Revitalization of Axial Flow Pump/Turbine h26 Test Rig

Jad Kassab

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Approval of the Institute of Graduate Studies and Research

———————————————
Prof. Dr. Mustafa Tümer
Acting Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Mechanical Engineering.

———————————————
Assoc. Prof. Dr. Hasan Hacışevki
Chair, Department of Mechanical Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Mechanical Engineering.

———————————————
Assoc. Prof. Dr. Hasan Hacışevki
Supervisor

Examining Committee

1. Prof. Dr. Fuat Egelioğlu   ———————————————

2. Assoc. Prof. Dr. Hasan Hacışevki   ———————————————

3. Asst. Prof. Dr. Davut Solyalı   ———————————————

ABSTRACT

Various solutions are available in the market to enhance the quality of laboratory experiments, but the majorities are expensive. In this study, we present a low-cost approach for the automation and computer aided control of an axial flow pump-turbine test rig, which can be easily adapted to varying demands of laboratory applications.

Essentially, this design is developed by upgrading the existing available system by selecting an optimum system configuration comprising an Arduino platform which is an open-source prototype based on a microcontroller; sensors, motors, relays, etc. based upon the system requirements and specifications. The system is controlled by Visual Studio software that is an expert in visual basic programing language and installed on a personal computer located in the hydraulic laboratory of Mechanical Engineering Department at Eastern Mediterranean University.

The proposed system is designed for cost, flexibility, modularity, maintenance, and re-configurability. A user-friendly interface is developed for performing measurements, calculation, plotting and automating the task of laboratory equipment. It also offers some modules to control various experiments in the hydraulic laboratory in order to extend the number and type of conceivable experiments in education.

Keywords: Laboratory experiments, Automation, Axial flow pump/turbine, Arduino, Visual Studio

ÖZ

Laboratuvar deneylerinin kalitesini arttırmak için piyasada çeşitli çözümler mevcuttur, ancak çoğunluk pahalıdır. Bu çalışmada, laboratuvar uygulamaları için düşük maliyetli, değişen taleplere kolayca adapte edilebilir bir eksenel akış pompa-türbin test seti için otomasyon ve bilgisayar destekli control sistemi tasarlanıp uygulanmıştır.

Esasen, bu tasarımı bir mikrodenetleyici tabanlı açık kaynak prototipi olan Arduino platformu ile oluşan bir optimum sistem yapılandırması seçerek varolan kullanılabilir sistem; sensörler, motorlar, röleler, sistem gereksinimleri ve özellikleri göz önüne alınarak geliştirilmiştir. Sistem Visual Studio uzman programlama dilinin Doğu Akdeniz Üniversitesi Makine Mühendisliği Bölümü hidrolik laboratuvarda bulunan bir kişisel bilgisayar üzerine yüklenmiş Visual Studio yazılımı tarafından kontrol edilir.

Önerilen sistem düşük maliyet, esneklik, modülerlik, bakım ve yeniden yapılandırma için tasarlanmıştır. Kullanıcı dostu arayüzü laboratuvar cihazlarının ölçümleri gerçekleştirmesi, hesaplamaları yapması, grafiksel çizim ve işlemleri otomatikleştirmesi için geliştirilmiştir. Ayrıca modüler yapı sayesinde hidrolik laboratuvarında çeşitli sayıda ve tipte deneylerin yapılabilmesine olanak sağlamaktadır.

Anahtar Kelimeler: Laboratuvar deneyleri, Otomasyon, Aksiyel eksenli pompa/türbin, Ordinyo, Görsel studyo

ACKNOWLEDGMENT

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INTRODUCTION

1.1 Presentation Of The Problem

One of the major difficulties engineering students are facing these days after graduating is the lack of technical exposure to high quality laboratory equipment. The modern industry requires engineering students to be familiar with up to date equipments which they might use in their future working environment.

However, most of the universities and high schools are not providing a strong and adequate engineering infrastructure to their students. A study was carried out on hundreds of recently graduated mechanical engineering students at the University of Johannesburg to try to explain the reasons behind their poor performance in the industry. This study showed that the main reasons behind the failure of those students when facing the real working environment is the lack of career advising provided to them in addition to the lack of strong technical infrastructure in their high schools and universities (Ionescu, 2014).

According to Naimi (2007), most of the laboratory experiments performed in universities are still using conventional equipment which have many drawbacks such as:

1. Conventional equipment are not capable of connecting to computer aided software and thus data and results cannot be monitored online.

2. Engineering students are spending more time in the labs for preparation and performing the experiments when using the conventional equipment.

3. Using analog instrument to carry out experiments are less accurate than digital measurements provided by advanced equipment.

4. Performing the experiment using a computer software will help the student to gain time and keep focusing on the main objective of the experiment which might be scattered when using an old fashioned instrument.

5. The experiment results cannot be recorded accurately due to the fast changing readings on the analogue devices which are not sensitive enough as digital ones.

Most universities laboratory staff stress on the need to provide students with laboratory teaching aids. Many developed countries are nowadays providing students with beneficial and powerful educational products which are very expensive and hard to be found in less developed countries (K. Mallalieu, R. Areatas, and D. So'Brien, 1994).

1.2 A Felt Problem That Needs A Solution

In view of the above, necessary actions should be implemented beginning from high school to help students meeting the challenges of the recent competitive working industry.

Recent studies have shown that engineer's poor performance in the industry can be reduced by following certain steps. One major step is to frequently expose the future engineer to the real world of industry by providing internship programs which will help them familiarize themselves with their special working field. Another important

step is to introduce more laboratory sessions to the engineering syllabus which will give the students strong practical expertise in addition to their theoretical knowledge (Ionescu, 2014).

In fact, the above mentioned ideas of early industrial exposure and strong practical expertise constitute the basis of a successful learning methodology that will surely help future engineers to tackle any difficulty they might face in the future.

In addition, all educational institutions nowadays should be equipped with the most recent and advanced equipment or should develop their existing ones if possible to help students familiarize themselves with the most recent technologies. However, since the price of those advanced equipment is respectively high, manufacturers should provide the market with tools that can be upgraded to newer versions whenever a new technology arises (Greg M, 2002).

1.3 Motivation

Nowadays, education alone is not enough. Instead, it should be accompanied with advance technology such as the "World Wide Web" in order to produce a final strong product suitable for students to face real life challenges. One version of this technology which is experiencing a noticeable growth nowadays is the web-based laboratory instruments which can be connected to computer software resulting in better quality and easy monitoring of experiment's outcomes (J.M Sebastian et al, 2003).

The Accreditation Board for Engineering and Technology (ABET) organization has also urged universities to be equipped with advanced laboratory equipment which it

considers a key factor in a successful modern engineering industry (P. Antsaklis et. Al,1999)

In addition, through computerized laboratories, engineers and scientists are now connected to each other online and can communicate together worldwide which can help in solving many recent scientific dilemmas (Layne, S. P., Beugelsdijk, 1998).

Furthermore, engineering laboratory experiments involving the pump/turbine testing using computer aided software enable students to monitor results easily and obtain accurate measures without any possible human errors.

The above mentioned technology for pump/turbine laboratory experiments has many advantages such as:

1. Easy monitoring, controlling and handling of experimental data through flexible and user friendly computer software.

2. Diversity of testing options using a multipurpose software.

3. Cost effective compared to traditional testing procedures.

4. It allows the conversion from a traditional system to an advanced computerized one and thus helps educational institutions save money.

5. Giving poor educational institutions the chance to share remotely advanced laboratory equipment.

6. Ability to update its current computerized system with newer versions whenever new technologies are discovered in the market.

7. More accurate readings and measurements with the help of a micro-controller based instruments.

All academic professionals agree on the importance of implementing advanced technologies in engineering laboratories for the many reasons listed above. However, they disagree with each other on the way this technology should be implemented in education institutions. The debate here is significant since the technology implemented will modify the educational system in engineering schools and affect it degree of effectiveness (Nickerson, Corter, Esche, & Chassapis, 2007).

1.4 Statement Of The Problem

All the above ideas of working efficiently while saving time have inspired me to perform the following experiment where other mechanical engineers will benefit from in the future.

In this study, an axial flow pump/turbine is selected for revitalization by using electronic sensors units controlled by software, which is cost effective and adaptable to any situation which we may encounter during the laboratory experiment. Basically, the experiment consists of upgrading the current available system based on specific requirements and specifications using optimum configurations involving: motors, microcontroller, sensors, relays etc.

The experiment will be conducted and monitored by the specialized software "Visual Studio" which can be found in the hydraulic laboratory of Mechanical Engineering Department at the Eastern Mediterranean University (EMU).

The study starts first by describing the machine that will be upgraded with an explanation of the remote laboratories technology used. Afterward, a description of the model is presented. The approach of implementing the design will be presented

progressively. At the end, the results of a pilot study are presented accompanied with a discussion of their implications.

Chapter 2

LITERATURE REVIEW

2.1 Importance of Laboratories In Education

Lab classes are undoubtedly essential in engineering studies for they help the future engineer to obtain a suitable training. Although these lab classes have been traditionally carried out in the lab classroom, the current evolution of communications and computing resources in general, allows the conducting of remote practices to be faced with increasing means.

Among others, in areas such as automation, robotic or electronics, different approaches of remote laboratories are emerging, which allows the access to didactic or professional material of different kind. For example, in Indrusiak et al. (2007) the reader can get a general overview of remote laboratories for digital systems design. Andújar et al. (2011) presents an example of this kind of lab, which allows programming and interacting with a Field Programmable Gate Array (FPGA) based development board. Vargas et al. (2011) and Santana et al. (2013) show remote labs devoted to Automatic Control. In addition, in the last one a comparative of the most outstanding remote labs of this kind is included. An example of remote labs applied to the engineering measurement can be seen in Restivo et al. (2009). Marín et al. (2005), Jara et al. (2008), and Mejías and Andújar (2012) present different remote labs devoted to teaching robotics.

However, in these and many other approaches, the designed solutions to develop labs can be considered specific. Each of them solves in its own way the different aspects implicated in the remote lab development.

2.2 Technologies Used To Update Laboratories

Control education passed through a rapid development in recent years. A whole set of new methodologies of student-subject interaction were set by the upsurge of modern information technologies. This phenomenon has affected almost all fields of education and science, but mostly those within technical areas.

The developed solution for remote labs using DAQ is being used in the Higher Technical School of Engineering at the University of Huelva (SW Spain) to develop remote labs in different subjects into the Computing Engineering, Energetic Engineering and Industrial Electronics Engineering degrees.
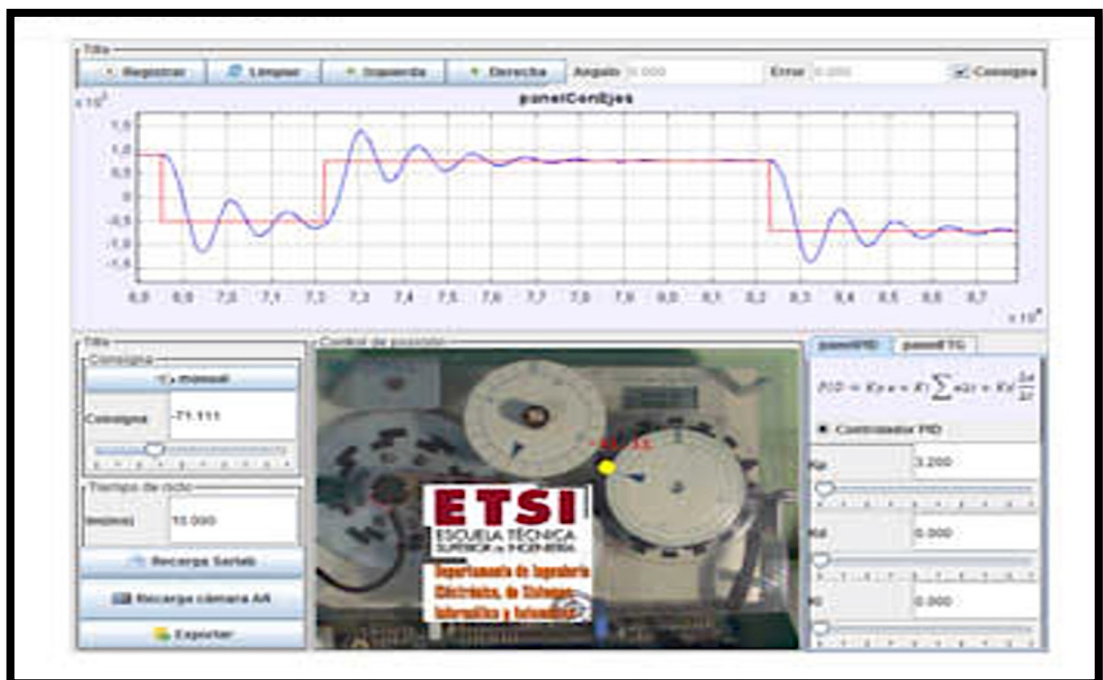
Figure 2.1: A remote experiment using a servo fundamentals trainer from Feedback^{TM} Instruments, (Feedback, 2013)

As an example, figure 2.1 shows the HMI developed with the tools presented in this work: a classical control system, where the student must adjust a PID controller to fix the position of a servomotor. The HMI allows several configurations of the controller to be tested, displaying the behavior of the position for the different input conditions. It also provides the possibility of exporting data for their further processing by means of tools such as Matlab/Simulink, SciLab, etc. An AR system has been added in this HMI, stating to the student the position that the servomotor must achieve (a yellow circle) and the value of this objective (angle).
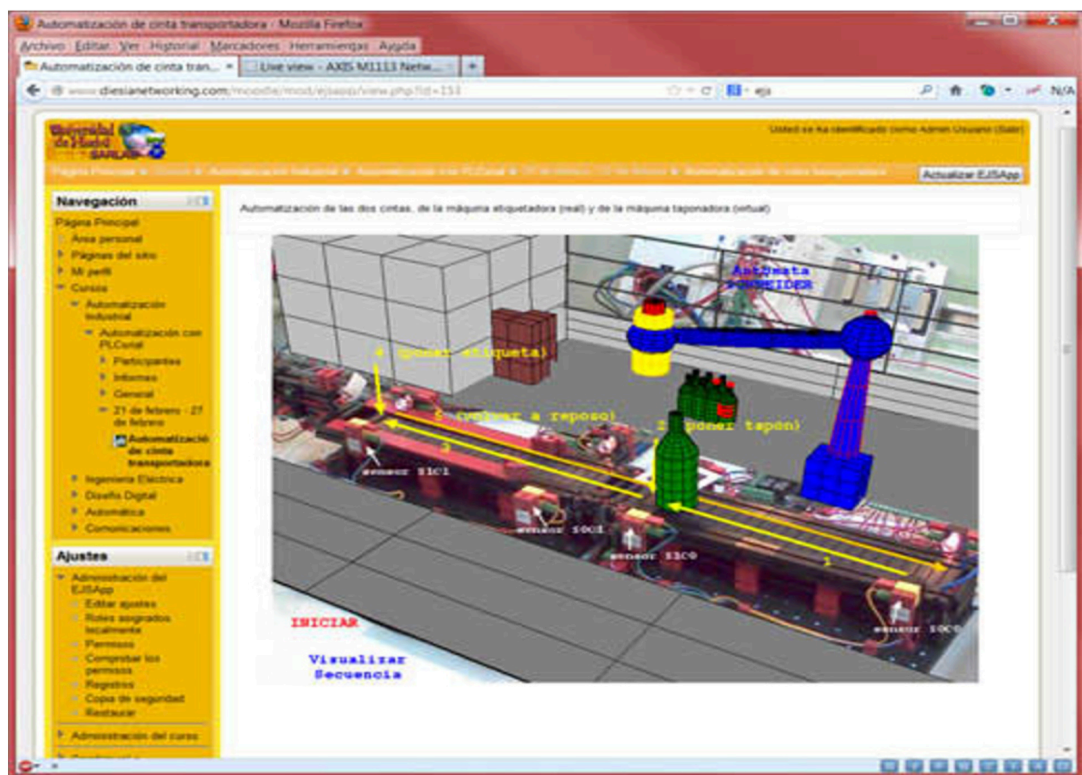
Figure 2.2: The HMI (inside Moodle platform) of a remote experiment with a PLC and an industry training model from Fishertechnik^{TM}, (Fishertechnik, 2013)

Figure 2.2 shows the interface of an industrial automation experiment. The student programs a PLC to automate a real laboratory plant, which is "augmented" by 3D virtual objects that interact with the real ones. This figure may be compared with

figure 2.3, which shows the original video stream received from the camera located in the University lab classroom.
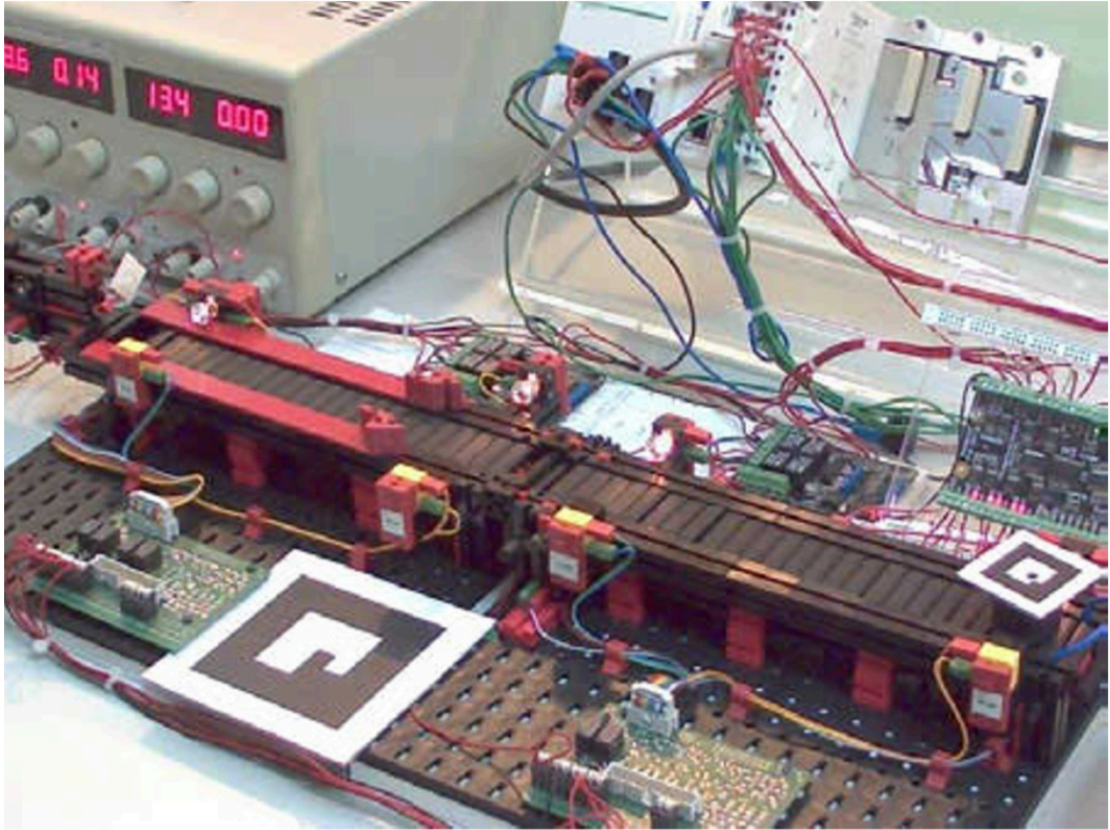
Figure 2.3: Appearance in the laboratory classroom of the remote experimental system corresponding to Figure 2.2, (Fishertechnik, 2013)

In this figure, the ARToolkit markers used to properly superimpose the 3D virtual elements can be seen. Via his computer interface, the student can operate the remote PLC, so that he can observe the evolution of the real plant according to the schedule that he has sent to the PLC. The AR system converts the conveyor belt in an installation which must place a plug and a label into the bottle, which is moved by the belt. In this case, real and virtual elements interact with each other, sharing the same three-dimensional space.

Theses types of commercial ready-made technologies can significantly reduce the

effort on development and implementation (less hardwired connections, easy troubleshooting, higher resolution), but can also rapidly increase the price. These facts truly follow the well-known argument "the more you pay, the more you get".

2.3 Revitalization Technology Applied

In a science world of research and experiments, it becomes eminent for the researcher to seek tools that simplify and easily controls parameters during the experiments. This required the intervention of an expert in electronics and programming to develop such a device. In which case, the result sometimes differs from the researcher's initial requirement, but at present, it is common to get simple units able to meet the requirements of the researcher adequately and which is also easy enough to be self-manipulated in specific applications. In this study, the use a custom-designed system based on microcontrollers and sensors for need is presented. It needs more effort than the ready-made technologies since it requires extra hardware like transistors and relays, but its low cost is worth dealing with.

In related works, Al-Busaidi (2012) uses the Arduino Mega board as embedded control system for biped robot, and introduces an interesting communication method between robot and MATLAB environment. Another use of Arduino is described in Barber and Crespo (2013), where authors apply this micro-controller as a cheap hardware interface to link Simulink models to physical laboratory systems without need of expensive DAQ cards. Neto et al. (2012) use the same controller extended with Ethernet module to build remote laboratory for DC motor PID control, with network communication capability. Campos et al. (2012) show a low-cost platform for Web-based experimentation developed on PIC micro-controllers. They allow students to exercise with different electrical devices like light diodes, LED panels,

switches, and servo drives. A very nice example of inexpensive experimentation setup is given in paper by Sobota et al. (2013), where the REXduino platform is introduced. This platform is based on Raspberry Pi computer equipped with REX Control System and connected to physical instrument by Arduino board.

