TecnoCampus Escola Superior Politècnica

Centre adscrit a la Universitat Pompeu Fabra Barcelona

Grau en Enginyeria Electrònica Industrial i Automàtica

TECHNICAL CHARACTERIZATION OF A HANDWRITING ANALYSIS PRESSURE SENSOR FOR BIOMETRICS APPLICATION.

Memòria

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Dedication

Als meus pares, que sense ser enginyers, m’han donat la curiositat i l’esperit crític que m’ha portat a ser-ho jo.

A la Ginger, que m’ha acompanyat tots aquests anys.

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Resum

Continuació de la línia de recerca del Signal and Data Processing Research Group i que té l'objectiu de linealitzar un sensor de pressió de digitalització de signatures i escriptura. La normalització del sensor permetrà utilitzar dades de pressió en diferents dispositiu digitalitzadors, amb aplicacions mèdiques i també de reconeixement de persones.

Resumen

Continuación de la línea de investigación del Signal and Data Processing Research Group y que tiene por objetivo linealizar un sensor de presión de digitalización de firmas y escritura. La normalización del sensor permitirá usar datos de presión en distintos dispositivos digitalizadores, con aplicaciones médicas y también de reconocimiento de personas.

Abstract

Continuation of the Signal and Data Processing Research Group research line which aim is a digitising signature and writing pressure sensor linearization. The sensor normalisation will permit to use pressure data in different digitising devices, applicable in medicine and also in identity recognition.

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Glossary.

aka	Short for “Also known as”
BBDD	Base/s de Datos – Base/s de Dades
CBMS	Code Book Multi Section
Cobot	*Collaborative robot*
DB	Data Base
DCF	Detection Cost Function
EMR	Electro Magnetic Radiation
ES	Electrostatic
FAR	False Acceptance Ratio
FRR	False Rejecting Ratio
FSR	Force Sensing Resistor
Full scale	Maximum value that an electronic system can represent or output.
MCYT	Signature Database called after the Spanish Ministerio de Ciencia Y Tecnología
τ (tau)	Time constant
TFG	Treball de Final de Grau (Bachelor’s Degree Final Project)
TSR	Technical Specification or Requirement
VQ	Vector Quantisation
Wacom	Wacom Company, Limited

1 Aim

1.1 Intention

The aim of this project is to model and linearize a pressure sensor that is used to acquire handwriting samples so the pressure data obtained from different sensors can be compared. Then, this will be applied to the signature recognition field.

To make this possible the project involved the following stages: obviously, the first step consisted in gathering all the information from the Signal and Data Processing Research Group previous work and to expand it according to this project's needs; secondly, the modelling of the writing tools used to take the writing samples; thirdly, the normalization itself; and lastly, its application to biometric recognition task (identification and/or verification) in a mismatch scenario: training and testing samples which can be acquired using different handwritten sensors or stylus.

1.2 Purpose

The main purpose of this project and the reason why it is realised is to make a Bachelor's Degree final project that includes knowledge from the Electronic Engineering Degree[1] and that proves the author's ability to carry out a typical engineer job. In this case, the improvement of online handwriting biometric systems by means of pressure normalisation.

At the same time, this project continues the tutor's, Professor Marcos Faúndez-Zanuy, previous research and projects in biometrics. In particular, it will make it possible to use pressure data in writing samples obtained with different devices. The project will be continued in the future as well, as a part of an open research line.

[1] Enginyeria Tècnica Industrial: Especialitat Electrònica Industrial

1.3 Object

The result is a conversion from a writing output data provided by the analogue-to-digital data converter (ADC) into standard pressure values, the normalisation of the pressure sensor. Concurrently, a modelling process and the model of the writing set will be made, as well as some conclusions about using pressure data in biometrics.

1.4 Scope

Besides the typical research in the state of the art and the background of this project's field, an analysis of the previous work of this university[2] will be done. This includes definitions, terms, techniques, tools, technology, etc.

In addition, the project has a feasibility analysis and a budget plan. It also includes a time planning with, at least, 400 hours of work. The planning has been developed together with another TFG plan, made simultaneously, and the academic schedule. Also, the plan has been controlled during its progress.

The behaviour and characteristics of the pressure sensor, consisting of a set of an electronic tablet and pen, have to be modelled. To do it, one or more tests have been designed, executed and analysed, backing it all up with documentation. When the tests required the use of some kind of machinery, the use of tools and machines from the university or from collaborators has had priority. The test documentation will include an analysis of possible inaccuracy and error. The calibration of the tablet and pen set is not expected, according to their manuals.

The main part of the project is the normalization of the sensor based on the above-mentioned test results. The normalization must suit previous tools developed during prior projects. In short, it must convert raw pressure data into standard pressure units. The normalization have been used on data sets already gathered on previous research to obtain pressure values; more samples will be collected if necessary. Biometric recognition experiments have been performed to evaluate the relevance of sensor mismatch in biometric classification accuracy. Lastly, the project incorporates a conclusions section.

[2] From now on, the term "university" or "this university" will refer to "Tecnocampus Mataró-Maresme"'s "Escola Superior Politècnica" university, where this project is developed.

2 Background

2.1 Introduction

2.1.1 Definition of Biometrics

The literal meaning of *biometrics* is the measurement of life, or of something alive. [1]

Besides this, there are two more definitions for this term:

1 - Biometrics is the measurement and analysis of a *biometric characteristic*, mainly, in order to make *biometric recognitions*, or in other words, to verify, to authenticate people's identity or to recognise individuals. Those measurements and analysis are usually automated. The term *biometrics* also refers to the technology used to do so.

2 - Biometrics can be also understood as the statistical and mathematical methods used to analysis data problems from biological sciences, like agriculture, forestry, medicine, pharmacy, psychology, environment and pollution.

[2] [3]

In the scope of this project...

The definition that concerns this project is the first one: studying whether pressure data is significant in identity recognition or authentication. However, the result of this project could set a basis to apply to apply it to biological sciences as well.

2.2 Identifications vs Authentication

Subject *identification* consists in comparing a sample with a database in order to see if there is a match.

Subject *authentication* (a.k.a. *verification*) consists in checking the identity: the subject identifies himself and he provides a biometric that is compared with a *print* or *model* associated to this identity. It is the same idea as a user and password set.

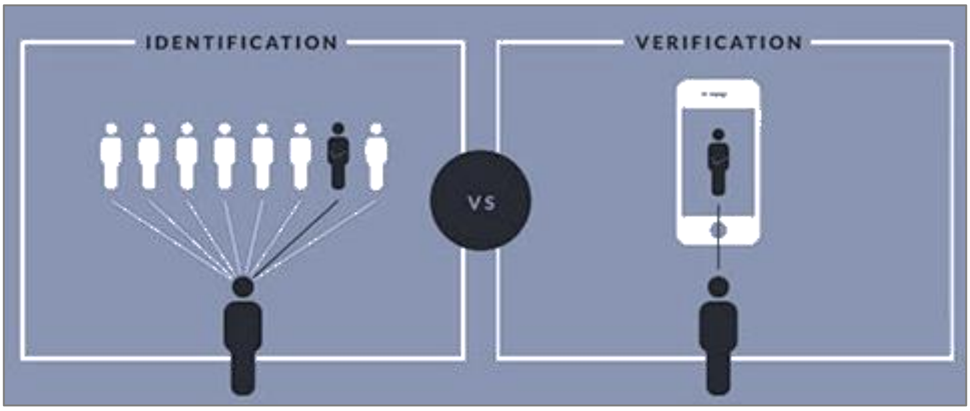


Fig. 2.1 - Identification vs. Authentication. Source: Bayometric.com

Biometric samples, biometric templates, biometric print and biometric model are different expressions referring to the same term.

2.3 About biometric characteristics

A **biometric characteristic** is a unique physical, biological/physiological or behavioural feature that can be used to make biometric recognitions.

They must be:

- Measurable, so they can be analysed and compared objectively, avoiding any ambiguity.
- Recordable, so they can be used at any time and a database can be created in order to compare the required samples.
- Universal, inclusive: they have to be able to be measured in as many people as possible, ideally, in everybody. As biometrics consist in measuring parts or phenomena of the human body (see §0), people having functional diversity must be considered, as well as differences between genders, age, culture, etc.

If the biometric characteristic is wanted to be used to identify people, it also must be:

- Unique, different for each individual, so it allows to distinguish, to identify them.
- Invariable, permanent over time. Otherwise, it would not be possible to compare somebody's biometric measure with its template. [1] [4]

2.3.1 Types of biometric characteristics

Morphological. This means, related to parameters of the human body that can be measured. Some examples: the shape of the **ear**, some **iris**' features, the **retina**'s patterns of veins, the **face** (facial patterns or attributes; *Eigenface*), the **fingerprint**, the **friction ridges** found on plantar or palmar surfaces of primates, like fingertips [2], the **finger** and the **hand** geometry or shape.

Behavioural: actions performed by a subject. For instance: the **gait** – the manner of walking, the **typing** style, **handwriting** and **signature**.

The Speech is a biometric characteristic which is both morphological and behavioural.

- Speaker identification, by comparing the speaker's voice with a large set of samples from a database. This is used to identify talkers in recordings, systems…
- Speaker authentication: verifying a speaker's identity by comparing his voice to his supposed identity voice print, which is known. An example where this is applied is telephone banking.

Note that those two cases are different from *speech recognition*: identifying what is being said by a speaker.

Other relevant biometric characteristics are: the DNA (DNA matching is made through DNA segments analysis and comparison); olfactory features: odour of an individual; **vein patterns** of the fingertip or the hand palm; EEG (Electroencephalogram), ECG (Electrocardiogram) and MRI (Magnetic Resonance Imaging).
The last three ones cannot be used on identity recognition or authentication, but they are widely used in biological sciences.

[3] [5] [6] [4]

2.4 About the use of biometric recognition

2.4.1 Security and private sectors

One of the most spread use of biometric recognition is to control access to restricted areas, physical or virtual, that require some degree of security such as computers and other devices, accounts, buildings, borders, airlines etc. and/or to accurately determine people's identity.

Australia got the first operational facial recognition system and it was set in all the country's major international airports by 2009.

Within private sectors, it has been applied in call centres, drug dispensing facilities, pubs, clubs and schools. [3]

2.4.2 Medicine and Health

Handwriting and signature signals are not only useful for identity verification solutions but also to support **diagnose and monitoring** some diseases. They commonly involve motion and / or coordination deficiency and, sometimes, they are degenerative diseases. For example: Alzheimer's, mild cognitive impairment (age-associated mental performance deterioration that is faster than the average cases), Parkinson's, essential tremor (a neurological disorder causing shakings, often affecting hands, but also other body parts; different to Parkinson's is some aspects), dysgraphia, autism or obsessive-compulsive disorder. [7]

Moreover, handwriting tests are used in **mental pathologies** analysis such as depression, anxiety or stress, the first one performing the worse among the three.

[5] [6]

2.4.3 Metadata extraction

Metadata (or Meta-data) is data that contains information of other data. Biometrics metadata can be extracted making a statistical analysis. [2]

Personal biometric metadata can refer to gender, origin and age; in the case of handwriting analysis, language is considered metadata too. [6]

2.5 Obstacles in biometrics

2.5.1 Privacy issues

Some people regard the spreading of biometrics use as a threat to their privacy and there exist even organisations that fight for this cause. Indeed, there have been cases of information stealing or misuse, but in the world of today, information plays a consequential role and regulations have been developed in this sense. Also, globalisation and IT development have brought the need to more exhaustive security barriers. [8]

Some institutions, as the Biometrics institute, state that the creation of standards in collection and protection of information can improve privacy. It is obvious that if no information is collected, it cannot be stolen and their owners' privacy cannot be violated. However, biometric data is usually gathered in order to protect people's privacy or security in different ways; so biometrics can be a tool to protect privacy. In any case, though, laws and norms must be followed so as to reduce any risk of privacy issues. [3] [6]

2.5.2 Stealing of biometrics

Although some could think that physical biometrics, such as the fingerprint or the iris print can be stolen, their removal from the owner body or their use after their owner's death is not viable. Also, some biometric scanning systems can detect if the sample is alive or not.

In behavioural biometrics, like handwriting, could be learned at some extent, but more precise systems, that use a greater number of variables void this kind of tricks.

Another way to use somebody else's biometrics would be to obtain their biometric data and to expose it into the biometric scanner, fooling its system. This, nevertheless, would be a way more difficult manner to do it.

More advanced systems would have encrypted data and would use different biometrics at the same time or they would change them randomly. [3]

2.5.3 Health threats

Iris and face scans are made by infra-red light. As the exposure is very short there is no risk of damage.

Regarding systems that require physical contact, like fingerprint scans or signature readers, they could be a way of infection, but no higher than any other surface like knobs or bannisters. [3]

2.5.4 Change of a person's biometrics

They are mostly constant after one's has finished growing. They can change as well when coming to an old age. [9] [3]

2.6 Signature

Devices to perform online writing and signature became cheaper and popular during the recent years. They are now present in the daily life, mainly in paying devices, contracts, certificates and other official documents that are signed from a distance using a computer or even the phone. [10]

This fact has brought us the possibility to make deeper and easier studies on this biometric characteristic and it has made it more important to know how to use it.

Whereas writing signals for identity verification are well studied and used, researches in medicine areas are being developed and there are already results that prove this as a useful support tool in this field.

2.6.1 Characteristics of handwriting biometric analysis.

Depending on the changeability of the analysed text, there are two types of handwriting analysis:

- *Text-dependent*: using a fixed text. Signature is a particular case of text-dependent handwriting analysis and it is the most common writing type in identity authentication.
- *Independent*: using any text, with no restrictions.

Regarding the **data acquisition method**, which conditions the amount of information got from the writing and that will be available to be used for the recognition or authentication, there are two more types [11]:

· *Static*: the comparison of two stored paper-supported scanned signatures using algorithms; the only information is the trace itself: its shape.
· *Dynamic*: a signing device reads the signature in real-time; it stores more data besides the signature itself, dynamic data. It can be used to create a biometric template to authenticate the signature's owner identity afterwards. The authentication can be done at the same time the signature is performed or later.

Note that when writing on an electronic device, the terms are usually called *Online signature*. The opposite term would be *Offline signature* or just *signature*. In the general cases of writings, the adjectives are used analogously: *online writing* and *offline writing*.

Static signatures are considered *offline signatures* (even though the scanner is an electronic device, it is not a signing device and it does not acquire dynamic data). [12]

Generally, researches and studies results have the following characteristics:

- The accuracy is grater in authentication than in identification.
- The more words used, the greater the probability to succeed.
- Online writing gets better results than offline writing.

In fact, the **amount of words** used can vary a lot: a single word, a signature, a set of words, a short sentence, a paragraph, an entire document…

Also, a test by Sesa & Faundez-Zanuy shows that the use of **capital letters** improves a lot the identification rate: while using 370 users, a 92.38 % and a 96.46 % was achieved using one and two words, respectively. [13]

To conclude this part, the importance of writing **air movements** must be highlighted. The incorporation of air movements into all sorts of handwriting tests analysis (medicine, metadata and identity applications) provide better results, which means that they contain a great amount of information.

[6] [3]

2.6.2 Dynamic online handwritten signals.

As said above, *dynamic* means that data is time-tied and so it is obtained and stored at the same time that the user is writing. To register dynamic online handwritten signals, a digitising tablet and a consistent pen are needed; they act as a sensor, a complex one.

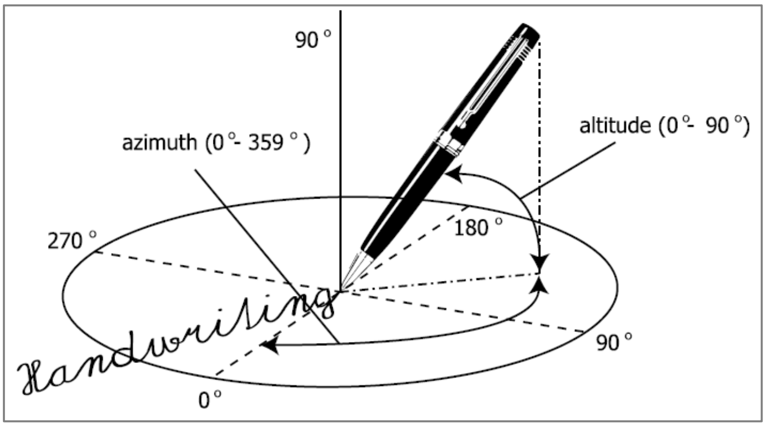


Fig. 2.2 - Online writing parameters schematic explanation [6].

The signal created while performing online handwriting is sampled using a determined sampling period. When the pen is touching the writing surface, **typical parameters** that can be acquired are the following:

- Two coordinates position on the writing surface (x, y). This data can be recorded if the pen is relatively close to the surface; it depends on the pen and surface features. This means that, for a short distance, the position of the pen in the air can still be known: for instance, if the trace is started before touching the surface, if the writer's hand shakes, or other gestures.

  Several works proof that in-air movements provide as much information as on-surface ones, and it is very helpful in diagnose and monitoring of disorders like Alzheimer, Parkinson, dysgraphia, high-functioning autism…
- Two angles orientation of the writing pen (azimuth: orientation in relation to the surface's coordinates; altitude: orientation in relation to the vertical axis, it indicates how vertical the pen is).
- A Boolean variable that denotes whether the pen is touching the writing surface or not. While the pen is out of range this is the only parameter sampled or known.
- The pressure that the pen makes on the surface.
- A timestamp: it stores information about the time when each sample of the signature was got.

The samples provide raw data and has to be processed afterwards to get actual information.

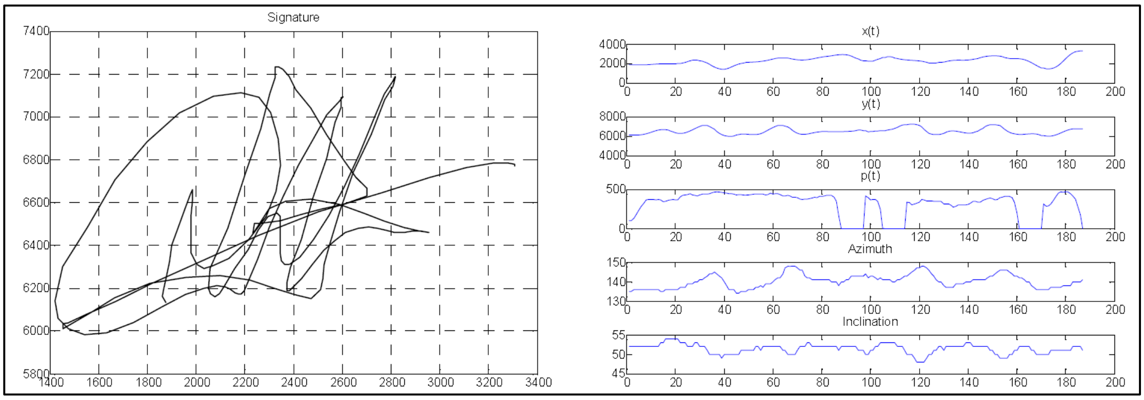


Fig. 2.3 - Example of online signature acquisition [14].

In the scope of this project...

The pressure sensor output has to be handled in order to know real pressure data.

2.6.3 Digitising devices or tablets

- Tablets that provide visual feedback.
  - The tablet itself has a display and it shows the traces in real-time.
  - Digitising tablets that can work while writing on a paper placed on its surface and using an ink pen.

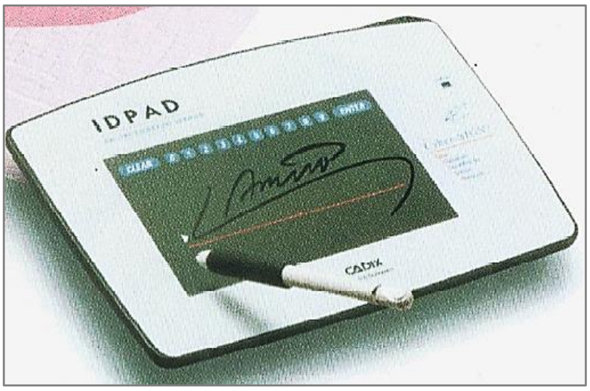


Fig. 2.4 - Digitising tablet providing visual feedback by displaying the pen's trace. [12]

Fig. 2.5 – A paper-and-ink-pen compatible digitising tablet. Source: Discovery Center learn.corel.com

- Tablets that do not provide visual feedback: the traces performed by the user do not appear on the tablet: they can be displayed in an external monitor or not. This makes it less natural to use them.

Fig. 2.6 - Wacom Intuos connected to a smartphone in order to provide visual feedback. Source: Wacom

Note: ink-less pens are also called "plastic" pens, since their nib is made of this material.

2.6.4 Positive and negative traits of signature over other identity recognition biometrics.

- ✓ It is difficult for an impostor to learn and execute the dynamic parameters of somebody else's signature.
- ✓ Signature is a traditional authentication mean, so it is broadly used and accepted.
- ✓ It can be changed at will, not as other biometrics.
- ✖ Changeability:
  - In general, signature presents greater variability than other biometrics: there are significant variations between signatures of the same person and they cannot be predicted.
  - Signature can change over time and, as other handwriting, it can be affected by the emotional state of the user and by other elements.
  - For some people, the signature presents a higher changeability than the average. This is common if the person is not used to sign.
- ✖ Forgery:
  - Experts could cheat on signature authentication, although in dynamic signature is much more difficult.
  - It is easier to forger than other types of biometrics.

[11]

2.7 Online writing material of this project

Here there is a description of the tablet-and-pen writing sets available at the university, their technology and their features. This is an indispensable step to design the experiment that will provide the data that is required to normalise the pressure samples. They are all from Wacom® Co,. Ltd.

- Wacom Intuos, a "pen tablet" + ink pen.
- Wacom STU 530, a signature pad.
- Others might be introduced during the project development, such as Cintiq.

Those pens are pressure-sensible, wireless and battery-less, so they are passive. [15] [16]

2.7.1 Active ES Technology

Active ES, or Active Electrostatic, is a digital pen technology used in Wacom® devices. It consists in an electrostatic capacitive coupling between the pen and the tablet. The tablet's display has a multiple electrostatic grid-shaped sensor net: the pen and one of the grids create an electric field; whereas the rest of the grids act as receivers and detect the presence this field.

Fig. 2.7 - Wacom Active ES Technology ilustration. Source: Wacom.com

This technology requires the pen to have batteries (AAAA type, 1.5 V) and a "super-capacitor" cartridge. Both of them can act as the pen's power supplier.

A super-capacitor (aka ultra-capacitor or double-layer-capacitor) that can hold energy in static charge form. [17] [18]

Features:

- High response - Millisecond data exchange rate.
- Hand rejection: only the pen can generate inputs.
- Hovering / in-air detection

2.7.2 EMR Technology

This EMR (Electro-Magnetic Resonance) technology is patented by Wacom® and it is based on electromagnetic induction.

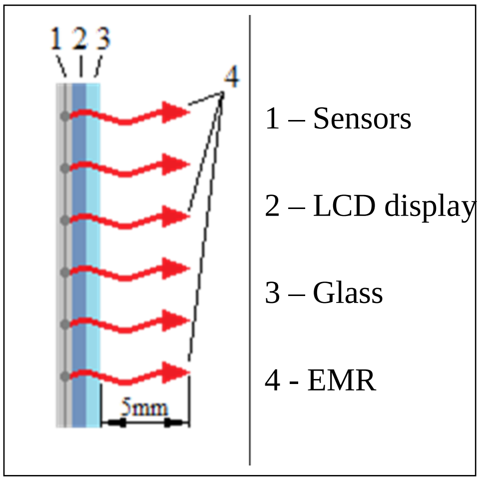


Fig. 2.8 - EMR Technology illustration.

A low power EM field is emitted by a grid-shaped layer of coils. This EM field belongs to the radio frequency spectrum (between 3 kHz and 300 GHz). [2] [14]. The coil grid layer is placed behind an LCD display and a hardened glass, but the EM can go through them and reach a distance of 5 mm further, approximately (this means that the pen can be detected while being within this range, providing *in-air* data).

The pen features a resonance circuit: another coil and a condenser, so when the pen is in the EM field range, it resonates, emitting a signal back to the digitising tablet. The resonance circuit and the coil grid compose the emitting unit.

The electromagnetic waves are returned by the pen, causing a variation on them that carries information about its parameters and that can be detected by the sensing unit. This one consists of the same emitting coils: they change from transmitting to receiving mode, and vice-versa, each 20 microseconds (time-division multiplexing). Note that the trace is got as a digital signal because it is sampled discreetly.

Finally, the signals gathered by the sensors become actual data after passing through a modulator and being processed through algorithms.

With this technology, the writing pen does not need batteries and it is wireless: the EM field provides energy to the pen.

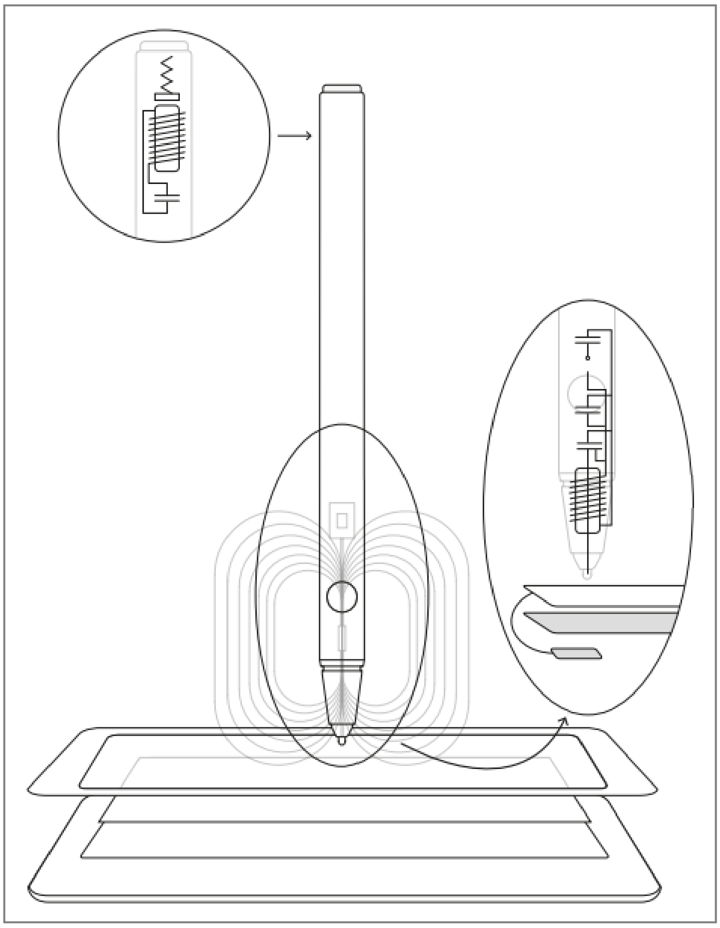


Fig. 2.9 - Wacom's digitising pen and tablet with EMR technology. Source: Wacom Co., Ltd. [17]

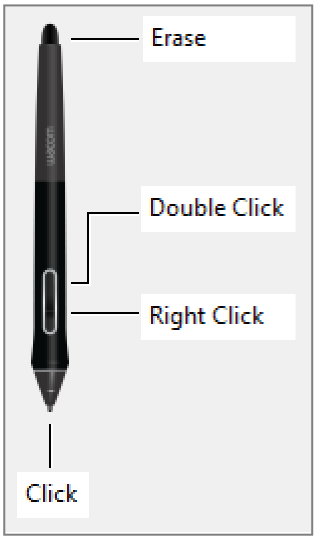


Fig. 2.10 –Pen buttons. Source: Wacom.

2.7.3 Other pen features

The main parts of the pen are the following:

- The pen tip. It acts as the left click of a mouse. It gets worn by use and has to be replaced. Also, it exist different types of tips with specific rigidness, thickness and ID, which is a parameter that changes the virtual drawing tool.
- The eraser. It works the same way as the pen tip but instead of writing, it erases the traces.
- Buttons. They can be configured to perform some actions.

2.7.4 The database.

The **MCYT**[3] database is an FPG-formatted public database produced by the Biometric Recognition Group ATVS in 2003. It is a bimodal database: it contains signatures and fingerprints too.

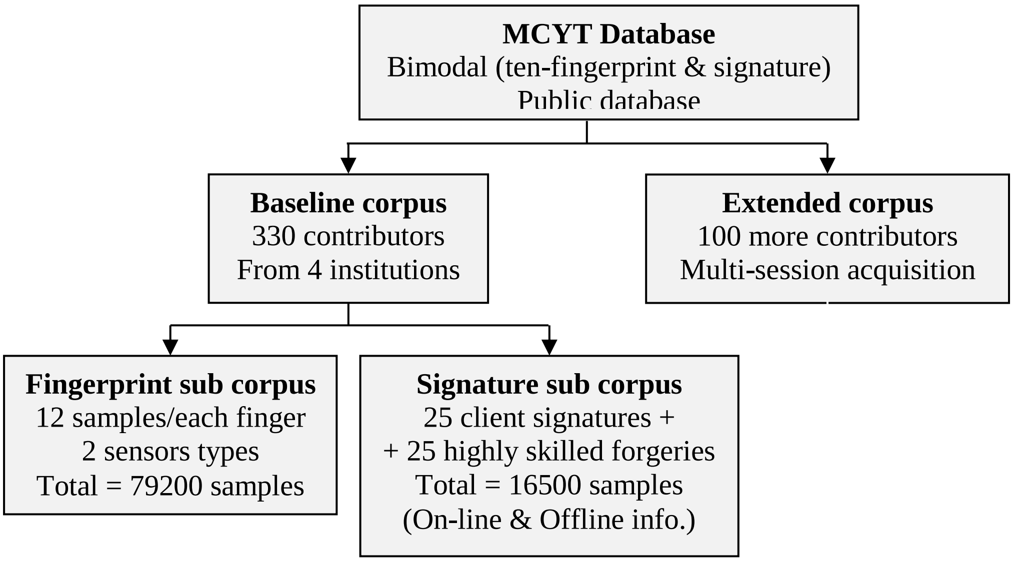


Fig. 2.11 - MCYT database structure and information. Own Work. Source: [19][4]

The signatures are online and were acquired by a Wacom Intuos A6 USB digitising pen and tablet set to 100 Hz sampling frequency, a resolution of 100 lines/mm and dividing the capture area in several acquisition frames.

The skilled forgeries are provided in 5 sets of 5 different signatures (25 in total) after training by copying the static signature.

Fig. 2.12 - Wacom Intuos A6 USB. Source: Wacom.

[3] MCYT stands for Ministrio de Ciencia y Tecnología, Spanish Sciene-and-Technology Ministry. [19]

[4] *Skilled forgeries* (a.k.a. *freehand forgeries*) are those that try to imitate the signature that they are intending to forge, both the static and dynamic traits. Oppositely, *substitution* or *random forgeries* use the own one, an invented one or another different from the genuine. [34]

2.7.5 The reference article

The article "Efficient on-line signature recognition based on multi-section vector quantization", by Marcos Faúndez-Zanuy and Juan Manuel Pascual-Gaspar serves as a main reference to this project and their results using the MCYT database will be compared with the ones obtained in this project. [11]

The original results of such article are shown below. Not all of them appeared in the paper, but it does contain Graphic representations of them. Also, some archives from that project were provided by Marcos.

Sections	Bits per section							
	1	2	3	4	5	6	7	8
1	48.67	77.21	91.27	95.27	95.58	95.52	95.21	94.24
2	80,61	92,55	97,09	97,21	96,97	96,97	96,67	*
3	91,33	96,30	97,58	98	97,82	97,45	*	*
4	94,24	96,79	97,58	97,45	97,21	97,21	*	*
5	95.39	96,67	97,15	97,33	97,33	96,91	96,42	96,18

Table 2.1 - Random forgeries Identification results from reference article. Source: [11] and old archives from 2005, provided by Marcos. (: not available data).*

The data from the table above has been plotted in Fig. 2.13. It coincides exactly with the one from the original article.

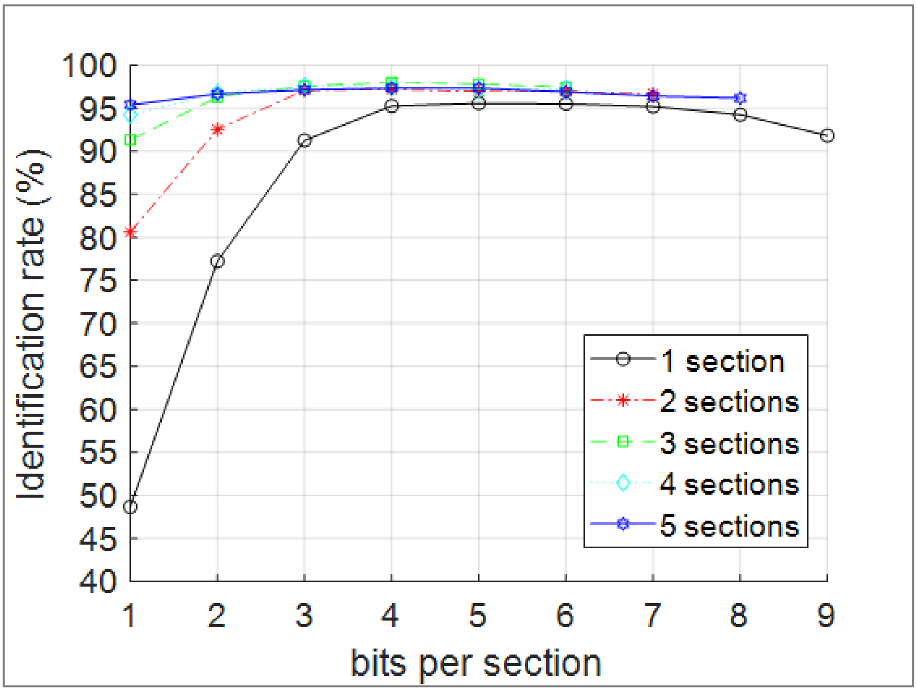


Fig. 2.13 - Random forgeries Identification results: plot of Table 2.1's data.

