Even for the people that do not practice sports would play an important role. Performing one of the tests that the product will offer, every user would be aware of his cardiovascular state. This is a powerful tool for disease prevention. Furthermore, in the same product they would also have basic instructions to improve their health.

For all these reasons, I think the project would have an important repercussion in the athletics world and out of it as well.

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