2.3.1 Microcontrollers

Microcontrollers are quite similar to microprocessors, but they differ in several ways both are both embedded systems. The microprocessor is a normal CPU (Central Processing Unit) as can be found in a PC, its communication with external devices is done via a data bus, and why a chip mainly features data and address pins with some control pins. It is worth mentioning that a microprocessor cannot be operated independently as it requires at least a memory and some peripherals such as an output device to be useful.

Meanwhile, a microcontroller consists of all components which allow it to function independently, being designed for the specific tasks of monitoring and control. A typical microcontroller consists of the following (Gunther Gridling, 2007):

— A 8 or 16-bit microprocessor

— RAM.

— Programmable ROM and/or flash memory.

— Parallel and/or serial I/O.

— Timers and signal generators.

— Analog to Digital (A/D) and/or Digital to Analog (D/A) conversion

Devices that make use of microcontrollers include most of our daily used devices such as; cars, electronics (microwaves, phones, cameras, DVDs, etc), computer peripherals (keyboards, scanners, printers, modems, etc), test and measurement

equipment, traffic lights, and many more such devices where measurements and control is required. In the market today, one could get a list of affordable microcontrollers from a list of manufacturers such as MicroChip, Atmel, Intel, etc. For the sake of this study, the Arduino Uno was used and it makes use of the Atmel microcontroller chip.

The use of microprocessors and microcontrollers did not begin until 1970 and 1971 when both Intel and Gary Boone designed the first chips. At that time, Intel was working on the microprocessors which were a big step up from the bulky and intricate system that the form electronic devices were using, but still the microprocessor was not the landmark for the computing and electronic world of today. Then an engineer at the Texas instrument company came up with the microcontrollers (Trevennor, 2012).

Microcontrollers generally have a basic design; figure 2.4 shows a block diagram of it with all its components connected via an internal bus and are all incorporated on a single chip, with the modules connected through I/O pins.
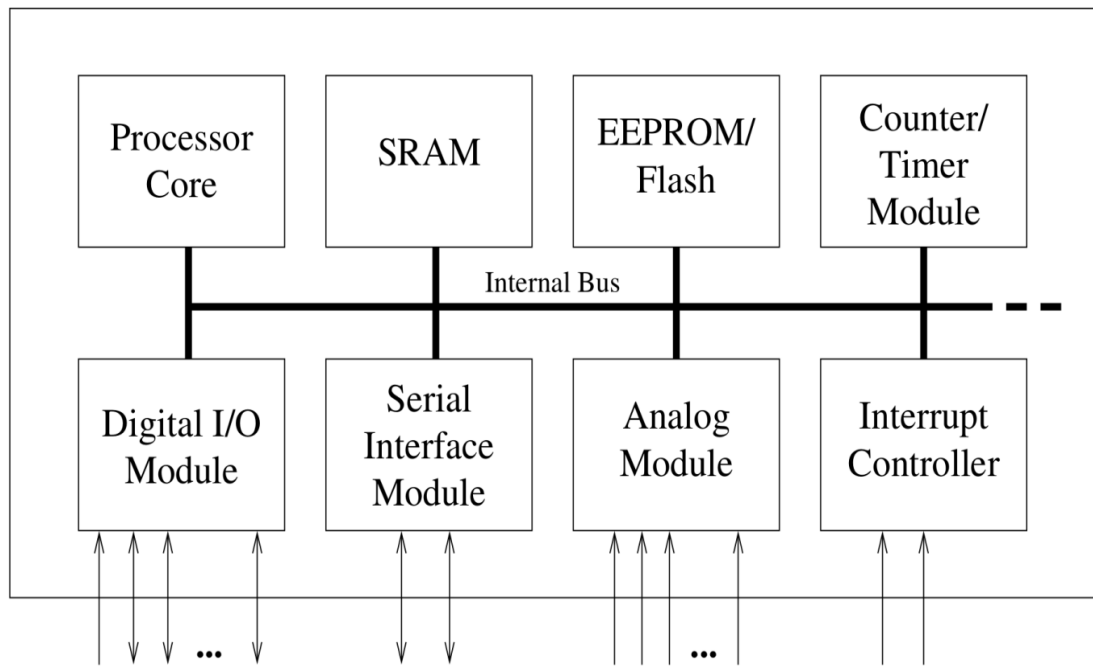
Figure 2.4: Block diagram of Microcontroller Architecture (Gunther Gridling, 2007)

2.3.2 Arduino Hardware

Arduino is not microcontroller chip but a platform which consists of an onboard an Atmel microcontroller chip, power supply and USB port to communicate with PC. It provides a standard programmable board which simplifies the process of creating a control system, and the board is connected to the system without the need of sophisticated PCB design and implementation. Arduino is an open source hardware, the details of its design could be easily gotten online, and one could modify to suit the personal need. It was designed by Banzi et al (John, 2014), with the sole purpose of reducing cost and also making it easier to teach students electronics. Its coding and ideas originated from Wiring, the work of Hernando Barragan, which was his project, geared at making it easy for artist and designers to work with electronics and not be burdened with the intricate and complicated details of it (Barragán, 2004).

There are different types of the Arduino system as shown in figure 2.5 and each one with a unique feature and chosen to correspond with the desired need of the system. The available types include:

Arduino Uno, Arduino Leonardo, Arduino Lilypad, Arduino Mega, Arduino Mini, Arduino Mini Pro, Arduino Nano, Arduino BT, below is a figure showing each of these systems.
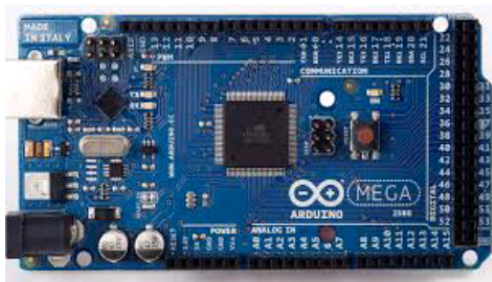
Arduino Mega
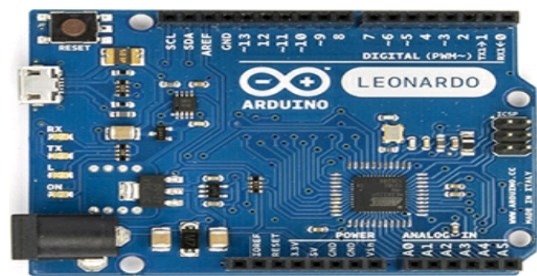
Arduino Leonardo
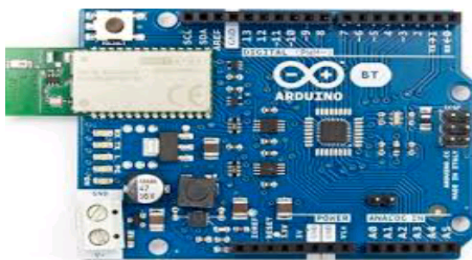
Arduino BT
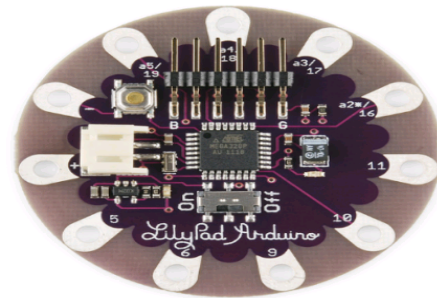
Arduino Lilypad
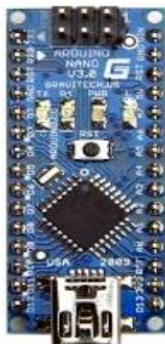
Arduino Nano
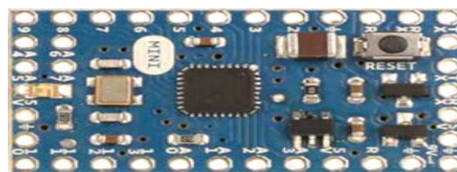
Arduino Mini

Arduino Mini Pro
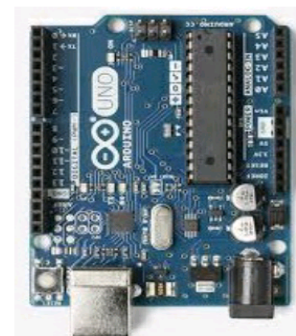
Arduino Uno

Figure 2.5: Types of Arduino packages (Arduino 2016)

In this study the Arduino Uno was used. The simplicity and user friendliness is the key to the selection. Figure 2.6 shows the technical specifications of the Uno board utilized in this study.
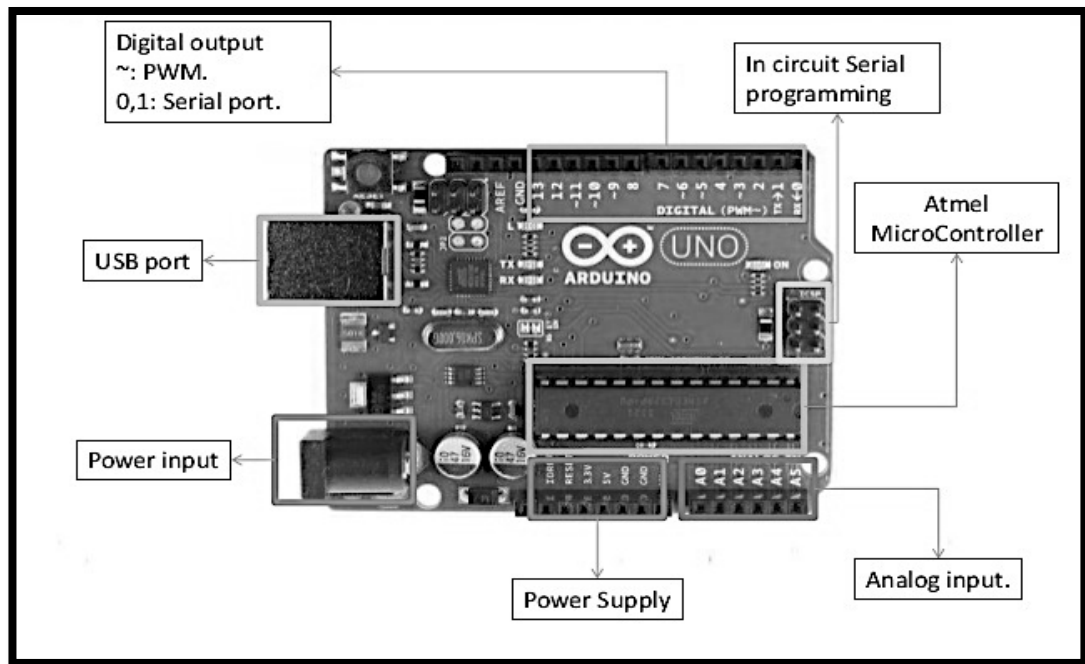
Figure 2.6: Schematic of an Arduino Uno (Sakr, 2013)

The Arduino Uno was the initial microcontroller board made by Arduino and it uses the ATmega328P. The components of the board include: Fourteen digital input/output pins, six analog inputs, a sixteen MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. The Uno is simply connected to a computer with a USB cable or could be powered with an AC-to-DC adapter or battery to get started. The chip is quite cheap and reduces the instrumentation cost and could be easily replaced if damaged, which makes it suitable for even beginners (Arduino UNO & Genuino UNO).

2.3.3 Micro-controllers Choice

Nowadays, there are many micro-controllers that are relatively cheap and feasible to all students. The most two widely used and recommended by users are the "Arduino uno" and "Raspberry Pi".

Table 2.1: Arduino Uno and Raspberry Pi specifications

	Arduino Uno	Raspberry Pi
Processor	AVR ATmega328p	Broadcom ARM1176JZF-s
Clock speed	16 MHz	700 MHZ
Registered Width	8-bit	32-bit
RAM	2k	512 MB
GPIO	20	8
I/O Current Max	40mA	5-10 mA
Power	175 mW	700 mW

As you can see in the table 2.1, the "Raspberry pi" has a clock speed faster than the "Arduino" and based on a 32 bit Registered Width. In addition, the "Arduino" RAM is shown in kilobits whereas the "Raspberry pi" is shown megabits. Both hardware have a GPIO (general purpose I/O), but the "Raspberry pi" can only sync up to 10 mA. Moreover, the "Raspberry pi" consumes 4 times more power than the "Arduino".

At first glance, people would say the "Raspberry" is better since it has better specifications with the same price. However, choosing one of these two controllers depends on the project nature and requirements. If we compare the GPIO, "Arduino" has a stronger I/O capabilities which allows it to drive external hardware directly unlike the "Raspberry" which needs transistors to function properly. Both controllers

have a solid place in the market and their demand depends on the application. If the experiment is more related to controlling instruments, the "Arduino" is the best choice. However, if the experiment needs to process a huge number of data, then the "Raspberry" would be the best choice.

In this project, the "Aduino" mirco-controller was chose since it mainly consists of controlling motors and sensors. Other projects that require cameras, graphical interphases or complex math are best suited with the "Raspberry".

2.3.4 Sensors

In today's world, the use of sensors cannot be ignored, as they are part of almost all our daily electronic device and machines. A Sensor acts as a medium that interacts between our physical environment and the complex environment of the microcontrollers. They sense and translate physical phenomena to the processor of the computer, and that becomes the data that the microcontrollers use in its function or analysis. For instance, Avenas et.al used it constructing the measurement of damage indicators in order to estimate the aging status of the power device (Avenas, Dupont, Baker, Zara, & Barruel, 2015). Also Hu et.al, in his work, stated the importance of keeping a close watch and care for the engine of an aircraft using sensors (Hu & Youn, 2011). There are two types of sensors, which are: Analog and digital sensors.

The analog sensors are wired to the microcontroller and communicate with it by sending it an electrical voltage. The microcontroller identifies where the voltage falls and thereby interprets the voltage signal into a numeric value. This means that the analog sensors could only function within a given range of numbers. While the digital sensors, just like the analog, but the voltage does not fall between a range of

numbers but on zero or maximum (Ross, 1997). And this is desirable wherein situations such as that of the door opening, where only two signals are required. In application, analog sensors are desired in Cds Cell, potentiometers, etc, while digital sensors are required for cases like switches and infrared detectors.

The major distinction between the two types of sensor is the inability of the analog sensor to maintain an exact and specific voltage in a live circuit, but the digital sensor sends and maintains a reliable signal irrespective of how noisy the condition might be, and that is because it only has two values, i.e. either HIGH or LOW (VEX)

2.4 Contribution To Education

During the engineering studies, it is very important for students to acquire the practical experience alongside the theoretical knowledge. This can be achieved by letting students operate themselves laboratory equipment under the supervision of their instructors who are responsible of teaching them how to handle these precise machines in a timely and efficient manner. In our experiment inside the hydraulic laboratory, students will be able to control and monitor an axial pump/turbine testing machine with a computerized system which can be considered a great self-learning tool. This advanced system provides a wide range of experimental test conditions allowing students to easily modify, compare and analyze different test results.

This computerized technique provides many benefits for the overall educational system. First, it allows for easy monitoring, controlling and handling of experimental data through flexible and user friendly computer software which provides more accurate readings and measurements with the help of micro-controller based instruments. Second, it is more cost effective compared to traditional testing

procedures as it has the ability to update its current computerized system with newer versions whenever new technologies are discovered in the market. Also, it gives poor educational institutions the chance to share remotely advanced laboratory equipment.

This system can adapt to various demands of laboratory instructions. It consists of several equipment connected together and linked to a computer through a data acquisition system, which has a module based control software capable of easily conducting measurements and automating instruments. It provides many modules capable of controlling all types of experiments and thus allows the users to modify or add new laboratory instruments to the existing system

2.5 Laboratory Equipment Revitalized

The need for a conversion of mechanical energy to fluid energy and vise versa is often a major concern to most researchers and engineers. There are a number of hydraulic machines used for this purpose vary considerably in principle and design making the selection of the correct pump for a particular application crucial for efficient, satisfactory operation (Shrestha, February 2007).

2.5.1 Description Of The Apparatus

For experiment purposes, the test rigs are used which consists of an impeller that usually has twelve blades, and the guide vane which has seven vanes. The experimental set up such as that used for this work majorly consists of a drive motor, control systems, storage and calibration tanks, and the axial pump. Different impellers are attached to the pump, and the pump characteristics are obtained (Kaya, 2003).

In a hydraulic machine, energy is transformed from one form into another, e.g. mechanical energy into an output of fluid energy (in pumps and compressors) or an input of fluid energy into mechanical energy (turbines).

The apparatus used in this work is the Axial flow water pump/turbine Test Rig H. 26 found in the Hydraulics laboratory at the mechanical engineering department of Eastern Mediterranean University. It has been designed to measure the principal phenomena in both pumps and turbine which are speed, torque, flow rate and pressure drops. It also demonstrates the operating characteristics of different types of pumps which include the pumps characteristic curves of Head versus flow, power absorbed versus flow and pump efficiency versus flow for some selected speeds.

The lab equipment is mounted on a metal support provided with a plastic laminate covered working surface as shown in figure 2.7. Here are some of the components housed in the framework and the measuring devices integrated within the instrument panel mounted on the working surface.

A test axial flow pump/turbine, the pump drive motor, an auxiliary centrifugal pump, an electronic tachometer mounted in the instrument panel indicates the motor speed; the Torque Balance is coupled to the motor and comprises a torque dial. The diagram below displays a schematic diagram of the system.
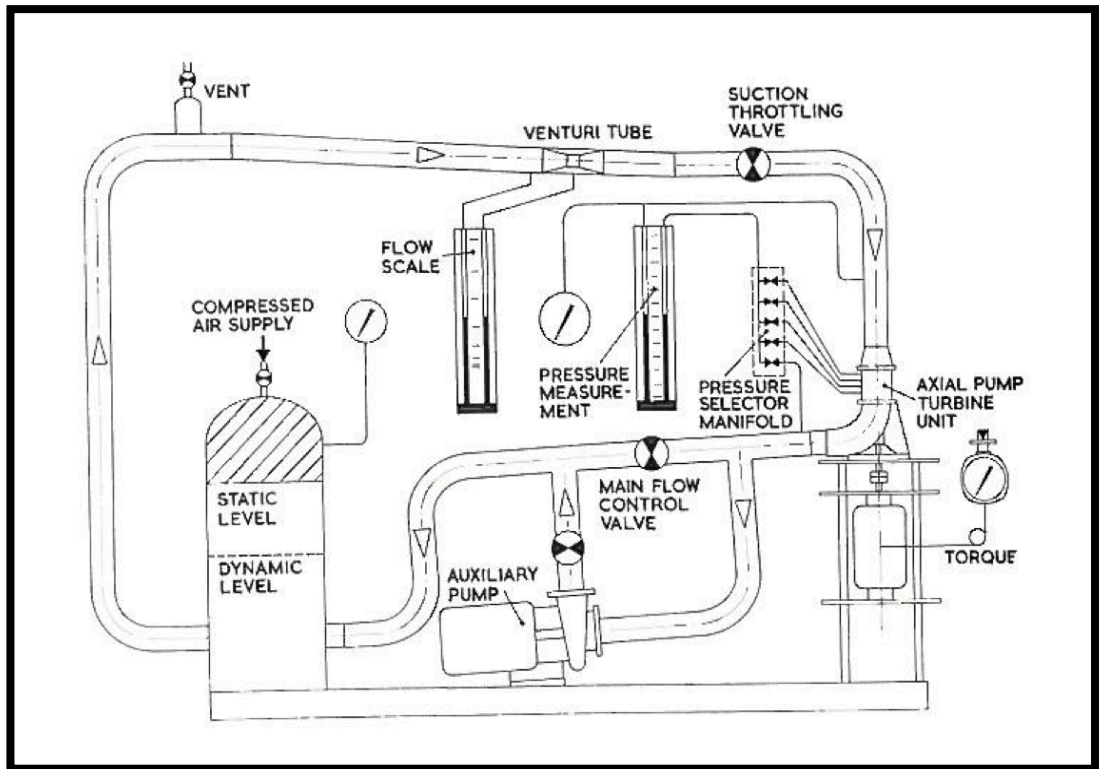
Figure 2.7: Apparatus schematic diagram (Tecquipment catalogue, n.d)

2.5.2 Brief Information About The Pumps Utilized

Several Test rigs are available to enable researcher to measure the operating characteristics of the following pumps:

1. Centrifugal Pump

2. Axial Flow Pump

2.5.2.1 Centrifugal Pumps

Centrifugal pumps contain an impeller (shrouded) that is attached and runs on the main spindle and supported by bearings as shown in figure 2.8. It works with a suction which makes it not self-priming. It has a single impeller that rotated in a snail-shaped volute casing, with water entering the eye axially and discharged along the impeller circumference. Energy is transferred to the fluid as it flows through the impeller which results in an increase in the exit pressure and velocity of the fluid.
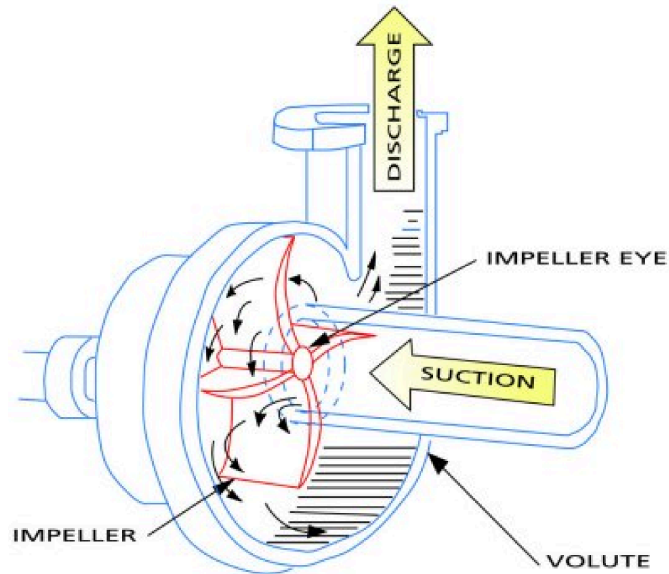
Figure 2.8: Centrifugal pump (Kumar, 2016)

The major disadvantage of the centrifugal pump is the limitation in the delivery
pressure and the fact that it is not self-priming.