The detection cost function data is shown in Table 2.2 and its plot (Fig. 2.14) matches the original as well as the former.

Sections	Bits per section							
	1	2	3	4	5	6	7	8
1	29.21	19.49	10.81	6.49	5.37	4.8	4.31	4.39
2	20.04	10.32	5.529	3.721	3.145	3.053	2.974	*
3	12.75	6.770	3.731	2.770	2.559	2.513	*	*
4	10.17	5.489	3.231	2.496	2.485	2.481	*	*
5	8.425	4.305	2.827	2.222	2.294	2.330	2.504	2.600

Table 2.2 - Random forgeries Detection Cost Function results from reference article. Source: [11] and old archives from 2005, provided by Marcos. (: not available data).*

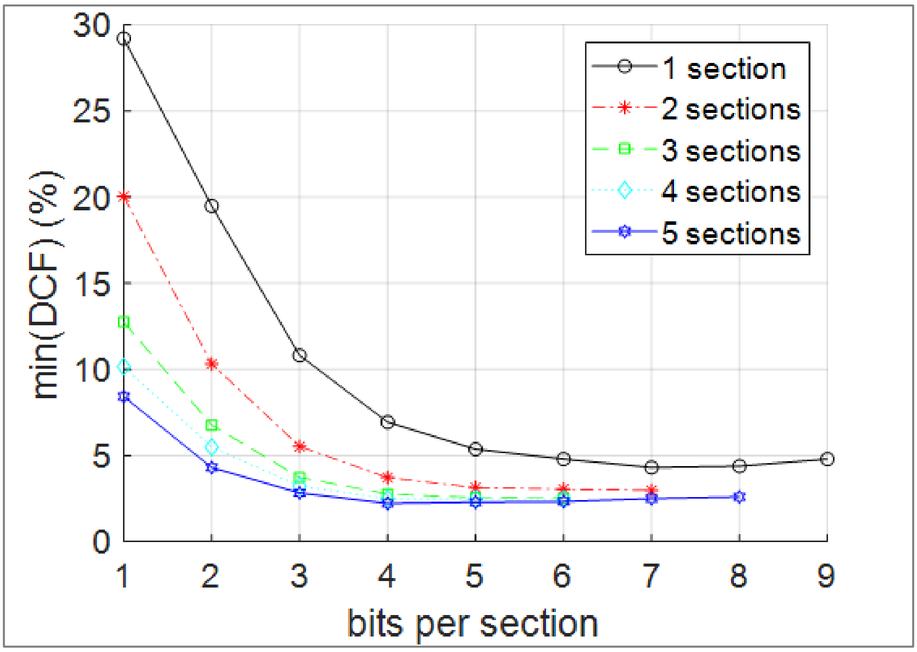


Fig. 2.14 - Random forgeries Detection Cost Function: plot of Table 2.2's data.

This parameter, often shortened as DCF, is a weighted sum of the False-Acceptance Ratio and the False-Rejecting Ratio, where the weights are the costs of the FAR and the FRR, respectively. [20]

```
[P_miss,P_fa] = Compute_DET (true_speaker_scores, impostor_scores);
C_miss = 1;          C_fa = 1;
DCF_vector = Cmiss * Pmiss * Ptrue  + Cfa * Pfa * Pfalse;
```

Fig. 2.15 - Extract from the project's algorithms - DCF calculation.

2.8 Methods of Signature Analysis for Identity recognition

Fig. 2.16 shows the general scheme and functioning of a biometric recognition system. Particularly, the sensor used for signatures are digitising tablets (see § 2.6.3). The features, or parameters, are extracted from the sensor data: static and dynamic parameters of the signature sample (see § 2.6.1 and §2.6.2). [21]

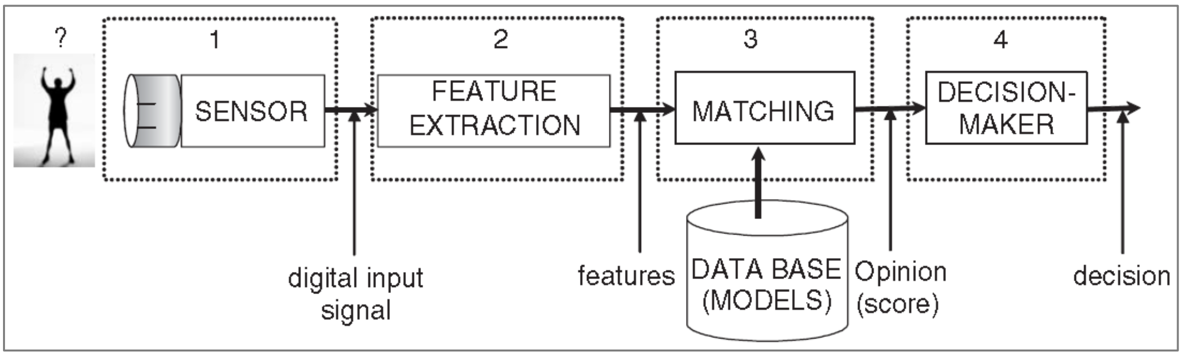


Fig. 2.16 - Basic identification process by biometric analysis. [21]

2.8.1 Position normalisation

In order to compare two signatures, the first step is to compensate the translations within the writing space (the signature is not always performed in the same position). This is achieved by determining their centre or origin. A simple manner to do it consists of calculating the mass centre of the signature points. [14]

2.8.2 Vector Quantisation and Multi-Section Vector Quantisation

Vector quantisation (VQ) is a multiple component generalisation of Scalar quantisation. **Scalar quantisation** consists in relating ranks of input values and an only output value, while the output set is discrete, but the input one is not. As the input set is bigger than the output one[5], some information is missed during a quantisation process, and this fact has the following consequences:

- An error is committed (a quantisation error).
- This process is irreversible.
- The input signal is compressed: less computing and storage capacity is needed.

[5] # output values = $2^{\# bits}$

The irreversibility prevents obtaining the signature from the stored data (codebooks), which makes it attractive regarding privacy. [11]

The relation between the size of the input and output sets tells to what extent this effects will appear. Taking the two *extreme* cases:

– If the two sets were equal, the original signal would not be modified: there would not be any error nor compression.
– If the output set was just a binary digit: the compression would be maximum.

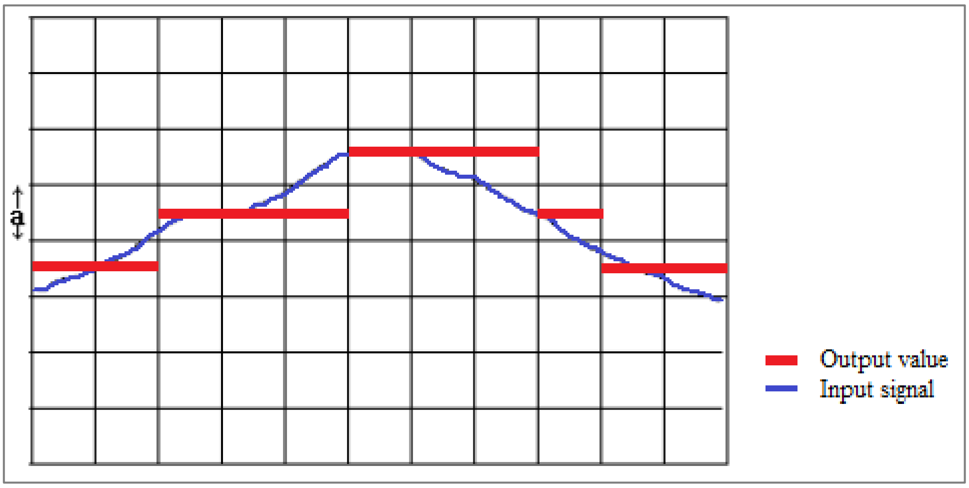


Fig. 2.17 - Constant quantization step enlightening example [22].

In the example of the figure above, the quantisation step is constant, but this is not a must in quantisation. For instance, if more sensitivity is wanted in some ranks, the path can be smaller only there, so the size of output data does not increase significantly.

At all events, the margins whereby the input space is divided and their corresponding output values, are determined by an array-like data arrangement or by a function.

So, whereas scalar quantisation works in a unidimensional input and output space, **vector quantisation** is the generalisation of the same idea but into a multidimensional (N dimensions) space: the input vectors are converted into a determined number of output vectors (K).

In this case, the input-output association is made employing a **codebook**. The codebook contains N-dimension *codevectors*, which contain the association information. The *codevectors* inside the codebook are indexed by scalars called *codewords* (# codewords =

$2^{\#\ codebook\ bits}$). To quantitate an input value, the closest codeword is reached and the corresponding association with an output value is made, according to the codevector. [23]

The **multi-section vector quantisation** is a vector quantisation enhanced version capable of time evolution modelling, which is quite relevant in signature recognition and it is a drawback of plain VQ. Simply put, MSVQ separates a signature sample into a number of sections and applies the VQ technique in each of them (thus, one codebook is obtained for each section); the final result is an average combination of each section's outcome. [11]

2.8.3 Other methods

The Nearest Neighbour (NN) is a simple method that predicts the class of a sample by choosing the closest object in an N-dimension feature space: the idea is that close objects in the feature space are likely to be similar. The main disadvantages of this method are that it is rather slow and it is sensible to irrelevant or random parameters. [24]

The Hidden Markov Models (HMM) is a statistical matching method that is popular to model time-sequenced data such as speech, handwriting or gestures, especially because it can manage different length samples. [25] [21]

The Dynamic Time Warping (DTW) is a template matching algorithm that compares the signature sample with a database-stored model and compares their distance, their differences. In the case of the signature, it must include an approach to manage the differences in the sample's lengths [21]

2.8.4 Result assessment

The assessment of identity verification has to be done with classification model performance indicators. The performance of the model can be analysed by checking the relation between the real class of an instance and the class assigned by the model. If this relation is studied while applying the model to a determined population, several performance rates can be calculated: they represent the model performance.

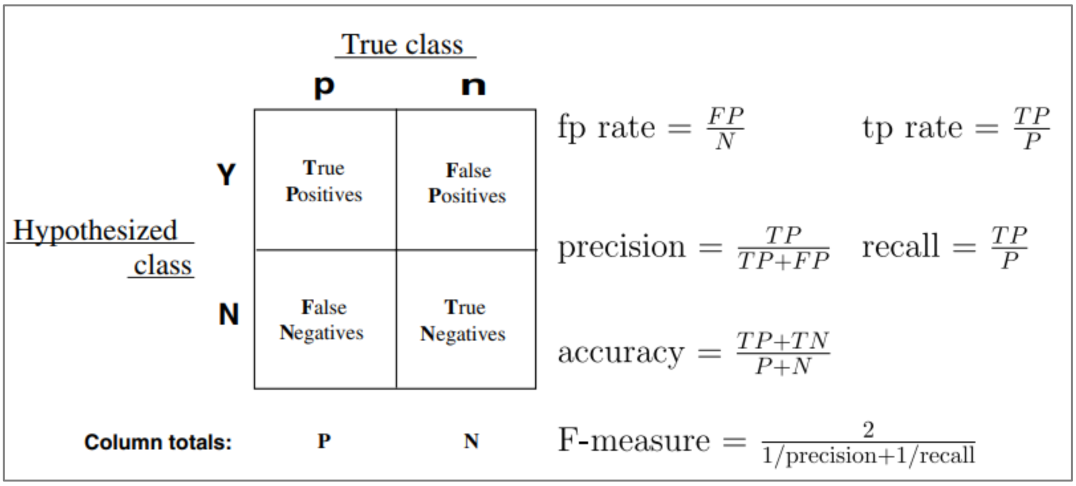


Fig. 2.18 - "Confusion matrix" and common performance metrics [26].

Usually, combined metrics are calculated from those.

One of them, the ROC (**receiver operating characteristics**) graph, plots the true positive rate as a function of the false-positive rate. A true positive is considered a desired output, while a false positive is an undesired one. [26] [27]

$$ROC \equiv \{TPR = f(FPR)\}$$

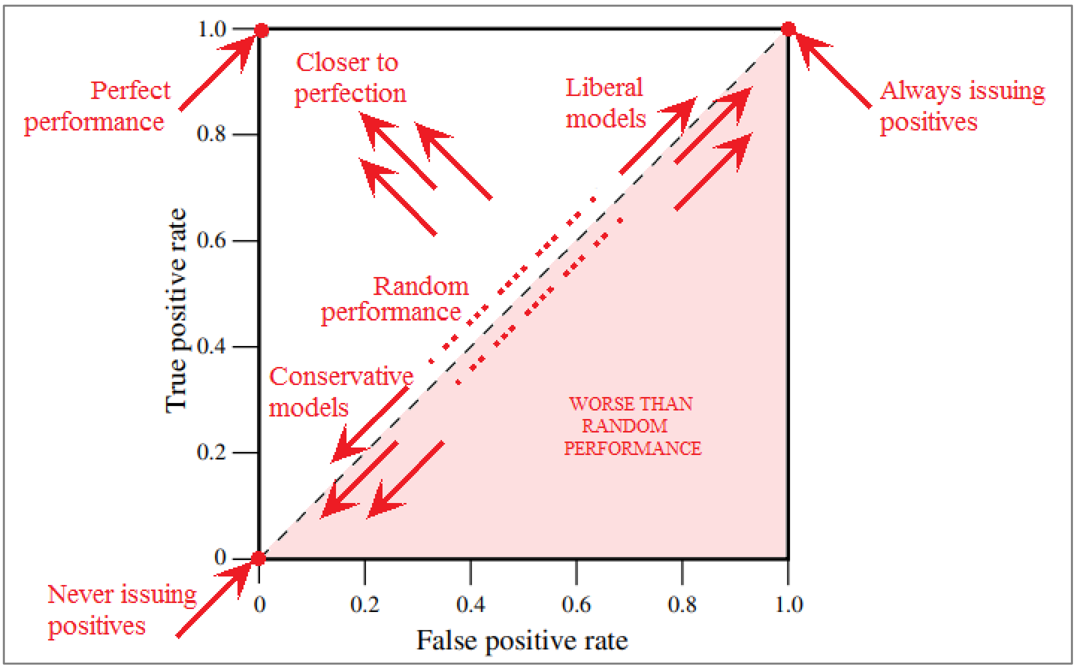


Fig. 2.19 - Basic interpretation of ROC results. Modified from: [21]

The random performance is the average result of a model that guesses the sample class by chance (actually it would have points over the knitted line and points under it). To improve this performance (upper triangle zone, in white), the model must acquire extra information from data. If the model got its results in the lower triangle (pink), it would be performing worse than randomly: however, if its decisions are inverted, then it would be performing better than randomly. Indeed, a model performing worse than randomly has more information than a model performing randomly.

Another performance parameter is the DCF, introduced in §2.7.5.

2.8.5 More on Confusion Matrixes

When confusion matrixes are applied to an identification problem (instead of authentication, or identity verification, as seen above: Fig. 2.18) it has a bigger dimension but it works the same way.

C = Category
P = Predicted Category
Correct Prediction
High Error
Midium Error
Low Error

P \ C	1329	1352	1396	1379	1482	1520	1384	1383	1466	1484	1522	1457	1389	1337	1357	1369	1467	1521	1440	1387	1405	1468	1370	1313	1461
1329	340	2	0	1	0	1	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
1352	0	19	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1396	30	0	118	0	3	0	5	1	0	0	0	0	0	19	5	4	0	0	13	0	5	0	1	3	0
1379	0	0	0	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1482	0	0	0	2	22	0	4	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1520	0	8	1	3	0	54	1	0	7	0	3	0	0	1	0	0	0	2	0	0	0	0	0	0	0
1384	0	1	0	3	1	0	9	4	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0
1383	0	1	0	3	6	0	1	22	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
1466	0	16	0	7	2	36	5	5	29	2	3	0	0	0	0	0	1	1	0	0	0	0	0	0	0
1484	0	2	0	27	8	0	4	2	0	6	0	2	1	0	1	0	0	0	0	1	0	0	0	0	1
1522	1	0	0	1	0	2	0	0	1	0	9	0	0	0	0	1	0	0	0	0	0	0	0	0	0
1457	0	1	0	2	0	0	0	1	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0
1389	0	0	1	1	1	0	1	5	0	2	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
1337	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
1357	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	4	0	0
1369	0	0	2	1	0	0	2	0	0	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
1467	0	2	0	4	0	0	1	1	0	1	0	0	1	0	0	0	16	2	0	0	0	0	0	0	0
1521	1	10	1	1	5	2	1	1	1	0	0	0	0	0	0	1	5	17	0	0	0	0	1	0	0
1440	9	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1387	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0
1405	3	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	8	0	1	1	1
1468	0	0	0	3	1	1	1	1	0	1	3	0	0	0	0	1	0	0	0	0	0	12	1	0	0
1370	12	1	2	0	4	2	5	3	0	1	0	0	0	3	23	0	1	0	0	0	0	0	2	0	0
1313	0	3	0	1	3	0	2	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	4	0
1461	0	7	0	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6
No Suggestion	3	43	0	8	9	1	6	6	0	4	3	1	0	0	0	0	0	2	0	0	0	0	0	0	1
Count	422	136	133	117	108	111	95	83	45	38	35	33	32	31	30	26	24	22	24	22	17	14	13	12	10
Precision	0.97	0.90	0.56	0.91	0.67	0.68	0.38	0.58	0.27	0.11	0.60	0.85	0.71	1.00	0.17	0.46	0.55	0.36	0.00	0.78	0.40	0.48	0.03	0.15	0.35
Recall	0.81	0.14	0.89	0.09	0.20	0.49	0.09	0.27	0.64	0.16	0.26	0.67	0.94	0.06	0.03	0.23	0.67	0.77	0.00	0.64	0.47	0.86	0.15	0.33	0.60
Category	1329	1352	1396	1379	1482	1520	1384	1383	1466	1484	1522	1457	1389	1337	1357	1369	1467	1521	1440	1387	1405	1468	1370	1313	1461

Fig. 2.20 - A 25-class confusion matrix example. Source: MicroFocus.

The difference is that instead of comparing just two classes (yes/no, positive/negative), there are several. In the example at

Fig. 2.20 the correct identifications are filled green: the true category (first row) coincides with the predicted category (first column), the other cells are incorrect identifications. For instance, the #30 filled in red are the times that the category 1329 was identified as 1396, etc.

2.9 About instrumentation parameters

Below there are some instrumentation parameters, referring to force sensors, transducers. [28] [29]

- **Load**: a physical quantity input or applied to the transducer. It is the object of measure, the *measurand*.
- **Load range**, **range**, **rated load**, **capacity**, **rated capacity** or **full scale**: maximum design load, set in the sensor's specifications. **Safe over-range**: maximum load range (above-rated capacity) that will not affect permanently the sensor's performance.
- **Resolution**: minimum load variation that is sensed by the transducer, leading to a change in its output. It is affected by the sampling process.
- **Output**: an electrical signal range, a consequence of the load applied.
- **Full-scale output** (FSO) or **full-scale span** (FSS): the difference between the minimum output and the output at rated capacity.

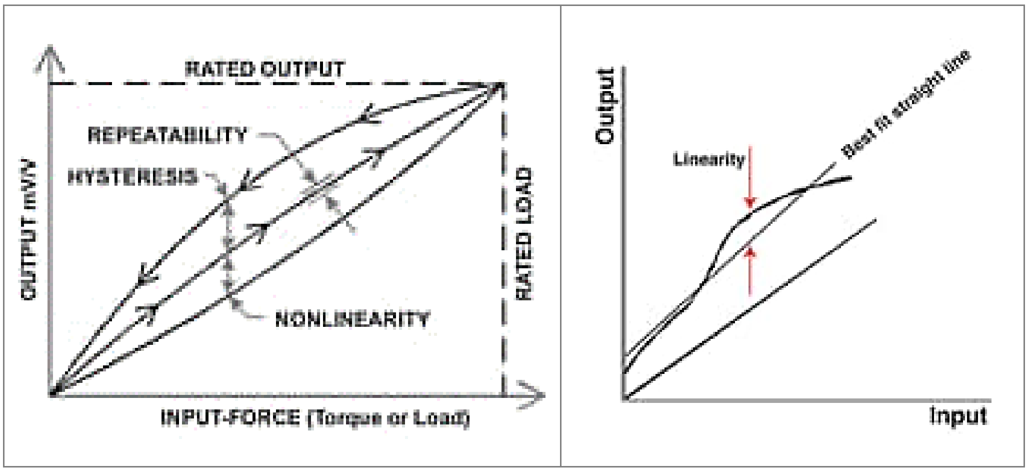
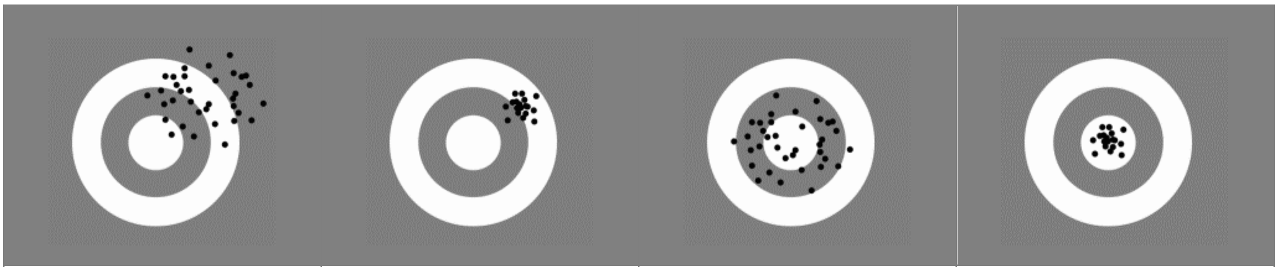


Fig. 2.21 - Illustrative scheme of some of the concepts explained in this section. [28]

- **Sensitivity**: the relation between the output's change and its corresponding input variation. In a plot of the input (abscissa) against its output (ordinate), the sensitivity would be the curve's slope.

- **Repeatability**: it is the maximum difference between repeated readings when the same load is input, under the same conditions, direction and environment. This maximum difference is often expressed as a % of FSS. Single part repeatability. Part to part repeatability.
- **Linearity error**: maximum readings deviation from a straight line from zero to full scale. It is often expressed as a % of FSS.
- **Drift** or **stability**: it is a low-frequency sensor performance change in time.
- **Hysteresis**: while performing a measuring cycle from zero to full scale, the hysteresis is the output difference between an input while increasing from zero and the same input while decreasing from full scale. The output lags the input. Often expressed as a % of FSS.
- **Accuracy**: it is the combination of linearity, repeatability and hysteresis errors. It is the difference between the read or measured value and the true value. Often, the data has to be compared with a recognised standard.
- **Frequency response**: frequency range of the input variation in which the sensor output can follow such input.

Mainly, they are related with §4.2.2,



Not precise nor accurate.	Precise but not accurate.	Accurate but not precise.	Accurate and precise.

Fig. 2.22 - Illustration on precision and accuracy. [30]

2.10 Creating functions from a set of measurements. Fitting and look-up tables.

In scientific research, experimental data sets have to be analysed in order to understand them and to make predictions. Usually, the known points have to be interpolated and extrapolated, fitted into a function or curve. In short, interpolation calculates points between the data set's ones, and extrapolation defines points that are further on; they predict values that are not included in the data set. [31]

In this project, the data sets are pairs of pressure information, in the tablet's units and in real or standard units, or in a tablet's units and in another tablet's units. If a function that fits them is found, it can be used to convert the data and to normalise it so it can be compared with other data and used altogether.

2.10.1 The look-up tables

A look-up table consists in having some points of the normalisation function pre-calculated into a list of coordinates, so for an input coordinate (i.e. "x"), the closest value is searched and the matching coordinate ("y") is outputted. It is somehow a discrete function.

The normalisation function is obtained by applying some kind of regression to the measurements set.

When functions are complex and take a significant computing effort, the look-up tables can be a good option. For use in embedded systems, the optimisation of its size is studied. Their main problem is the estimation uncertainty but they work in many situations such as fast evaluation of functions, numeric calculations, to make corrections in DAQs and ADCs, embedded measuring systems… [32]

2.10.2 Linearization

The linearization of a sensor process is similar to what is done in this project. Here the sensor is the tablet and the non-linearity function is the pressure data acquisition: the input pressure is standard (MPa, for instance), but it is registered including some distortion (in the tablet's units). [32]

$$x = f^{-1}(f(x)) = f^{-1}(y) = z$$

x: sensor input
y: sensor non-linear output
f^{-1}: linearization / normalisation
z: linearized / normalised sensor output

2.10.3 The least squares regression

The most typical way to fit a curve into a data set is the least squares regression. It consists in finding the parameters of a type-function which have the minimum residual sum of squares (RSS). [31]

Regression type	Parameters	Shape	Residual sum of squares
Linear	m, b	$f(x) = mx + b$	Given data points $(x_1, y_1), (x_2, y_2), \ldots (x_n, y_n)$ $RSS = \sum_{i=1}^{n} [y_i - f(x_i)]^2$
Exponential	β, m	$f(x) = \beta e^{mx}$	
Power	β, x	$f(x) = \beta x^m$	

Table 2.3 - Some basic regression types and the RSS definition. [31]

2.11 Gender perspective

The University Quality Agency (AQU) recommends the incorporation of the gender perspective in the activities developed in the universities. [33]

When it comes to science and technology fields, the gender perspective plays an important role during product development, user interfaces design, etc. Studying age, origin and functional diversity is recommended as well.

Regarding this project, the signature is an identity authentication and verification method that can be used by every person who is able to write, no matter gender, age, functional diversity, socio-economic level or origin. Databases used in this project incorporate signatures from men and women. However, as those signatures were provided by engineering students, where there is a bigger presence of men, this is reflected in the database content.

The gender perspective is a technical specification of this project. In order to know how it is applied during the project development, see the Technical Solution section (§4).

3 Technical specifications and requirements

The desired features for the project's solution are the following:

i. The results must be compared with previous research findings so they can be objectively compared.
ii. The solution to conduct the experiments must be compatible with the available online writing material, pen and tablet, provided by the university.
iii. The solution must be safe for the online writing material: if the solution is automated, there should be no risk of crush or damage for the digitising pen and tablet.
iv. The experiments should be fast and easy to set up and use, so at least one set of experiment is assured. Other experiments, using more complex solutions, should be left to be done after a previous experiment is completed.
v. The quality of the result obtained is essential, and it must be assured.
vi. Repeatability of tries: this is a desired quality for the designed experiment procedure. It can be useful to check the quality of results and to repeat experiments under different conditions.
vii. A professional appearance is desired so the report looks attractive.
viii. The project has to incorporate a gender perspective.

The technical solution used to achieve the project's goals, at the same time that the former requirements are obeyed, will be determined in the next section: the Technical Solution.

4 Technical Solution

This section intents to design the most suitable technical solution to elaborate this project. The approach to fulfil the project's aim within its scope, consists of several steps, or minor aims, that will be attained by conducting the following activities:

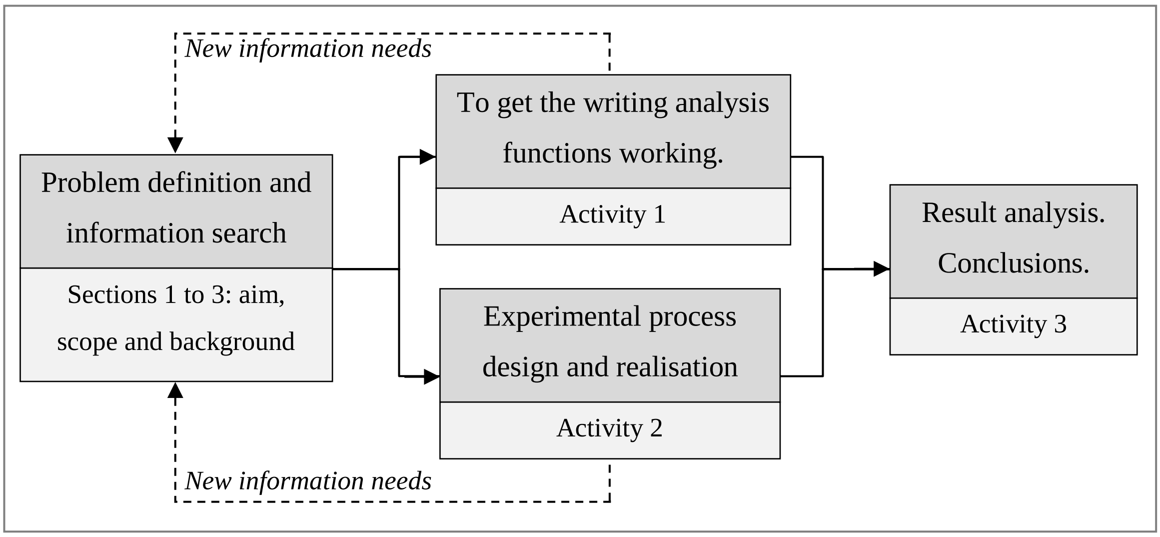


Fig. 4.1 - Solution approach.

Note that:

- Activities 1 and 2 are being developed simultaneously.
- The information search is resumed when the development of the other activities make it necessary and the information obtained is attached to the Background section of this report.

Activity two, can also be split into two major tasks: one involves the lab work and the other, the coding and computing.

4.1 Activity 1

To get to use the writing analysis functions developed in prior project, published as "Efficient on-line signature recognition based on multi-section vector quantization" [11] and test them in order to achieve the same results got. This is needed to compare the result of the current project with the previous ones so the usefulness of pressure data is objectively proved.

A good thing is that this software worked correctly at some point, which betokens a future success in this activity. However, some of them were modified for other researches and must be adjusted; the computation time can be quite long in some cases. Another drawback is that there is a great number of functions that work together.

4.1.1 Function operation description

The functions used in this project perform a signature recognition based on a multi-section vector quantisation algorithm (refer to § 2.8.2). They are used on the MCYT database. [11]

The algorithm can be executed separating the samples in several sections. Also, the functions can be set to calculate each section using a number of bits. Following the work done on our base project, the functions were executed using 2 to 5 sections and 1 to 8 bits per section.

There are three steps to execute this algorism, which correspond three principal functions:

- The *mainVQfirmasMS* creates the codebooks from the samples.
- The *testVQfirmasMS* calculates the distance from the models and executes the recognition.
- The verifica_firmasVQMS checks the recognition performance and calculates the DCF.

These functions have a different version for each number of sections, but the number of bits per section can be set from the code. In Fig. 4.2, note that there exist versions of these functions ending in 2, 3, 4 and 5 or **nothing**, 3, 4 and 5. Each of them outputs 8 files (except for the *verifica_firmasVQ*) and uses 8 files as inputs too (except for the *mainVQfirmas*).

Finally, a function called *graf_CBMS* can be used to obtain graphic representations of the results.

Note, also in Fig. 4.2, that there are specific *testVQfirmasMS* and *verifica_firmasVQMS* for the skilled forgeries. They are made in order to know the performance on the algorithm in this case.