2.5.2.2 Axial Flow Pump

They are many applications and designs of the axial pump today, and these pumps
are basically modeled for high flow rate and low-pressure applications. They are
desired for their ability to pump a large volume of water and this at a low head. The
axial pump has a propeller-shaped rotating element, and the discharged fluid flows in
an axial direction unlike in the case of the centrifugal pump. See figure 2.9.
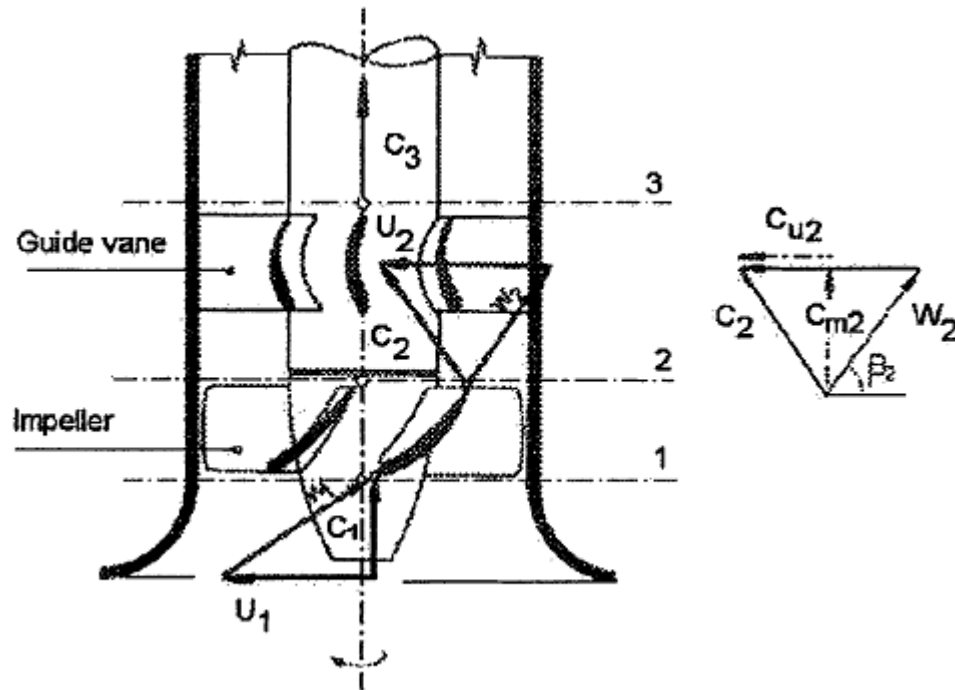
Figure 2.9: Velocity vector diagrams for an axial flow pump (Kaya, 2003)

Just like in the centrifugal pumps, the impellers play a major role in the axial flow pump coupled with the guide vanes. The blades are cross-sectioned in an aerofoil shaped; the figure 2.9 above shows the velocity vector diagram of the axial pump.

A brief comparison of the axial and centrifugal pumps could be made regarding the energy transferred to the flowing fluid, and they include:

• There is no accelerated velocity of the impellers in the axial pump unlike in the centrifugal pumps.

• In the centrifugal pumps, there is channel flow between the blades but this is not found in the axial flow pumps, and therefore there is no expansion in the channel cross section; and this means that there is no transformation of kinetic energy into pressure in the case of the axial flow pumps.

• Due to the aerofoil shape of the blades in the axial pumps, there is a very limited deflection of flow.

Looking at the points stipulated above, we could see that the total head achieved with the axial flow pumps are quite smaller than that of the centrifugal pump. Also, the energy transfer comes in due to the tangential acceleration of the fluid as it comes in contact with the blades of the impeller and leaves in a vortex as shown in figure 2.9 above, the direction of C2 is not same as the axial direction.

Chapter 3

METHODOLOGY

This project took about seven months to be finished; two months to receive all the tools ordered and five months working on the field. This period passed through many steps of working including the renovation of the apparatus, system interface design, installing the sensors and programing the software. Figure 3.1 shows the initial condition of the apparatus.

Figure 3.1: The apparatus before starting the project

3.1 Renovation

The apparatus was installed in the hydraulic laboratory since more than thirty years ago and left years without maintenance which caused us to face many unexpected problems that delayed the plan.

3.1.1 The Reservoir

The reservoir tank, due to its long-term of use, was welded many times in the past. Because of the high water pressure imposed during the experiment, it was exploded from the bottom which forced us to weld it again as shown in figure 3.2. This problem obliged us to lower the pressure required in the experiment from 2 bars to 1 bar maximum to prevent any new explosion or leakage in the system.

Figure 3.2: Welding the reservoir

3.1.2 The Joints

The leakage of water and air was a serious problem in the system. It was present in many places through the system: first the reservoir that is welded, then the rubber joints connecting the pipes which is fixed by adding metal clips and by tying well the old ones, finishing by the turbine and its plastic joint that was cracked as shown in figure 3.3 which contribute to the production of another one in the workshop presented in figure 3.4

Figure 3.3: Old broken turbine joint   Figure 3.4: Reproduced turbine joint

3.1.3 The Pump

On the test rig, there is a centrifugal pump shown in figure 3.5 driven by a 5.5 kW (7.3hp), 3-phase electric motor, providing a wide range of heads and flow turbine operation. It is used to pressurize the water in the system. We have cleaned the centrifugal part since it was rusted as shown in figure 3.6.

| Figure 3.5: Cleaning the pump | Figure 3.6: Auxiliary pump |

3.1.4 The Pump/Turbine

Due to cancellation of the old system, the tubes connecting the pressure gauge to the turbine were removed and replaced by plugs. A hole inside the turbine was welded and cleaned. The seal is improved to prevent leakage and two thrust bearings are changed to ease the rotation between parts on the shaft. See figure 3.7 and figure 3.8

| Figure 3.7: Turbine repaired elements | Figure 3.8: Repairing the blades |

Changing the rotors, stators and blades was completed by removing the short vertical pipe section above the pump, which was held in position by quick release couplings.

The blades supplied are made from molded plastic. They may be set at any desired stagger angle in the rotor/stator discs. Figure 3.9 and figure 3.10 show different types of blades for different camber angles that were used for pump and turbine operation, which affected the results.
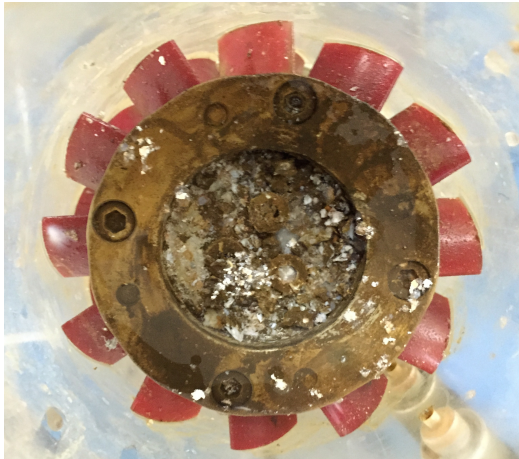
Figure 3.9: Old rotor and blades.

Figure 3.10: New rotor and blades.

3.2 System Design

Basically, this design is developed by upgrading the existing available system through selecting an optimum system configuration shown in figure 3.11 comprising of microcontroller, sensors, motors, relays etc. based upon the system requirements and specifications.
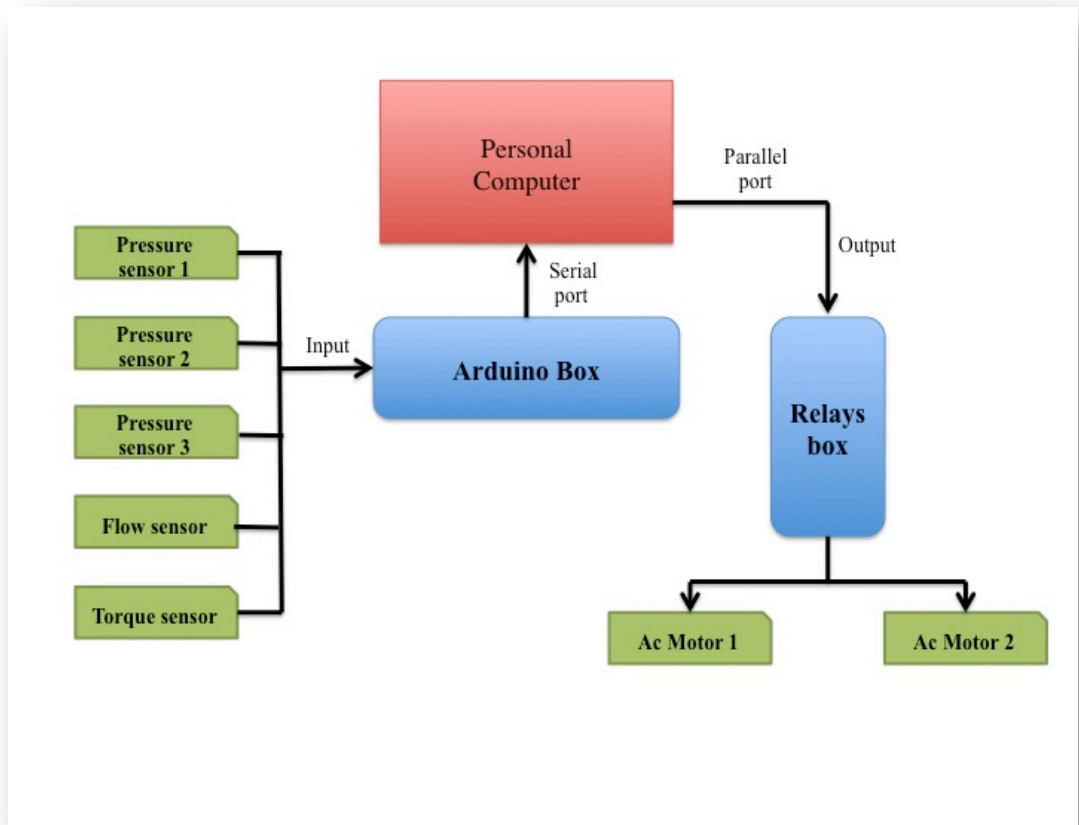
Figure 3.11: Schematic of the system interface

The experimental data is transmitted to the data acquisition system represented by the arduino box through the sensors as voltage signals and scaled by the microcontroller configuration module to generate the real measured numbers. Meanwhile, the motors are activated by signals ordered from a local user throughout the data acquisition system and controlled by the relay box

3.2.1 Arduino Box

Arduino box shown in figure 3.12 is the brain of the project, where the main processes occur. It is a microcontroller interface with a series of digital and analog input and output devices. It is capable of reading information from the sensors and turning them into an output in order to control the motors.
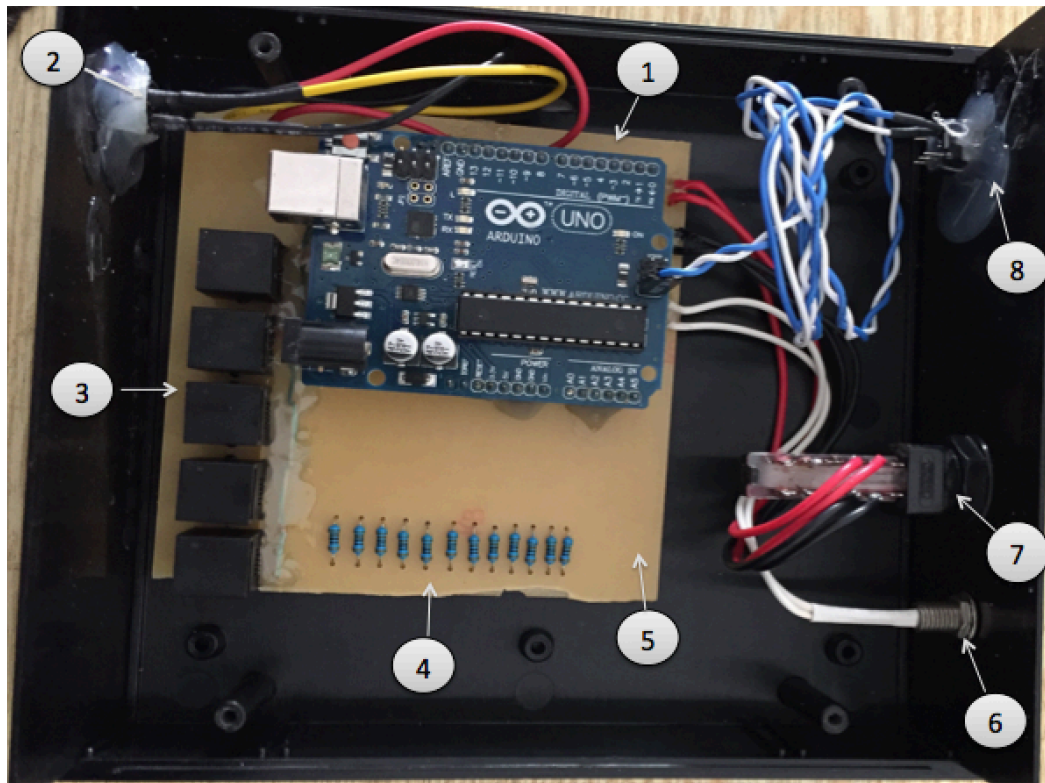
Figure 3.12: Inside the Arduino board

1. **Arduino board:** It is a microcontroller development system having 14 digital input/output pins and 6 analog inputs.

2. **Power supply:** It is a pc power supply for the sensors.

3. **Sensors plugs:** where the sensors are connected to the microcontroller.

4. **Resistors**: 12 parallel 250 ohms resistors to transform the output of the flow meter from 0-20mA to 0-5 V.

5. **PCB**: Own made Arduino shield for the sensors.(Appendix C)

6. **Reset button:** to reset the system.

7. **On/Off button:** to turn on and off the system.

8. **LED:** It shows if the system is on or off.

3.2.2 Relays Box

The relay box shown in figure 3.13 and figure 3.14, is formed by an electric circuit with four relays. Two relays are used for each motor, having the function of switches

that open and close the circuit when actuated with an electrical signal received from the arduino board. Their job is to turn on/off the motors and to automate their motion either clockwise or anti-clockwise in order to open and close the existent valves.
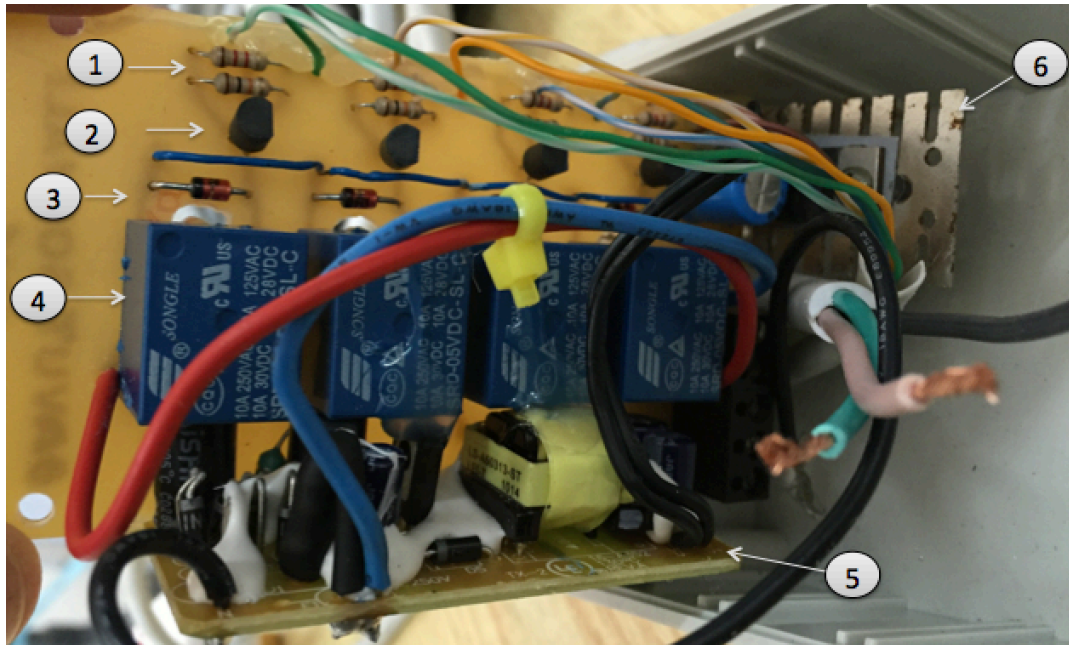
Figure 3.13: Relays board

1. **Resistors:** they prevent the noise of transistors.

2. **Transistors:** they are switches for the relays.

3. **Diode:** they are used to protect transistors.

4. **Relays:** electrically operated switches.

5. **Power supply**: Switch mode non-Bolated power supply for the relays (220-240 AC to 5V DC)

6. **LM7805 Regulator**: used to regulate the +5V DC from the power supply.
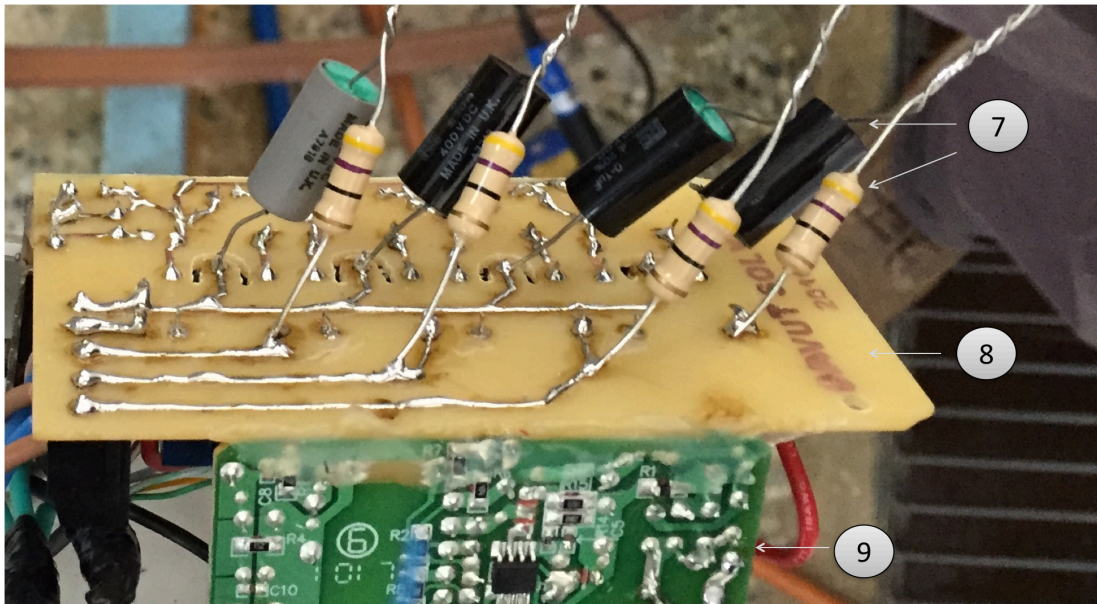
Figure 3.14: Lower part of the relay board

7. **Snubber circuits:** used to prevent spiking of the relay contacts.

8. **PCB**: Own made shield for the relays.(Appendix C)

9. **Power supply:** lower part of the power supply.

3.3 Transducers: Sensors And Actuators.

A transducer is a device that converts a signal from one physical form to another, making it an energy converter or modifier.

A sensor is one version of an input transducer. Its main purpose is to receive signals or stimuli and respond to them by generating a corresponding output. The output is usually a signal that is transmitted electronically to a measuring instrument or converted directly to a readable display at the sensor location.

An actuator is one type of an output transducer. It is a motor responsible of moving or controlling an object or system. It can function by many sources of energy especially the electric current.