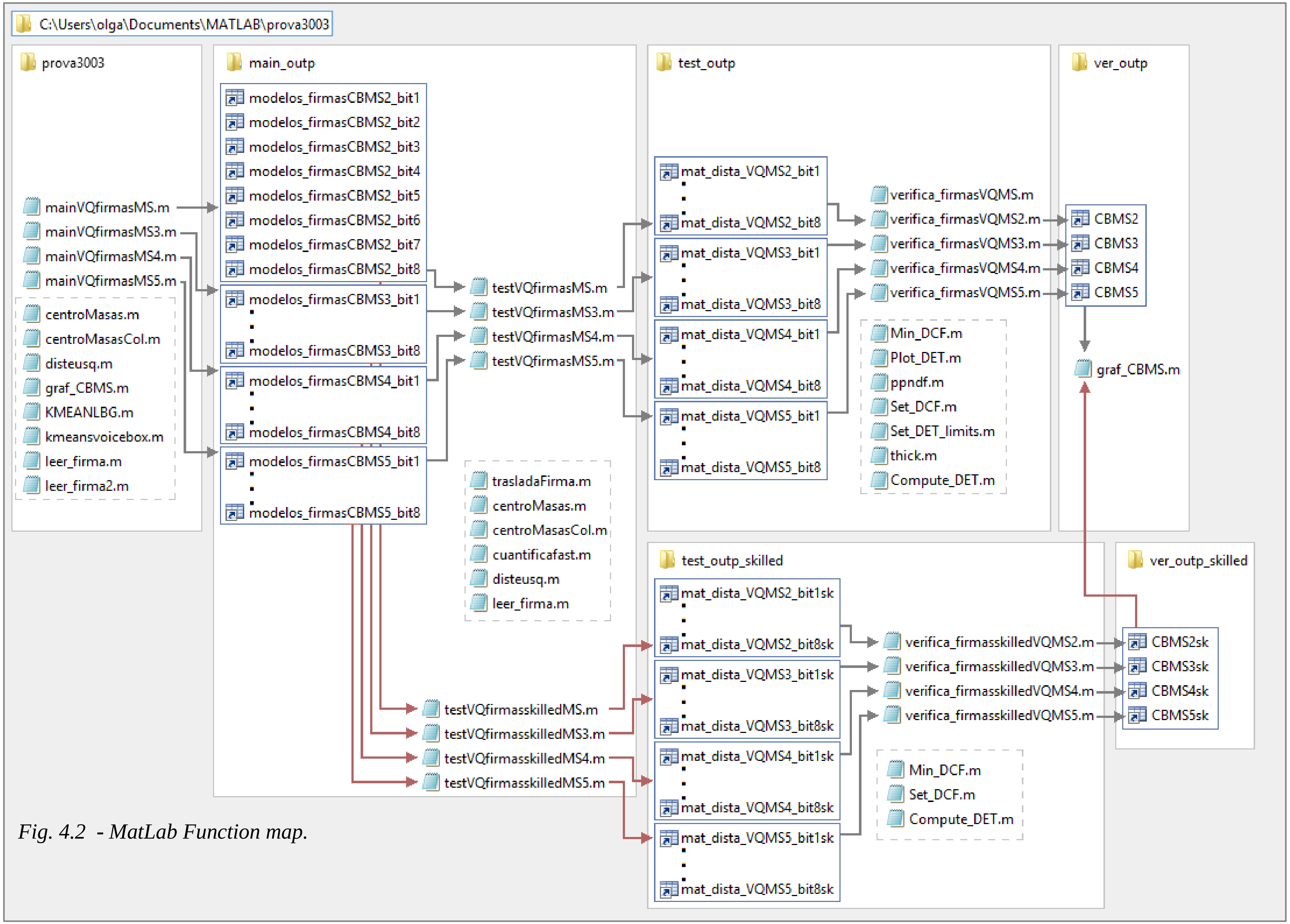


Fig. 4.2 - MatLab Function map.

4.1.2 Troubleshooting

- Each principal function requires sub-functions (inside the dashed rectangles of Fig. 4.2). The first error that was found while executing the algorithm was that MatLab couldn't find the sub-functions. The problem was solved by simply copying them in the working folder.
- The main problem when executing the functions was a lack of the algorithm understanding and the structure of the functions. Even though the MatLab code does not include much comments, the information from the prior project publication did help a lot. In the end, the function map from Fig. 4.2 could be done in order to express this knowledge.
- The lack of experience using MatLab to create and read files was a hindrance as well, that took time checking at MatLab documentation. Moreover, the file names of the results *CBMSx* did not appear in the files that had to generate them, so they appeared to make no sense. Some of the functions of more sections created *CBMS* files and its structure was replicated on the other functions.
- In this algorithm, the computer paths are very important because: the *main* function has to access the MCYT database information in specific folders; the files created in each step of the algorism have to be stored in a certain place and having a certain name; the same happens when reading these files. Note that the names of the files are generated from the function code, depending on the number of bits.
- As not to be constantly checking over the function execution the bit variable was looped from 1 to 8 (1:8). Some executions lasted for hours, especially when increasing the number of sections and in the "Test" step.

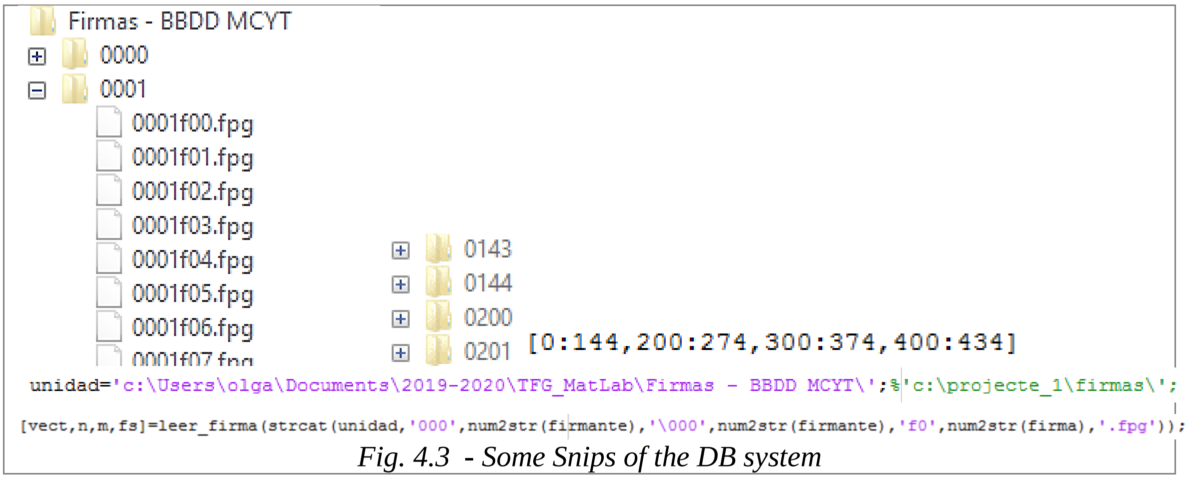


Fig. 4.3 - Some Snips of the DB system

4.1.3 Results of this part

Hereafter, the graphic and numeric results of the algorithm execution (explained above at §4.1.1) are exposed.

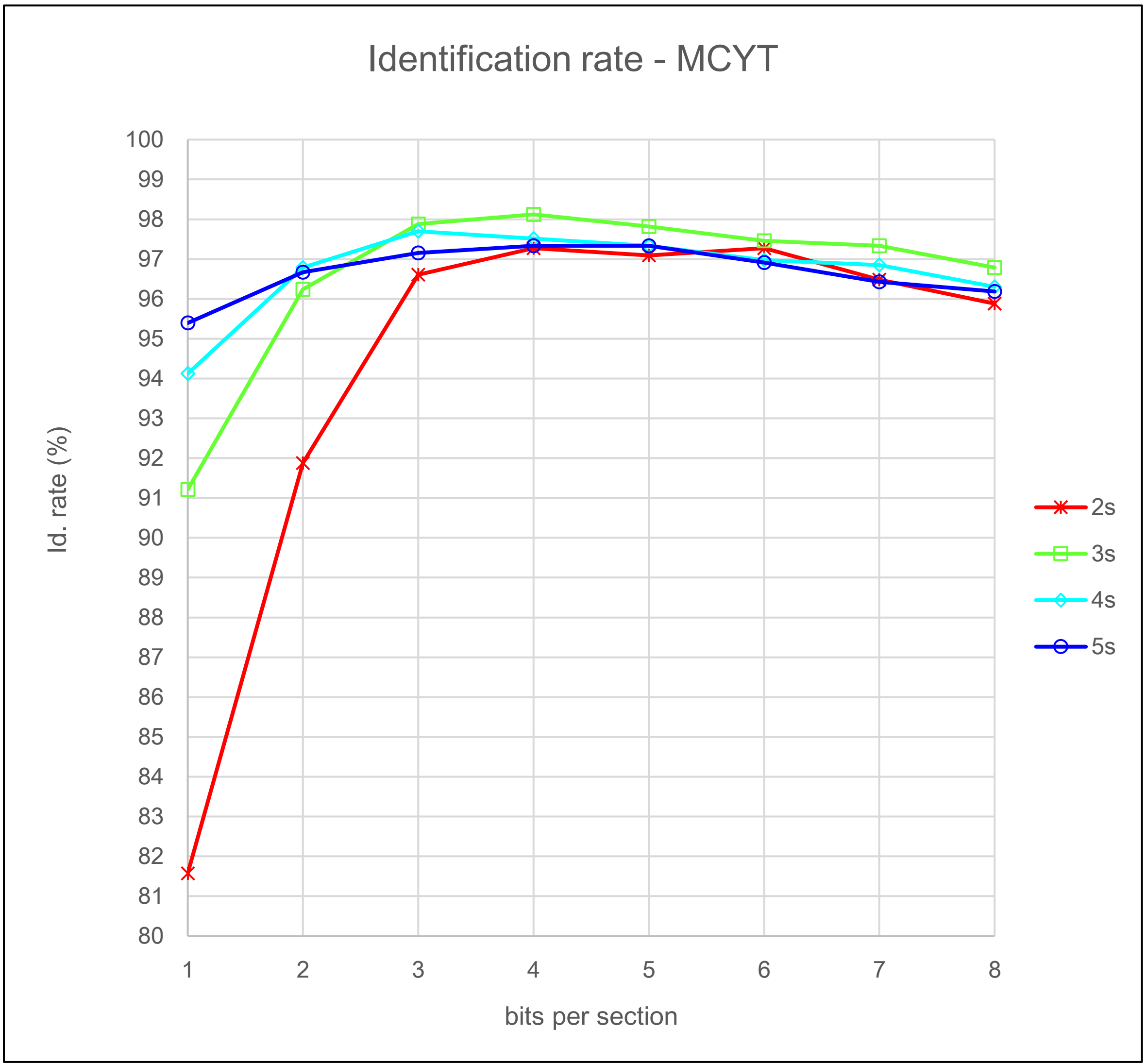


Fig. 4.4 – Identification rate results plot.

Sections	Bits per section							
	1	2	3	4	5	6	7	8
2	81,5758	91,8788	96,6061	97,2727	97,0909	97,2727	96,4848	95,8788
3	91,2121	96,2424	97,8788	98,1212	97,8182	97,4545	97,3333	96,7879
4	94,1212	96,7879	97,697	97,5152	97,3333	96,9697	96,8485	96,3030
5	95,3939	96,6667	97,1515	97,3333	97,3333	96,9091	96,4242	96,1818

Table 4.1 – Identification rate results data.

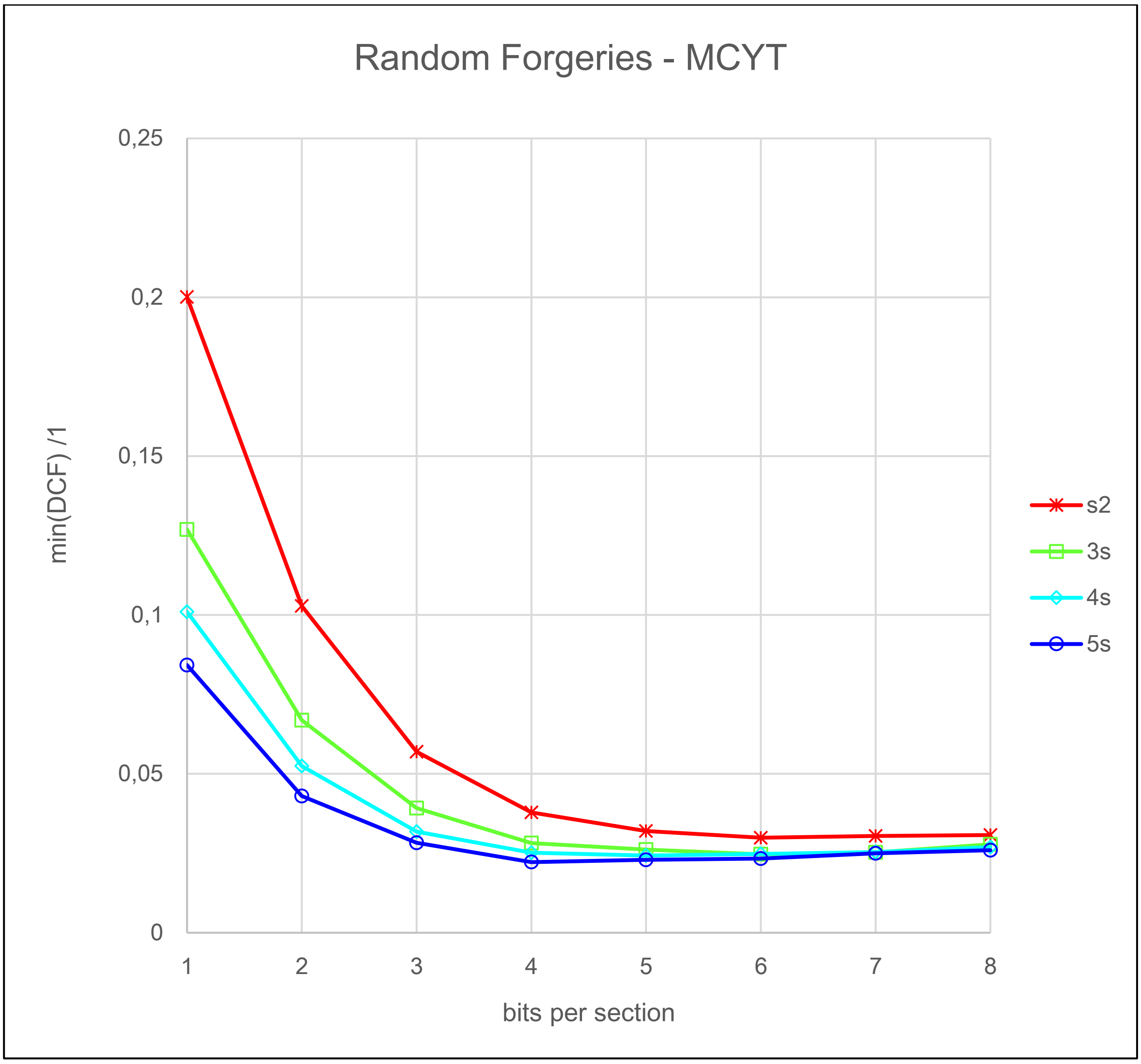


Fig. 4.5 – Minimum DCF results for random forgeries plot.

Sections	Bits per section							
	1	2	3	4	5	6	7	8
2	0,20008	0,10287	0,05698	0,03786	0,03198	0,02991	0,03041	0,03077
3	0,12694	0,06685	0,03918	0,02821	0,02619	0,02469	0,02527	0,02784
4	0,10103	0,05247	0,03187	0,02519	0,02429	0,0248	0,02537	0,02698
5	0,08425	0,04305	0,02827	0,02222	0,02294	0,0233	0,02504	0,026

Table 4.2 – Minimum DCF results for random forgeries data.

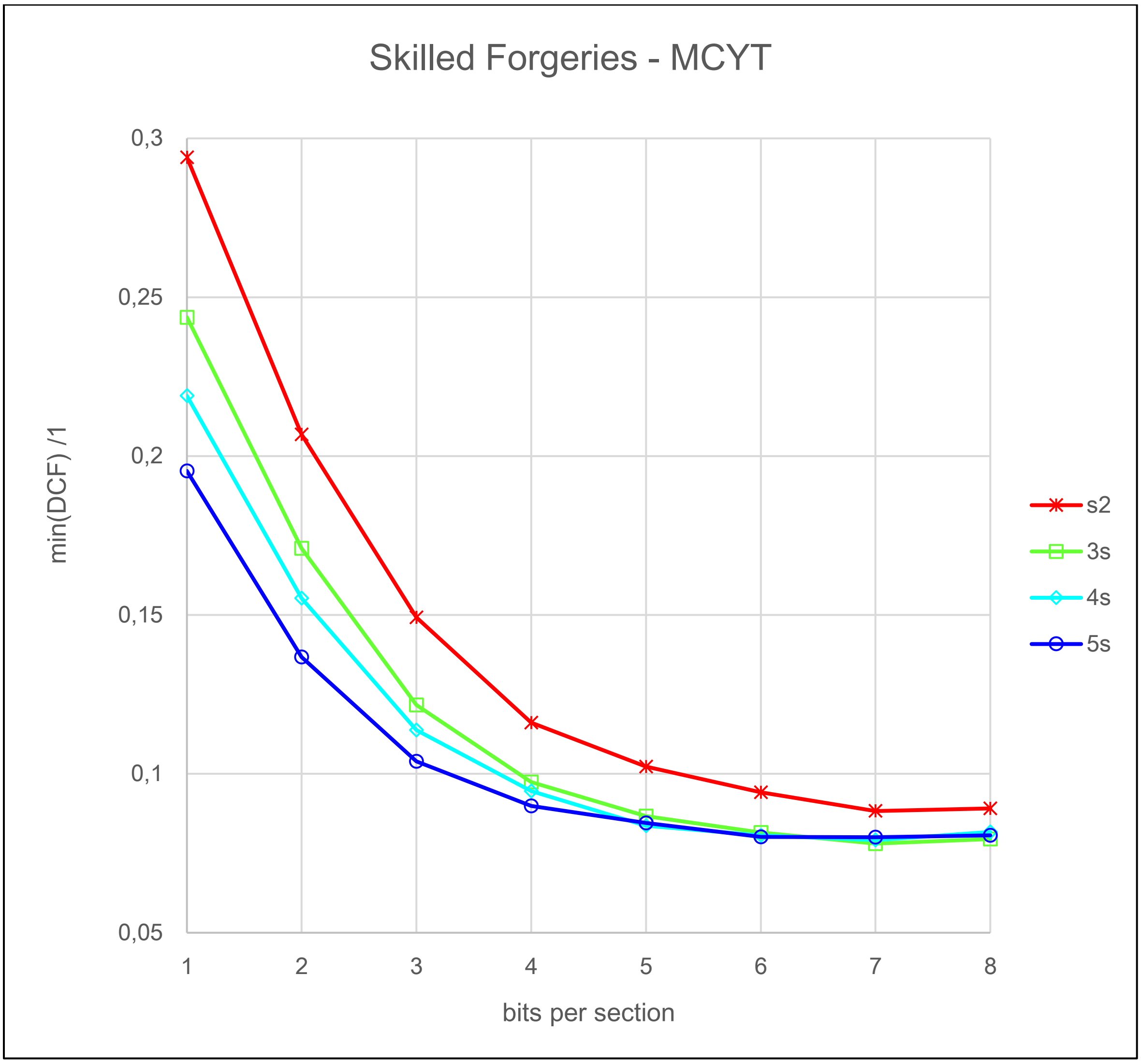


Fig. 4.6 - Minimum DCF for skilled forgeries results plot.

Sections	Bits per section							
	1	2	3	4	5	6	7	8
2	0,29406	0,20685	0,14927	0,11612	0,1023	0,09418	0,0883	0,08915
3	0,2437	0,17097	0,12164	0,09739	0,08673	0,08152	0,07806	0,07945
4	0,21897	0,15527	0,11382	0,09455	0,0837	0,08061	0,07915	0,0817
5	0,19533	0,13673	0,10394	0,08988	0,08455	0,08012	0,08006	0,08067

Table 4.3 - Minimum DCF for skilled forgeries results data.

4.1.4 Technical specs fulfilment

If compared with the results of the prior article, these are certainly similar. However, this cannot be verified at the moment because the data is stored in a computer at the university and it is closed due to COVID-19 lockdown measures. See §6.

4.2 Activity 2.1

This activity aims to design and execute an experimental procedure that permits the testing of online writing tools (a digitising tablet and its corresponding pen) and to obtain pressure data from them. It includes the selection of the equipment needed and the description of the steps to take. It all must suit the technical specifications defined above (§3), which will be considered when choosing these methods and tools.

By using the pressure measurements, the following questions are intended to be resolved:

Q. *Question:* What is the relation between the pressure values measured by the digitising tablet (in “pressure levels”) and values in standard pressure units (“Mega Pascals” (MPa) or other equivalent units)?

1. *Hypothesis*: The tablet is evenly sensitive.
2. *Hypothesis*: The performance is not time-dependent (it is constant in time)

The first task is to define some technical solutions to move the pen through the tablet surface (§4.2.1), to measure and to apply the pressure on the tablet (§4.2.2), and to attach the pen to the previously selected motion solution (§4.2.3).

Posteriorly, the steps to put in practice these solutions will be described (§0), including material needs, tips and verifications. The tests to resolve the hypotheses and question previously set will be defined as well. That done, it is the time for the actual performance.

To conclude this phase of the project, the data and information obtained has to be introduced into the recognition algorithms (§4.3 “Activity 2.2”).

The realisation of this part of the project has changed due to external reasons: see §4.2.5.

4.2.1 Motion solution Selection.

Even though no specific material or methods exist in order to move the pen through the digitising tablet, being at the university can bring options to obtain material and advice. At the university compound there are the following alternatives:

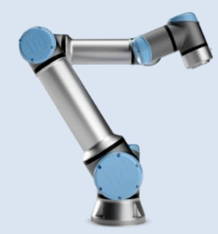
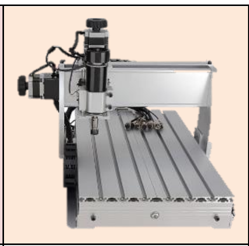
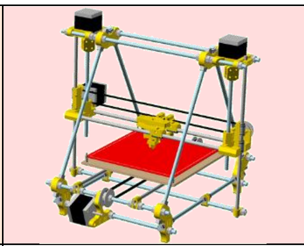
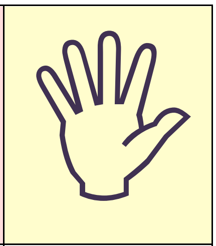
				
A	**B**	**C**	**D**	**E**
Collaborative Robot (CoBot)	Robot Arm, (traditional axial robot)	CNC Machine (Cartesian robot)	Custom 3D Printer (Cartesian)	Human Hand
Source: Universal Robots	*Source: ABB*	*Source: Sumsour*	*Source: RepRap.org – J. Keegan*	

Table 4.4 - Available motion alternatives.

The best solution will be chosen by means of a quantitative assessment of the specifications (see section §3). The accomplishment of some of them, though, is not affected by this part of the solution:

i. This requirement is treated in the software adaptation that will allow to use standard pressure data.

iii. A mock-up of the digitising pen and tablet will be made so initial tests can be safely done. Thus, the choice of one moving solution or another is not relevant for this specification.

viii. This part of the project is meant to test a digitising tablet in a standard manner. For this reason, it does not affect the diversity perspective of the project.

On the other hand, the **assessment criteria** for the applicable specifications is explained below:

ii. If it is compatible: 1; if it is not: 0.

iv. Neither fast nor easy: 1; Not fast or not easy: 2; Fast and easy: 3. All the options are feasible, so rating 0 is excluded.
Weight: 1/2

v. Here, "quality" means that the solution permits the acquisition of unbiased results. It also implies that the solution is flexible so as to perform the desired movements or to apply a certain pressure.
Excellent quality: 3; Medium quality: 2; Low quality:1; Inadmissible: 0.
Weight: 1

vi. Repeatability. Possible: 1; not possible: 0.

vii. It can make the project more attractive: 3; Neutral: 2; Could give an unprofessional impression: 1.
Weight: 1/4

If a solution obtains a "0" rating in any specification, it will be considered unsuitable, regardless of its total score.
The total score will be calculated: $Score = P(ii) \cdot P(vi) \cdot \{0.5 \cdot P(iv) + P(v) + 0.25 \cdot P(vii)$
Finally, the rating of each solution is the following:

	ii.		iv.			v.				vi.		vii.			Score	Ranking
	0	1	1	2	3	0	1	2	3	0	1	1	2	3		
A		X			X				X		X			X	5.25	1
B		X	X						X		X			X	4.25	3
C		X		X					X		X		X		4.5	2
D		X		X				X			X	X			3.25	4
E		X			X		X			X		X			0	-

Table 4.5 - Motion systems options assessment results.

About specification iv, as the test will be done on a surface (the tablet's screen), it is more natural to work with Cartesian robots than with the axial ones. The Cobot, though, is supposed to be programmed in a plain and intuitive way. Anyway, the easier and faster solution is, of course, using the own hand, especially because there would not be needed to design a clamp to attach the pen.
That being said, the CNC and the 3D printer could be easily programmed as well, using a prototyping-like board (Tiva C[6], Raspberry) and coding in plain C language. This could be possible because there are no real-time restrictions in these experiments and both machines use steppers and other basic hardware. Regarding the pen clamping, it could be placed on the extruder or the drill holding, respectively.

[6] The Tiva C is a series of microcontrollers by Texas Instruments featuring ARM Cortex-M MCU

Respecting specification v., programmable solutions have a clear advantage. The Cobot is the most modern of the available solutions, it has a high precision. Also, the robust CNC could obtain good quality results.

In conclusion and according to the assessment, the main option is the collaborative robot, followed by the CNC machine. Moving the pen with the hand is not a good enough solution.

4.2.2 Pressure sensing and application solution

First of all, the range or scale of the sensor has to be determined. As stated in Annex I, the digitising tablet pressure readings would reach digital full scale when approximately 5 N are applied[7]. This means that any sensing measure must admit, at least, a 4.5 N load (4.5 N ≈ 0.46 Kg ≈ 1 lbs). This value also gives an idea of the sensor admissible resolution and error: usually, higher load sensors will have lower resolution.

Secondly, notice that the way pressure is applied to the tablet and the mean to measure this pressure are closely related. There are two options:

A Connecting a ***force*[8] sensor** to the robot in order to make a closed-loop control. This way, the applied pressure can be programmed.

B Placing a known **weight** at the top of the pen: the pressure equals the weight divided per the nib's area.

Using a force sensor.

For the first option (A), there are two different types of solutions:

1. Using a robot-integrated sensitive cell.

   The FT300 is an XYZ Force and Torque sensor. It can measure force ranging ±300 N and ±30 N·m. The worse feature of this sensor (regarding this application) is a 1 N contact force threshold. The AXIA80 is another high resolution and accuracy sensor.

   These sensors, though, are excessive for the needs of this project. Besides, they cost several thousands of dollars, so they are dismissed as possible solutions. [34]

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[7] Note that whereas the applied force is approximately the same (4N) the resulting pressure is different for the ink-pen and the plastic-pen because their nib's surface is different. The force is what will limit the sensor regardless.

[8] Actually, force cannot be measured directly because it is always applied through a determined area, so forces are really pressures.

(a)
FT300 Force-Torque sensor by Robotiq [35]

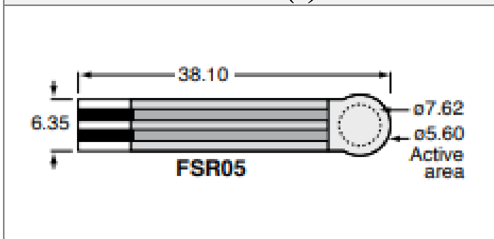
(b)
AXIA80 Force-Torque sensor by ATI [36]

Fig. 4.7 – Some Robot-arm integrated sensors.

2. The other solution would be to use a force transducer. Some candidates for this category are force-sensing resistors (**FSR**) like FSR05CE, by Ohmite, and FlexiForce A201, by Tekscan.

   Another type of force transducer valid for this experiment's purpose is the **load cell**. Some adequate models are Honeywell's FSA series and LCMKD-1KG by Omega.

(a) FlexiForce A201 by Tekscan [37]



(b) FSR05 by Ohmite [38] [39] [40]

(c) FS2050-0000-0500G by TE Connectivity [41] [42]

(d) FSAGPDXX005WCAB5 by Honeywell [43] [44]

(e) LCMKD-1KG by Omega [45]

Fig. 4.8 – Selection of force transducers.

Candidate (Fig. 4.8)	**a**	**b**	**c**	**d**	**e**
Brand	Tekscan	Ohmite	TE Connectivity	Honeywell	Omega
Model	FlexiForce A201	FSR05CE	FS2050-0000-0500G	FSAGPDXX005WCAB5	LCMKD-1KG
Type	Piezo-resistive	FS Resistor	Load Cell	FS Amplified	Load cell
Max. width	14 mm	7.2 mm	17.27 mm	17.36 mm	9.6 mm
Active diameter	9.53 mm	5.6 mm	12.2 mm	12.7 mm	2.2 mm
Actuation or threshold force[9]	-	< 30 g	-	-	-
Load range or capacity	4.45 N	5 Kg	4.9 N	5 N	10 N
Single part repeatability	<±2.5 %	2 %	±0.8 %	Combined error: ±3 %** (includes *)	±0.1 %
Part to part repeatability	-	±4 %	-		-
Linearity error	<±3 %	-	±1 %		±0.25 %
Drift/stability	<5 %/log(t)	<2 %/log(t)	±0.5 %	±1.3 %	-
Hysteresis	< 4.5 %	5 %	±0.8 %	*	0.25 %
Temperature sensitivity	0.36 %/ºC	-	±1 %	±5 % (includes **)	±0.02 %
Excitation (Vdc)	-	-	5 Vdc ±0.5 %	5 Vdc ±10 %	5 Vdc (max.: 7)
Approx. price (€/u)[10]	20	10	100	140	650 [46]

Table 4.6 - Sensing options comparison.[11]

Besides the technical data, some of these sensors have other highlights:

– Tekscan also sells a "Quickstart Board", an integration kit including two A201 sensors that permits a quick implementation for a 3.3-9 V input and 0-5 V output. Unfortunately, despite it features a sensitive-adaptation variable resistor, it is scaled for bigger loads and it would not serve for this experiment (the maximum applied force will be less than 0.5 Kg ≈ 1.1 lb).

Fig. 4.9 - FlexiForce Quickstart board. Source: Tekscan.

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9 Datasheet call this parameter "force" even though they provide a mass.
10 The shipping cost is not included.
11 According to the manufacturers' datasheets, % are "over full scale", respect full scale output (FSO) or full scale span (FSS).

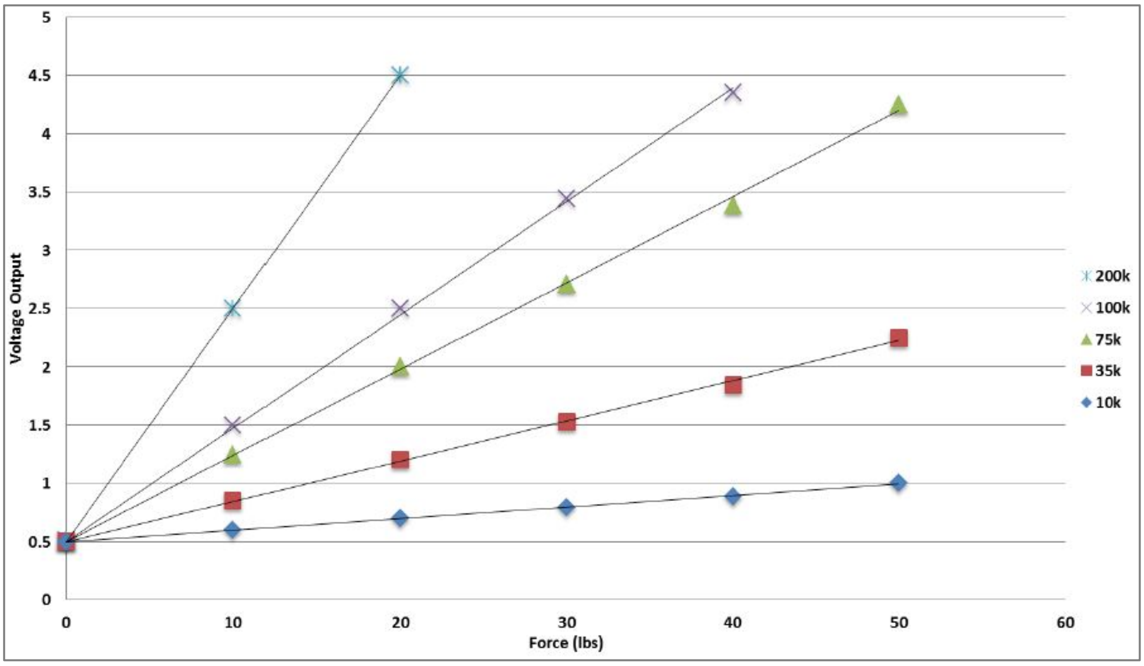


Fig. 4.10 - Quickstart board Voltage output. Source: Tekscan.

– Also, Honeywell's sensor has common catalogue listing with off-the-shelf sensor versions (the reference code specifies 6 parameters, so there is a wide variety), which can be acquired faster. For the selected sensor, FSAGPDXX005WCAB5, the FSAGPDXX001RCAB5 is a good alternative: it ranges 4.45 N instead of 5 N.

Finally, Honeywell's sensor is the final choice: its characteristics are slightly below TE Connectivity's, but its package is more robust and some recommendations have been received for Honeywell's products. The FSRs were competitive on their reduced size, but their performance is significantly lower than the rest. Last, Omega's would have the best qualities among the selected options, but its price is much higher.

Applying the pressure employing a known weight

As the best motion solution has turned out to be the robot, using a sensor is more convenient because it can create a control loop with it and it enables dynamic tests. The option of applying the pressure by means of a known weight, which could be valid as well, would misuse this potential, so it is dismissed.

4.2.3 Pen attachment to the motion system

This part of the solution is important since it allows the moving system to apply the pressure to the sensitive screen through the nib.

First approach

A manner to attach the pen to the robot could be creating a system that guided the pen trough the tablet’s surface, allowing the pen to move vertically. As the pen is not cylindrical, it would need a case that gave it this shape, so it could slide along the robot clamp. See Fig. 4.66. The pressure would be exerted on the pen’s upper end.

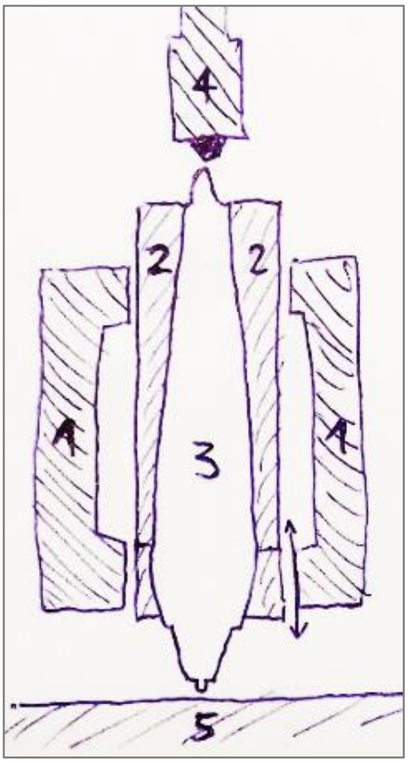


Fig. 4.11 –Parts of the pen fitting to the robot clamp.

1) Robot clamp. Vertical movement between this part and part 2 must be allowed. Its mission is to position (x, y) the pen (part 3) along the tablet’s surface (part 5).
2) Custom pen case. It has to grip the pen and give it a cylindrical outer shape, so it can slide from part 1. It can be 3D printed from a negative model of the digitising pen.
3) Writing pen. It must suit the digitising tablet.
4) As explained in §4.2.2, there are two options to apply the pressure to the pen and to monitor the value of this pressure:
   a. If #4 is the clamp actuator. It will apply a vertical force into the writing pen: the same force will be exerted to the tablet by the pen. It must have a pressure or force sensor.
   b. If #4 is a known mass, its weight plus the pen’s weight divided by the tip surface, equals a known pressure. The mass could be changed in different tests.

   The sensor option is already selected.
5) Digitising tablet surface.

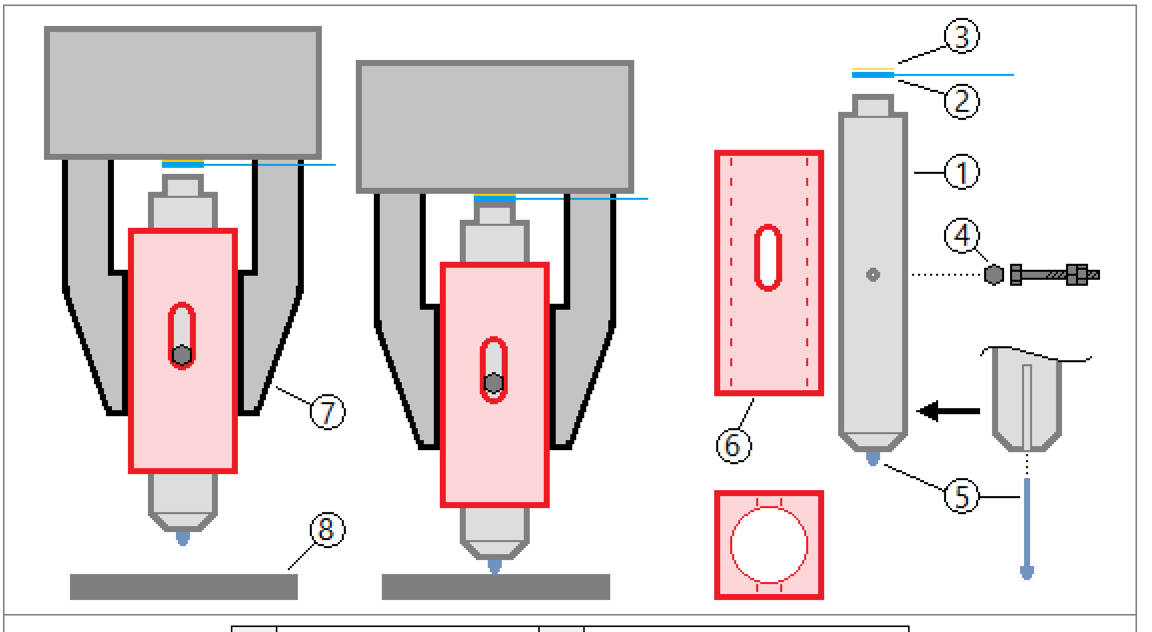
An extra actuator might be necessary in order to click some buttons of the writing pen, but the buttons can be disabled or just not used; they are used to bring extra functionalities of the digitising pen, which are not needed for this experiment.

Second approach

Starting from the previous approach, if the original digitising pen is replaced for a custom piece, the solution improves in two points:

– Firstly, there would be no risk of damaging the pen.
– The mock-up pen could be handier and more compact. Also it could be adapted to future design needs.

Also, instead of using an extra actuator, the pressure could be exerted by the robot clamp itself:

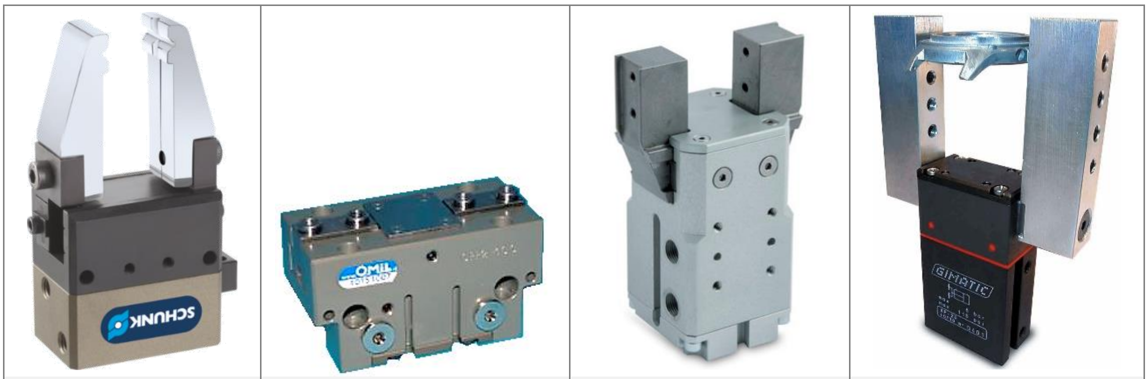


1	Mock-up pen	5	Original spare pen nib
2	Force sensor	6	3D printed custom hull
3	Double-sided tape	7	Robot clamp
4	Dowel / bolt	8	Sensitive screen

Fig. 4.12 - Pen attachment to the motion system – Schema (top) and legend (bottom).

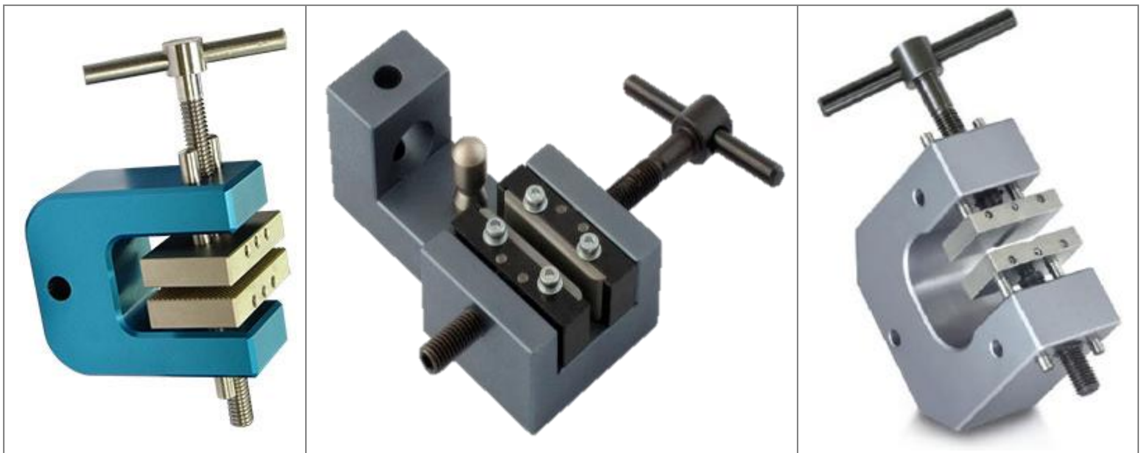
However, using a mock-up pen is not feasible because, in order to get the writing data in the tablet, the pen has to be specific (see §2.7.2). For this reason, this part of the attaching solution has to be as specified in the previous approach.

Note that instead of an actual robot clamp, any permanent subjection can serve because during the experiment there will be no need to pick up and release the writing tool. In any case, if a robot clamp is eventually used, it must be a parallel gripper with a flat bottom, so the sensor can rest on it correctly. See some examples in Fig. 4.13 and Fig. 4.14.



(a)	(b)	(c)	(d)
MPG by Schunk	OPP series by Omil	P1K series by Metal Work	SZ series by Gimatic

Fig. 4.13 - Flat-bottomed pneumatic parallel grippers.



(a)	(b)	(c)
By Admet Inc.	By Fereteria Unceta, S.A.	By MV Tecnik

Fig. 4.14 - Flat-bottomed manual parallel grippers

Final approach

Given the clamp finger would have to be mechanised anyway and the subjection can be static, constant, the final choice is to design a manual parallel gripper that can be attached directly to the robot flange[12] and that can fit the pen case and the sensor.

Fig. 4.15 - Image of the Cobot flange. Source: KingBarcode.com.

[12] The robot specifications sheet can be found at Annexe III.

4.2.4 Practical phase Explanation and Steps description.

The selected method to move the pen through the tablet's surface is a collaborative robot, present at the university. The pressure applied to the testing pen and tablet will be monitored employing a miniature load cell (see §4.2.2), which can be close looped with the robot control system.

The testing procedure is explained hereunder. All the steps are intended to be done using the equipment available at the university.[13]

STEP 1: Making a tablet mock-up.	STEP 5: Assembling everything
STEP 2: Tablet fastening	STEP 6: Connecting the sensor to the robot.
STEP 3: Making the mock-off pen.	STEP 7: Moving the robot.
STEP 4: Sensor testing	STEP 8: Carrying out the experiments.

Table 4.7 - Summary of the practical steps.

- **STEP 1:** Making a tablet mock-up

  Aim: To have a model of the digitising tablet, so the experiment can be set and tested not having to worry about damaging the device.

  Information, warnings and tips:

  It is better to get the mock-up smaller than bigger than the real tablet. One millimetre precision is enough.

  Equipment and material needs:

  – An approximately 8mm-thick board made of wood, plastic or any other available material. The size of the board
  – A ruler. A Vernier calliper.
  – A felt pen or a pencil, whichever draws better on the board's material.
  – A wood saw.

[13] As the practical realisation of this part of the project could not be developed due to the lockdown of the university (§7.1.1), some of this points have not been totally developed.

Procedure:

1. Utilising the ruler, measure the tablet length and width.
2. Draw the measured distances on the board and cut it. Revise the resultant dimensions.
3. Measure the sensitive screen position and dimensions. In this case, a Vernier calliper may be more useful than just the ruler.
4. Draw the sensitive screen area on the mock-up.

Fig. 4.16 - How the mock-up could look like.

Result validation:

The mock-up does not exceed the digitising tablet dimensions. The screen shape is correctly positioned.

- **STEP 2:** Tablet fastening

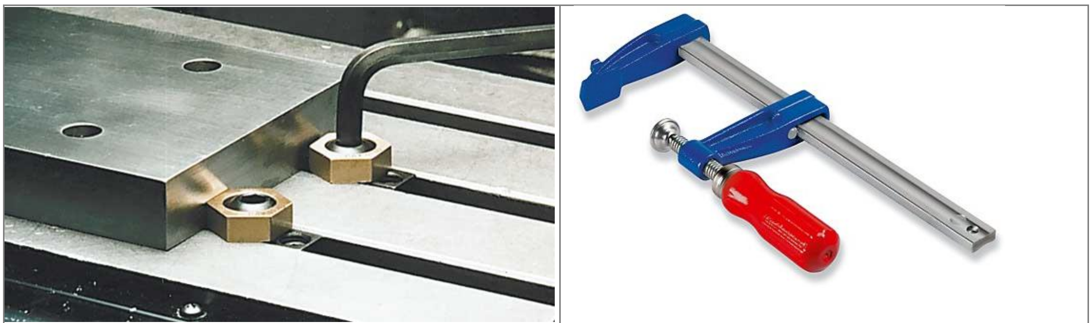
Aim: To provide a solution to attach the tablet to the working table. Only planar subjection is needed.

Equipment and material needs:

– A clamping solution: either T-Slots or other clamps.
– Some wood studs. Some woodwork reminders from the workshop might serve. They will be fixed with the clamps, so they limit the tablet position without damaging it (See Fig. 4.20).

Also, might need:

– Other clamps, brackets or bolts.



(a) T-Slot clamping system. Source: CECS OF CT LLC.

(b) F-clamp. Other similar available clamps can serve as well. Source: Leroy Merlin

Fig. 4.17 - Some clamping options.

Information, warnings and tips:

Depending on the digitising tablet model used, the sensitive screen surface may not be parallel to the working table surface, however, this should not be a problem since the solution will have a pressure-sensitive closed loop.

Fig. 4.18 - Some Wacom tablets section view. Source: Wacom.com

The robot and the tablet should preferably be attached to the same table. In case this is not possible and they can only be fixed in different boards, they both have to be fastened together.

The T-Slot solution is preferred to separate clamps.

Also, keep in mind the robot working range:

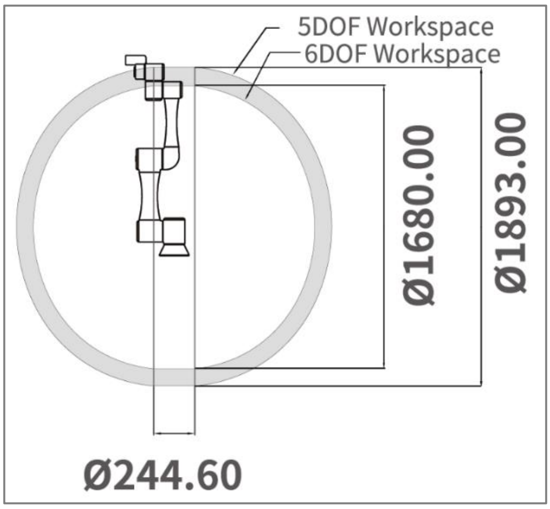


Fig. 4.19 - TM5 – 900 Working Area. Source: TechMan Robot..

Procedure:

1. Analyse the bench or table where the robot is installed. Determine if it is possible or not to set the tablet in the same place.
    a. *If it is not possible*: find another table that can be placed next to the robot's one. Make sure they can be firmly attached (using clamps, brackets, bolts, etc.). Put it together.
2. Choose the clamping solution that will be used to attach the tablet to the working board. If the robot or the tablet are placed in a T-Slot plate, select T-Slot clamping. Find the clamping material.
3. Select a region from the table where to place the table. Make sure that the robot can reach it: place the mock-up and move the robot end-of-arm (with no-tool) through the fake screen. Correct the position if necessary.

4. Put the actual tablet on the selected region and clamp it as shown in Fig. 4.20, using the studs. Mark two of the studs (shown in the same image): these will not be removed nor manipulated. The other two can be loosened in order to exchange the tablet and its reproduction.

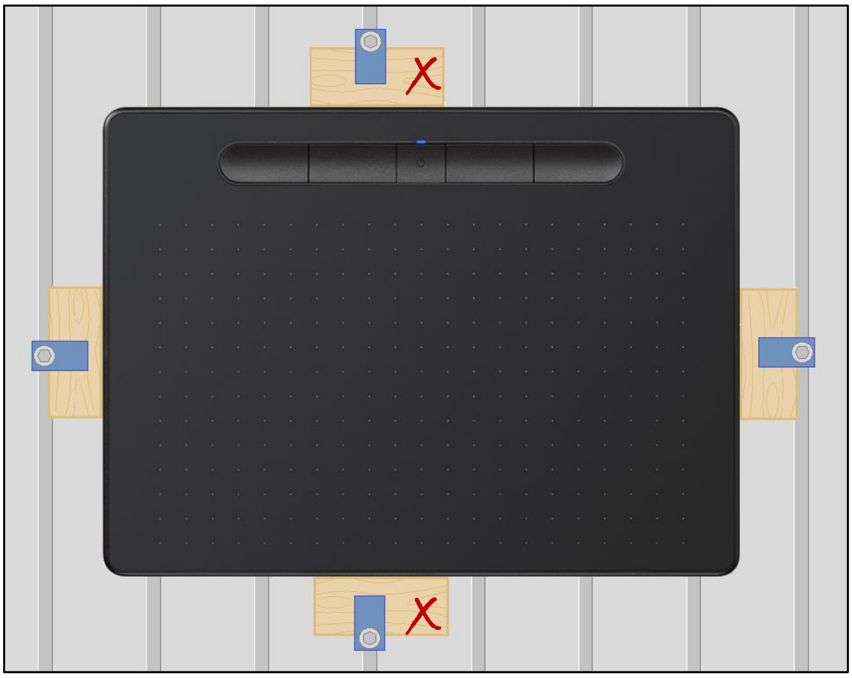


Fig. 4.20 -Tablet subjection scheme.

Result validation:

The device is held steady.

- **STEP 3:** Designing and making a cylindrical pen case (see Fig. 4.11).

- **STEP 4:** Sensor testing

Aim: To understand the sensor's behaviour and its relation between input force and output voltage.

Information, warnings and tips:

– The sensor's datasheet.

Equipment and material needs:

– Electronic testing material: a protoboard, jump wires, a multimeter…
– A PC that has the tablet acquisition software installed.
– …

Result validation:

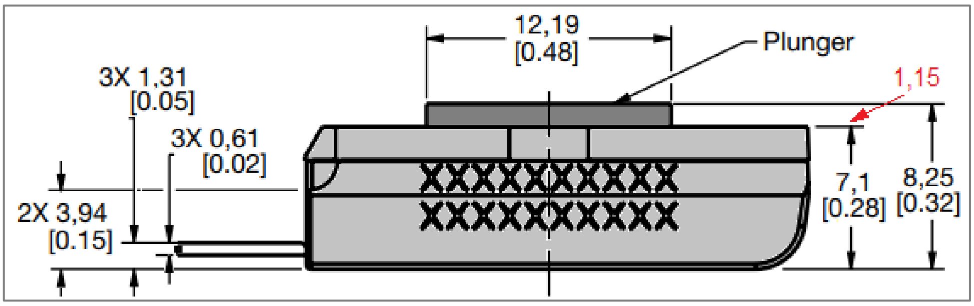
Confirm that the tablet and the sensor behave the same way, in a qualitative manner (no pressure situation, increasing/decreasing, etc.). To do this, use the acquisition software and measure the sensor output simultaneously.

- **STEP 5:** Assembling everything.
  Aim: To assemble the pen-and-hull set, the sensor and the robot flange.

Information, warnings and tips:

The double-sided tape is adequate to stick the sensor because it assures a flat and regular contact between the sensor and the clamp's bottom surface. Using another alternative, like glue, this cannot be assured.

The tape can serve to stick the sensor's protoboard as well. A good place can be the robot arm itself.



Sensor height measurements. Source: Honeywell. Edited.

Equipment and material needs:

– The pen case and hull formerly assembled (Step 3).
– The sensor and the rest of the components needed to make it work (defined in Step 4).
–

Result validation: The hull is held steady. The pen can act on the sensing plunger. The sensor keeps working (no connection has been loosed).

- **STEP 6:** Connecting the sensor to the robot.
  Aim: Getting the robot correctly reading the sensor output.

Information, warnings and tips:

The sensor will be connected to one of the robot's analogic inputs.

Equipment and material needs:

– A robot compatible connector. If a new connector has to be attached to the sensor, some specific tool will be needed.

- A cable extension might be needed. If the cable is long, some ribs to hold the cable may be necessary. Cable cutting and stripping instruments.
- The robot's manual.

Procedure: Follow the instructions on the robot's manual.

Result validation: The robot is getting the sensor data.

- **STEP 7:** Moving the robot.

  Aim: Learn how to move the robot and how to condition its movement on the measured force.

  Information, warnings and tips:

  Do it using the mock-up tablet.

  Probably, the easiest way to get the sensor measurements is by making the robot act by steps and reading the sensor output. The alternative would be modifying the acquisition software to include a new data source, provided by the sensor.

  Equipment and material needs:

  Just the manual and the material used in previous steps.

  Procedure: Refer to the robot's manual.

1. To get the robot moving along the screen perimeter while executing a constant force. Meanwhile, see the measures acquired by the sensor.
2. To get the robot making a variable force on the tablet, covering the full pressure range (obtained in Step 4).
3. To program the following routines:

   A To move the pen through the whole surface applying a determined pressure (See Fig. 4.21). An alternative path to sweep the surface could be a spiral course, but the one proposed should be easier to code.

   B To apply an increasing pressure in a determined point of the tablet.

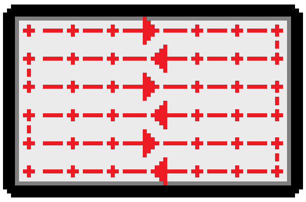


Fig. 4.21 - Proposed "S" path to sweep the sensitive surface.

4. Execute the routines using the mock-up tablet. If everything works correctly, execute them again using the real tablet and using the acquisition software at the same time to monitor its response.

Result validation:

The robot can reach the whole screen surface. The tablet measures pressure in all its range.

- **STEP 8:** Carrying out the experiments.

Aim: Relate the pressure values measured by the tablet with standard pressure units. Moreover, the hypotheses set out at the beginning of section 2 will be solved.

Information, warnings and tips:

Using the actual tablet.

Equipment and material needs:

The material and equipment already used.

Procedure:

1. Execute routine A for diverse pressure values. Fill Fig. 4.22. If any area of the screen is perceived to behave differently, repeat the experiment in such zone and pausing the robot, if necessary.
2. Determine if the tablet sensitivity is even in the whole surface.
3. Repeat routine A and compare the results with the previous ones. Determine whether the measures are time-sensitive.
4. Execute routine B in determined points of the tablet.
5. Process the data obtained and determine the relationship between pressure units.

Result validation:

	Pressure applied (sensor units)	Pressure measured (by the tablet) / range of values	The measures are homogeneous?
≈ 0			
≈ 100			
≈ 400			
≈ 700			
≈ 1000			

Fig. 4.22 - Blank table to register the results for Step 8.1.

Series	Position	
#	x =	y =
Pressure measures		
Wacom	Sensor	
0		
. . .		
1024		

Series	Position	
#	x =	y =
Pressure measures		
Wacom	Sensor	
0		
. . .		
1024		

Series	Position	
#	x =	y =
Pressure measures		
Wacom	Sensor	
0		
. . .		
1024		

Fig. 4.23 - Blank table to register the results for Step 8.4.

4.2.5 Pressure data.

The lockdown measures due to COVID-19 (refer to §6) that keep the university closed make impossible the realization of the experiments on the digitising tablets that would have provided information to normalise the writing pressure data. Fortunately, Professor Carles Paul Racarens did a similar experiment some time ago. His results are attached in Annexes I and II.

4.3 Activity 2.2

In this section, different ways to introduce the pressure data into the algorithm are discussed and several experiments are performed. The experimentation process is explained, presenting its results. Their analysis is conducted in §4.4.

Note. Even though the data acquisition phase of the project could not be done, Professor Carles Paul Racarens had made some measures some time ago (see Annex I). They have been used to prepare the algorithm. In case that no data had been available, an arbitrary curve would have been used instead.

The tests conducted are the following:

§	Title
4.3.1	First normalisation. Using a look-up table.
4.3.2	Improved normalisation using a look-up table.
4.3.3	Using a polynomial curve
4.3.4	Mismatch tests: ink-pen and plastic-pen
4.3.5	Using a synthetic exponential curve

Each test has separated steps, explained in the corresponding sub-section (a, b, c…).

4.3.1 First normalisation. Using a look-up table.

a) Preliminary study

Before designing the normalisation or any other change for the pressure data, it is necessary to learn wherein the algorithm the pressure data is.

By searching into the algorithm's functions, it can be deduced that the function "leer_firma", present in the "Main" block, reads the database information and stores the signature information in variable "temp". This variable is then arranged into a 5 column matrix, where each column corresponds to one of the digitised parameters: coordinate x, coordinate y, pressure (z), azimuth and tilt ("inclinación"); the number of rows equals the number of samples in that signature. See Fig. 4.24.

So now, the place within the functions where the pressure data can be modified is known: in the third column of variable "vect", both in the "Main" function or in "leer_firma". The structure for the "Test" phase is the same: the "leer_firma" function inputs the "vect" variable, where its third column contains the pressure data.

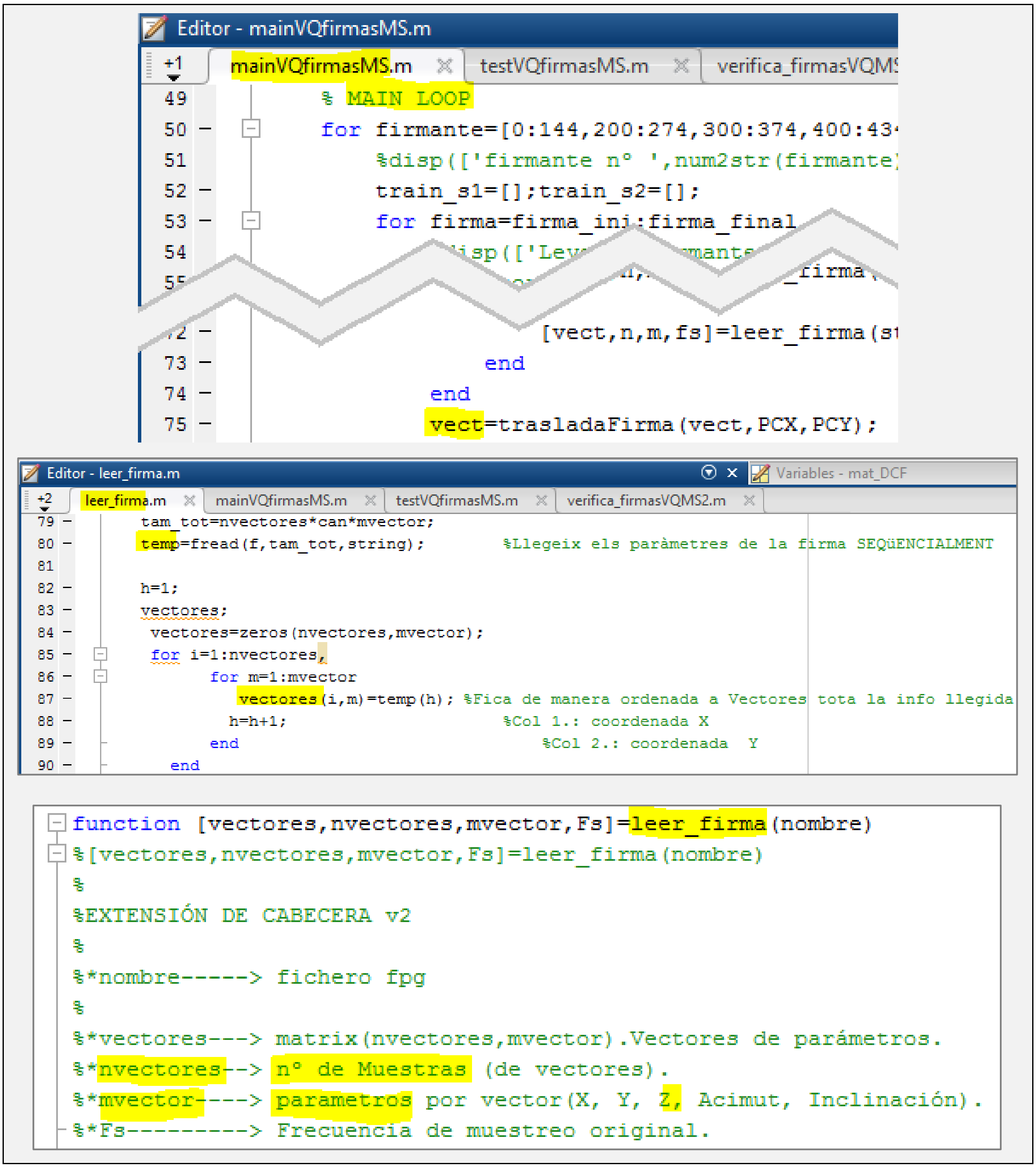


Fig. 4.24 - Extracts from the algorithm's functions that show where the pressure data is stored.

b) Making a polynomial fitting

In Fig. 4.25, lines 1 and 2, the measurements of pressure in standard units (Mega Pascals → "mpa") and in the units provided by the digitising tablet (Wacom → "w") are introduced as vectors.

A polynomial regression is made from these values so as to be able to create a standard curve with a determined number of points or a step between them. This curve will be later used to convert values in Wacom units to Pascals and vice-versa. The built-in MatLab function "polyfit" can perform a polynomial fit (least-squares method) of a selected degree. In this case, the best curve (continuous, positive and monotonous within 0 to 1024 w range) is performed with a 7^{th}-degree fit.

The following script makes the fitting and plots its result.

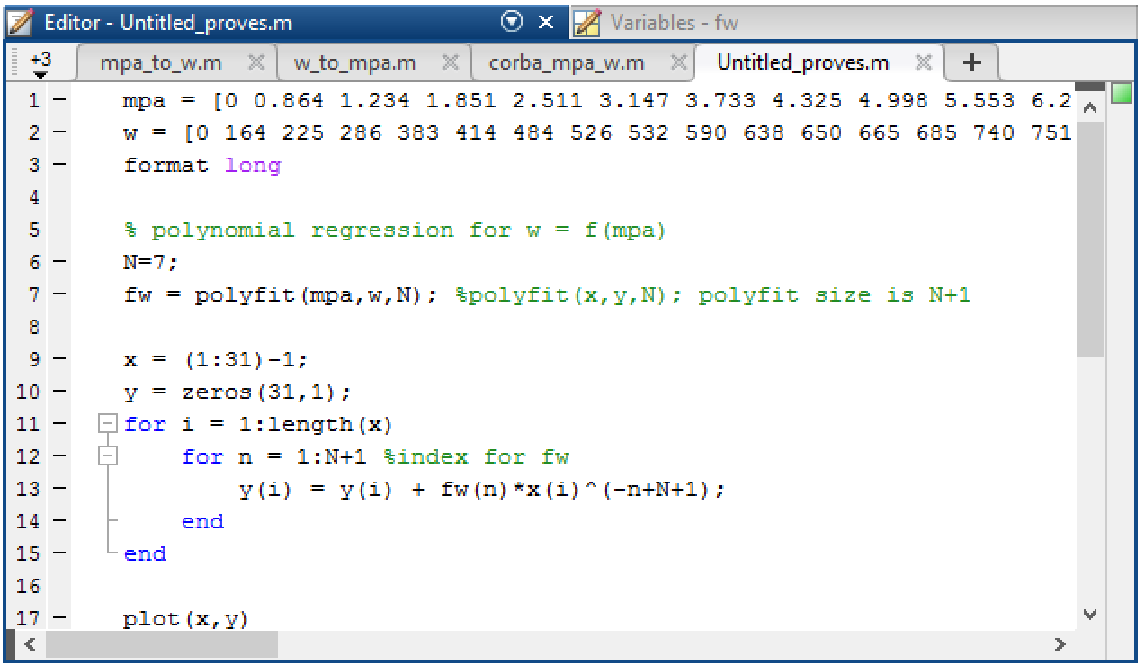


Fig. 4.25 - MatLab script: performs the polyfit and makes a plot.

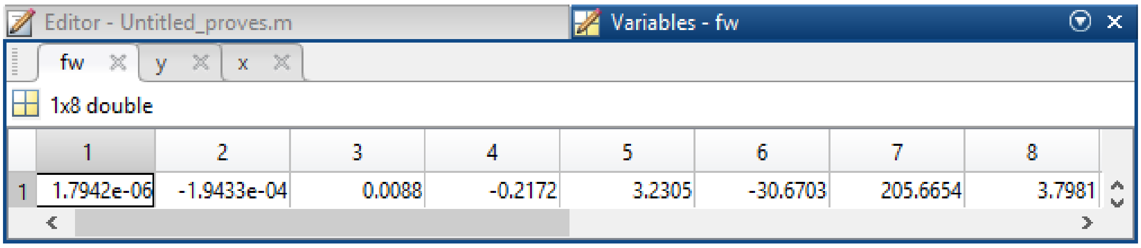


Fig. 4.26 - Obtained fitting parameters.

The result of the fitting, showed in Fig. 4.27, fulfils the desired characteristics: it covers the pressure values that the Wacom tablet can provide (0 to 1024) and it is continuous, positive and monotonous within this range, and maintains its concavity as well.