Figure 3.15 shows the process between these different types of transducers.
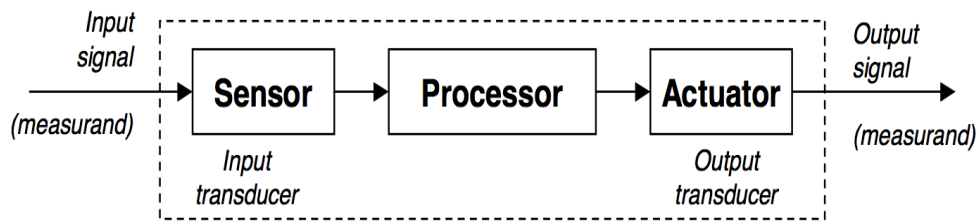
Figure 3.15: Signal process (Gutierrez-Osuna, 2011)

Before using any sensor, different shapes of brackets were designed that are suitable for sensors installation. Then, each sensor is calibrated by applying numerous known physical inputs and recording the signal output response of the system. This procedure leads to know the equations representing the performance of the sensors. Those equations were used in programing the software.

3.3.1 Pressure Transducers

The system includes three water pressure transducers shown in figure 3.16. Each one operates in the range of 0 to 60 psi as an input pressure, and 0.5 to 4.5 Volts as an output analog measurement. The transducer is powered by 5 Volts provided from the computer power supply. Refer to Appendix A for more technical information related to this pressure transducer.
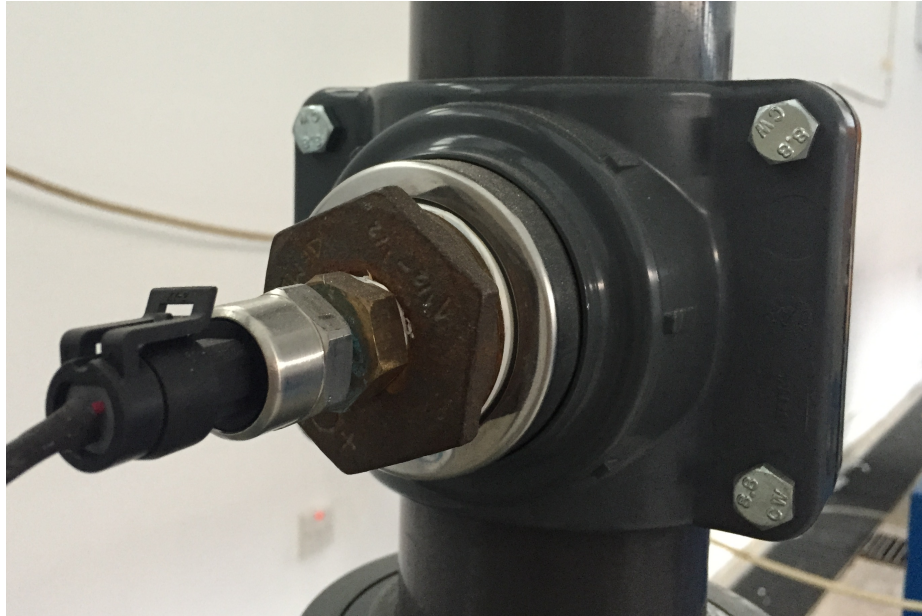
Figure 3.16: Installed 60-psi pressure transducer

A saddle was needed to fix each sensor on different positions of the pipes as shown in figure 3.18 in order to measure the pressure at distinctive points. In addition, some adapters were manufactured in the workshop for proper connection of the sensors with the saddle. The adapters were covered with Teflon tape to prevent water leakage as shown in figure 3.17

Figure 3.17: Adapters covered with Teflon   Figure 3.18: Pressure Saddle

Using an air compressor available in the workshop, the three 60 psi pressure transducers are calibrated and mapped as shown in table 3.1 that contribute to obtain a linear equation of 1st order shown in figure 3.19 used later in programming the sensor:

$$y = 0.0723x + 0.5254 \hspace{3cm} (3.1)$$

Having a correlation of 0.99951, which is a great fitting between the equation and the graph.

Table 3.1: Pressure sensors mapping table

Pressure (psi)	Voltage (v)
0	0.498
20	1.984
30	2.715
40	3.42
50	4.182
60	4.81
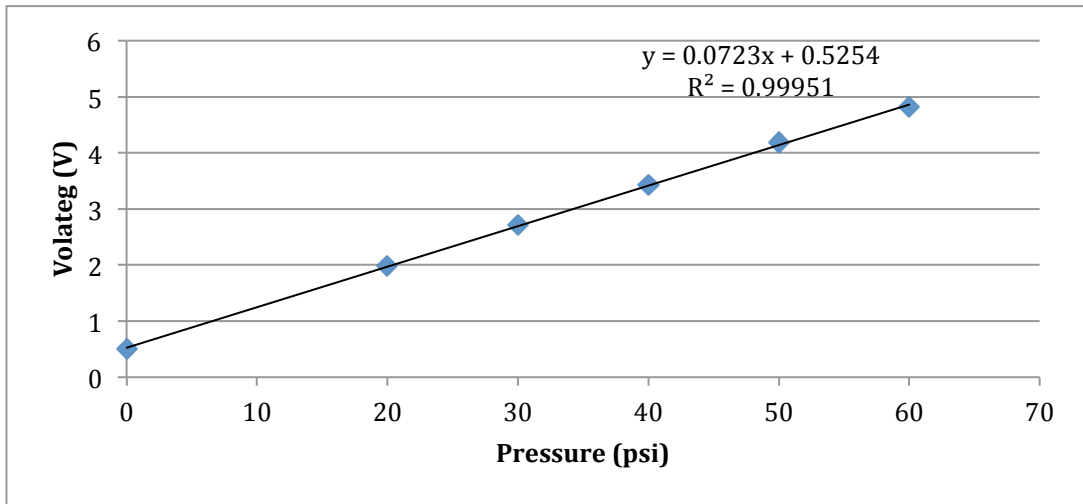
Figure 3.19: Pressure sensors mapping curve and equation

3.3.2 Paddlewheel Flow Sensor

A paddlewheel flow sensor produced by Bass Instruments Company in Turkey presented in figure 3.20, is used in the system in order to measure the flow rate of the water passing through the pipes of the rig. It operates between 0 and 110 m^3/h as input flow and generates between 4 and 20 mA as output current which is converted to 0-5 Volts via 12 resistors of 250 ohm each in order to be compatible with the data acquisition system requirements. The flow sensor is powered by 12 Volts provided from the computer power supply. Refer to Appendix A for more technical information related to this flow sensor.

Figure 3.20: Installed Paddlewheel flow sensor

The paddlewheel flow sensor is calibrated and mapped as shown in table 3.2, using the flow meter existing on the apparatus, to obtain an exponential equation of second order as shown in figure 3.21 that will be programmed later:

$$y = 0.0002x^2 - 0.1057x + 12.03 \tag{3.2}$$

Having a correlation of 0.9984 that is a great fitting between the equation and the graph.

Table 3.2: Flow sensor mapping table

Flow rate (kg/s)	Software value (non dimensional)
0	219
2	327.8
4	360.6
6	387.6
8	415.4
10	438.6
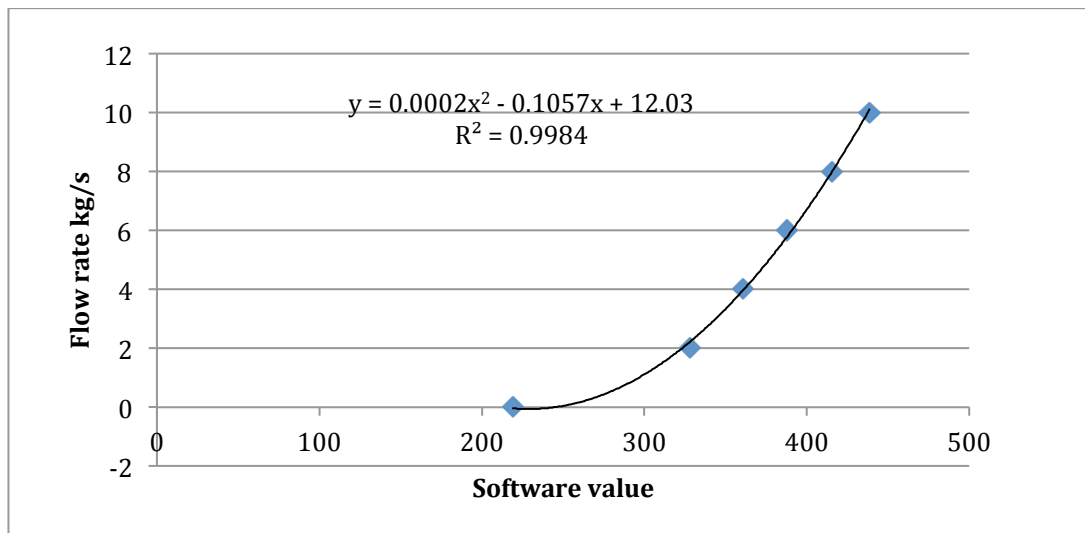
Figure 3.21: Flow sensor mapping curve and equation

3.3.3 Torque Meter

Actually it is not a torque meter. It is a linear potentiometer shown in figure 3.22 functioned as a torque meter, having the task of a three-terminal resistor with a sliding interaction that creates an adjustable voltage divider. It operates between 0 to 10 N.m as input, and generates between 0 to 10 KΩ resistance as output. It was directly mapped on the software due to its flexibility in use.
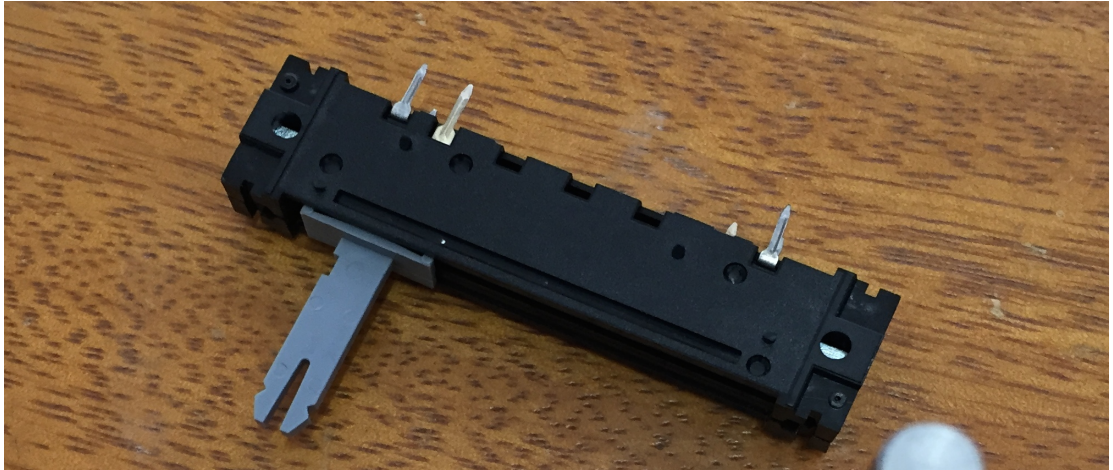
Figure 3.22: Linear potentiometer

Figure 3.23 shows a mechanism of two pieces brackets linked with a wire that was made in the workshop in order to fix the potentiometer on the old torque meter, and thus measuring the torque produced by the axial pump turbine shaft.

Figure 3.23: Potentiometer fitted on the old torque meter

3.3.4 Actuators

Two AC motors shown in figure 2.25 were needed to control the rotational motion of the two valves existing in the apparatus as shown in figure 3.24 and thus regulating

the water flow rate passing in the pipes. These motors have a brand name of ST

MOTOR.
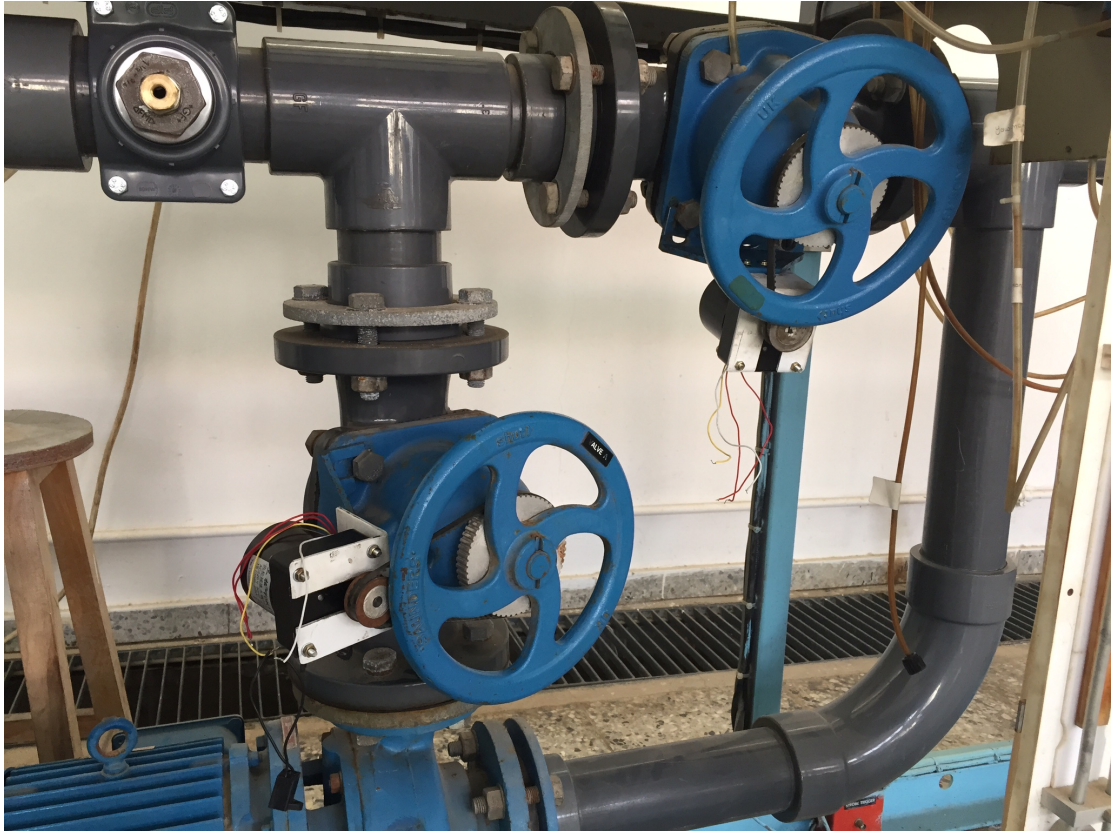
Figure 3.24: Two motors fitted on 2 valves mechanism

Each motor is powered by 220 AC voltage, has a rotational speed of 15 rpm and

generates an output torque of 50 kg.cm to be able to automate the valves. Refer to

appendix A for more technical information related to these motors.

Figure 3.25: AC 220V motor

For each motor, a metal bracket having the shape shown in figure 3.26 was designed in the mechanical engineering workshop in order to fix the motors in a suitable and sensitive position to be able to operate the valves through a gearbox mechanism linked with a belt shown in figure 3.27.

| Figure 3.26: Motor's bracket | Figure 3.27: Installed motor |

3.4 Software And Computer System

The fundamental element of the testing is the system software, which is designed in Microsoft visual studio, an expert software in visual basic programing language. It is installed on a personal computer located in the hydraulic laboratory, having hardware requirements of Windows 7 or more and 64bit resolution in order to control the testing apparatus through on board data acquisition system afforded.

3.4.1 Visual Studio: The Software

Microsoft Visual Studio is an integrated development environment (IDE) produced by Microsoft. It is commonly used to build computer software, websites, web services (XML) and applications (ASP.NET), desktop and mobile applications. It supports many programming languages and codes such as Visual Basic, C# and C++. Those languages all use the same integrated development environment (IDE), which allows for easy tool sharing and creation of mixed-language solutions. Also, these languages benefit from the functionality of the ".NET Framework" which enables the access to latest technologies that help in the development of XML web services and

ASP applications ("introducing," n.d.). Figure 3.28 shows the menu created on this software.
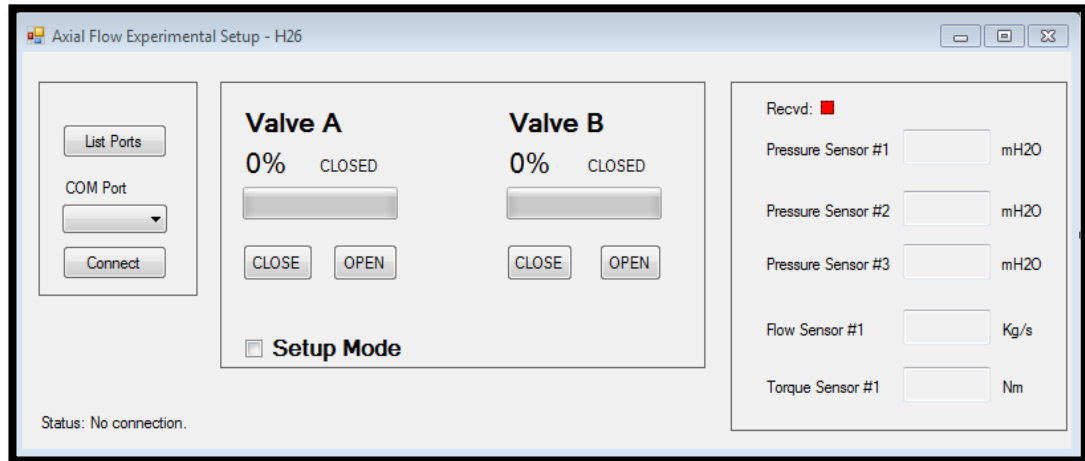
Figure 3.28: Software menu.

3.4.2 Visual Basic: The Code For Programming

Visual basic is a programming language engineered for efficiently developing safe and object oriented applications. It enables programmers to easily update Windows, Web and mobile devices. As we have discussed previously, Visual Basic can target the Microsoft .NET Framework allowing programs to exchange information easily and rapidly in a highly secured manner ("Visual," n.d.).

```
Form1.vb [Design]    Form1.vb ⊕ X
WFA_ArduinoSerial_001                                    Form1                                    RecData
        1 reference
    Function RecData()

        If cnt < avrgfactor + 1 Then
            datarray(0) = datarray(0) + Math.Round((Int(serialarray(4)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(1) = datarray(1) + Math.Round((Int(serialarray(3)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(2) = datarray(2) + Math.Round((Int(serialarray(2)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(3) = datarray(3) + Math.Round(0.00020825 * ((Int(serialarray(5) - 219) ^ 2)), 2)
            datarray(4) = datarray(4) + Math.Round(Int(serialarray(1))) / 200
            cnt = cnt + 1

        Else

            sen1.Text = datarray(0) / avrgfactor
            sen2.Text = datarray(1) / avrgfactor
            sen3.Text = datarray(2) / avrgfactor
            sen4.Text = datarray(3) / avrgfactor
            sen5.Text = datarray(4) / avrgfactor

            datarray(0) = 0
            datarray(1) = 0
            datarray(2) = 0
            datarray(3) = 0
            datarray(4) = 0

            cnt = 0

        End If
        REM sen1.Text = Math.Round((Int(serialarray(4)) * 0.072 + 0.525 - 7) * 0.703, 2)
        REM sen2.Text = Math.Round((Int(serialarray(3)) * 0.072 + 0.525 - 7) * 0.703, 2)
        REM sen3.Text = Math.Round((Int(serialarray(2)) * 0.072 + 0.525 - 7) * 0.703, 2)
        REM sen4.Text = serialarray(5)
        REM sen5.Text = Math.Round(Int(serialarray(1))) / 200

        Return False
    End Function
        1 reference
    Function ReceiveSerialData() As String
        Dim Incoming As String
        Try
            Incoming = SerialPort1.ReadExisting()
            If Incoming Is Nothing Then
                Return "nothing" & vbCrLf
            Else
                Return Incoming
            End If
        Catch ex As TimeoutException
            Return "Error: Serial Port read timed out."
        End Try
100 %
```

Figure 3.29: System program.

Figure 3.29 shows the beginning of the program built inside the software, using visual basic code, was made in order to create the main brain of the system. Refer to Appendix D for more information regarding the program.

3.4.3 The .NET Framework: The Framework For Programming

The .NET Framework provides ideal solutions for engineering measurements and automation experiments, ranging from the most basic applications such as temperature measurement to the most complex systems such as robotics. It provides user friendly language constructs, interoperability between language and technology, strong communication functionality and many add on tools for enhancing .NET in automation and measurement applications.

Visual Basic and C# constitute the most popular .NET languages used. Most testing and measurement applications such as object orientation and memory management

rely on language constructs provided by Visual Basic and C#. Most of today's automation experiments consist of real world objects that require software representation. For that reason, the .NET Framework automation applications are the best candidates for object-oriented implementation (D'Anna, 2005).

3.4.4 Design and Procedures

A user-friendly interface is developed to perform measurements, calculations, plotting and automating the task of laboratory instrumentation as shown in figure 3.30

The system testing unit procures real-time test data from the apparatus, embodies it in real-time graphical format and generates reports using Microsoft Excel that can easily be printed out.
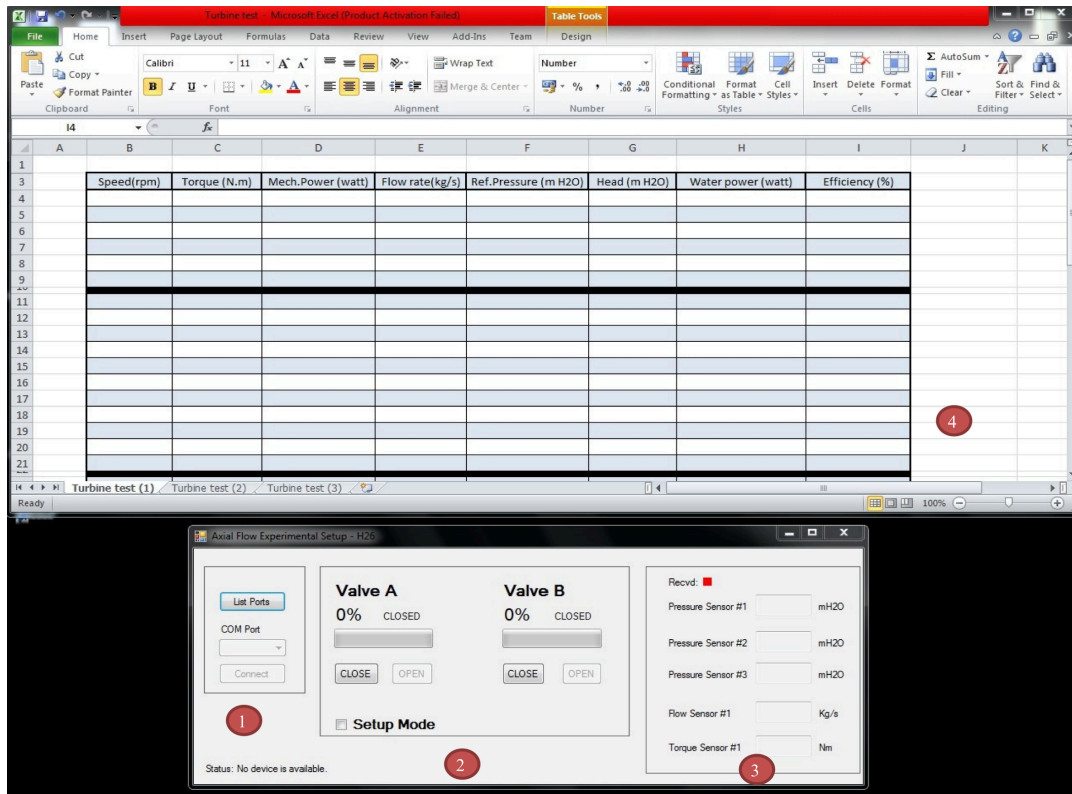
Figure 3.30: System design menu.

1. **Connections window**: where the port used is selected before starting the test.

2. **Valves window:** where the valves are controlled via ac motors showing the percentage of shut.

3. **Data window:** where the values of pressures, flow rate and torque are displayed.

4. **Excel sheet:** where the data is recorded in tables.

To start the system, some steps should be followed:

- **Software procedure:**

  1. Start up the pc.

  2. The compiled version of the software should be turned on from the desktop with the name of "Axial flow test".

  3. Click on list ports after being sure that the system is turned on.

4. Choose the COM port connected to the system.

5. Click on "connect" to finally activate to the system panel.

NB: Be sure before starting the experiment that the valves are fully closed by regulating them in the setup mode.

- **Turbine test procedure:**

    1. Set the reservoir air pressure to about 1.0 bar.

    2. Set the valves A and B to be fully closed.

    3. Set the Turbine speed control fully anticlockwise.

    4. Switch ON the main supply.

    5. Turn the selector switch to Turbine.

    6. Press start button (for the auxiliary pump).

    7. Open valve A until the required flow is obtained (fine flow control can be obtained by opening valve B slightly).

    8. Use loading resistors & the field rheostat to adjust the required speed.

    9. Take readings of: Speed, Torque, Flow rate, Ref. Pressure and Overall Head drop across the turbine.

    ❖ Adjust the speed to a series of selected valves to obtain a complete set of characteristics.

    ❖ Repeat the procedures for other selected Flow Rates.

    ❖ When tests are complete, turn off main supply.

Chapter 4

ANALYSIS AND DISCUSSION

4.1 Introduction

For a given turbine geometry, the fundamental variables are speed, torque, flow rate and pressure drop. In this experiment, the flow rate will be kept constant. Changing the dynamometer loading will vary the speed of the turbine. Dynamometer without any loading will run freely and the energy produced by the turbine will overcome only the frictional forces.

The maximum efficiency occurs when the outlet flow from the rotor is approximately axial. This can be expected since any swirling of flow at the exit represents energy which cannot be used.

4.1.1 Results

Three tests were conducted for different flow rate in order to obtain a complete set of characteristics. By opening valve A and slightly valve B, fine flow control can be obtained for each test. The required speed is adjusted several times during the experiment by using load resistors and a field rheostat in order to take readings for the speed, torque, flow rate, reference pressure and overall head drop across the turbine.

Figure 4.1: Revitalized Axial flow pump/turbine test rig

4.1.1.1 Test 1: For A Constant Flow Rate Of 7.4 Kg/s

Collected data for 7.4 kg/s flow rate is tabulated in table 4.1

Table 4.1: Recorded data for Flow rate 7.4 kg/s

Speed(rpm)	Torque (N.m)	Mech Power (watt)	Flow rate (kg/s)	Ref Pressure (m H2O)	Head (m H2O)	Water power (watt)	Efficiency (%)
600	0.2	12.56	**7.4**	9	1.7	123.41	10.18
500	0.3	15.70	**7.4**	9	1.5	108.89	14.42
450	0.4	18.84	**7.4**	9	1.3	94.37	19.96
400	0.45	18.84	**7.4**	9	1.2	87.11	21.63
350	0.4	14.65	**7.4**	9	1	72.59	20.19
300	0.4	12.56	**7.4**	9	0.9	65.33	19.22

4.1.1.2 Test 2: For A Constant Flow Rate Of 9 Kg/s

Collected data for 9 kg/s flow rate is tabulated in table 4.2

Table 4.2: Recorded data for Flow rate 9 kg/s

Speed (rpm)	Torque (N.m)	Mech.Power (watt)	Flow rate (kg/s)	Ref.Pressure (m H2O)	Head (m H2O)	Water power (watt)	Efficiency (%)
700	0.4	29.31	**9**	9	1.48	130.67	22.43
600	0.45	28.26	**9**	9	1.13	99.77	28.33
550	0.52	29.93	**9**	9	0.9	79.46	37.67
500	0.53	27.74	**9**	9	0.8	70.63	39.27
450	0.58	27.32	**9**	9	0.7	61.80	44.20

400	0.59	24.70	**9**	9	0.6	52.97	46.63
350	0.6	21.98	**9**	9	0.5	44.15	49.79
300	0.62	19.47	**9**	9	0.4	35.32	55.13
200	0.63	13.19	**9**	9	0.3	26.49	49.79
100	0.65	6.80	**9**	9	0.2	17.66	38.53
0	0.66	0.00	**9**	9	0.2	17.66	0.00

4.1.1.3 Test 3: For A Constant Flow Rate Of 11 Kg/s

Collected data for 11 kg/s flow rate is tabulated in table 4.3

Table 4.3: Recorded data for Flow rate 11 kg/s

Speed (rpm)	Torque (N.m)	Mech.Power (watt)	Flow rate (kg/s)	Ref.Pressure (m H2O)	Head (m H2O)	Water power (watt)	Efficiency y (%)
700	0.6	43.96	**11**	9	1.5	161.87	27.16
650	0.62	42.18	**11**	9	1.3	140.28	30.07
600	0.65	40.82	**11**	9	1.2	129.49	31.52
550	0.67	38.57	**11**	9	1	107.91	35.74
500	0.69	36.11	**11**	9	0.9	97.12	37.18
450	0.7	32.97	**11**	9	0.8	86.33	38.19
400	0.72	30.14	**11**	9	0.6	64.75	46.56
350	0.74	27.11	**11**	9	0.5	53.96	50.24
300	0.76	23.86	**11**	9	0.5	53.96	44.23
250	0.78	20.41	**11**	9	0.45	48.56	42.03
200	0.8	16.75	**11**	9	0.4	43.16	38.80
150	0.82	12.87	**11**	9	0.35	37.77	34.09
100	0.84	8.79	**11**	9	0.4	43.16	20.37
0	0.13	0.00	**11**	9	0.35	37.77	0.00

4.2 Accuracy And Systematic Errors

The accuracy of a measurement is how close the measurement is to the true value of

the quantity being measured indicating the deviation of the reading from a known

input which is called as error. It is frequently expressed as a percentage of full-scale

reading.

The accuracy of measurements is often reduced by systematic errors, which are difficult to detect even for experienced research workers. They can be caused by an imperfection in the equipment being used or from mistakes the individual makes while taking the measurement. A balance incorrectly calibrated would result in a systematic error. In many experimental situations we may not have a known value with which to compare instrument readings, and yet we may feel fairly confident that the instrument is within a certain plus or minus range of the true value. In such cases we say that the plus or minus range expresses the *uncertainty* of the instrument readings.

Accuracy can be improved up to but not beyond the precision of the instrument by calibration. The calibration of all instruments is important, for it affords the opportunity to check the instrument against a known standard and subsequently to reduce errors in accuracy. Calibration procedures involve a comparison of the particular instrument with a known input source. The importance of calibration cannot be overemphasized because it is calibration that firmly establishes the accuracy of the instruments.

In this system, the Pressure sensor having the accuracy of 1% is calibrated via a pressure gauge having an accuracy of 2%, which leads to a X=2% as a total accuracy in the pressure measurements.

The Paddlewheel flow sensor having an accuracy of 0.75% is calibrated through a Venturi meter having an accuracy of 1.5%, which leads to Y=1.125% as a total

accuracy in the flow measurements.

For the torque measurements, the potentiometer having an accuracy of 5% is calibrated through a torque dial having 2% accuracy, which give us a $Z=10\%$ total accuracy.

Since the efficiency equation of the system is a multiplication and division equation of the form:

$$Efficiency = \frac{2\pi nT/60}{gHm^{\cdot}} \tag{4.1}$$

The total accuracy percentage can be calculated by using this equation:

$$Total\ accuracy\ \% = \sqrt{\left((X^2) + (Y^2) + (Z^2) \ldots + (N^2)\right)} \tag{4.2}$$

The Total accuracy of the system is about 10.25 %, which can be improved by reducing the systematic errors.

4.3 Uncertainty & Error In Measurement

In every measurement there is uncertainty. This is due to some random errors caused by unknown and unpredictable changes in the experiment. The error has an unstable rate of change. This type of error is known as two-sided error causing the measurement to fluctuate around the mean. Some of the reasons behind this error may be cause by some changes in the environment throughout the experiment, voltage fluctuation in the circuitry and human estimation. Random errors cannot be removed, but can be reduced by running repeat trials.

4.3.1 Uncertainty Propagation Of The Torque Meter

Three trials were done in order to calculate the uncertainty propagation of the torque as shown in table 4.4 below.

Table 4.4: Uncertainty propagation of the torque meter

Speed(rpm)	Trial 1 Torque (N.m)	Trial2 Torque (N.m)	Trial3 Torque (N.m)	AVERAGE Torque (N.m)	Relative Uncertainty
600	**0.21**	**0.22**	**0.21**	0.213	0.0044
500	**0.32**	**0.29**	**0.31**	0.307	0.011
450	**0.42**	**0.4**	**0.41**	0.410	0.007
400	**0.45**	**0.42**	**0.44**	0.437	0.011
350	**0.4**	**0.4**	**0.42**	0.407	0.009
300	**0.42**	**0.4**	**0.42**	0.413	0.009

With a total torque average of $\overline{X}$= 0.364 N.m and a total average relative uncertainty of ΔX = 0.0085 creating a 2.33 % uncertainty as shown in figure 4.2 calculated from this equation:

$$Uncertainty\ percentage = (\Delta X/\overline{X}) * 100 \qquad \textbf{(4.3)}$$

Figure 4.2: Uncertainty propagation of the torque

4.3.2 Uncertainty Propagation Of The Pressure Transducer

Three trials were made in order to calculate the uncertainty propagation of the pressure as shown in table 4.5 below.

Table 4.5: Uncertainty propagation of the pressure transducer

	Trial 1	Trial2	Trial3		
Speed (rpm)	Head (m H_2O)	Head (m H_2O)	Head (m H_2O)	Average Head (m H_2O)	Relative Uncertainty
700	**1.6**	**1.56**	**1.4**	1.520	0.080
650	**1.3**	**1.32**	**1.3**	1.307	0.009
600	**1.2**	**1.2**	**1.2**	1.200	0.000
550	**1.05**	**1.01**	**1.02**	1.027	0.016
500	**0.9**	**0.9**	**0.9**	0.900	0.000
450	**0.82**	**0.8**	**0.83**	0.817	0.011
400	**0.6**	**0.62**	**0.6**	0.607	0.009
350	**0.52**	**0.5**	**0.51**	0.510	0.007
300	**0.46**	**0.5**	**0.48**	0.480	0.013
250	**0.47**	**0.45**	**0.45**	0.457	0.009
200	**0.42**	**0.4**	**0.44**	0.420	0.013

150	0.38	0.35	0.33	0.353	0.018
100	0.31	0.32	0.29	0.307	0.011
0	0.35	0.37	0.39	0.370	0.013

With a total torque average of $\bar{Y}= 0.734$ (m H_2O) and a total average relative uncertainty of $\Delta Y = 0.015$ creating a 2.033% uncertainty as shown in figure 4.3
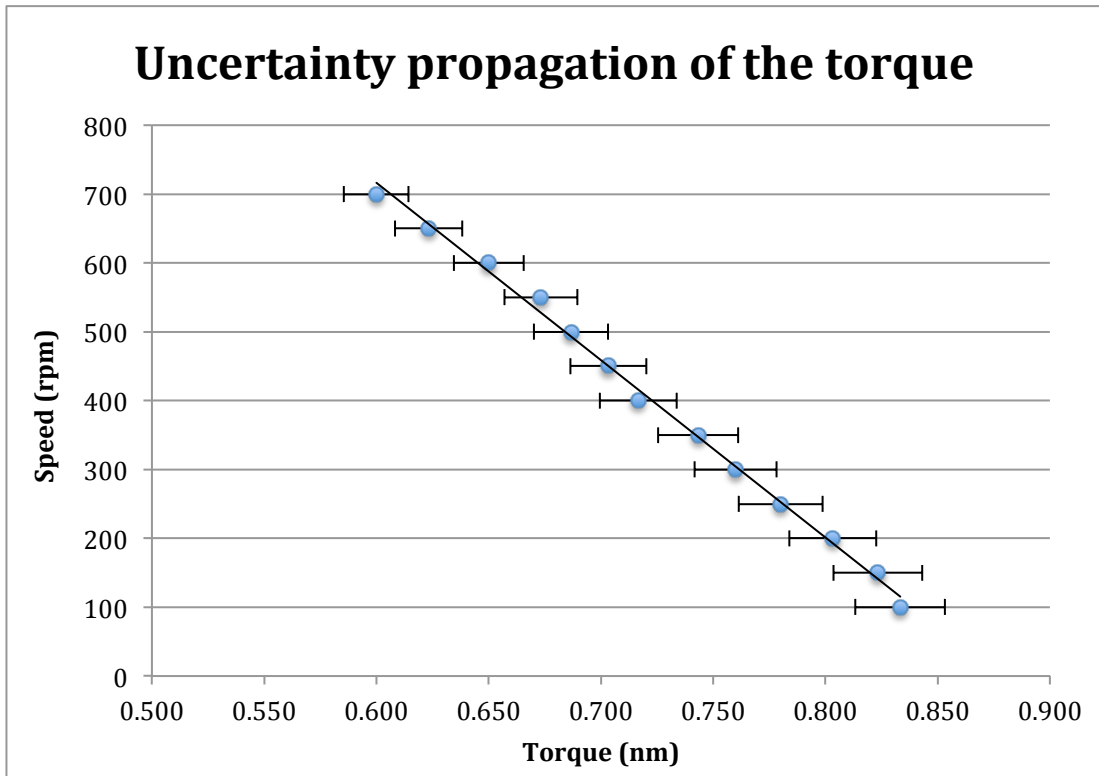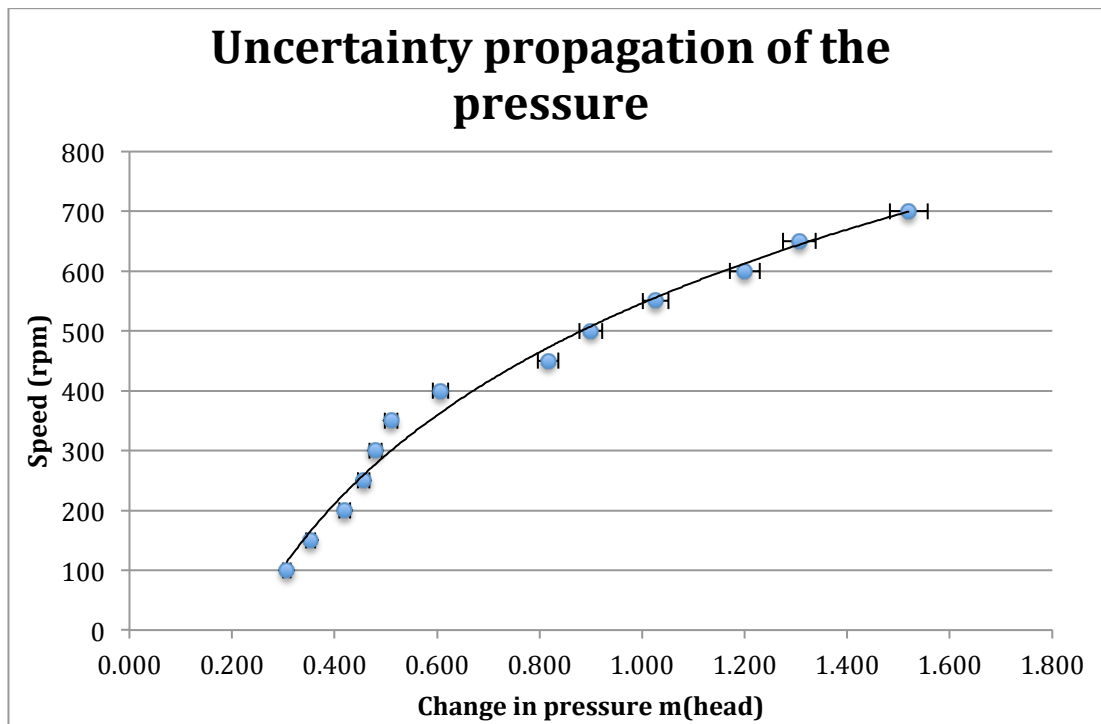

Figure 4.3: Uncertainty propagation of the pressure

4.3.3 Uncertainty Propagation Of The Flow Meter

Three trials were made in order to calculate the uncertainty propagation of the Flow rate as shown in table 4.6 below.

Table 4.6: Uncertainty propagation of the Flow meter

Speed (rpm)	Trial 1 Flow rate(kg/s)	Trial2 Flow rate(kg/s)	Trial3 Flow rate(kg/s)	AVG Flow rate	Relative Uncertainty
600	7.38	7.35	7.45	7.393	0.038
500	7.32	7.43	7.45	7.400	0.053
450	7.4	7.47	7.34	7.403	0.044
400	7.44	7.36	7.41	7.403	0.029
350	7.38	7.42	7.45	7.417	0.024
300	7.45	7.42	7.36	7.410	0.033

With a total torque average of $\overline{Z}$= 7.404 Kg/s and a total average relative uncertainty of $\Delta Z = 0.037$ creating a 0.50% uncertainty as shown in figure 4.4
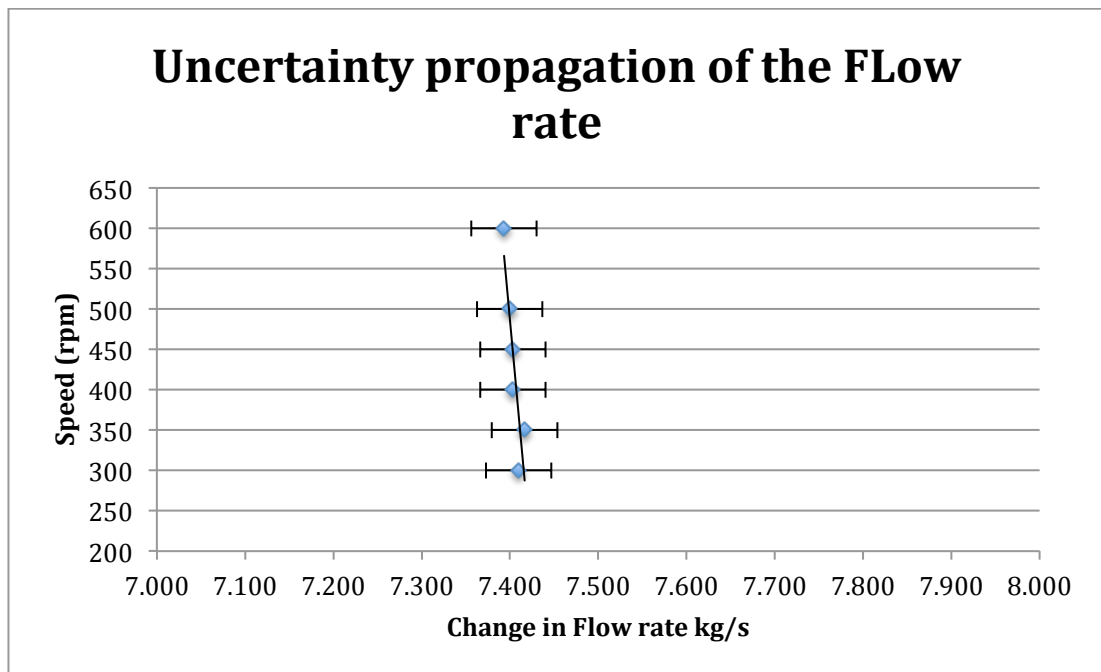
Figure 4.4: Uncertainty propagation of the Flow rate

4.3.4 Uncertainty Propagation Of The Total System

Normally, a total uncertainty is created in the whole system. Since the efficiency equation of the system is a multiplication and division equation of the form:

$$Efficiency = \frac{2\pi nT/60}{gHm\cdot} \tag{4.4}$$

The total uncertainty percentage can be calculated by using this equation:

$$Total\ uncertainty\ \% = 100 * \sqrt{\left(\left(\frac{\Delta X^2}{\bar{X}}\right) + \left(\frac{\Delta Y^2}{\bar{Y}}\right) + \left(\frac{\Delta Z^2}{\bar{Z}}\right) ... + \left(\frac{\Delta N^2}{\bar{N}}\right)\right)} \tag{4.5}$$

Table 4.7: Total uncertainty of the system

	AVG	Relative uncertainty	Percentage
Torque (N.m)	0.578709677	0.005519713	0.953796606
Flow rate (kg/s)	9.605483871	0.017562724	0.182840597
Head (m H2O)	0.821935484	0.006523297	0.793650794
TOTAL UNCERTAINTY %	1.254209006		

The Total uncertainty of the system is about 1.25 %, as shown in table 4.7, which is a small percentage describing the high precision of the system

4.4 Problem Description

Numerous uncontrollable problems were created in this obsolete apparatus during the past years, preventing the machine from working properly in order to give a completed recorded data by the new system, which can work accurately on any new apparatus. The current system is not able to endure more than 1 bar reference pressure. Some frictions were created inside the pipes because of rusting. The blades of the turbine were changed to different types and angle orientations. All these reasons and other miscellaneous contribute to some systematic errors, which may affect the accuracy of the system.