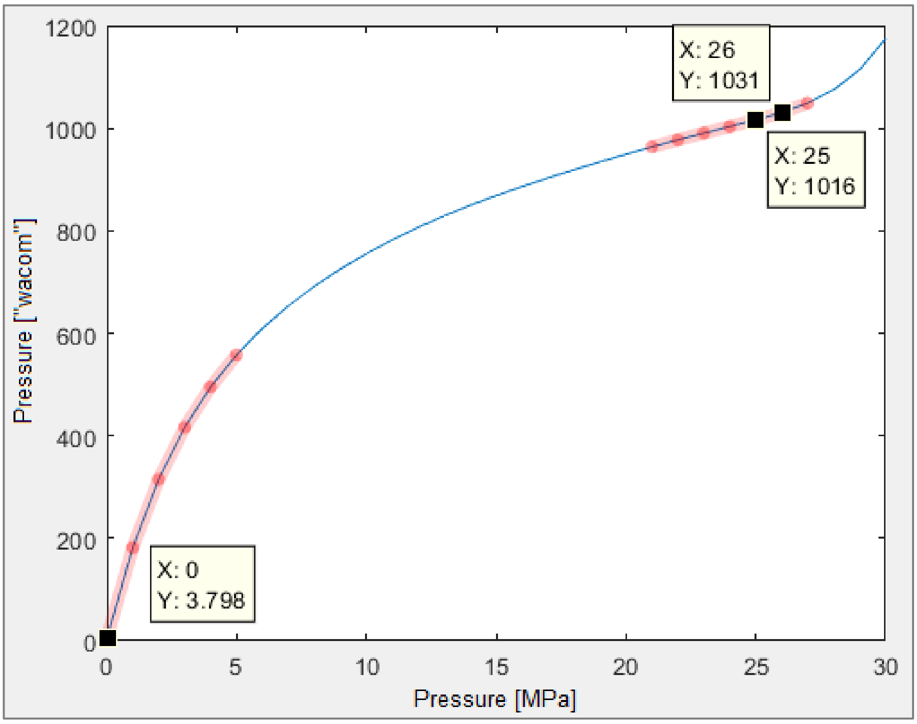


Fig. 4.27 - Plot resulting of script in Fig. 4.25.[14]

c) Creating a MatLab function that outputs the curve.

Once that the fitting can be performed correctly, a new function is created, aiming to make it callable and to store the result in a mat file, so it can be accessed from other functions. Also, the result has been improved by setting a smaller step (see Table 4.8, line 26) and using a native function called "polyval" (line 34), instead of a nested for loop (lines 29 to 33).

```
1  % Acquisition of a curve that converts pressure values in Wacom tablet
2  % units (from 0 to 1024) to MPa (from 0 a 25)
4  % obrotons@edu.tecnocampus.cat
5  % April 2020
7[15] %Related functions: mpa_to_w.m  &  w_to_mpa.m
10 function corba_mpa_w()
12    filename = 'corba_mpa_w'; % Where the curve (x,y) will be stored
13    savename = strcat('C:\Users\olga\Documents\MATLAB\prova3003\',
filename,'.mat');
15    % Pressure conversion values from MPa (mpa) to Wacom units (w)
16    % obtained through an experimental essay
17    mpa = [0 0.864 1.234 1.851 2.511 3.147 3.733 4.325 4.998 5.553
6.232 6.972 7.589 8.082 8.823 9.440 10.057 10.674 11.167 11.784 12.586
13.111 13.574 14.191 14.900 15.548 16.128 16.658 16.985 17.362 17.954
18.602 19.126 19.805 20.391 21.039 21.718 22.335 23.211 23.569 24.309
24.864 ];
```

[14] This can actually be improved; it does not cross the origin (0, 0). The whole normalisation and functions from this section are improved in the next one (§4.3.2).

[15] The missing lines were blank lines that have been removed so the table fits better in the document.

```
    w = [0 164 225 286 383 414 484 526 532 590 638 650 665 685 740 751
760 773 784 796 812 828 833 852 863 888 891 904 907 917 918 924 935
940 952 961 967 991 997 1000 1005 1013];
    format long
    % Obtainment of a polynomial regression for w = f(mpa)
    N=7;
    fw = polyfit(mpa,w,N); %polyfit(x,y,N); polyfit size is N+1
    X = 26; %max mpa value
    pas = 0.2;
    x = (0:pas:X); % empty vector to hold the mpa values ("x")

%   for i = 1:length(x) %i: index to move through x,y vectors
%        for n = 1:N+1 %index on fw
%            y(i) = y(i) + fw(n)*(i*pas-pas)^(-n+N+1);
%        end
%   end
    y = polyval(fw,x);
    save(savename,'x','y','pas')
end
```

Table 4.8 - MatLab function: "corba_mpa_w.m"

Now the .m file can be executed (from the command window or from another .m file):

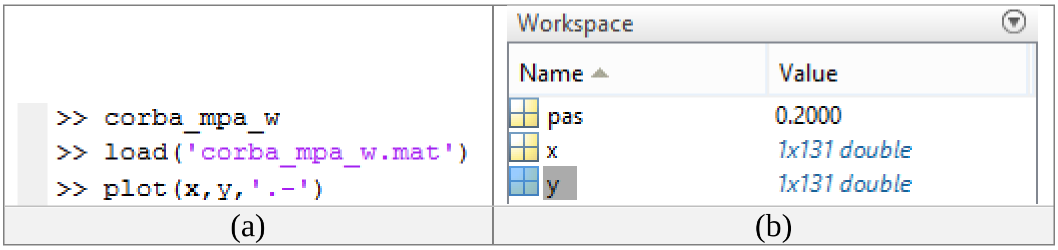


Fig. 4.28 - a: commands to execute corba_mpa_w.m and make a plot; b: variables stored in corba_mpa_w.mat.

The result of the curve plot is shown in Fig. 4.29.

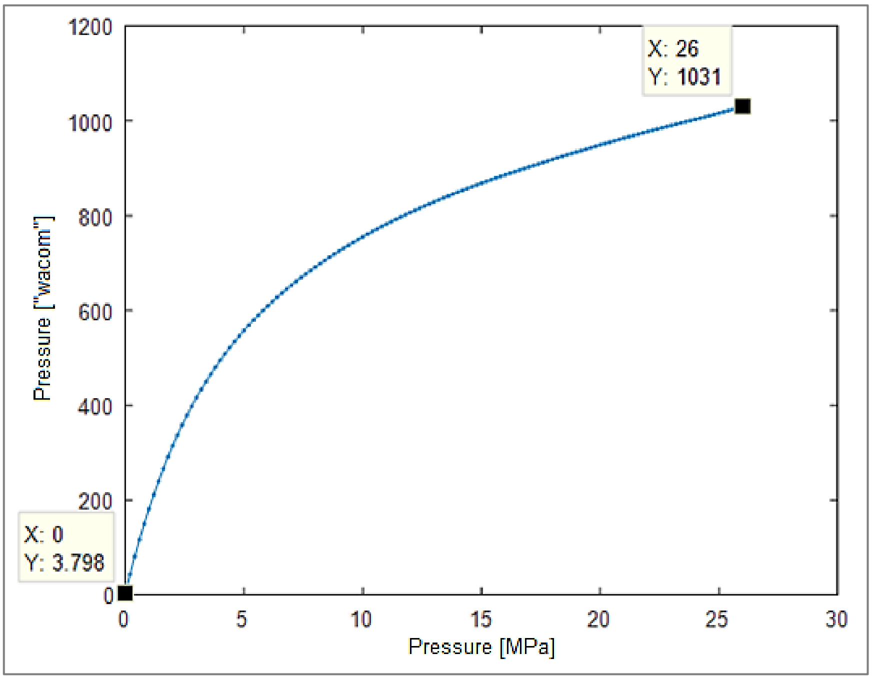


Fig. 4.29 - Curve plotted by commands shown in Fig. 4.28 (a).

d) The look-up table. Creating the searching functions.

Next, two more functions have to be created: one of them, to convert from MPa to w units, and the other, to do the opposite conversion. The first one has been called mpa_to_w; the second, w_to_mpa. Their respective scripts are attached in Table 4.9 and Table 4.10. Some errors and warnings cases have been included, although they should not happen.

```
% Function that converts pressure data in MPa (from 0 to 25) to Wacom
% tablet units (from 0 to 1024).

% obrotons@edu.tecnocampus.cat
% April 2020

%Related functions:corba_mpa_w.m  &  w_to_mpa.m

function f = mpa_to_w(F) %F is the value to convert, f is the
converted value
    % Loading the file containing the curve that relates MPa and w values
    % The file is created with the function called corba_mpa_w()
    % loadname must match “savename” variable from function corba_mpa_w
    filename = 'corba_mpa_w';
    loadname =
strcat('C:\Users\olga\Documents\MATLAB\prova3003\',filename,'.mat');
    load (loadname, 'x', 'y','pas')

    % Search the w value in the imported values from corba_mpa_w
    if F < 0
        strcat('ERROR: value to convert < 0 : ',num2str(F))
    elseif F > 26
        f = y(length(y));
    else
        f = y(find((x - F + pas/2)>0, 1));
    end % if
end % function
```

Table 4.9 - MatLab function: “mpa_to_w.m”

```
% Function that converts pressure data in Wacom tablet units
% (from 0 to 1024) to MPa (from 0 to 25)

% obrotons@edu.tecnocampus.cat
% April 2020

%Related functions: mpa_to_w.m  i  corba_mpa_w.m

function f = w_to_mpa(F) %F is the value to convert, f is the
converted value
    % Loading the file containing the curve that relates MPa and w values
    % The file is created with the function called corba_mpa_w()
    % loadname must match “savename” variable from function corba_mpa_w
    filename = 'corba_mpa_w';
    loadname =
strcat('C:\Users\olga\Documents\MATLAB\prova3003\',filename,'.mat');
     load (loadname, 'x', 'y')

```

```
    % Search mpa value in the imported values from corba_mpa_w
    if F < 0
        strcat('ERROR: value to convert < 0 : ',num2str(F))
    elseif 0 <= F && F < y(1)
        f = x(1);
    elseif F > y(length(y)) %y(length(y)) = 1030.7
        f = x(length(x));
        strcat('WARNING: value to convert > 1030.7 : ',num2str(F))
    else
     % the step between y values is not constant: need to calculate it
        p = find((y - F)>0, 1);
        if abs(y(p-1)-F) < abs(y(p)-F)
            f = x(p-1);
        else
            f = x(p);
        end % de if
    end % if F
end % function
```

Table 4.10 - MatLab function: "w_to_mpa.m".

e) Verification

A simple way to verify the coherence of both functions is to use them as if they were inverse functions:

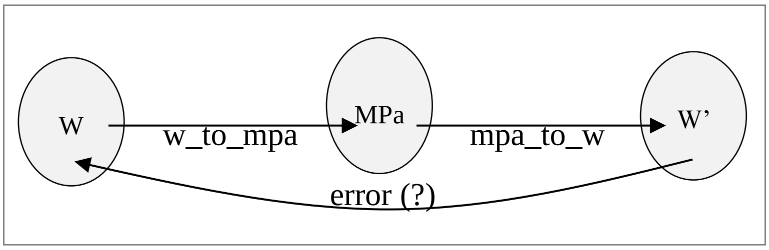


Fig. 4.30- Use of the conversion functions as inverse functions.

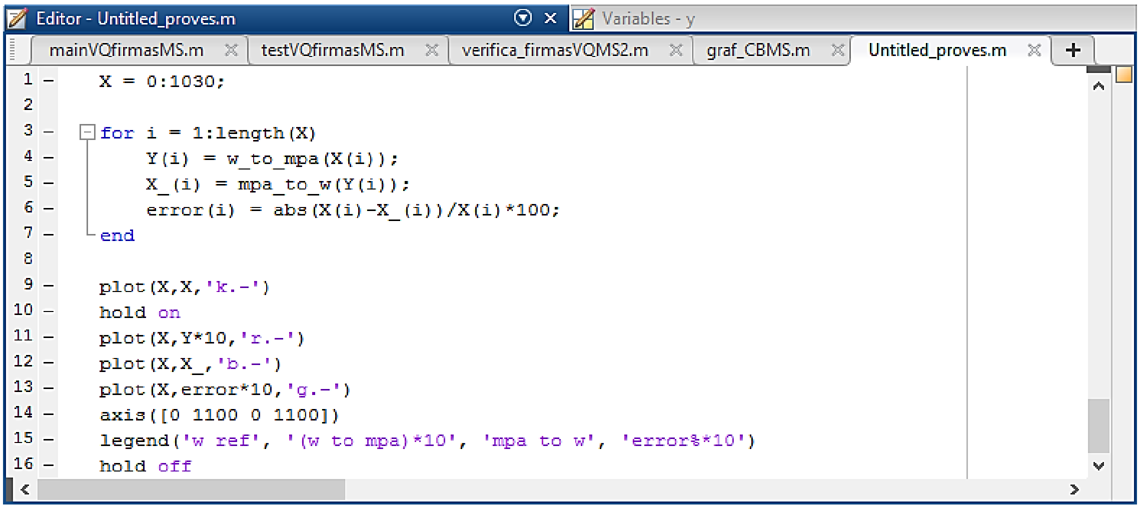


Fig. 4.31 - Script that tests the created conversion functions.

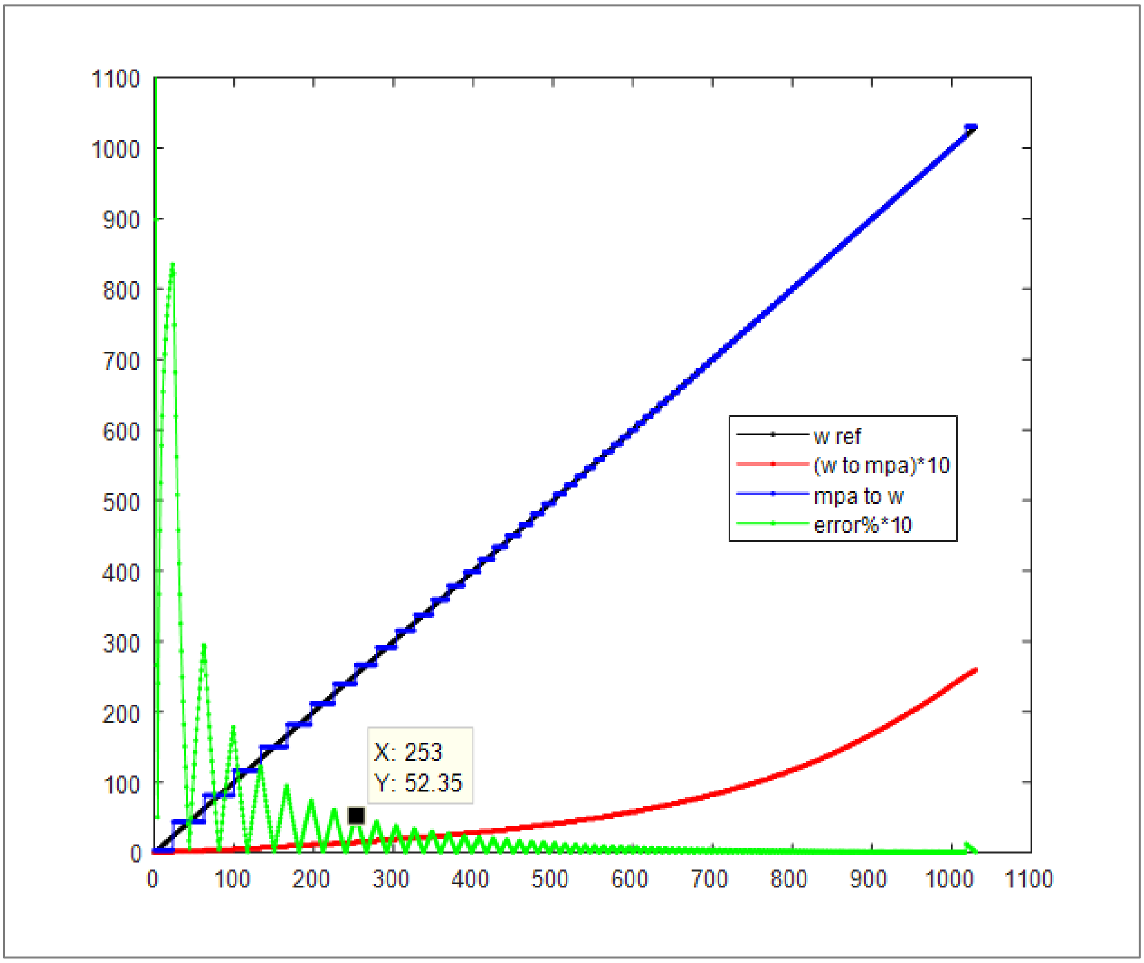


Fig. 4.32 - Plot generated from Fig. 4.31script.

The error is grater at low pressures because the look-up table has a constant step but the curve has a bigger slope in this part (see Fig. 4.29).

f) Implementation into the algorithm

The next step is adding these functions to the existing algorithm. As seen at the beginning of this section, the digital signatures from MCYT database are read using the user-made function “leer_firma” and then their position is normalised by another custom function, “traslada_firma” (see Fig. 4.33, line 54). This function outputs the variable “vect”.

Running the script from Fig. 4.33, which has a breakpoint at line 54, the variable “vect” can be quickly obtained: see Fig. 4.34.

The pressure values are at the third column of the output variable “vect”; these are the values that have to be converted. Fig. 4.35 contains a simple script to test the conversion of these values with the previously explained “w_to_mpa” function.

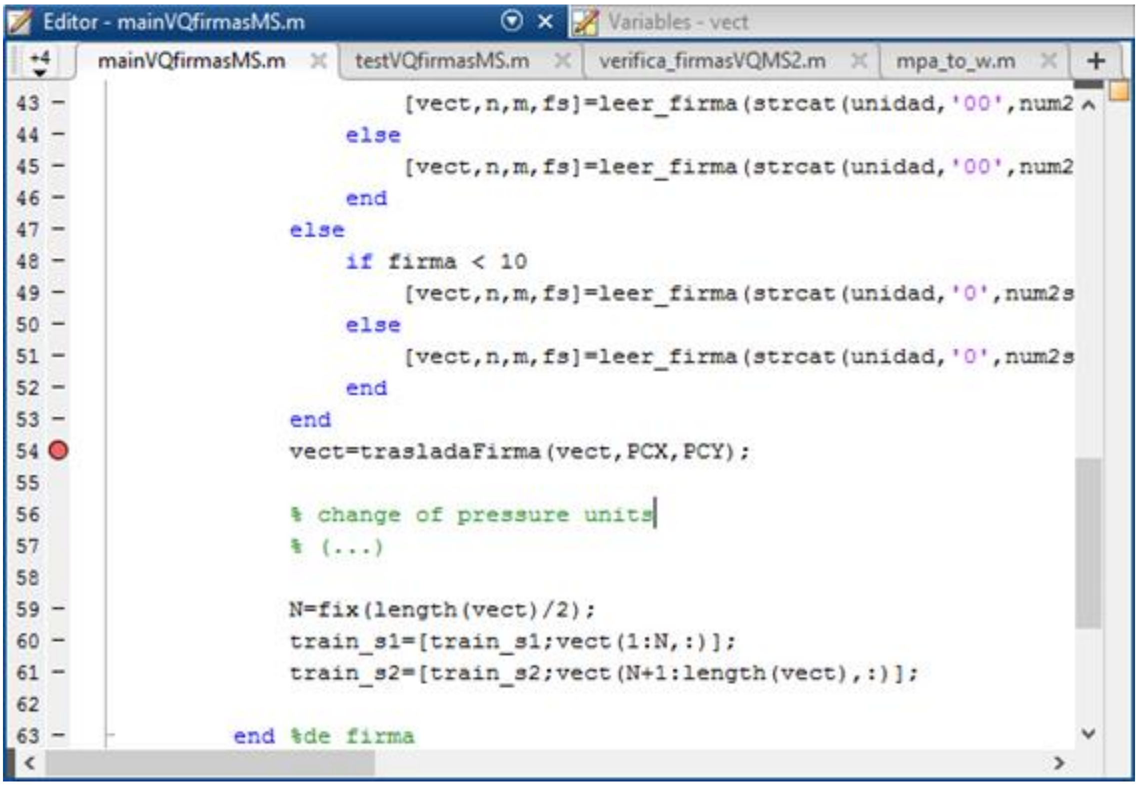
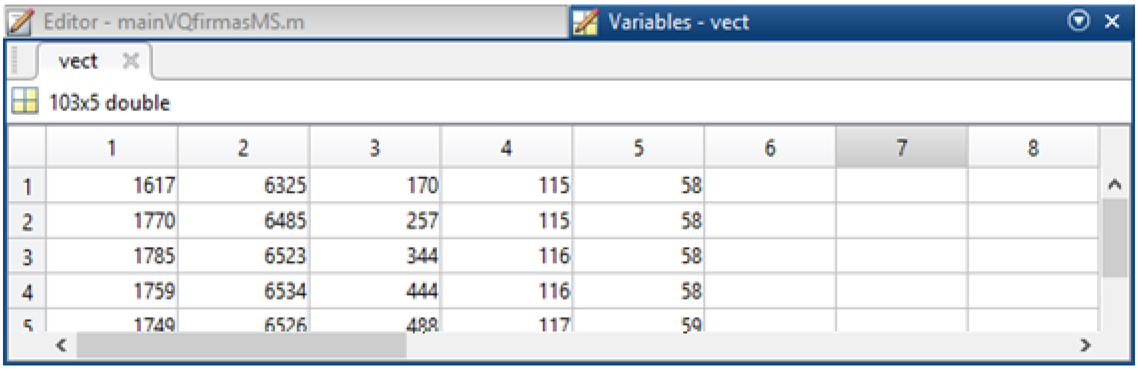


Fig. 4.33 - Part of main VQfirmasMS.m MatLab script.



	1	2	3	4	5	6	7	8
1	1617	6325	170	115	58			
2	1770	6485	257	115	58			
3	1785	6523	344	116	58			
4	1759	6534	444	116	58			
5	1749	6526	488	117	59			

Fig. 4.34 - First values of "vect" variable.

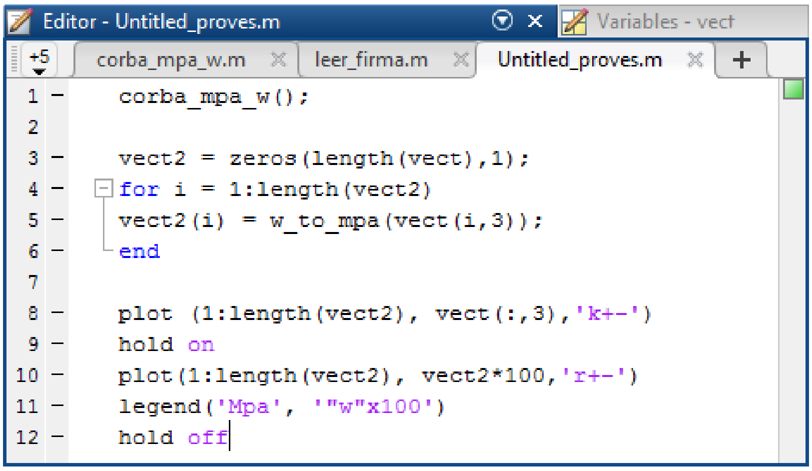


Fig. 4.35 - This script executes w_to_mpa on an actual signature and plots its corresponding pressure values in MPa and w.

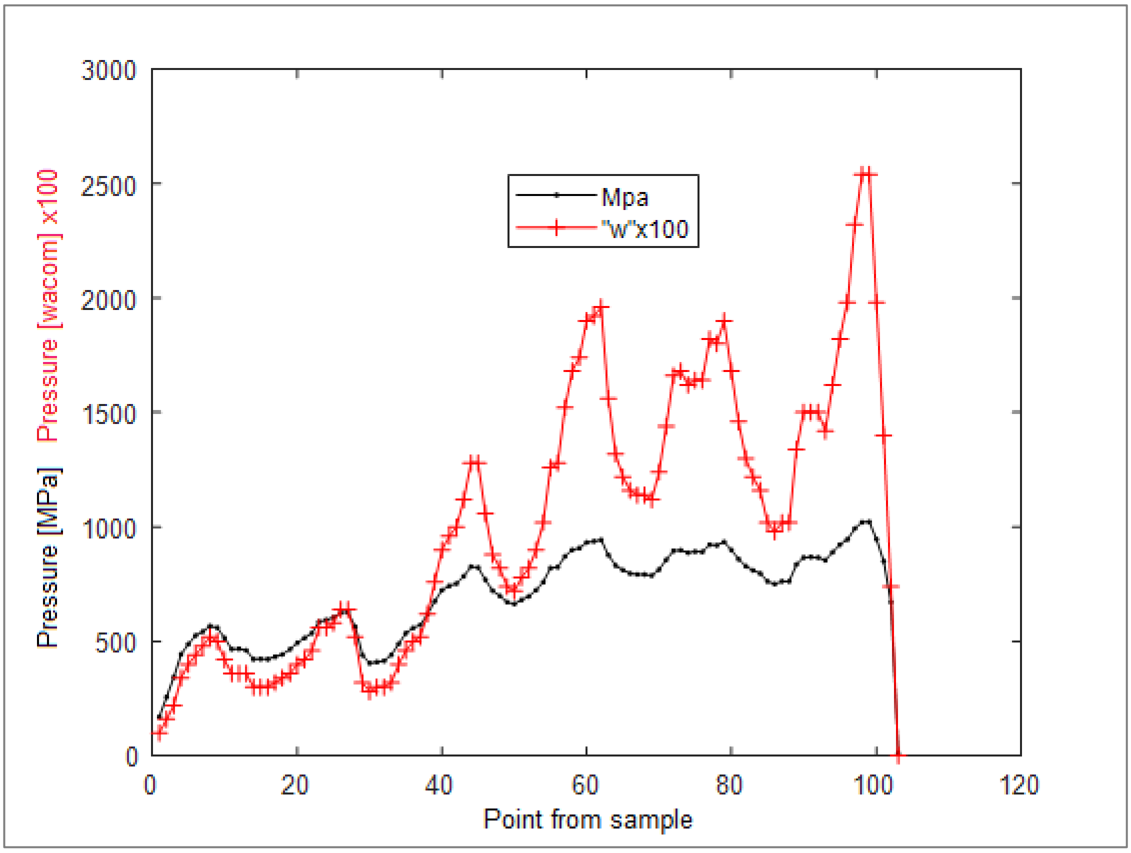


Fig. 4.36 - Plot of the pressure values of a MCYT signature sample in MPa (black) and w (red).

It seems to work correctly: the output ranges 0 to 25 MPa (see Fig. 4.36). It can be added to "mainVQfirmasMS.m" as planned (Fig. 4.37).

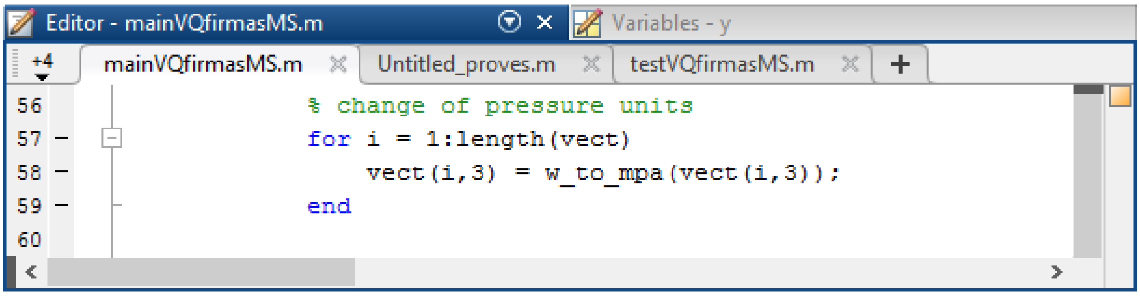


Fig. 4.37 - Implementation of the pressure conversion on the "mainVQfirmasMS" function.

As explained at the beginning of this section too, the implementation in the "Test" phase is equivalent to this one. The result of this implementation is that the algorithm, instead of working with "Wacom" pressure units, it is working with standard pressure unites (MPa).

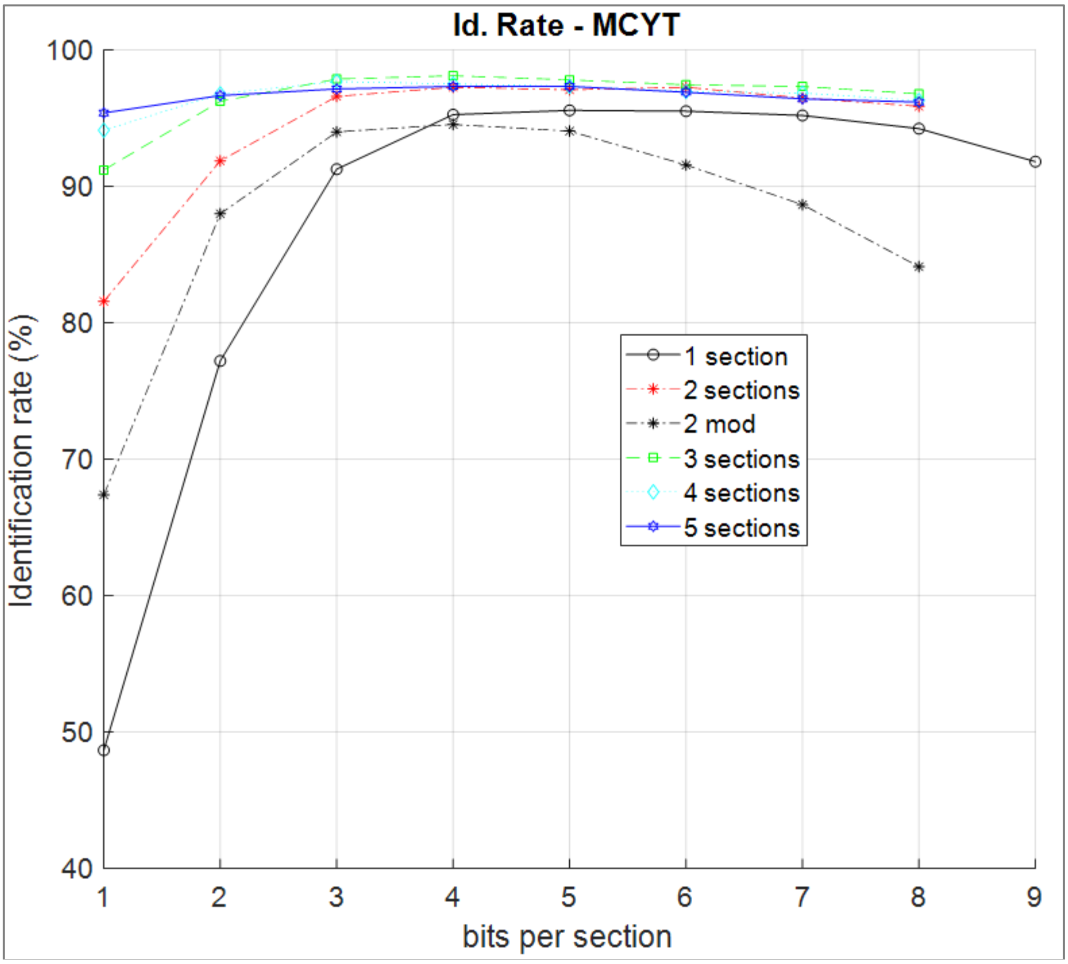


Fig. 4.38 –Result of the normalisation using "corba_MPa_w.m".

<u>Note</u>: in this graphic, all the curves correspond to the original result and the one obtained with the "corba_MPa_w2" normalisation has been added (See legend: "2 mod").

4.3.2 Improved normalisation using a look-up table.

a) Normalisation to MPa

To do this, a function called "corba_MPa_w2.m" (Table 4.11) is created from the previous one: it creates the look-up table and saves two vectors "x" and "y" (the coordinates of the curve's points) into a file called "corba_Pa_w" (Table 4.12). Another function, "w_to_mpa", receives a value (in "wacom units"), searches the index of closest match in vector y, and returns the corresponding value from vector x (in MPa).

The function is generated at "Main" 's initialisation and the normalisation is applied when variable "vect" is introduced into "Main".

Below, this curve is compared with the available experimental measurements (Annexe I). It fits them correctly.

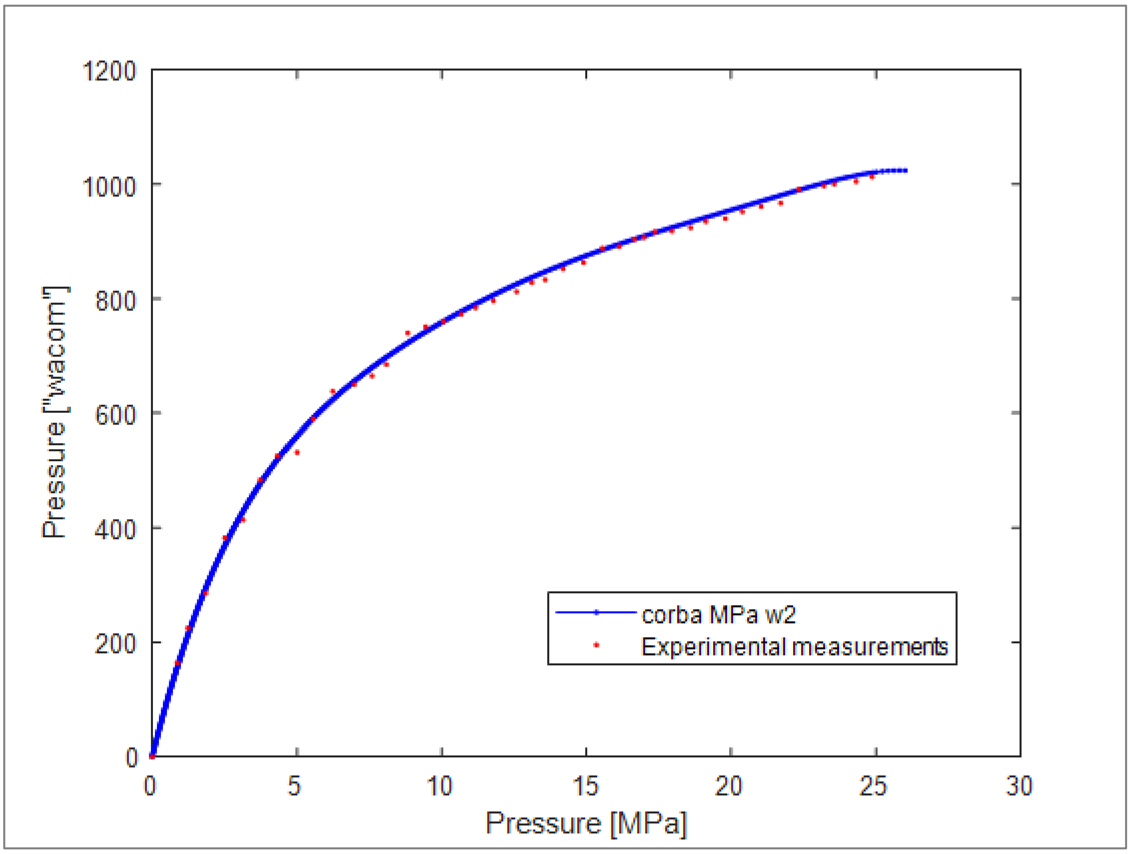


Fig. 4.39 - Curve generated with "corba_MPa_w2" and the experimental measurements.

```
% Obtenció de la corba de conversió de dades de pressió en unitats de
% la tauleta Wacom de 0 a 1024) a MPa (de 0 a 26) MILLORADA

% obrotons@edu.tecnocampus.cat
% Maig 2020
%Funcions Associades: mpa_to_w.m  i  w_to_mpa.m
function corba_MPa_w2()

    nom_fitxer = 'corba_Pa_w';
savename=strcat('C:\Users\olga\Documents\MATLAB\prova3003\',nom_fitxer
,'.mat');

    % Dades de conversió de pressió en MPa (mpa) a unitats de la tauleta
    % Wacom(w)obtingudes experimentalment
    mpa = [0 0.864 1.234 1.851 2.511 3.147 3.733 4.325 4.998 5.553 6.232 6.972 7.589 8.082 8.823
9.440 10.057 10.674 11.167 11.784 12.586 13.111 13.574 14.191 14.900 15.548 16.128 16.658 16.985
17.362 17.954 18.602 19.126 19.805 20.391 21.039 21.718 22.335 23.211 23.569 24.309 24.864];
    w = [0 164 225 286 383 414 484 526 532 590 638 650 665 685 740 751 760 773 784 796 812 828 833
852 863 888 891 904 907 917 918 924 935 940 952 961 967 991 997 1000 1005 1013];
    format long

    % Obtenció d'una regressió polinòmica per w = f(mpa)
    N=6;
    fw = polyfit(mpa,w,N); %polyfit(x,y,N); polyfit té mida N+1

    X = 26;%valor màxim de mpa
    x = 0:X;
    for i = 1:length(x)
        %calcular pas relacionat amb la pendent de la corba
        passos(i) = 1.3/abs(polyval(polyder(fw),x(i)));
    end

    clear x
    x = 0; enter = 1;
    pas_max = 0.5; %pas màxim
    while x(length(x))< 26 %definir el vector de x's amb pas adaptat
        while x(length(x)) < enter
            if passos(enter) < pas_max
                x(length(x)+1) = x(length(x)) + passos(enter);
            else
                x(length(x)+1) = x(length(x)) + pas_max;
            end
        end
        enter = enter + 1;
    end
    y = polyval(fw,x); %avaluar per les x calculades

    %ajustar y=0:1024
    y = y - y(1);
    factor = 1024 / y(length(y));
    y = y*factor;

    save(savename,'x','y')
    %plot(x,y,'.-')
end
```

Table 4.11 – Function “corba_MPa_w2”

```
1 % Funció per convertir dades de pressió en unitats de la tauleta Wacom
2 % (de 0 a 1024) a MPa (de 0 a 25)
3 % Versió 2
4
5 % obrotons@edu.tecnocampus.cat
6 % Maig 2020
7
8 %Funcions Associades: mpa_to_w.m  i  corba_mpa_w.m
9
10 function f = w_to_mpa(F) %F és el valor a convertir, f és el valor convertit
11     % Carregar la corba que relaciona valors en MPa i unitats de la Wacom
12     % El fitxer es genera amb la funció corba_Pa_w()
13     % el loadname ha de coincidir amb el savename de la funció corba_mpa_w
14     nom_fitxer = 'corba_Pa_w';%'corba_mpa_w';
15     loadname = strcat('C:\Users\olga\Documents\MATLAB\prova3003\',nom_fitxer,'.mat');
16     load (loadname, 'x', 'y')
17
18     % Cerca del valor en mpa
19     [~,closestIndex] = min(abs(y-F));
20     f = x(closestIndex);
21 end
```

Table 4.12 - Function "w_to_mpa". Searches a "w" value in a look-up table, which loads, and outputs the equivalent value in MPa.

Besides the comparison with the experimental measurements, another check that can be performed is to apply the normalisation (w → MPa) and the inverse function (MPa → w): the input values should be restored after applying the two functions (the same test as in §4.3.1). See Fig. 4.40. The inverse function is "mpa_to_w" and works the same way "w_to_mpa" does, but they use the "corba_Pa_w" oppositely; these search functions "mpa_to_w" and "w_to_mpa" work the same way as in the previous version, but the algorism has been simplified (see Table 4.12, lines 19 and 20).

The previous version of this function ("corba_MPa_w") reached higher errors because it used a constant step to create the look-up table. This was solved creating a step proportional to the function's slope (Table 4.11, lines 22-30). Moreover, the polynomial's grade has been reduced from 7 to 6 (line 22) because otherwise it kept making some performance warnings.

Even though the normalisation error is much lower in the second version of the normalisation curve, the algorithm's results are almost the same. The maximum identification rate is close to 95 %; for 1, 7 and 8 bits, the identification rate decreases significantly.

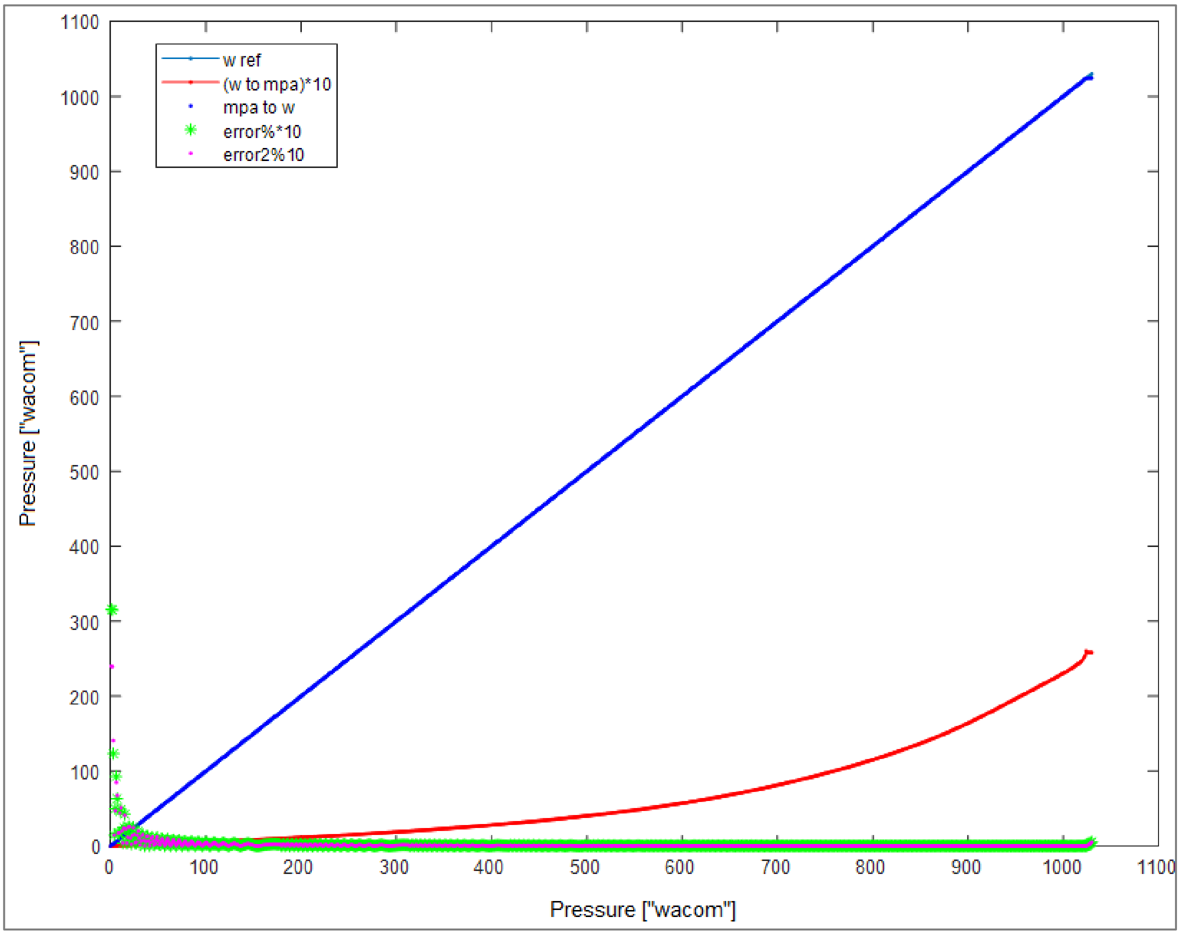


Fig. 4.40 – Error check while applying normalisation and denormalisation to a set of values (0-1024). Note that some parameters had to be scaled so they were readable.

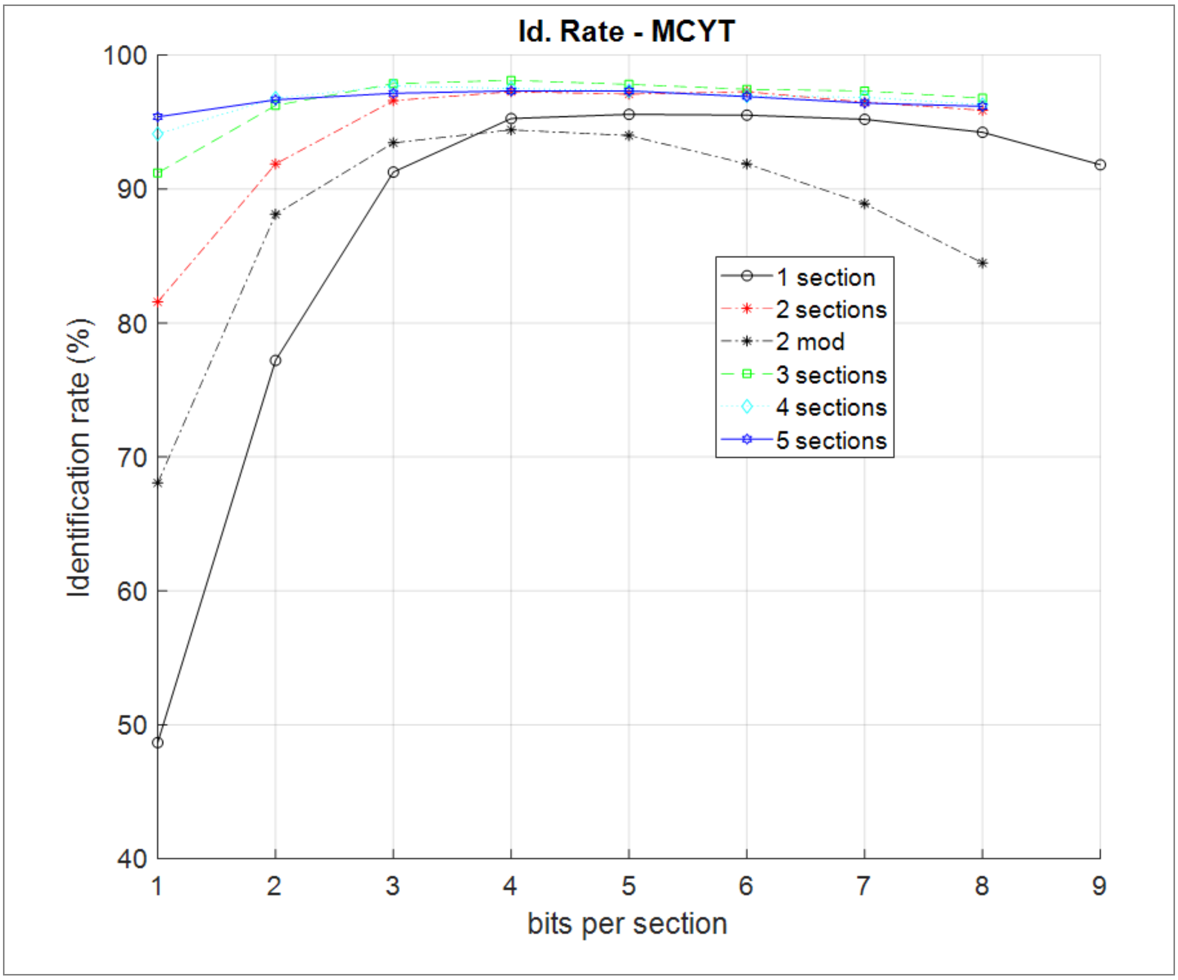


Fig. 4.41 - Results for normalisation with "corba_MPa_w2".

b) Curve Magnification

When the pressure is normalised, it maximum value decreases from 1024 to 25; this will make it recede in importance against the other parameters. In an attempt to improve the previous performance, the normalisation curve is magnified, by multiplying a factor to the MPa value.

This new normalisation is created in “corba_MPa_w3”: starting from “corba_MPa_w2”, the statement *x = x*factor;* is added at line 51 (see Table 4.11).

Three tries have been performed: for factor equal to 50, 100 and 10^6. Whereas the result was expected to improve, it got worse as the factor raised. See

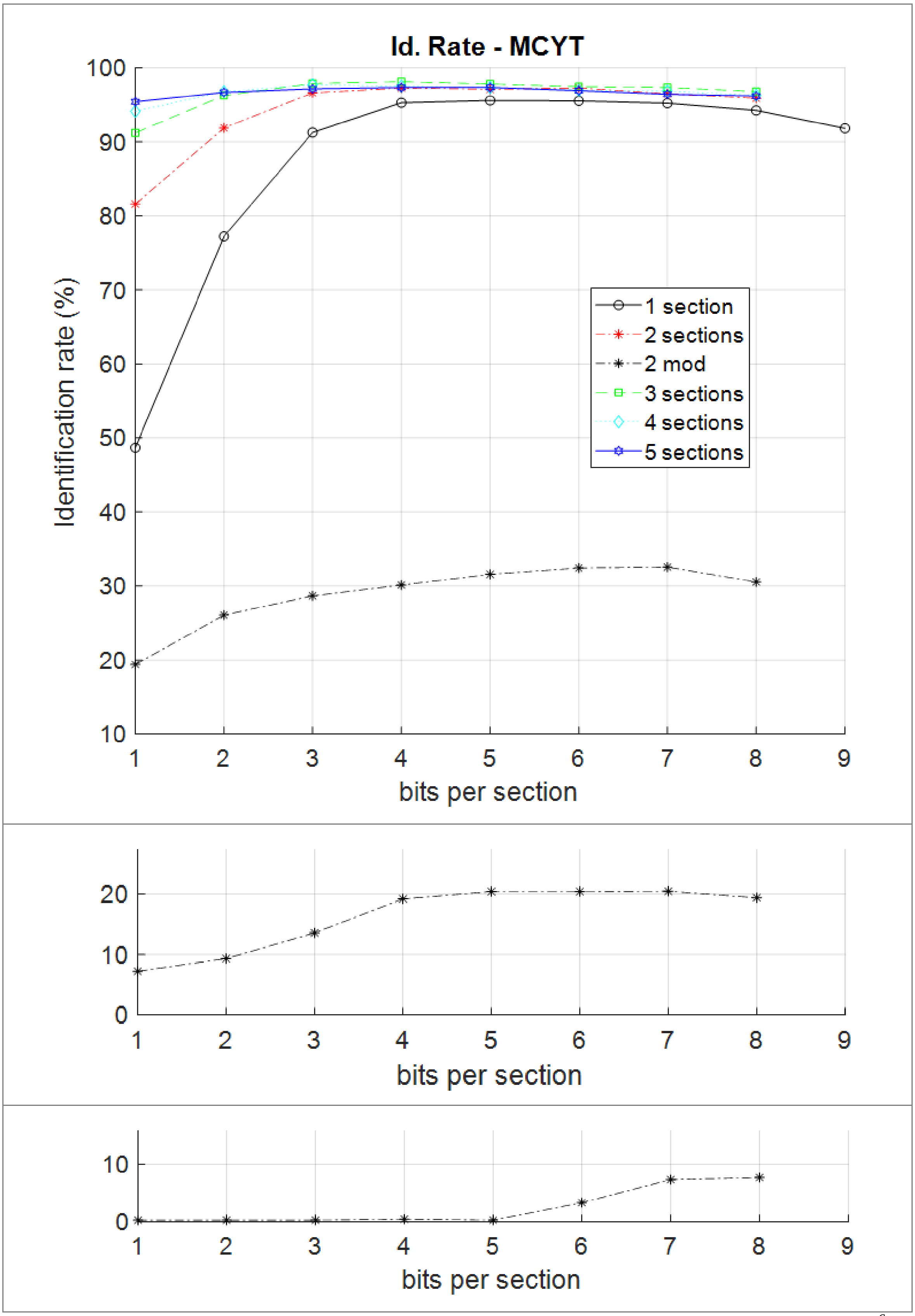


Table 4.13 - Results for "corba_MPa_w3". Factor applied (from top to bottom): 50, 100, 10^6.

c) Verification

After getting such bad and unexpected results a verification is realised. The function "corba_MPa_w4" is created from the previous one (_w3): the magnification statement (*x = x*factor;*) is replaced with *x = y;*. The resulting curve is a unitary slope line, so its outputs the same it gets as an input.

The previous curve "corba_MPa_w3" has to be replaced with the new one; as well as in the prior tests, the search function "w_to_mpa" does need to be changed. If the normalisation is correctly implemented, the result should coincide with the original one (red curve at Fig. 4.41; see also §2.7.5).

The result (Fig. 4.42 – "2 sections modificada") turns out to be correct, just having some "noise". This points out that the preceding tests are not mistaken.

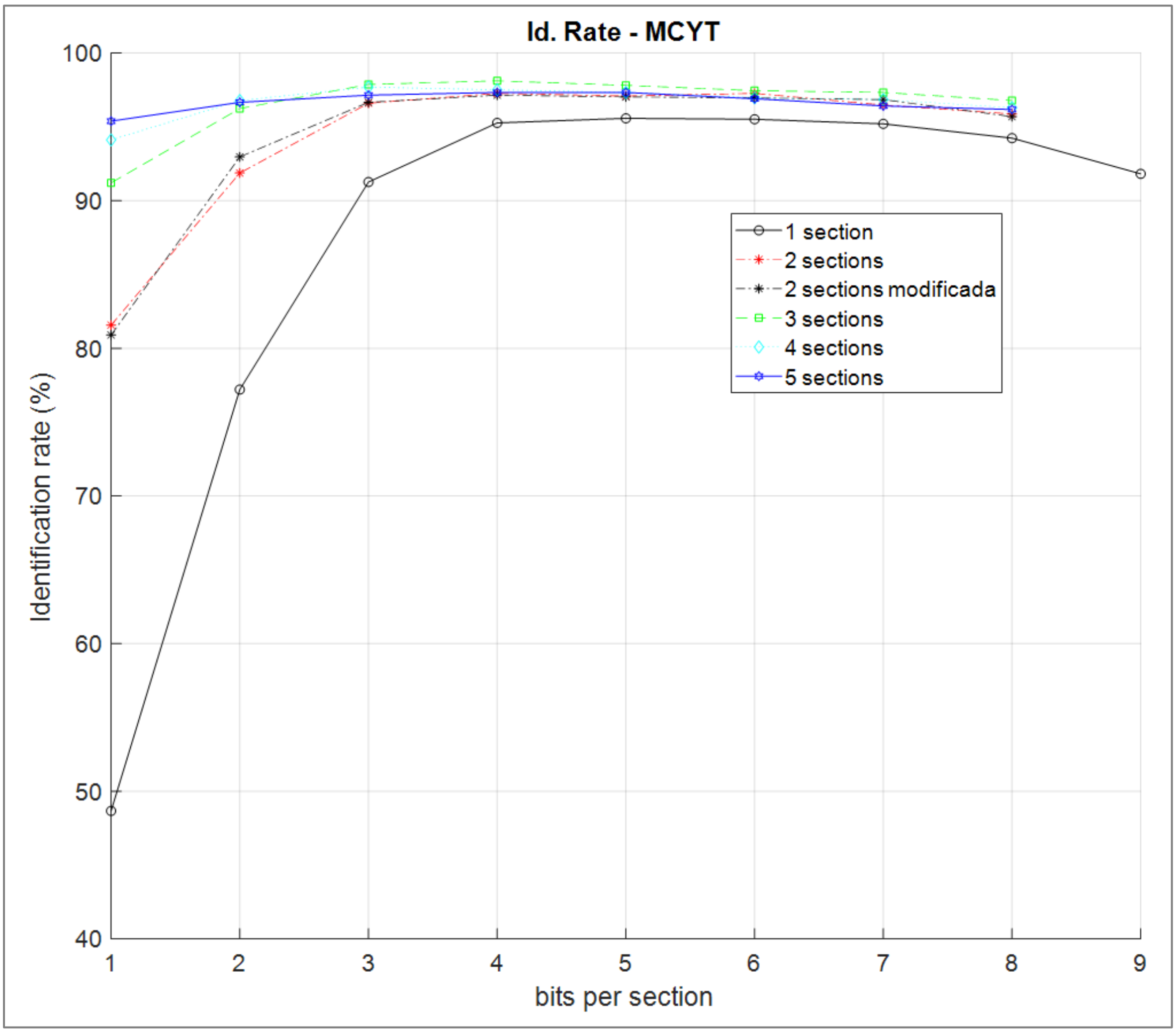


Fig. 4.42 – Look-up table normalisation check.

4.3.3 Using a polynomial curve

Now, instead of normalising the values by means of the look-up table, the input value (in “Wacom” units) will be evaluated for the normalisation function using the built-in function “polyval”. Also, a correction parameter is obtained from the “polyfit” function, which improves the polynomial and the fitting performance. [47]

a) Creating polynomial parameters to be evaluated

The following code uses the experimental measurements again and creates a variable containing its polynomial fitting parameters and a correction parameter “mu”. This is then evaluated for some points (in “Wacom” units; see line 20).

```
1  %% corba sencera amb correccions - intent d'integrar les correccions a fw
2  m = 1; %per fer més gran el rang de pressió / augmentar la sensibilitat
3  mpa = m*[0 0 0.864 1.234 1.851 2.511 3.147 3.733 4.325 4.998 5.553 6.232 6.972 7.589 8.082 8.823 9.440 10.057 10.674 11.167 11.784 12.586 13.111 13.574 14.191 14.900 15.548 16.128 16.658 16.985 17.362 17.954 18.602 19.126 19.805 20.391 21.039 21.718 22.335 23.211 23.569 24.309 24.864];
4  w = [0 0 164 225 286 383 414 484 526 532 590 638 650 665 685 740 751 760 773 784 796 812 828 833 852 863 888 891 904 907 917 918 924 935 940 952 961 967 991 997 1000 1005 1013];
5  % mpa=>y; w=>x
6  format long
7  [fw,~,mu] = polyfit(w,mpa,4); %polyfit(x,y,N); polyfit té mida N+1
8  X = [0:1024]; %rang desitjat de les w
9  Y = m*[0:mpa(length(mpa))]; %rang desitjat de mpa
10 %càlcul vector y de la corba i correcions
11 y = polyval(fw,X,[],mu);
12 c1 = y(length(y))/(y(length(y))-y(1)); c2 = y(1); %correccions de la y
13 fw = c1*fw; fw(length(fw))=fw(length(fw))-c2;%correcció a fw
14 y = polyval(fw,X,[],mu);
15 %corba generada
16 plot(X,y,'.-c'); hold on
17 %mesures experimentals
18 plot(w,mpa,'.r')
19 %p: proves
20 xp = [0:100:1000]; yp = polyval(fw,xp,[],mu);
21 plot(xp,yp,'*g'); grid on
22 %axis([0,1100,0,(y(length(y))+100)]);
23 legend('Conversion curve', 'Experimental Measurements', 'Test points')
24 xlabel('Pressure [Wacom units]'); ylabel(strcat(['Pressure [MPa x ',num2str(m),']']))
25 hold off
26 % per fer la conversió només cal el polinomi (fw) i la mu.
27 % s'executa el polyval amb la xp (unitats "w") donada i s'obté en mpa*m
28 % m és un factor per fer més gran el valor de sortida
29 % Ho implemento a corba_MPa_w5 i no cal funció de conversió (w_to_mpa) pq es fa amb el polyval.
```

Table 4.14 – Creating and evaluating polynomial parameters for a pressure normalisation essay.

Besides this changes, the place where the normalisation is applied has been changed; now the “fw” and “mu” parameters, after being load at “Main” or “Test” Workspace, are introduced into “leer_firma” function. To do so, two inputs have been added to this function (see the original function definition at Fig. 4.24 (bottom)). This implementation uses an existing for-loop: Fig. 4.49.

The result of executing the previous lines is:

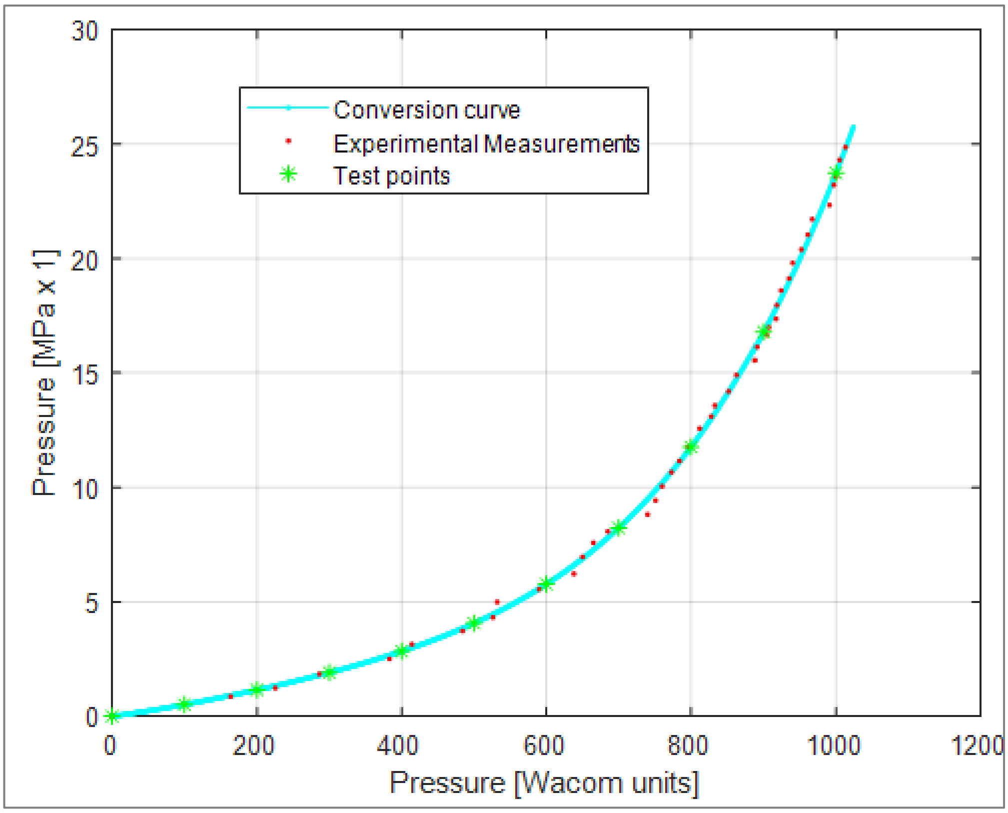


Fig. 4.43 - A polynomial curve for pressure normalisation, integrating a polynomial correction.

b) Generating a test curve

The code from Table 4.14 is used to create a new function: “corba_MPa_w5”. This function, instead of creating the x and y vectors, as did while working with the look-up table strategy, outputs the polynomial curve parameters “fw” and the correction parameter “mu”. As said, MatLab features a built-in function, “polyval”, that can evaluate this “fw” and “mu”, so the search functions used in the past, “w_to_mpa” and “mpa_to_w”, are not needed anymore.

This time, the test curve has been applied before the actual normalisation, with the same aim as in previous test: making sure that it does not affect the algorithm.

Using the same code that would be used to create a genuine polynomial, a unity slope is generated. If the result of this implementation matches the original result, it will prove that this implementation does not affect the original algorithm. Then a real normalisation curve can be safely implemented, using this implementation with different parameters.

```
  % Prova amb conversió d'unitats de pressió i amb correcció en la regressió.
% Per comprovar que la conversió no afecta l'algorisme.

% obrotons@edu.tecnocampus.cat
% Juny 2020

%Funcions Associades: mpa_to_w.m  i  w_to_mpa.m
%Es parteix de corba_MPa_w4()
function corba_MPa_w5()

    nom_fitxer = 'poly_corba';
savename=strcat('C:\Users\olga\Documents\MATLAB\prova3003\',nom_fitxer,'.mat');

    % multipliying factor to increase pressure units range
    m = 1;
    % Experimental measurements     % mpa=>y; w=>x
%     mpa = m*[0 0.864 1.234 1.851 2.511 3.147 3.733 4.325 4.998 5.553 6.232 6.972 7.589 8.082 8.823 9.440 10.057 10.674 11.167 11.784 12.586 13.111 13.574 14.191 14.900 15.548 16.128 16.658 16.985 17.362 17.954 18.602 19.126 19.805 20.391 21.039 21.718 22.335 23.211 23.569 24.309 24.864];
    mpa = [0 164 225 286 383 414 484 526 532 590 638 650 665 685 740 751 760 773 784 796 812 828 833 852 863 888 891 904 907 917 918 924 935 940 952 961 967 991 997 1000 1005 1013];
    w = [0 164 225 286 383 414 484 526 532 590 638 650 665 685 740 751 760 773 784 796 812 828 833 852 863 888 891 904 907 917 918 924 935 940 952 961 967 991 997 1000 1005 1013];

    format long
    % polynomial fitting (fw) and correction (mu)
    [fw,~,mu] = polyfit(w,mpa,4); %polyfit(x,y,N); polyfit has size N+1
    X = [0:1024]; %desired w (wacom) range
    % Y = m*[0:mpa(length(mpa))]; %desired mpa range
    % curve's vector y and more corrections correcions
    y = polyval(fw,X,[],mu);
    c1 = y(length(y))/(y(length(y))-y(1)); c2 = y(1); %correccions de la y
    fw = c1*fw; %this scales the curve according the measurements
    fw(length(fw))=fw(length(fw))-c2; %this offsets the curve to (0,0)
    %fw(length(fw)) is the constant term of the polynomial

    save(savename,'fw','mu')
%    plot(X,y,'.-')
end
```

Table 4.15 - Code for a non-normalising test curve. Function "corba_MPa_w5".[16]

[16] Actually, the notation of the function could be clearer: "w" is the input and "MPa" is the output.