Axial flow pump/turbine H26 rig was installed more than thirty years ago in the Department of Mechanical Engineering at Eastern Mediterranean University and it

was implemented by minor and major losses test at the same time. The mechanical gauges, flow meter and torque meter were badly used and were not calibrated, so we tried to eliminate most of them to obtain a better looking and functional new apparatus.

Chapter 5

COST ANALYSIS

The budget factor is always the main concern when buying new equipment and tools for any laboratory. Therefore, during the planning phase of constructing a new laboratory facility, it is preferable to search for flexible equipment that can be upgraded with time. As such, universities will save money by not purchasing new equipment when new technologies arise. Since the concept of data acquisition system is becoming more widespread in the control and instrumentation field, universities are now focusing on buying flexible low cost instruments.

5.1 Project Cost

Our project mainly consists of a low budget computer aided system with its related software, along with the "Arduino" microcontroller board. The whole system can be used for educational or industrial purposes and can perform local or remote experimental projects. As we have said in previous sections, the whole system can be found in our Hydraulics laboratory. Table 5.1 below shows the breakdown cost of the project items.

Table 5.1: Project components cost

Component	Unit cost ($)	Quantity	Total cost ($)
Arduino board	16.50	1	16.50
4 Relays card	5	1	5
Pressure transducer	20.5	3	60.50
Sliding potentiometer	5	1	5
Paddlewheel flow sensor	632	1	632
Ac Motor	65	2	130
Different components (cables, screws, resistors, ect.)			20
Shipment			40
Grand Total	$909		

The project total cost is around $909 and could have been lower, but we were concerned not have low quality material. The budget for this plan is somehow acceptable and effective compared to other methods used.

An old similar project was performed in 2007 by a mechanical engineering student called Sepanta Naimi in the same university, and was about computerizing a pump's system where the project cost was $3230: $986 for the data acquisition card and the rest amount was for the sensors and actuators. The only item that can be compared with our project is the data acquisition hardware since the rest items can differ in price due to many factors such as quality, quantity, etc... In our days, the DAQ cards

needed for project requirements cost around $400, which are still expensive compared to the $16.50 Arduino.

In their acticle, Barber and Cre-spo (2013) revealed that they have used the Arduino as a cheap micro-controller hardware to link "Visual Studio" representations to real life physical laboratory instruments without the need of an expensive data acquisition system.

However, cheap tools which are featureless in their origin cannot cope with the rapid development of technology as the case of remote laboratory systems. Those systems ask for flexible tools that can be easily developed as per project requirements.

Chapter 6

FUTURE WORK

Nowadays, the control education field needs greater attention. However, by using Arduino, we are targeting the initial objectives. Also, advanced laboratories are now using technological features that allow students to share remotely through the internet and manipulate real instruments located in different geographical locations (Aktan et al.,. 1996; Antsaklis et al, 1999; Dominguez et al., 2001;Dormido, 2002).

As discussed previously, we can upgrade the feedback system to perform new control features in practical sessions. However, the system requires an Ethernet Shield expansion device in order to be accessed from a remote area.

The above system was first implemented in Spain where very advanced remote labs were implemented at the "National University of Distance Education in Madrid" (UNED, 2013). The labs there are called "Unilabs" providing various remote and virtual instruments for control & instrumentation education where five different universities are now cooperating together.

The current objective is to familiarize students with this new system by conducting many practical sessions at an affordable cost and to connect this system with the existing laboratory instruments to manipulate and control their data. Different options can be used such as:

➢ HTTP: using Arduino as a web server

➢ AJAX: using Arduino as a web server and sending data to an AJAX client running on a web browser

➢ Web socket: using Arduino as a web server establishing full-duplex single-socket connection. The client side is a web browser.
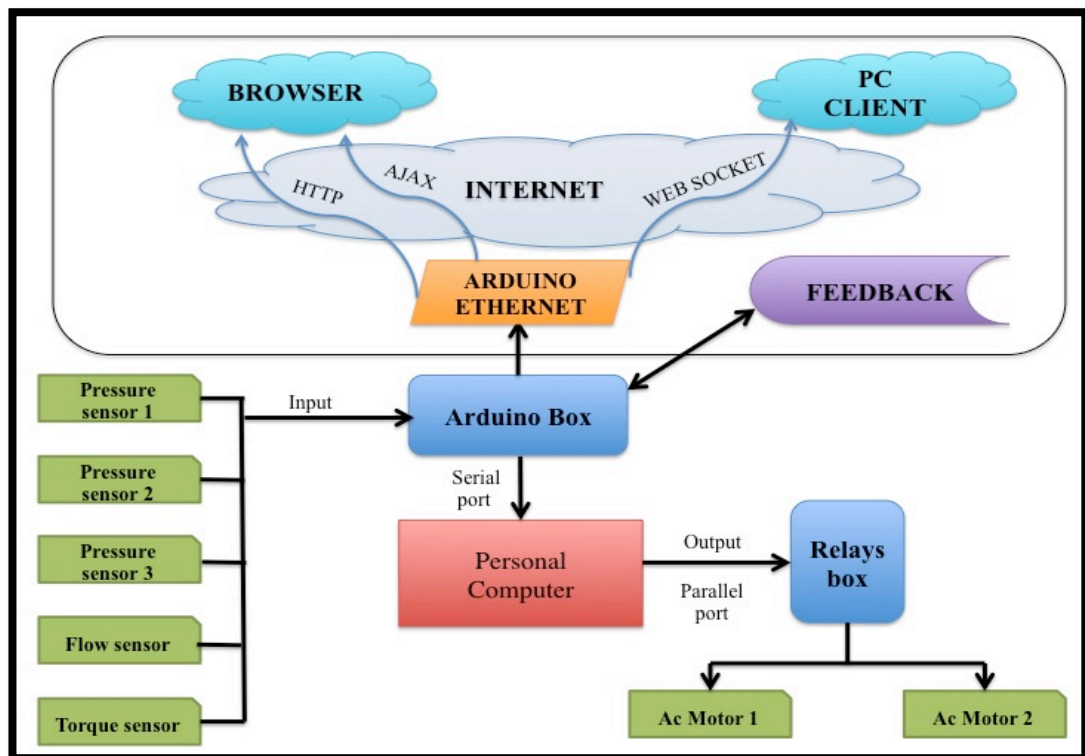
Figure 6.1: Remote operation options using Arduino.

The above Arduino representation in figure 6.1 shows that the feedback system is upgraded every time and can be used in new applied tasks such as motor identification, velocity alteration, and positioning control through different algorithms.

Eventually, we suggest to use the web services for remote applications. In this case, the feedback system will generate many web services that operate on demand. In

other words, the interconnection between structures is now very simple as new services can be added and existing web services can be upgraded without major alterations to the client section at the remote lab.

Chapter 7

CONCLUSION

In this study, we have presented a recent and cost effective approach to improve laboratories equipment. We have introduced and described the data acquisition system as a fundamental element in developing the advanced remote laboratory concept which allows students to perform their experiments without any restrictions and in various testing conditions unlike the traditional hand on laboratories.

The feedback system has been upgraded via the previously explained Arduino schema to allow multiple tasks to be performed within the system based on the encoder's feedback values. The suggested schema is a low budget solution to update the engineering automated education, which is now more attractive and appealing to motivated students. By using Arduino, we have completed our initial objectives. The remote access can be achieved through web services provided by the feedback system.

Eventually, our automated computer aided pump/turbine testing system has proven to be very effective and provided accurate results that were easily monitored and controlled without any possible human error that we could have encountered. The whole system is now available in our Mechanical Engineering Department Hydraulic laboratory and can be used by all students who are seeking further knowledge in the "Fluid Mechanics" field.

REFERENCES

Aktan, B., Bohus, C. A., Crowl, L. A., & Shor, M. H. (1996). Distance learning applied to control engineering laboratories. *IEEE Transactions on education*, *39*(3), 320-326.

Avenas, Y., Dupont, L., Baker, N., Zara, H., & Barruel, F. (2015). Condition Monitoring: A Decade of Proposed Techniques. *IEEE Industrial Electronics Magazine*, *9*(4), 22-36.

Bencomo, S. D. (2002). Control learning: present and future. *IFAC Proceedings Volumes*, *35*(1), 71-93.Arduino UNO & Genuino UNO. 2016 йил 12-April <https://www.arduino.cc/en/Main/ArduinoBoardUno>.

Domínguez, M., Marcos, D., Reguera, P., González, J. J., & Blazquez, L. F. (2001). Connection pilot plant to the internet. *IFAC Internet Based Control Education. IBCE01*.

Fraenkel, P. L. (1986). Water Lifting Devices. Food and Agriculture Organization of the United Nations.

Geyer, C. Distance Learning-Advantages and Disadvantages of Take-home Hardware.

Gibb, A. M. (2010). *New media art, design, and the Arduino microcontroller: A malleable tool* (Doctoral dissertation, Pratt Institute).

Hanumolu, P. K., Brownlee, M., Mayaram, K., & Moon, U. K. (2004). Analysis of charge-pump phase-locked loops. *IEEE Transactions on Circuits and Systems I: Regular Papers*, *51*(9), 1665-1674.

Hu, C., & Youn, B. D. (2011). Adaptive-sparse polynomial chaos expansion for reliability analysis and design of complex engineering systems. *Structural and Multidisciplinary Optimization*, *43*(3), 419-442.

Ionescu, D. (2015). The Importance of Working Integrated Learning and Relevant Laboratory Experiments in Engineering Teaching. *Procedia-Social and Behavioral Sciences*, *174*, 2825-2830.

Kalúz, M., Čirka, Ľ., Valo, R., & Fikar, M. (2014). ArPi lab: A low-cost remote laboratory for control education. *IFAC Proceedings Volumes*, *47*(3), 9057-9062.

Kaya, D. (2003). Experimental study on regaining the tangential velocity energy of axial flow pump. *Energy Conversion and Management*, *44*(11), 1817-1829.

Layne, S. P., & Beugelsdijk, T. J. (1998). Mass customized testing and manufacturing via the Internet. *Robotics and Computer-Integrated Manufacturing*, *14*(5), 377-387.

Mallalieu, K., Arieatas, R., & So'Brien, D. (1994). An inexpensive PC-based laboratory configuration for teaching electronic instrumentation. *IEEE Transactions on Education*, *37*(1), 91-96.

Mason, G. (2002). A handheld data acquisition system for use in an undergraduate data acquisition course. *IEEE transactions on education*, *45*(4), 388-393.

Murakami, M., & Minemura, K. (1983). Effects of entrained air on the performance of a horizontal axial-flow pump. *Journal of fluids engineering*, *105*(4), 382-388.

Nickerson, J. V., Corter, J. E., Esche, S. K., & Chassapis, C. (2007). A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers & Education*, *49*(3), 708-725.

Ochmann, K., Podpora, M., & Kawala-Janik, A. (2015, December). Increasing the motivation of learning in HMI workshops with the use of simple embedded platforms. In *QUAESTI-Virtual Multidisciplinary Conference* (No. 1).

Oh, H. W., & Kim, K. Y. (2001). Conceptual design optimization of mixed-flow pump impellers using mean streamline analysis. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *215*(1), 133-138.

Reguera, P., García, D., Domínguez, M., Prada, M. A., & Alonso, S. (2015). A LOW-COST OPEN SOURCE HARDWARE IN CONTROL EDUCATION. CASE STUDY: ARDUINO-FEEDBACK MS-150. *IFAC-PapersOnLine*, *48*(29), 117-122.

Sebastián, J. M., García, D., & Sánchez, F. M. (2003). Remote-access education based on image acquisition and processing through the Internet. *IEEE Transactions on Education*, *46*(1), 142-148.

Trevennor, A. (2012). *Practical AVR Microcontrollers: Games, Gadgets, and Home Automation with the Microcontroller Used in the Arduino*. Apress.

APPENDICES

Appendix A: Sensors Technical Information

1. Pressure Sensor

Figure A.1: 60-PSI Pressure sensor

1.1 Specifications

- Pressure transducer. 316 Stainless steel body.

- Input: 0-60 psi (Gauge Pressure);

- Output: 0.5-4.5V linear voltage output. 0 psi outputs 0.5V, 30 psi outputs 2.5V, 60 psi outputs 4.5V. Works for oil, fuel, diesel, gas, water or air pressure. Can be used in oil tank, gas tank, diesel tank etc. Accuracy: +/-1%FS;

- Thread: 1/8" NPT;

- Wiring Connector: Packard plug-in unit is included;

- Wiring: Red: +5V; Black: ground; Green: signal output;

- It's an advance pressure sender than traditional mechanical pressure sender;

- Overload Capacity: 2-4 times;

- Working Temperature: -40+120°C;

- Compensation Temperature: -20+80°C;

- Protection Class: IP67;

- Pressure Medium: The gas and liquid which is compatible with 316L stainless steel; Load Resistance: $\leq$ ((supply power-6.5V/0.02A) Ω;

- Long-term stability: Less than 0.1%FS/year;

- Temperature Effect on Zero: Typical:0.02%FS/°C; Maximum:0.05%FS/°C; Temperature Effect on Sensitivity: Typical:0.02%FS/°C; Maximum: 0.05%FS/°C;

- Shock Resistance: 1000g;

- Anti-Shock: $\leq$+/-0.01%FS (X, Y, Z axes, 200Hz/g);

- Response Time: $\leq$1ms;

- Insulation Resistance: >100mΩ 500VDC;

- Weight: 55g;

- Explosion-proof Class: ExiaTTCT6;

- Electromagnetism Compatibility: EN50051-1.

2.Paddlewheel Flow sensor

Figure A.2: Paddlewheel flow sensor

2.1 APPLICATIONS

- Water treatment and regeneration

- Industrial wastewater treatment and recovery

- Textile finishing

- Water distribution

- Processing and manufacturing industry

- Filtration systems

- Chemical production

- Liquid delivery systems

- Cooling water monitoring

- Heat Exchangers

- Swimming pools

- Pump protection

2.2 MAIN FEATURES

- CPVC, PVDF, Brass or Stainless Steel sensor body

- Two sensor lengths to cover from DN15 up to DN600 • Easy insertion system

- IP65 or IP68 protection class

- Measurement range over 50:1

- High chemical resistance

- Version for battery powered system

- Push-Pull output for universal electrical connection

2.3 General information

- Pipe Size Range: DN15 to DN600 (0.5" to 24") please refer to installation

  Fittings section for more details

- Flow Rate Range: 0.15 to 8 m/s (0.5 to 25 ft./s)

- Linearity: ± 0.75% of full scale

- Repeatability: ± 0.5 % of full scale

- Minimum Reynolds number required: 4500

- Enclosure: IP68 or IP65

- Wetted Materials:

  - Sensor body: CPVC, PVDF, Brass or 316L SS

  - O-rings: EPDM or FPM

  - rotor: ECTFE (Halar®)

  - shaft: Ceramic (AL_2O_3)/316L SS (only metal sensors)

  - bearings: Ceramic (AL_2O_3)

2.4 Specifications

- Supply voltage: 12 to 24 VDC ± 10% regulated

- Supply current: < 30 mA @ 24 VDC

- Output signal:

    - Square wave

    - Frequency: 45 Hz per m/s nominal(13.7 Hz per ft/s nominal)

    - Type: Push-Pull (for connection to NPN and PNP inputs)

    - Output current: 20 mA max

- Cable length: 8m (26.4 ft) standard, 300 m (990 ft) maximum

2.5 Standards & Approvals

- Manufactured under ISO 9001

- Manufactured under ISO 14001

- CE

- RoHS compliant

- GOST R

2.6 Maximum Operating Pressure / Temperature (25 years lifetime)

- CPVC bodyL

    - 10 bar (145 psi) @ 25°C (77°F)

    - 1,5 bar (22 psi) @ 80°C (176°F)

- PVDF body:

    - 10 bar (145 psi) @ 25°C (77°F)

    - 2,5 bar (36 psi) @ 100°C (212°F)

- Brass or SS body:
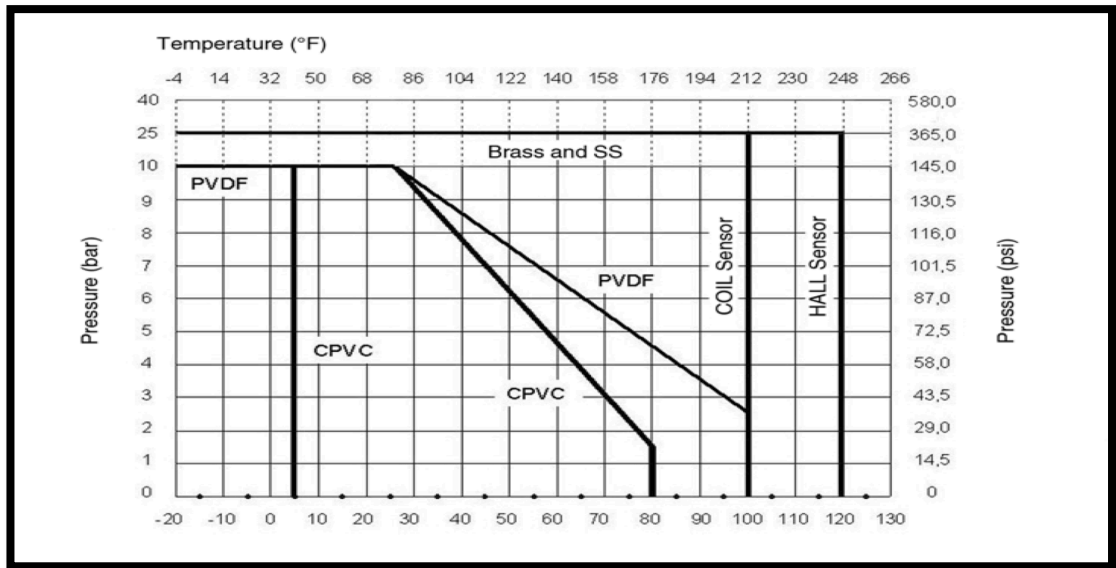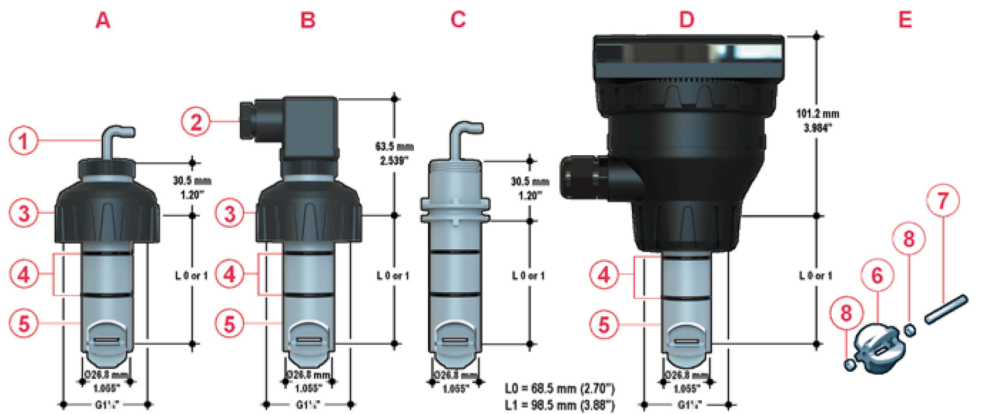
    - 25 (363 psi) @ 120°C (248°F)