The resulting curve is plotted below:

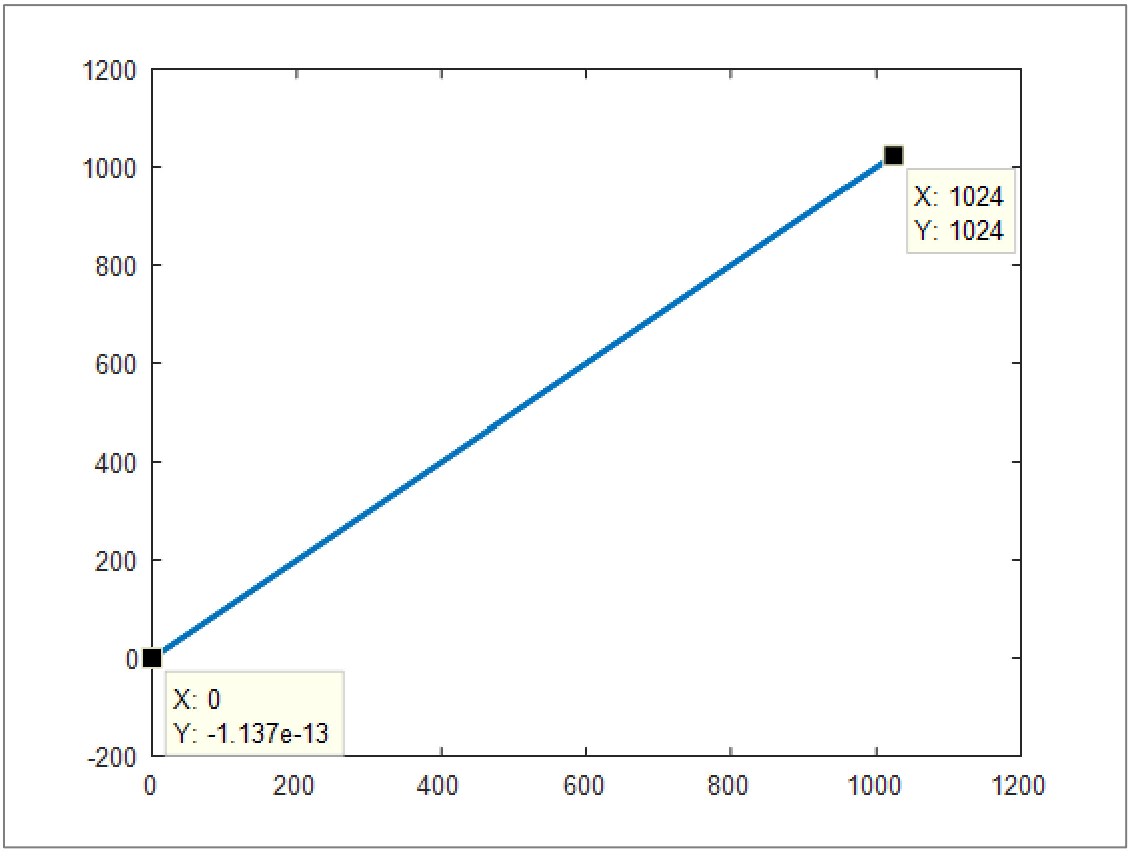


Fig. 4.44 - Non-normalising test curve generated with code from Table 4.15.

The result of the implementation is good: it matches the original result, only having some "noise".

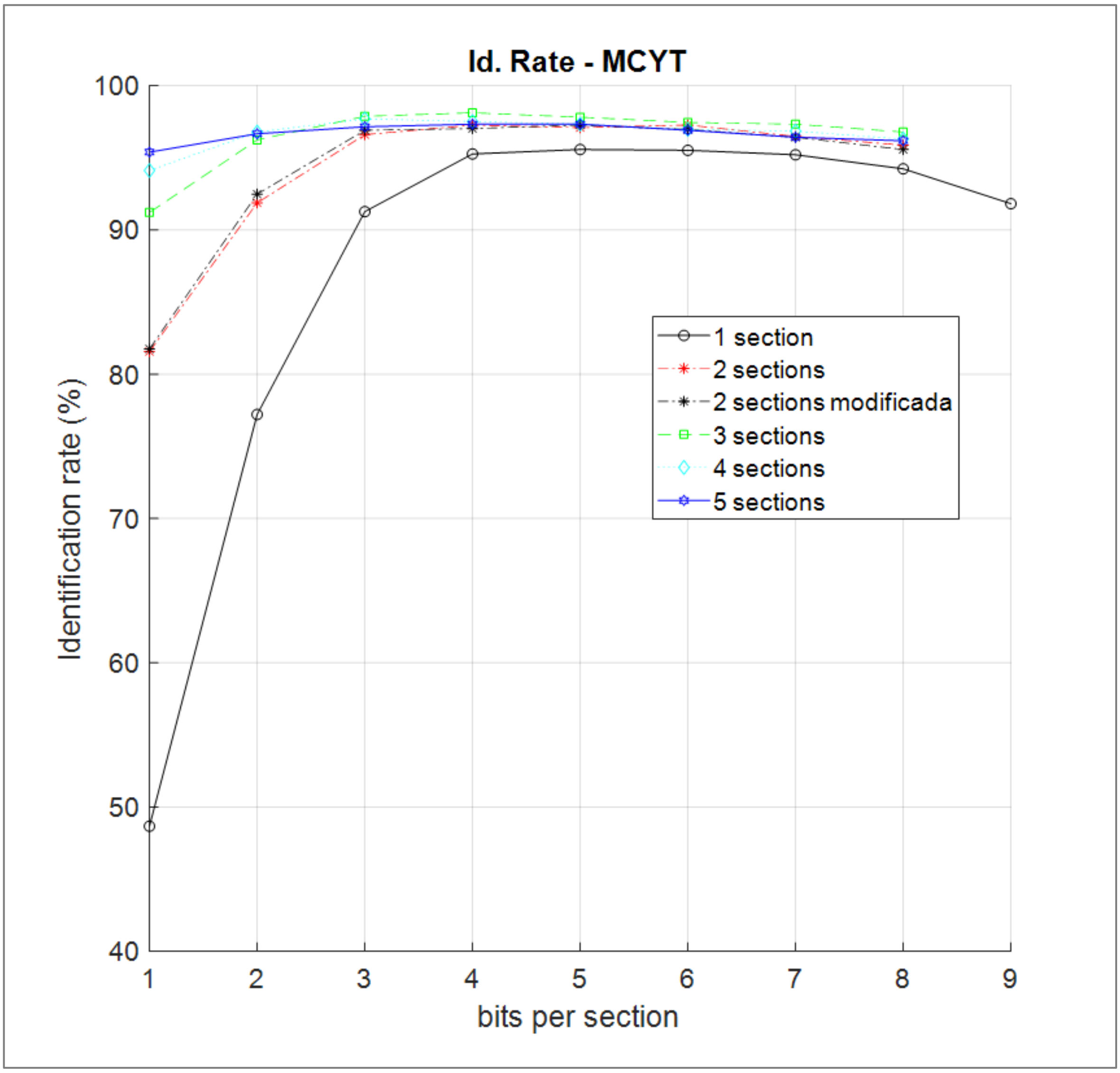


Fig. 4.45 - Result of the non-normalising polynomial curve.

The result is slightly better than the non-normalising using a look-up table (Fig. 4.42, §4.3.2 c). It proves that the implementation is correct.

c) Normalisation to MPa

To apply the actual normalisation, the "corba_MPa_w5" is modified the following way: line 20 is disabled and line 19 is enabled (Table 4.15).

Due to this change, the normalisation curve saved in "poly_corba.mat" file now is the one shown at Fig. 4.43.

The result of this normalisation is the curve "2 sec. poly" from the image below:

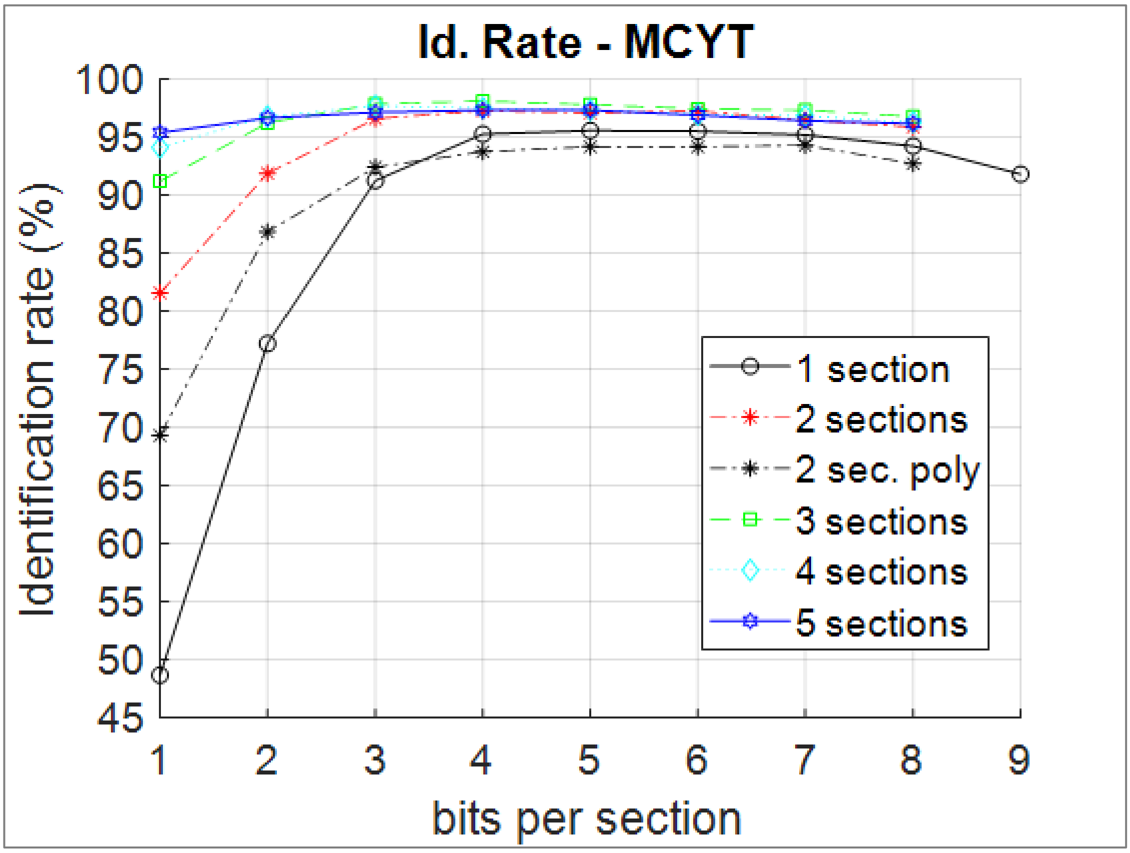


Fig. 4.46 - Result for normalisation to MPa wih "corba_MPa_w5".

d) Magnification

Now, the statement at Table 4.15, line 17, has been replaced with m = 39.75. This factor makes the normalised output maximum equal to the non-normalised maximum pressure value, 1024 (see Fig. 4.47).

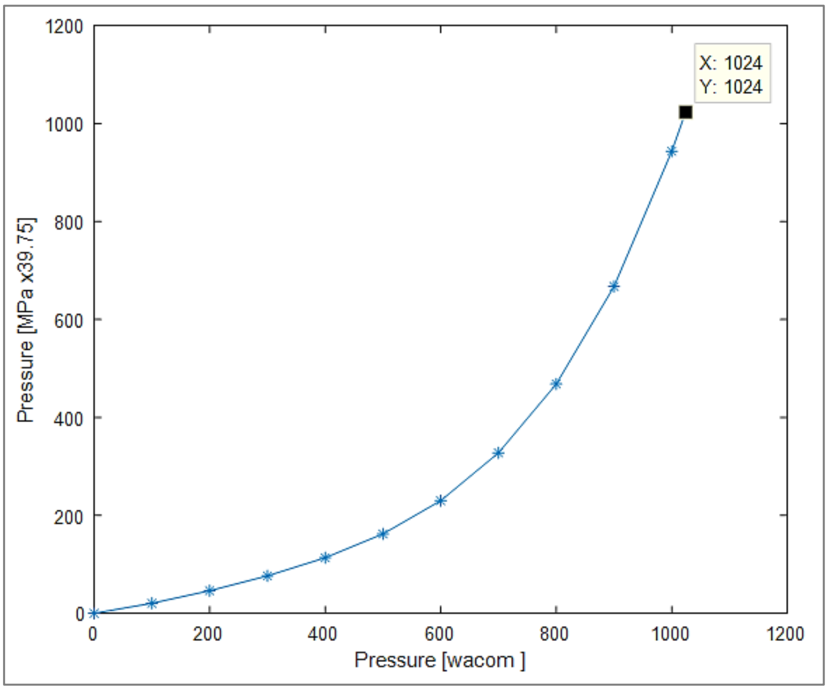


Fig. 4.47 - Polynomial normalisation curve including a 39.75 factor.

The result of this test reaches very high identification rates:

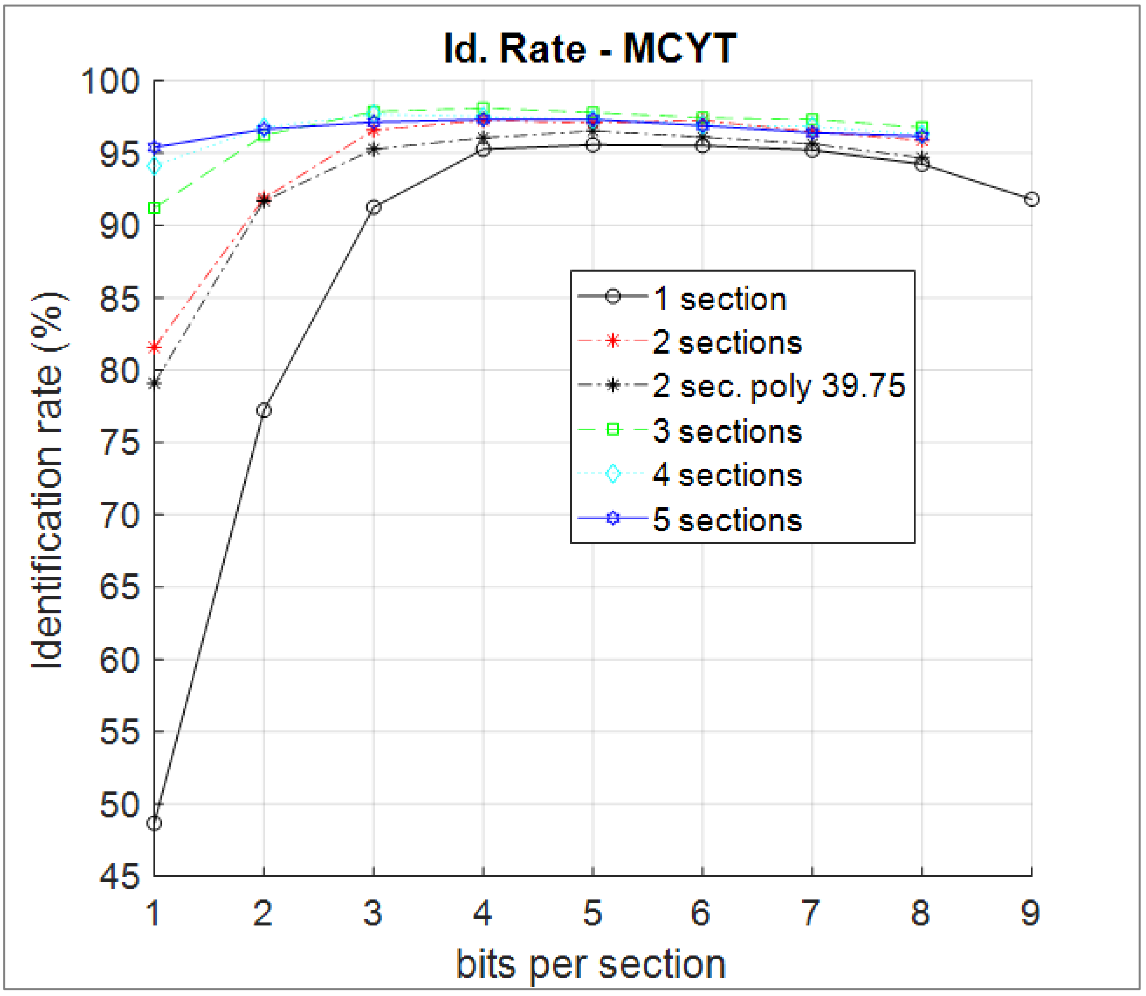


Fig. 4.48 - Result using a 39.75 factor polynomial normalisation.

To make sure that the result is good, the function's operation can be verified by setting some breakpoints at the "leer_firma" function (Fig. 4.49) and executing the following statements:

```
K>> p = temp(3:5:length(temp));
K>> p2 = vectores(:,3); plot(p,p2,'r*'); hold on
K>>  plot([0:100:1000,1024],polyval(fw,[0:100:1000,1024],[],mu),'b.-')
K>> legend('1st sample pressure data', 'normalisation curve "corba MPa
w5" (factor=39.75)')

K>> xlabel('Pressure [Wacom]'); ylabel('Pressure [MPa x 39.75]')
```

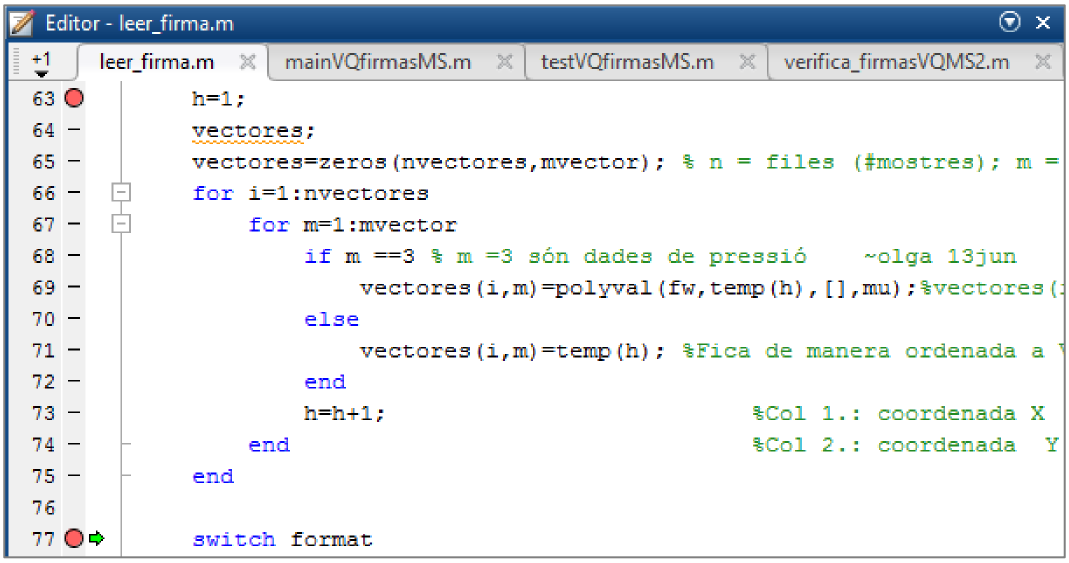


Fig. 4.49 – Breakpoints at "leer_firma" that allow an inspection of its operation.

As it can be seen in Fig. 4.50, the normalisation does work correctly:

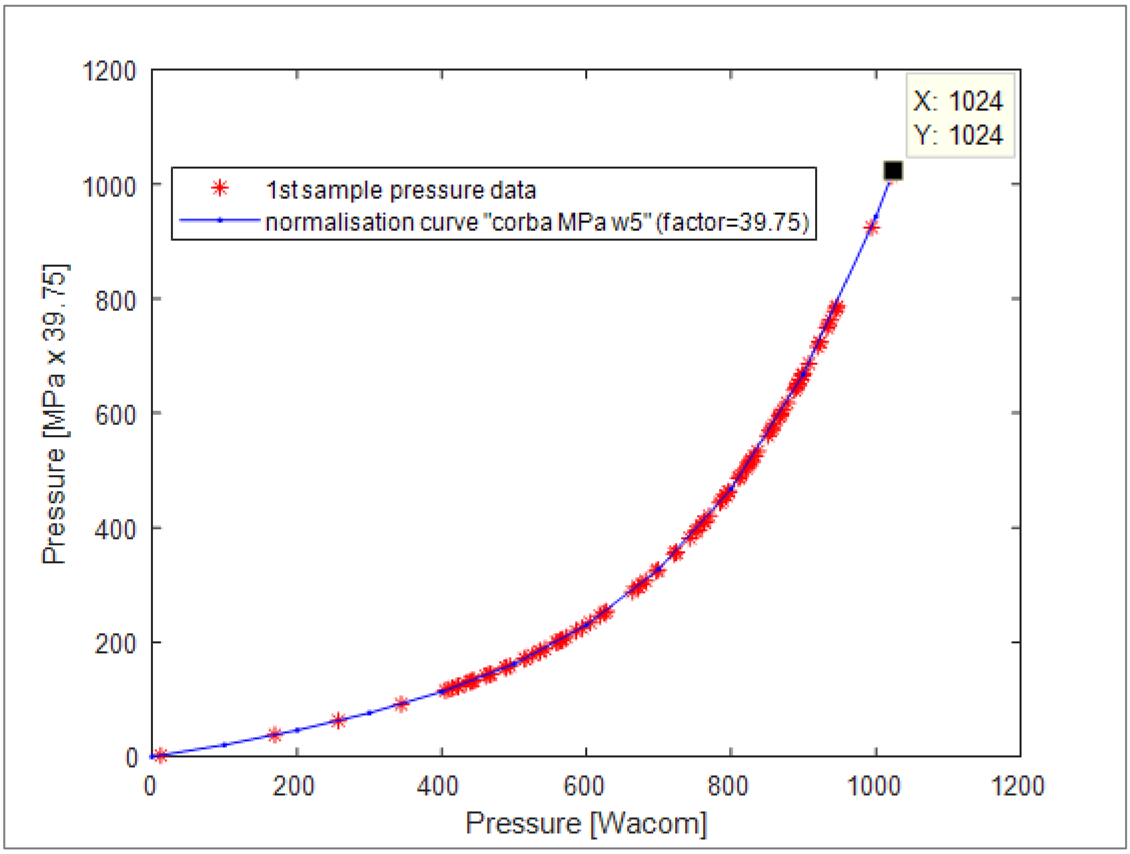


Fig. 4.50 - Verification of the 1st sample normalisation with "corba_MPa_w5" and a 39.75 factor.

4.3.4 Mismatch tests: ink-pen and plastic-pen

While pen position and angle can be recorded equally by different digitising tablets and pens, the pressure data will depend on the sensor that is used. If the pressure is normalised, translating it into standard units, the pressure information acquired by different sensors will be able to be compared.

Even though the influence of the sensor while acquiring biometrics is well known, following this section there is an essay on this subject. Studying a mismatch scenario is important because in real applications the database digitising tablet and the one used to input signatures to identify may not be the same. In such a situation, the recognition algorithm may have troubles to work, but this can be overcome if the database and the inputs are normalised, each one according to its own acquisition device.

When experimenting with other biometrics, such as voice, the samples can be recorded simultaneously with several sensors, which provides equivalent databases for them and the mismatch test can be performed straightforward. In this case, the MCYT database was acquired using an ink-pen[17] tablet. As experimental measurements are available for ink-pen and for plastic-pen, the database can be modified as if it has been acquired by a plastic-pen. Also, an ink-pen normalisation curve can be created so there are different options to make crossed tests.

a) Creating the Ink-pen normalisation curve and applying it.

Starting from "corba_MPa_w5" and using the available experimental data for the ink-pen, the standard pressure is defined as the input and the Wacom's pressure data is set as the output.

```
% Prova amb conversió d'unitats de pressió i amb correcció en la regressió.
% Amb corba de conversió per tinta (INK)
% obrotons@edu.tecnocampus.cat
% Juny 2020
%Funcions Associades: mpa_to_w.m  i  w_to_mpa.m
%Es parteix de corba_MPa_w5()
function corbaINK_w_MPa()
    nom_fitxer = 'poly_corba';
```

[17] The former essays have been performed using the plastic normalisation because there was a misunderstanding.

```
savename=strcat('C:\Users\olga\Documents\MATLAB\prova3003\',nom_fitxer,
'.mat');
    % multiplying factor to increase pressure units range
    m = 1;
    % Experimental measurements (INK)     % mpa=>y; w=>x
    mpa = [2.698 3.679 4.905 6.254 7.382 8.768 9.871 11.098 12.508 13.611
14.899 17.057 18.516 19.865 21.030 22.073 23.532 24.648 27.161 29.430
30.043 31.968 33.047 33.722 35.745 38.259];
    w = [64 161 226 301 361 393 446 485 527 557 576 646 668 682 711 724
760 767 806 857 857 879 910 914 940 957];
    format long
    % polynomial fitting (fw) and correction (mu)
    [fw,~,mu] = polyfit(w,mpa,5); %polyfit(x,y,N); polyfit has size N+1
    X = [0:1024]; %desired w (wacom) range
    % Y = m*[0:mpa(length(mpa))]; %desired mpa range
    % curve's vector y and more corrections correcions
    y = polyval(fw,X,[],mu);
    c1 = y(length(y))/(y(length(y))-y(1)); c2 = y(1); %correccions de
la y
    fw = c1*fw; %this scales the curve according the measurements
    fw(length(fw))=fw(length(fw))-c2; %this offsets the curve to (0,0)
    %fw(length(fw)) is the constant term of the polynomial
    save(savename,'fw','mu')
    y = polyval(fw,X,[],mu);%plot(X,y,'.-')
end
```

Table 4.16 – Function "corbaINK_w_MPa" normalises pressure data in "Wacom" units using the ink-pen experimental measurements.

The function operation is verified as done previously at §4.3.3 d; it works correctly:

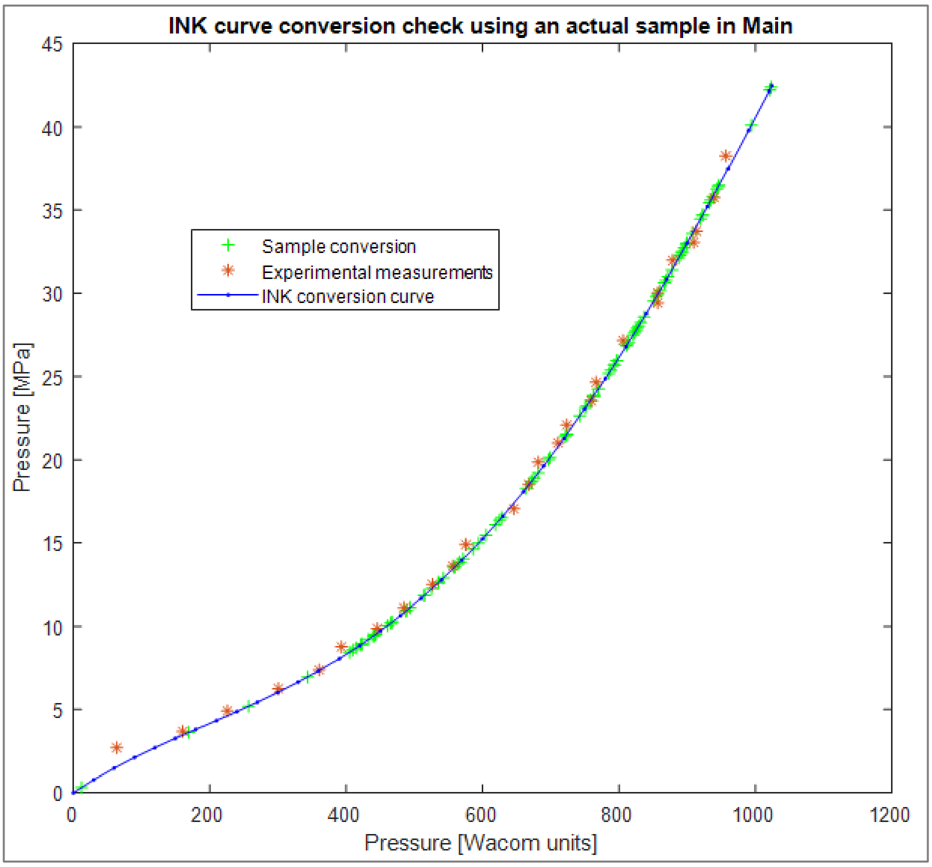


Fig. 4.51 - 1st sample normalisation verification for "corbaINK_w_MPa".

Using this normalisation in both the “Main” and the “Test” phases have the result shown in Fig. 4.52. The performance is similar to the one achieved with the firsts normalisations (“corba_MPa_w” and “corba_MPa_w2”) at §4.3.1.

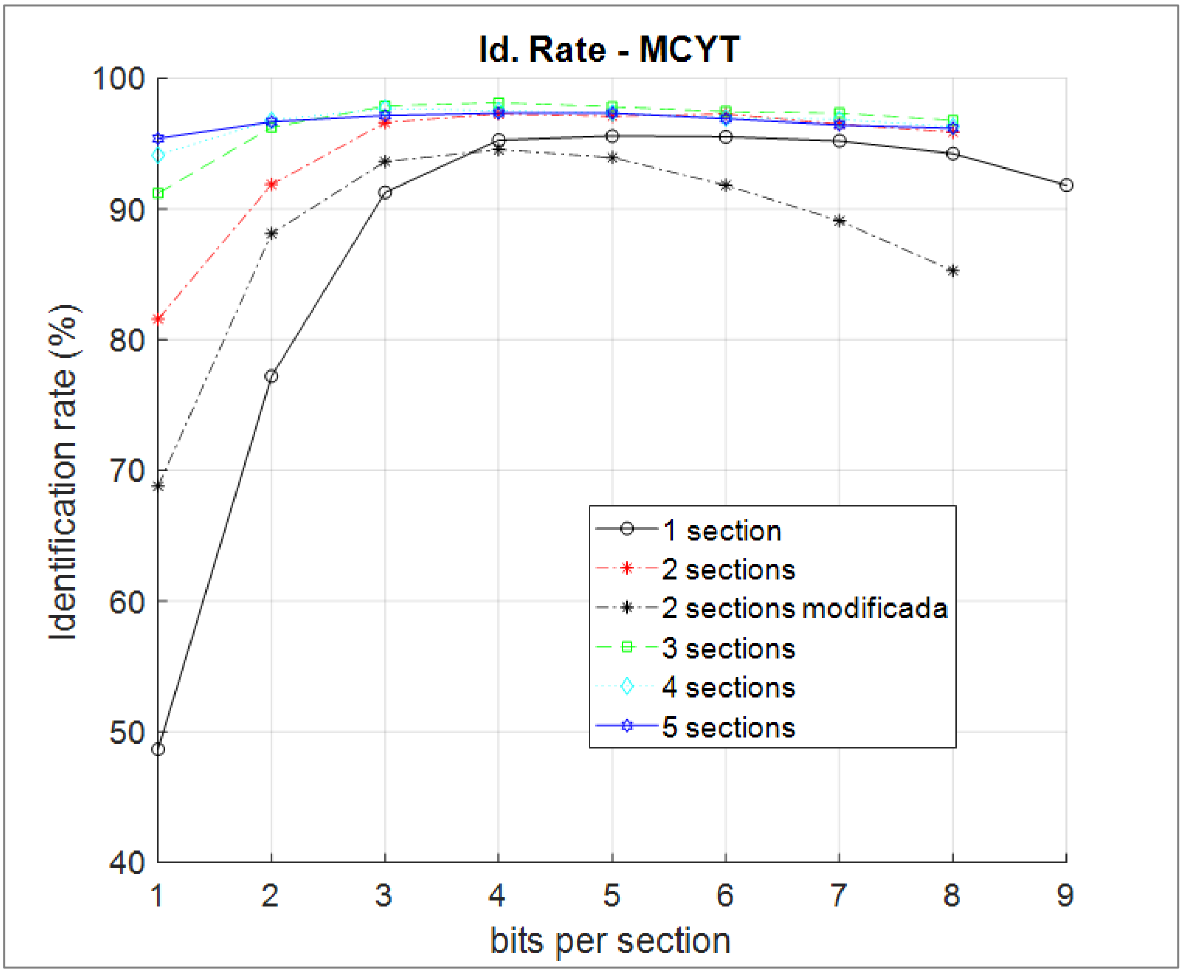


Fig. 4.52 - Result using the ink-pen normalisation.

b) Getting the inverse plastic normalisation.

This curve is needed before carrying out the Mismatch test (see Fig. 4.58), in order to obtain the pressure information from MCYT database as if it had been acquired by a plastic-pen.

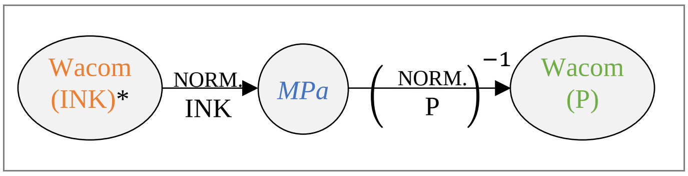


Fig. 4.53 - "Wacom plastic" data adquisition.

As explained in Fig. 4.54, when “Wacom (ink)” unit pressure is normalised into MPa using the ink-pen (dark green path) it can get higher values than the maximum MPa value in plastic-pen curve. So, to go back from MPa to “Wacom(plastic)” data (light green path) the

MPa values exceeding the maximum MPa value in the plastic-pen curve have to be treated separately (see Fig. 4.55).