Figure A.3: Maximum Operating Pressure / Temperature

2.7 Dimensions

A F3.00 IP68 Remote Sensor
B F3.00 IP65 Remote Sensor
C F3.01 Compact Sensor
D F3.01 Compact Sensor + Transmitter
  (sold separately)
E Paddlewheel system

1 Electrical cable: 8 m. (26.4 ft) standard
2 4 pole cable plug according to DIN
  43650-B/ISO 6952
3 UPVC cap for installation into fittings
4 O-Ring seals available in EPDM or
  FPM

5 CPVC, PVDF, Brass or Stainless Steel
  sensor body
6 ECTFE Halar® (registered trademark
  of Ausimont-Solvay) Open-cell rotor
7 Ceramic shaft
8 Ceramic bearings

Figure A.4: Dimensions

79

2.8 Sensor wiring connection

This is the connections. detail for the paddlewheel flow sensor wiring.
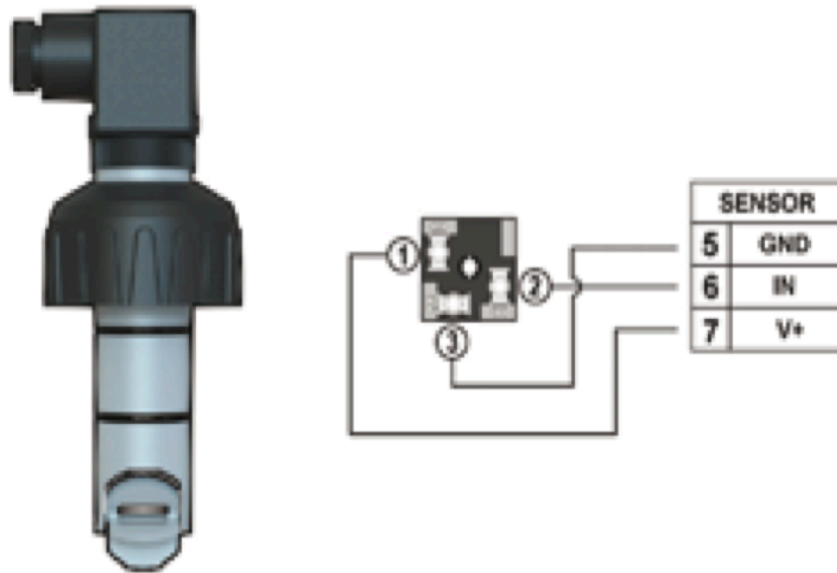
Figure A.5: Wiring connections

3.Potentiometer
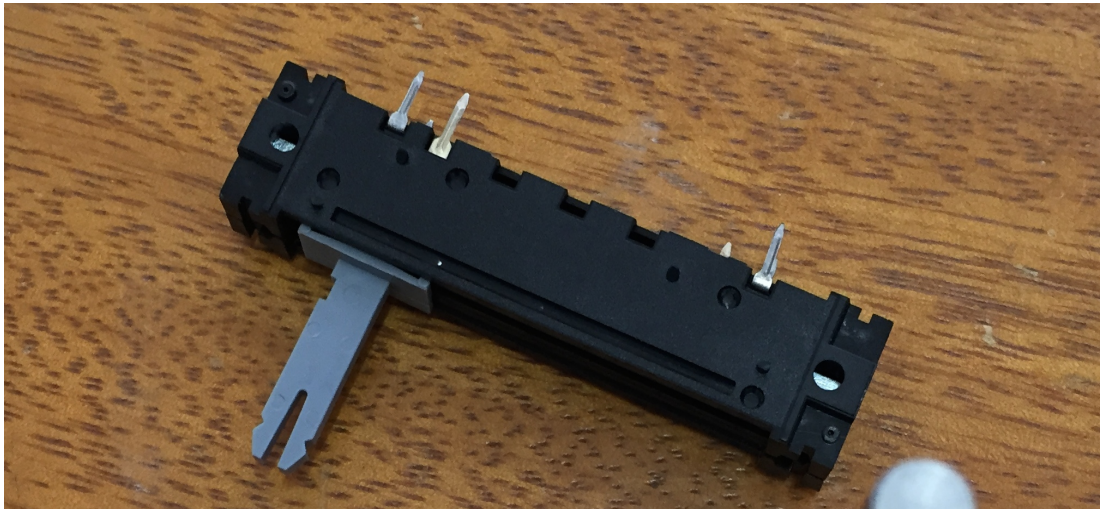
Figure A.6: Potentiometer

3.1 Appearance requirements

Product appearance: Product without rust, crack, and electroplating unhealthy phenomenon.

Packing method: According to the product specification packaging (with right quantity, type materials issue in compliance with.....)

3.2 Electrical characteristics

- Total resistance: 10 KΩ± 20 %

- Resistance taper: □A ■B □C □D □W

- Residual resistance: R≤10KΩ ≤10Ω 10K<R<250KΩ ≤20Ω R≥250K ≤0.1% max. of total resistance

- Ratings power: B Taper: AC500V 0.5 W; Other Tapers: AC350V 0.25 W

- Gang Error: -40~0db<=3db

- Slider noise: 100mV max

- Insulation resistance: DC 250V, 100MΩ 100MΩ min. at DC 250V

- Voltage proof: 1 minute at AC 300V

3.3 Mechanical characteristics

- Stopper Strength: 5-kgf.cm max. / 3 sec. From the base level to a point of

  2mm

- Operating Force: 50 ~ 300 gf.cm

- Click slip-out force: 50 ~ 300 gf.cm

- Lever Wobble: 2(2*L)/25 mm max. (L: lever length both side)

- Lever Push-Pull Strength: 5-kgf.cm max. at 10 sec.

- Lever Deviation: 0.5 max. (one side).

3.4 Anti-permeability

Rotational life: Permissible resistance change after 10,000±200 cycles on 600 r.p.h

without load ±15% max.

3.5 Solder way

- Manual welding: 300°C±10°C 3S±1S

- Wave soldering: 240°C±260°C 4S±0.5S

4. AC Motors

Figure A.7: Ac motor

4.1 Specifications

- Model: 70KTYZ

- Shaft: Eccentric shaft Voltage: AC220V

- Power: 20W

- Rated speed: 15rpm

- Output torque: 50kg.cm Weight: 1.1kg

4.2 Application

Electric equipment, Heating and Cooling Valve, Automated instrumentation, Electric

model, Electric advertising, Screen machines, Presses, Counter, Barbecue equipment,

ect.

4.3 Motors wiring connections
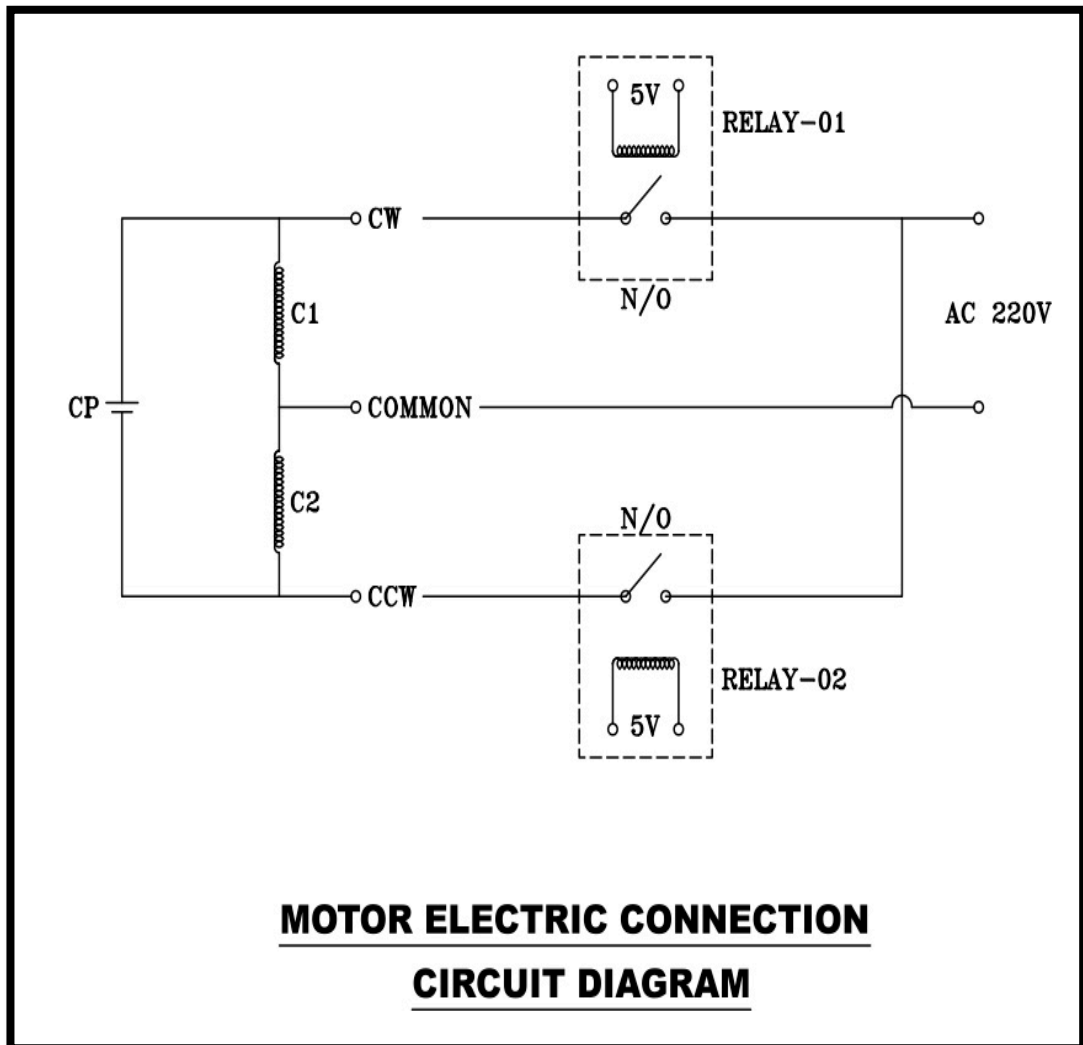
Figure A.8: Motor wiring connections

Appendix B: Project schematics produced
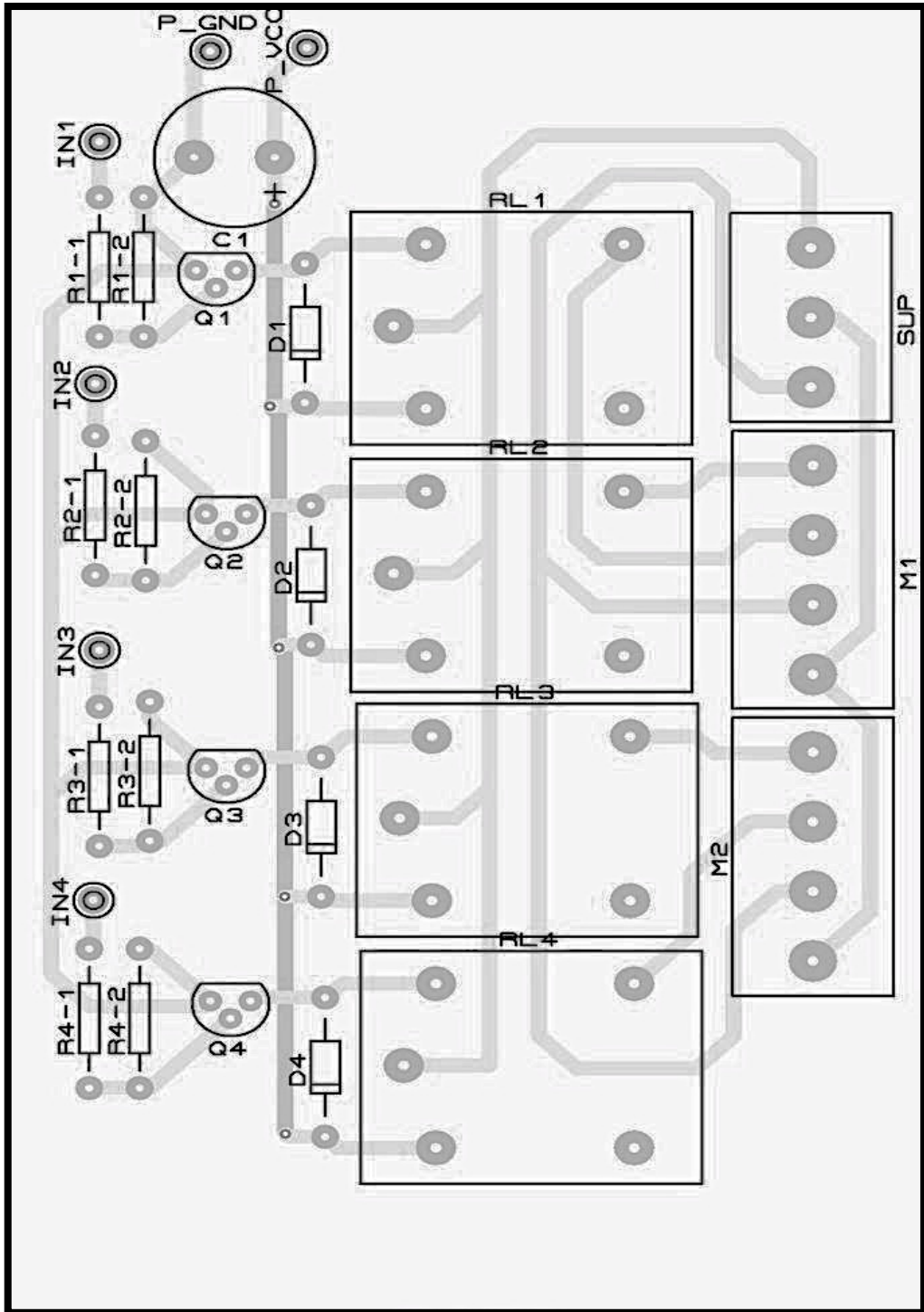
Figure B.1: Arduino PCB layout
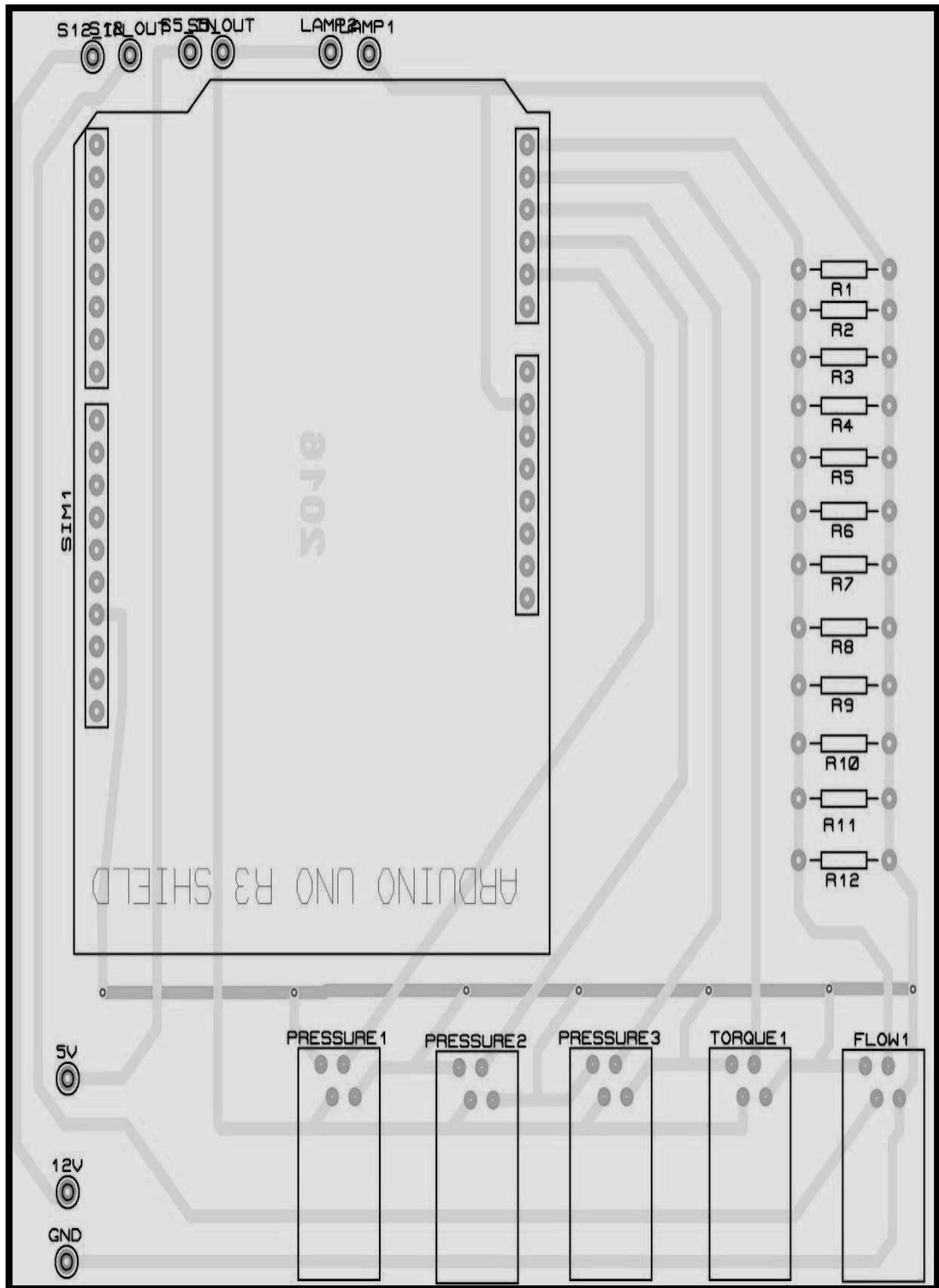
Figure B.2: Relays PCB layout
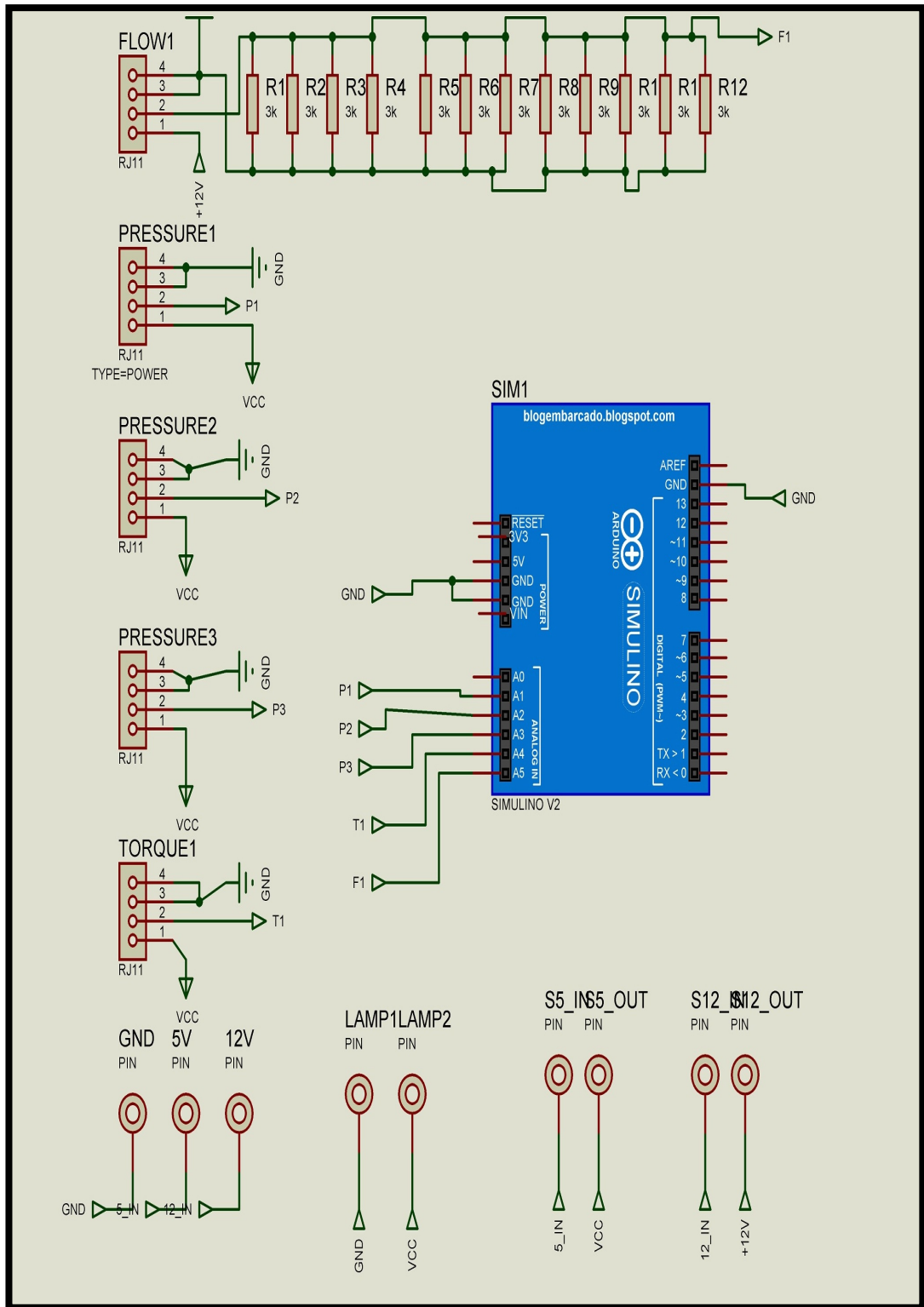
Figure B.3: Arduino box schematic
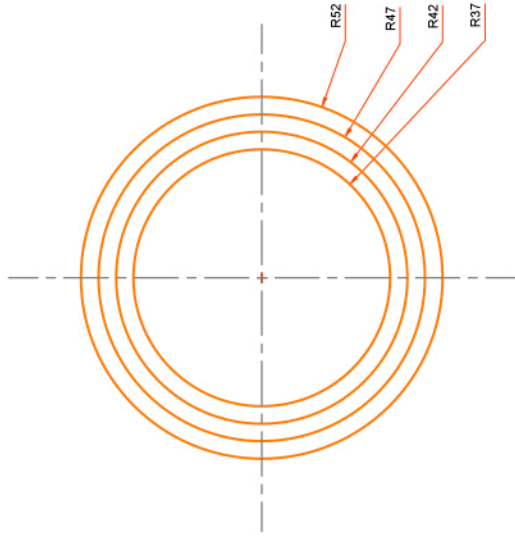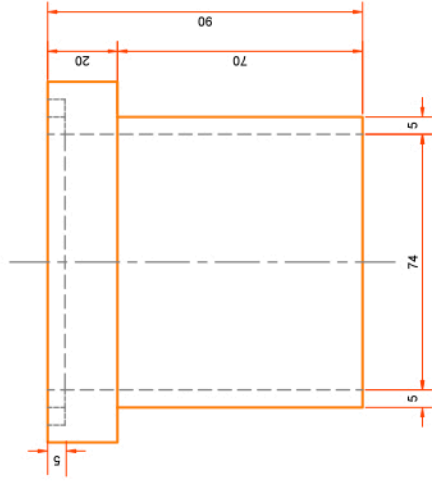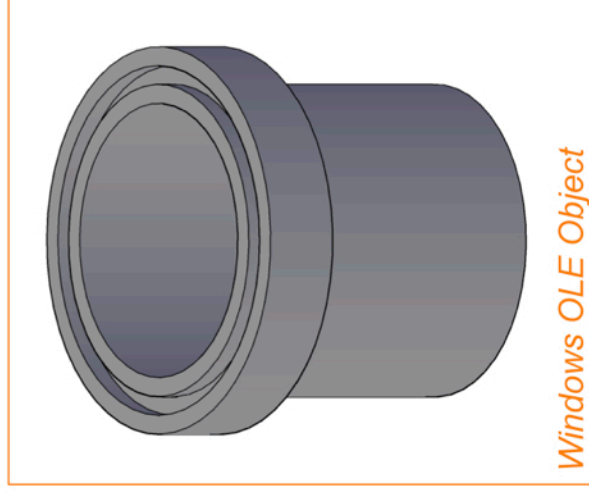
Windows OLE Object

3D SHADED VIEW

TOP VIEW

R52
R47
R42
R37

SIDE VIEW

90
20
70
5
74
5
5

APPROVAL:	DATE	PROJECT	COMPUTERISING AXIAL FLOW PUMP/TURBINE
DRAWN BY: JAD KASSAB	24/05/2016	DRAWING TITLE:	FABRICATION DRAWING TURBINE JOINT ADAPTOR
CHECKED BY: ASSOC. PROF. HASAN HACISEVKI	24/05/2016	MATERIAL TYPE.::	PVC
ISSUED BY: JAD KASSAB	24/05/2016	DRAWING NO.: SK - 1	SHEET: 1 OF 1
		SCALE: N.T.S	ANGLE OF PROJECTION

Windows OLE Object

3D SHADED VIEW

TOP VIEW

20

R5

10

30

40

30

25

15

4 holes Ø3

25

10

10

15

15

30

Side VIEW

3

10

10

3

10

95

75

3

15

30

10

5

Windows OLE Object

3D SHADED VIEW

TOP VIEW

Side VIEW

2 holes Ø3

Windows OLE Object

3D SHADED VIEW

ISOMETRIC VIEW

APPROVAL:	DATE	PROJECT	COMPUTERISING AXIAL FLOW PUMP/TURBINE
DRAWN BY: JAD KASSAB	24/05/2016	DRAWING TITLE:	FABRICATION DRAWING MOTOR BRACKET
CHECKED BY: ASSOC. PROF. HASAN HACISEVKI	24/05/2016	MATERIAL TYPE.:	STEEL
ISSUED BY: JAD KASSAB	24/05/2016	DRAWING NO.: SK - 4	SHEET: 1 OF 2
		SCALE: N.T.S	ANGLE OF PROJECTION

RIGHT SIDE VIEW

TOP VIEW

FRONT VIEW

APPROVAL.:	DATE		PROJECT	COMPUTERISING AXIAL FLOW PUMP/TURBINE
DRAWN BY: JAD KASSAB	24/05/2016		DRAWING TITLE:	FABRICATION DRAWING MOTOR BRACKET
CHECKED BY: ASSOC. PROF. HASAN HACISEVKI	24/05/2016		MATERIAL TYPE.::	STEEL
ISSUED BY: JAD KASSAB	24/05/2016		DRAWING NO.: SK - 4	SHEET: 2 OF 2
			SCALE: N.T.S	ANGLE OF PROJECTION

4 holes equi spaced R4

Appendix C: Programming codes

```vbnet
Imports System
Imports System.ComponentModel
Imports System.IO.Ports


Public Class Form1

    Dim comPORT As String
    Dim receivedData As String = ""
    Dim serialarray() As String
    Dim sel_motor As Integer

    Dim datarray(5) As Double
    Dim cnt As Integer
    Dim avrgfactor


    Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MyBase.Load

        avrgfactor = 20
        TSer.Enabled = False
        porting.Out(888, 0)

    End Sub




    Private Sub Timer1_Tick(sender As Object, e As EventArgs) Handles TSer.Tick

        receivedData = ReceiveSerialData()
        serialarray = Split(receivedData, ":")

        If serialarray.Length = 7 And (serialarray(0) = "OK") Then
            RecData()
            box1.BackColor = Color.Lime
            Status.Text = "Connected."
        Else
            box1.BackColor = Color.Red
        End If

    End Sub

    Function RecData()


        If cnt < avrgfactor + 1 Then
            datarray(0) = datarray(0) + Math.Round((Int(serialarray(4)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(1) = datarray(1) + Math.Round((Int(serialarray(3)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(2) = datarray(2) + Math.Round((Int(serialarray(2)) * 0.072 + 0.525 - 7) * 0.703, 2)
            datarray(3) = datarray(3) + Math.Round(0.00020825 * ((Int(serialarray(5) - 219) ^ 2)), 2)
            datarray(4) = datarray(4) + Math.Round(Int(serialarray(1))) / 200
            cnt = cnt + 1

        Else

            sen1.Text = datarray(0) / avrgfactor
```

```vb
        sen2.Text = datarray(1) / avrgfactor
        sen3.Text = datarray(2) / avrgfactor
        sen4.Text = datarray(3) / avrgfactor
        sen5.Text = datarray(4) / avrgfactor

        datarray(0) = 0
        datarray(1) = 0
        datarray(2) = 0
        datarray(3) = 0
        datarray(4) = 0

        cnt = 0

    End If
    REM sen1.Text = Math.Round((Int(serialarray(4)) * 0.072 + 0.525 - 7) * 0.703, 2)
    REM sen2.Text = Math.Round((Int(serialarray(3)) * 0.072 + 0.525 - 7) * 0.703, 2)
    REM sen3.Text = Math.Round((Int(serialarray(2)) * 0.072 + 0.525 - 7) * 0.703, 2)
    REM sen4.Text = serialarray(5)
    REM sen5.Text = Math.Round(Int(serialarray(1))) / 200

    Return False
End Function
Function ReceiveSerialData() As String
    Dim Incoming As String
    Try
        Incoming = SerialPort1.ReadExisting()
        If Incoming Is Nothing Then
            Return "nothing" & vbCrLf
        Else
            Return Incoming
        End If
    Catch ex As TimeoutException
        Return "Error: Serial Port read timed out."
    End Try

End Function




Function resetpanel()
    sen1.Text = 0
    sen2.Text = 0
    sen3.Text = 0
    sen4.Text = 0
    sen5.Text = 0
    Return False
End Function


Private Sub M1L_MouseDown(sender As Object, e As MouseEventArgs) Handles M1L.MouseDown
    porting.Out(888, 128)
    sel_motor = 1
    TMotA.Enabled = True
End Sub

Private Sub M1L_MouseUp(sender As Object, e As MouseEventArgs) Handles M1L.MouseUp
    porting.Out(888, 0)
    TMotA.Enabled = False
End Sub

Private Sub M1R_MouseDown(sender As Object, e As MouseEventArgs) Handles M1R.MouseDown
    porting.Out(888, 16)
```

```vb
            sel_motor = 2
            TMotA.Enabled = True
    End Sub

    Private Sub M1R_MouseUp(sender As Object, e As MouseEventArgs) Handles M1R.MouseUp
            porting.Out(888, 0)
            TMotA.Enabled = False
    End Sub

    Private Sub M2L_MouseDown(sender As Object, e As MouseEventArgs) Handles M2L.MouseDown
            porting.Out(888, 32)
            sel_motor = 3
            TMot.Enabled = True
    End Sub

    Private Sub M2L_MouseUp(sender As Object, e As MouseEventArgs) Handles M2L.MouseUp
            porting.Out(888, 0)
            TMot.Enabled = False
    End Sub

    Private Sub M2R_MouseDown(sender As Object, e As MouseEventArgs) Handles M2R.MouseDown
            porting.Out(888, 64)
            sel_motor = 4
            TMot.Enabled = True
    End Sub

    Private Sub M2R_MouseUp(sender As Object, e As MouseEventArgs) Handles M2R.MouseUp
            porting.Out(888, 0)
            TMot.Enabled = False
    End Sub

    Private Sub Form1_Closing(sender As Object, e As CancelEventArgs) Handles Me.Closing
            If SerialPort1.IsOpen Then SerialPort1.Close()
            porting.Out(888, 0)
    End Sub

    Private Sub TMot1_Tick(sender As Object, e As EventArgs) Handles TMot.Tick
            Select Case sel_motor
                Case 1
                    If pbar1.Value <> pbar1.Maximum Then
                        pbar1.Value = pbar1.Value + 1
                        LM1.Text = pbar1.Value & "%"
                        M1L.Enabled = True
                    Else
                        If Rst1.Checked = False Then
                            M1L.Enabled = False
                            TMot.Enabled = False
                        porting.Out(888, 0)
                    End If
                    End If

                    If pbar1.Value > pbar1.Minimum Then
                        M1R.Enabled = True
                    End If

                Case 2
                    If pbar1.Value <> pbar1.Minimum Then
                        pbar1.Value = pbar1.Value - 1
                        LM1.Text = pbar1.Value & "%"
                        M1R.Enabled = True
                    Else
                        If Rst1.Checked = False Then
                            M1R.Enabled = False
                            TMot.Enabled = False
```

```vbnet
                porting.Out(888, 0)
            End If

        End If

            If pbar1.Value < pbar1.Maximum Then
                M1L.Enabled = True
            End If

        Case 3
            If pbar2.Value <> pbar2.Maximum Then
                pbar2.Value = pbar2.Value + 1
                LM2.Text = pbar2.Value & "%"
                M2L.Enabled = True
            Else
                If Rst1.Checked = False Then
                    M2L.Enabled = False
                    TMot.Enabled = False
                    porting.Out(888, 0)
                End If
            End If

            If pbar2.Value > pbar2.Minimum Then
                M2R.Enabled = True
            End If

        Case 4
            If pbar2.Value <> pbar2.Minimum Then
                pbar2.Value = pbar2.Value - 1
                LM2.Text = pbar2.Value & "%"
                M2R.Enabled = True
            Else
                If Rst1.Checked = False Then
                    M2R.Enabled = False
                    TMot.Enabled = False
                    porting.Out(888, 0)
                End If
            End If

            If pbar2.Value < pbar2.Maximum Then
                M2L.Enabled = True
            End If

    End Select



End Sub


Private Sub ListButton_Click_2(sender As Object, e As EventArgs) Handles ListButton.Click
    comboPort.Items.Clear()
    comPORT = ""
    For Each sp As String In My.Computer.Ports.SerialPortNames
        comboPort.Items.Add(sp)
    Next

    If (comboPort.Items.Count <> 0) Then
        comboPort.Enabled = True
        comboPort.SelectedIndex = 0
        Status.Text = "Select the COM Port and click Connect."
        ConnectButton.Enabled = True
    Else
```

```vbnet
            Status.Text = "No device is available."
            ConnectButton.Enabled = False
            comboPort.Enabled = False
        End If
    End Sub

    Private Sub comboPort_SelectedIndexChanged(sender As Object, e As EventArgs) Handles comboPort.SelectedIndexChanged
        If (comboPort.SelectedItem <> "") Then
            comPORT = comboPort.SelectedItem
        End If
    End Sub

    Private Sub ConnectButton_Click(sender As Object, e As EventArgs) Handles ConnectButton.Click
        If (ConnectButton.Text = "Connect") Then
            If (comPORT <> "") Then
                SerialPort1.Close()
                SerialPort1.PortName = comPORT
                SerialPort1.BaudRate = 9600
                SerialPort1.DataBits = 8
                SerialPort1.Parity = Parity.None
                SerialPort1.StopBits = StopBits.One
                SerialPort1.Handshake = Handshake.None
                SerialPort1.Encoding = System.Text.Encoding.Default 'very important!
                SerialPort1.ReadTimeout = 10000
                Try
                    SerialPort1.Open()
                Catch ex As Exception
                    MessageBox.Show(ex.Message)
                    Exit Sub
                End Try

                ConnectButton.Text = "Disconnect"
                TSer.Enabled = True

                ListButton.Enabled = False
                comboPort.Enabled = False
                Status.Text = "Checking for connection."

            End If
        Else


            SerialPort1.Close()
            ConnectButton.Text = "Connect"
            TSer.Enabled = False
            Status.Text = "No connection."
            ConnectButton.Enabled = False
            comboPort.Enabled = False
            ListButton.Enabled = True
            box1.BackColor = Color.Red
            resetpanel()

        End If
    End Sub

    Private Sub Rst1_CheckedChanged(sender As Object, e As EventArgs) Handles Rst1.CheckedChanged
        Select Case Rst1.Checked
            Case True
                M1L.Enabled = True
                M1R.Enabled = True
                M2L.Enabled = True
                M2R.Enabled = True
```

96

```vb
        Case False
            If pbar1.Value = pbar1.Minimum Then
                M1R.Enabled = False
            End If

            If pbar1.Value = pbar1.Maximum Then
                M1L.Enabled = False
            End If

            If pbar2.Value = pbar2.Minimum Then
                M2R.Enabled = False
            End If

            If pbar2.Value = pbar2.Maximum Then
                M2L.Enabled = False
            End If

    End Select
End Sub

Private Sub TMotA_Tick(sender As Object, e As EventArgs) Handles TMotA.Tick
    Select Case sel_motor
        Case 1
            If pbar1.Value <> pbar1.Maximum Then
                pbar1.Value = pbar1.Value + 1
                LM1.Text = pbar1.Value & "%"
                M1L.Enabled = True
            Else
                If Rst1.Checked = False Then
                    M1L.Enabled = False
                    TMotA.Enabled = False
                    porting.Out(888, 0)
                End If
            End If

            If pbar1.Value > pbar1.Minimum Then
                M1R.Enabled = True
            End If

        Case 2
            If pbar1.Value <> pbar1.Minimum Then
                pbar1.Value = pbar1.Value - 1
                LM1.Text = pbar1.Value & "%"
                M1R.Enabled = True
            Else
                If Rst1.Checked = False Then
                    M1R.Enabled = False
                    TMotA.Enabled = False
                    porting.Out(888, 0)
                End If

            End If

            If pbar1.Value < pbar1.Maximum Then
                M1L.Enabled = True
            End If


    End Select


End Sub
End Class
```

Appendix D: Laboratory Handout

COURSE: FLUID MECHANICS MENG 353

Semester:

Name of Experiment: Axial Flow Turbine Test

Instructor: Assoc. Prof. Dr. Hasan Hacışevki

Group No:

Name and Surname: **Student No:**

1. ……………………………………………   …………………...

2. ……………………………………………   …………………...

3. ……………………………………………   …………………..

4. ……………………………………………   …………………..

5. ……………………………………………   …………………...

Date of experiment: ……………….

Date of submission: ……………….

EVALUATION

Activity During Experiment & Procedure	**30 %**	
Data, Results & Graphs	**35 %**	
Discussion, Conclusion & Answer to Questions	**30 %**	
Neat and tidy report writing	**5 %**	
Overall Mark		

Objective

To Obtain turbine characteristic curves of pressure drop, output power and efficiency against speed for a number of selected flow rates.

Apparatus

Figure D.1: Axial flow water pump/turbine test Rig H.26

THEORY

For given turbine geometry, the principal variables are speed, torque, flow rate and pressure drop. In this experiment the flow rate will be kept constant. The speed of the turbine will be varied by changing the dynamometer loading. Dynamometer without any loading will run freely and the energy produced by the turbine will overcome only the frictional forces.

The pressure drop across the turbine decreases with the increase in speed. Thus the power input also decreases with the increase in speed.

However the output power increases to maximum value then decreases as the speed of the turbine increases. The maximum efficiency occurs when the outlet flow from the rotor is approximately axial. This is to be expected since any swirling of flow at the exit represents energy, which cannot be used.

From the obtained graphs, it should be seen that the maximum output power and efficiency is about half the unloaded or run away speed. This is typical of a wide range of turbines.

Results and calculations

Turbine characteristic curves of pressure drop, output power and efficiency against speed will be obtained for different flow rates.

Speed (rev/min), Torque (Nm), Flow rate (Kg/s), Reference pressure (m H_2O),

Pressure drop (m H_2O) will be obtained during the experiment.

$Mechanical\ Power\ =\ 2\pi nT/60\ [watts]$

$Water\ power\ =\ gH\dot{m}\ [watts]$

$Efficiency = \frac{Mechanical\ Power}{Water\ Power}$

Procedure

- **Software procedure:**

  6. Start up the pc.

  7. The compiled version of the software should be turned on from the desktop with the name of "Axial flow test".

  8. Click on list ports after being sure that the system is turned on.

  9. Choose the COM port connected to the system.

  10. Click on "connect" to finally activate the system panel.

NB: Be sure before starting the experiment that the valves are fully closed by regulating them in the setup mode.
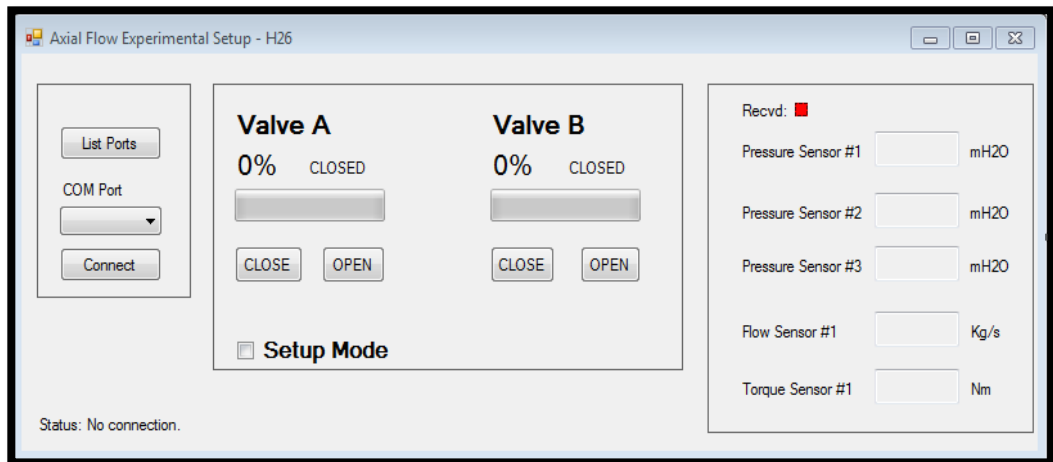
- **Turbine test procedure:**

    10. Set the reservoir air pressure to about 1.0 bar.

    11. Set the valves A and B to be fully closed.

    12. Set the Turbine speed control fully anticlockwise.

    13. Switch ON the main supply.

    14. Turn the selector switch to Turbine.

    15. Press start button (for the auxiliary pump).

    16. Open valve A until the required flow is obtained (fine flow control can be obtained by opening valve B slightly).

    17. Use loading resistors & the field rheostat to adjust the required speed.

    18. Take readings of: Speed, Torque, Flow rate, Ref. Pressure and Overall Head drop across the turbine.

    ❖ Adjust the speed to a series of selected valves to obtain a complete set of characteristics.

    ❖ Repeat the procedures for other selected Flow Rates.

    ❖ When tests are complete, turn off main supply.

EXPERIMENTAL DATA

Table D.1: Tabulated data

Speed (rpm)	Torque (N.m)	Mech Power (watt)	Flow rate (kg/s)	Ref Pressure (m H2O)	Head (m H2O)	Water power (watt)	Efficiency (%)

DATA ANALYSIS

GRAPHS

DISCUSSION & CONCLUSION