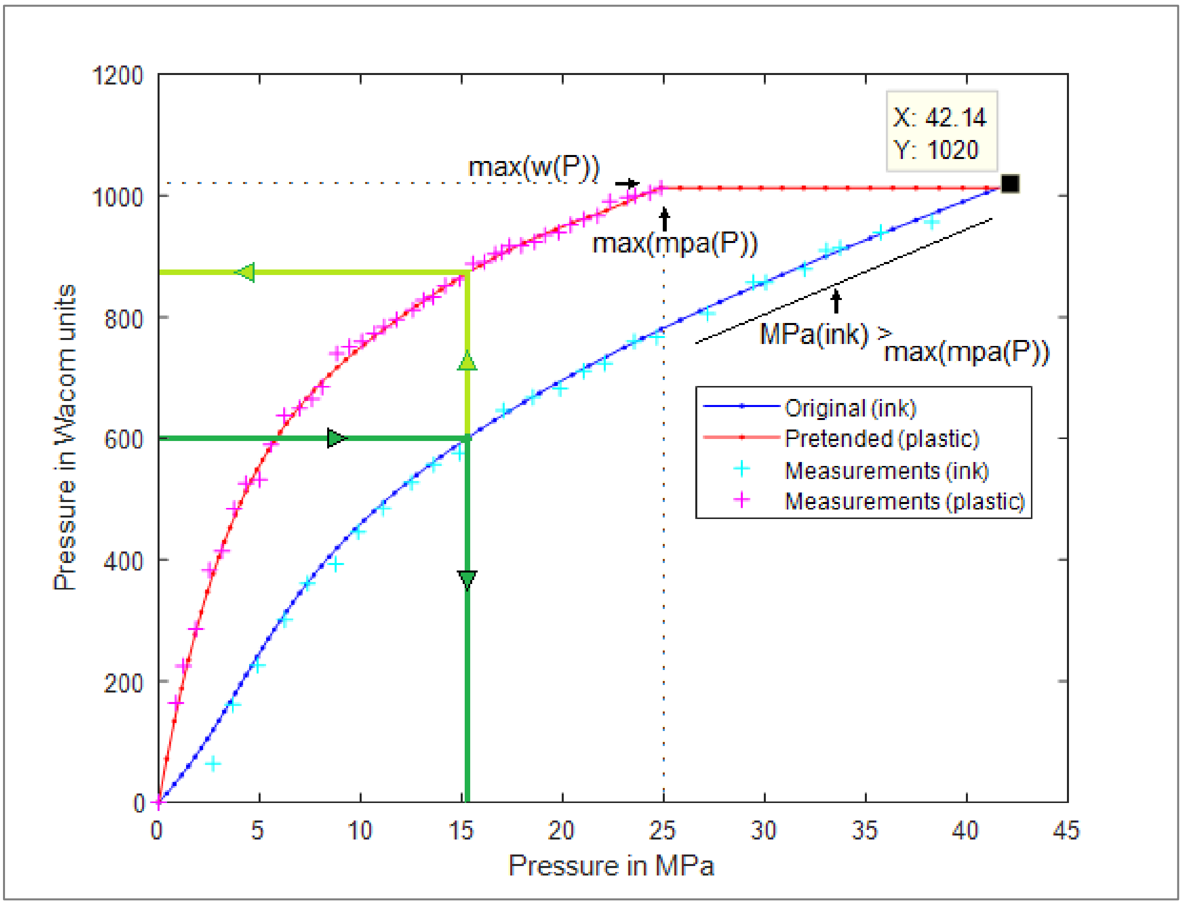
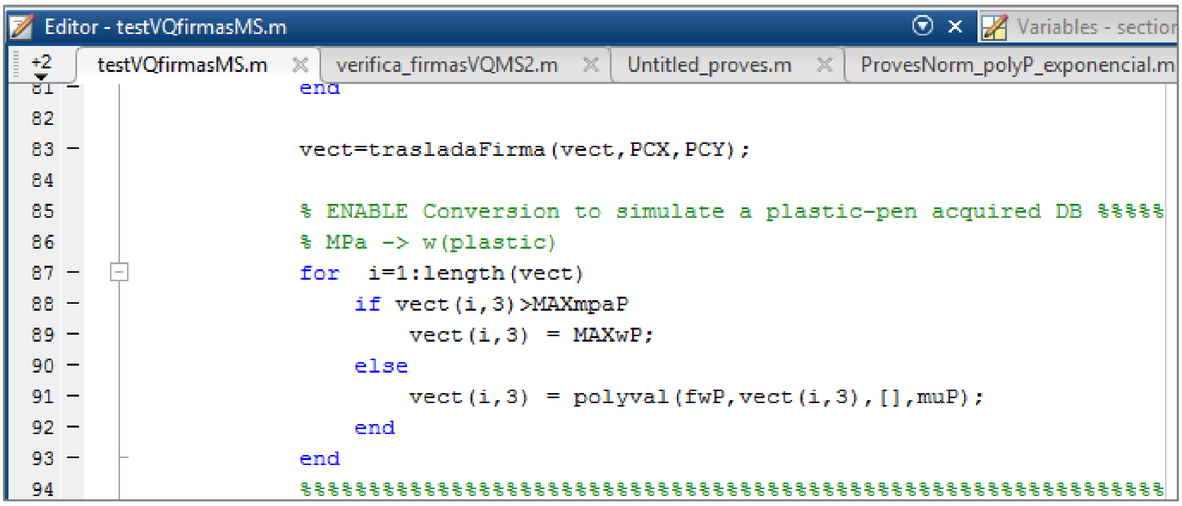


Fig. 4.54 - Differences in MPa range for the ink-pen and the plastic-pen measurements must be treated while applying the Fig. 4.53's process.[18]




```
                end

                vect=trasladaFirma(vect,PCX,PCY);

                % ENABLE Conversion to simulate a plastic-pen acquired DB %%%%%
                % MPa -> w(plastic)
                for  i=1:length(vect)
                    if vect(i,3)>MAXmpaP
                        vect(i,3) = MAXwP;
                    else
                        vect(i,3) = polyval(fwP,vect(i,3),[],muP);
                    end
                end
                %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Fig. 4.55 - Implementation in the "Test" block that will get pressure data in "Wacom(p)".

[18] w(P) or w(plastic) means "Wacom" units corresponding the plastic-pen acquisition; mpa(P) are pressure data normalised using the plastic-pen curve; mpa(ink) are pressure data normalised using the ink-pen curve.

Whether implementing this conversion in “Main” or in “Test”, its operation can be checked as shown in Fig. 4.56. The result of this verification (Fig. 4.57) works as it was planned at the beginning of this section *b*.

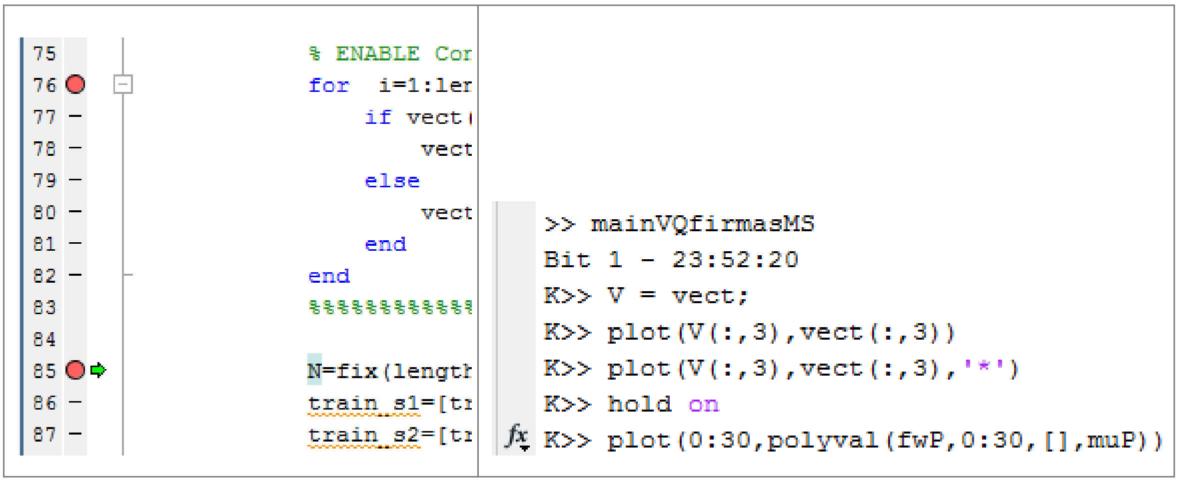


Fig. 4.56 - Checking the MPa-to-Wacom(plastic) conversion.

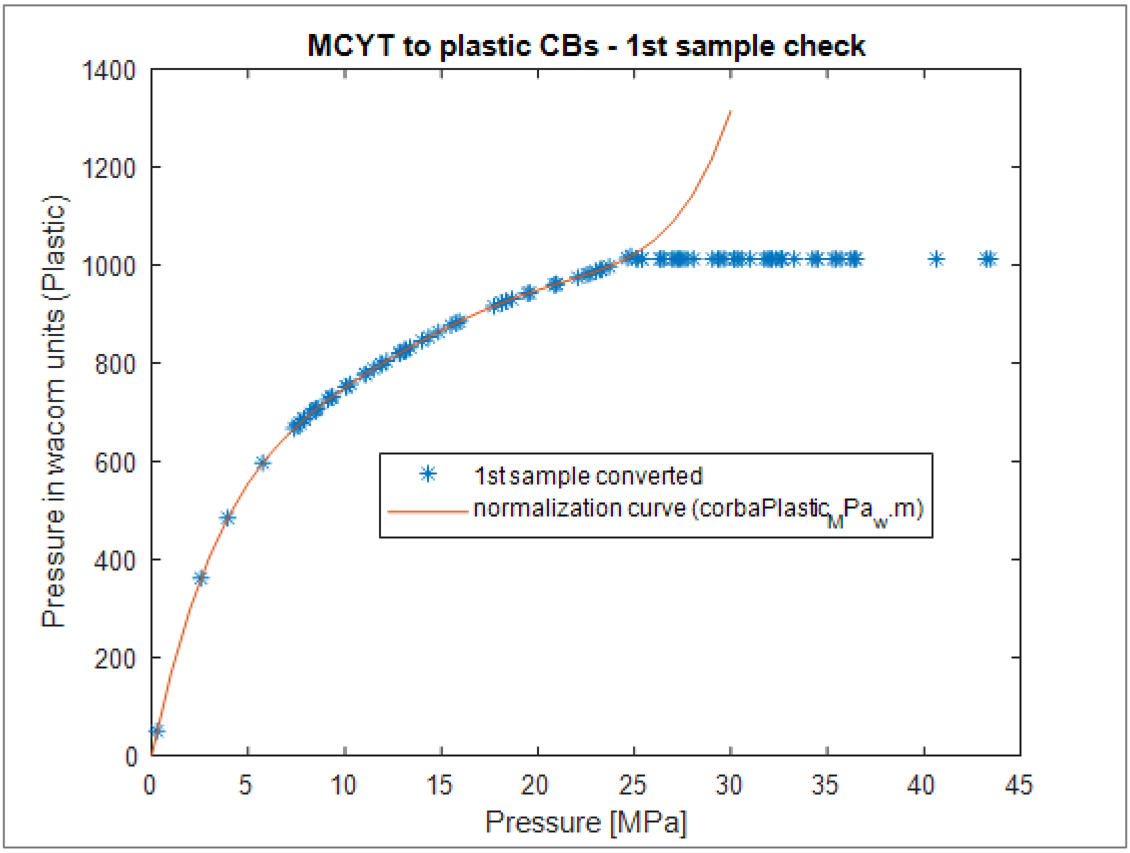


Fig. 4.57 – Result of MPa-to-Wacom(plastic) conversion verification.

c) Mismatch test.

To perform a Mismatch test, the “Main” phase will use original data (w(ink)) and the “Test” will use pressure data in “Wacom” units as if it had been acquired using a plastic pen (w(plastic)). In other words, the “Main” does not need any normalisation, and the “Test” has to be normalised with the ink-pen curve (“corbaINK_w_MPa”: (w(ink)->MPa)) and the MPa-to-w(plastic) conversion has to be applied as well. Lastly, the “Verifica” has to be loaded with the file created at “Test”: “`mat_dista_VQMS_INK_Plastic`”.

Note, though, that there is no need to process the “Main” step because the results in such conditions are already processed (file “`modelos_firmas_CBMS2`”).

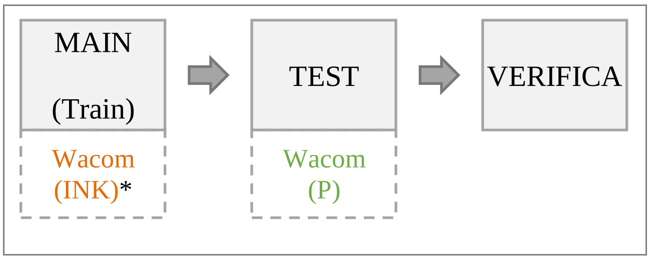


Fig. 4.58 - Procedure to perform the Mismatch test.

The result of this test has a very low identification rate, which makes sense given the nature of the test.

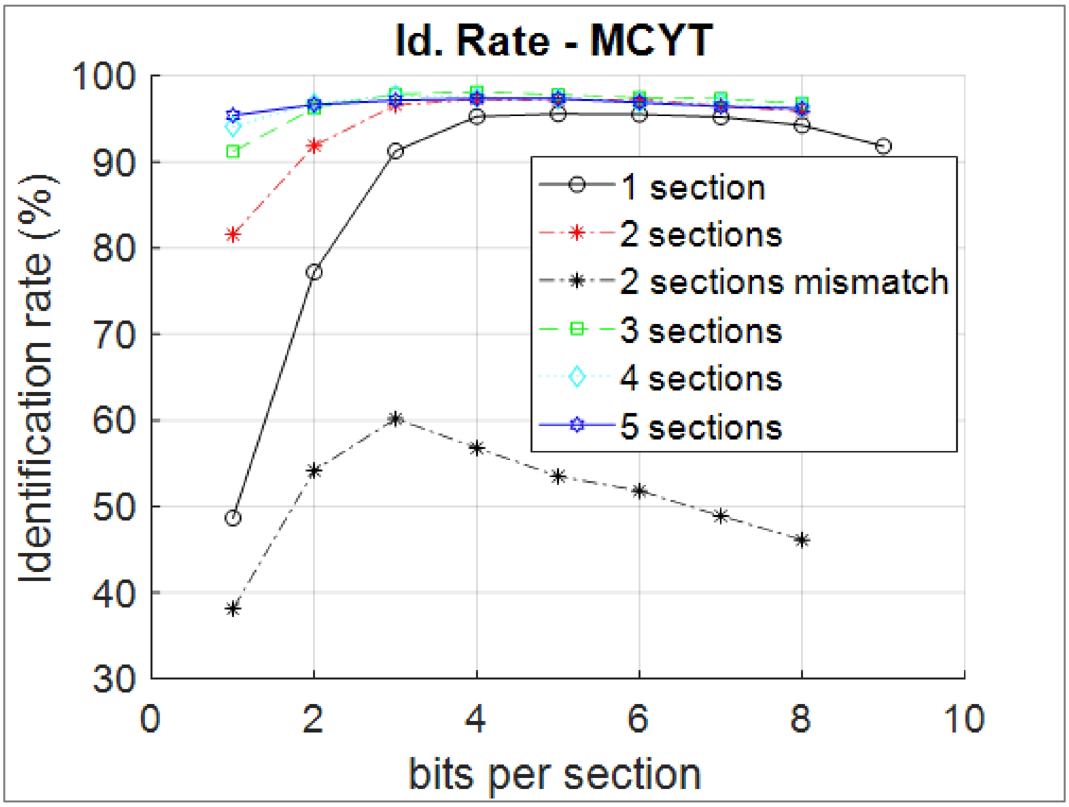


Fig. 4.59 - Mismatch test result.

d) Normalised mismatch test.

Now, starting from the mismatch situation, applying the correct normalisation in each phase should improve the algorithm performance because it will allow to compare all the pressure data in the same units (MPa).

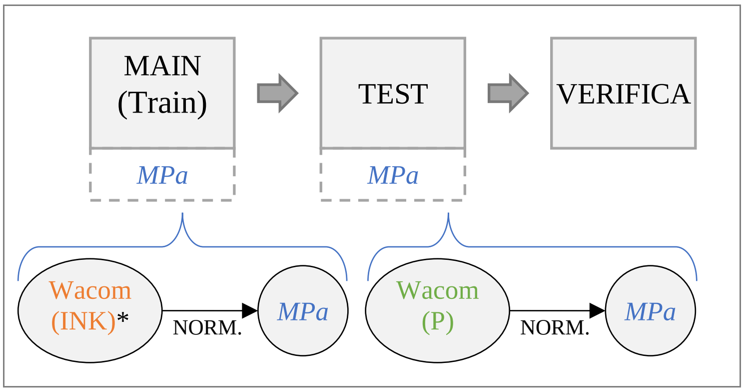


Fig. 4.60 - The normalisation will convert the pressure data into standard units.

On the one hand, the "Main" has to use the ink-pen normalisation:

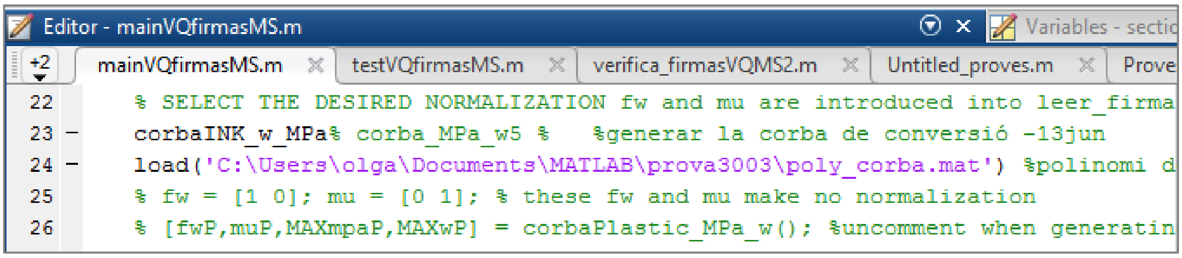


Fig. 4.61 - Configuration to run the "Main" function.

On the other hand, the "Test" has to maintain the previous conversions (w(ink) to MPa and MPa to w(plastic)) and also it has to apply the normalisation with plastic-pen curve:

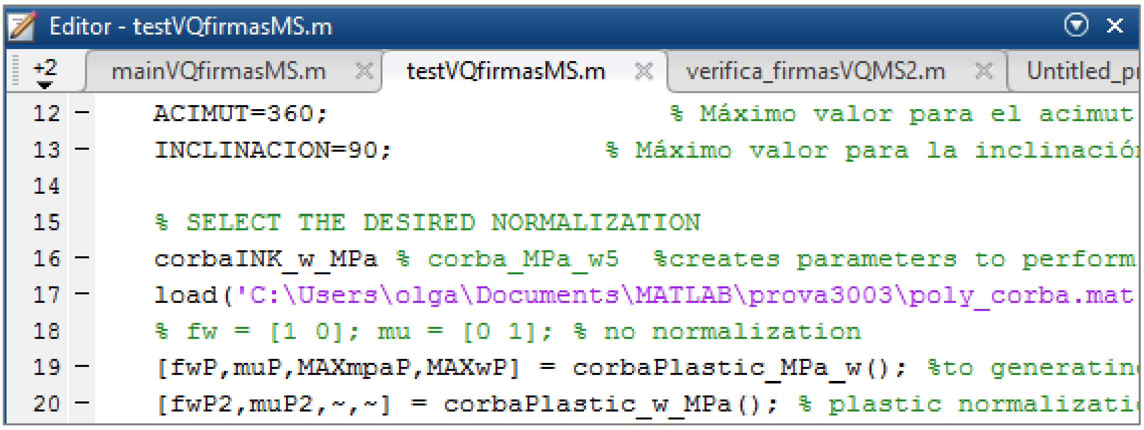


Fig. 4.62 – Configuration to run the "Test" function (1/2).

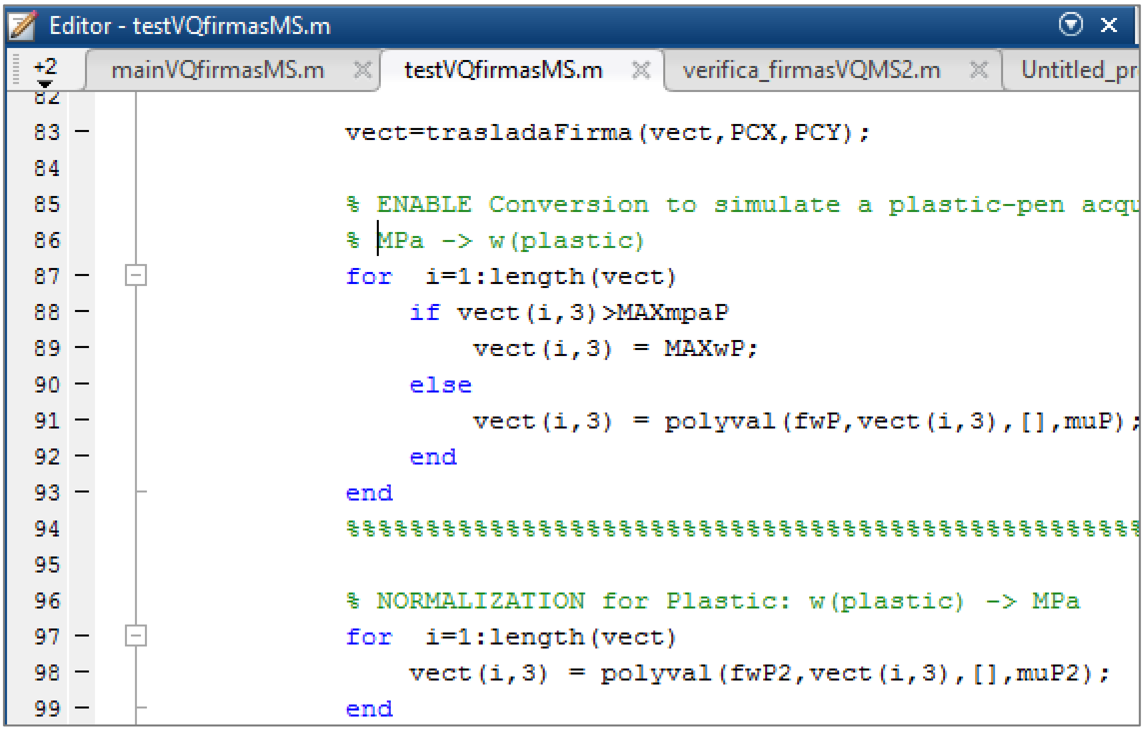


Fig. 4.63 – Configuration to run the "Test" function (2/2).

The performance is better than in the previous test, but it did not improve very much.

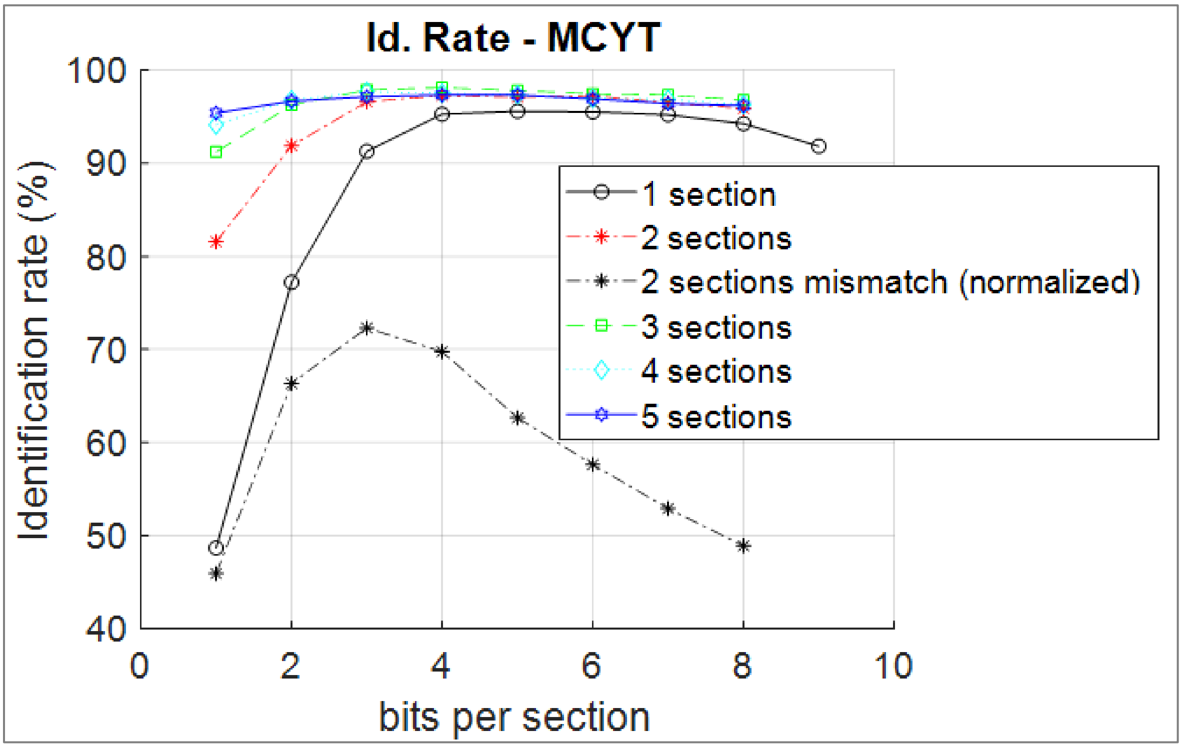


Fig. 4.64 - Result of the Mismatch scenario including the normalisation.

e) Original test check.

As a verification to make sure that no undesired change has been implemented, the original test (with "Wacom" ink, no normalisations) is going to be performed. To do so, the statement showed in Fig. 4.62, line 25 has to be enabled and the rest have to be disabled: this "fw" and "mu" parameters make no conversion when they are introduced into the "polyval" at "leer_firma". This has to be done both in the "Main" and the "Test" function.

As it happened in the other verifications there is a slight variation. The functions are considered to be correct.

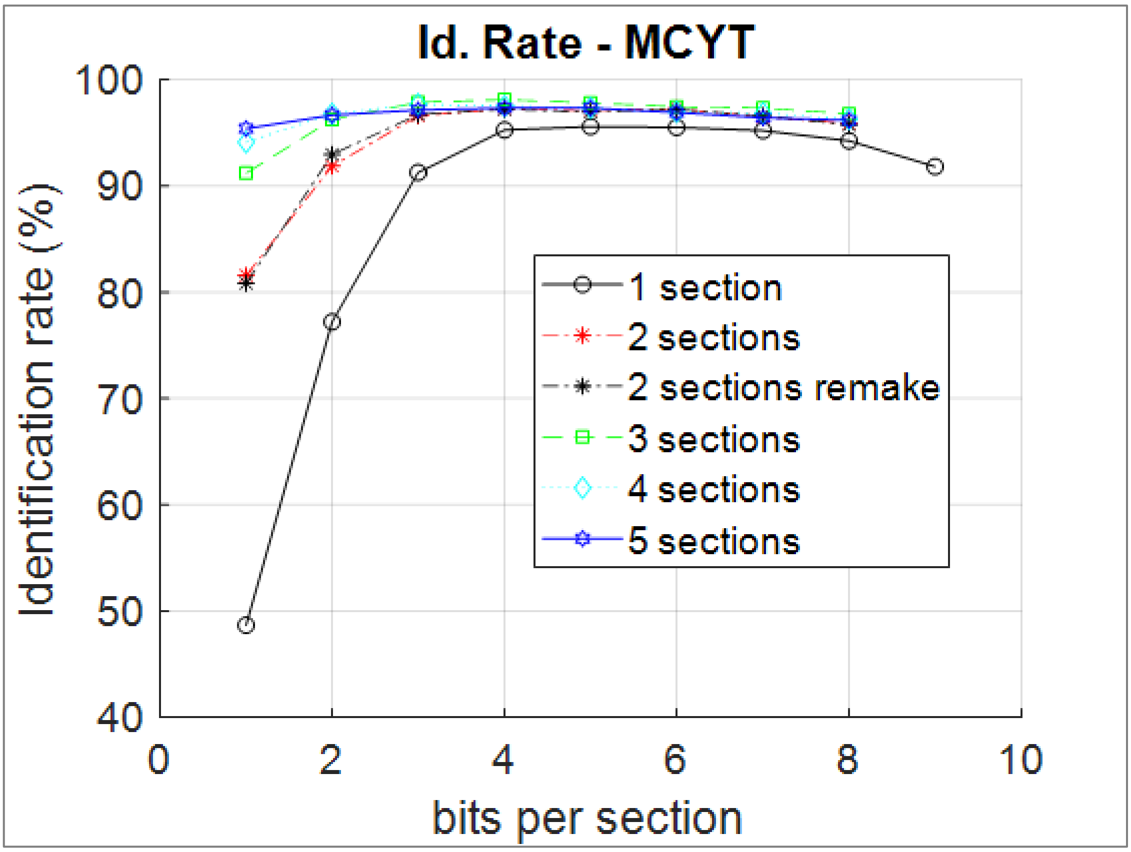


Fig. 4.65 – Remake of the original test using the last version of the algorithms.

4.3.5 Using a synthetic exponential curve

The polynomial fitting previously used is monotonically increasing within the digitising tablet's working range. Howbeit, outside from it, it has a different behaviour (see Fig. 4.57). In addition, it has a quite large number of parameters (for grade 5, it has 6 parameters, plus the correction for the deviation "mu").

An alternative way to create the normalisation curve could be using an exponential curve: its shape matches the experimental one, and besides, the number of parameters would be lower. Working with this kind of curve could be easier and effective.

a) Mathematical basis

Making an analogy from a capacitor change curve, the "time" would be the normalised pressure (in MPa) and the charge (Q) would be the tablet's pressure data (in "Wacom" units); in order to match the shape of the curves obtained experimentally, the abscissa must be the pressure in MPa and the ordinate, the pressure in "Wacom" units. The maximum charge has to be now the maximum "Wacom" value. If at 4τ the pressure has to be maximum, then τ equals the maximum pressure in MPa divided per 4. Putting it all together:

$$w = f(p) = w_{max} \cdot \left(1 - e^{-p/\tau}\right) \quad (1)$$

$$\tau = p_{max}/4 \quad (2)$$

Where: w: pressure in "Wacom" units; p: pressure in MPa; w_{max}: maximum "Wacom" value; p_{max}: maximum MPa value

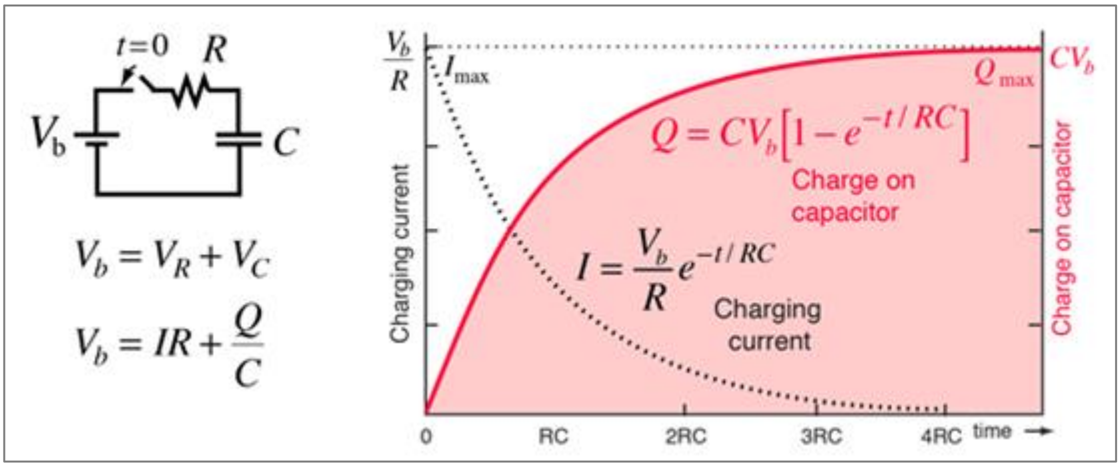


Fig. 4.66 - Capacitor charge curve, an exponential function. [48]

The inverse function can be found:

$$(1) \rightarrow e^{-\frac{p}{\tau}} = 1 - \frac{w}{w_{max}} \rightarrow -\frac{p}{\tau} = ln\left(1 - \frac{w}{w_{max}}\right) \rightarrow$$

$$p = f(w) = -\tau \cdot ln\left(1 - \frac{w}{w_{max}}\right) \qquad (3)$$

b) Curve design

Using the information deduced in the prior lines, the synthetic curve can be designed as it is shown at the next table:

```
clf
maxW = 1024; maxP = 40;
pas = 0.05;
tw = 0:pas:maxP;
tp = 0:pas:maxW;
tau=maxP/4;

figure(1)
subplot(211)
plot(tw,maxW*(1-exp(-tw/tau)),'.b') %w-->X
xlabel('Pressure [MPa]'); ylabel('Pressure [w]'); title('MPa to Wacom')
grid on
axis([0, maxP, 0 , maxW])
subplot(212)
plot(tp,-tau*log(1-tp/maxW),'.b')
grid on
xlabel('Pressure [w]'); ylabel('Pressure [MPa]'); title('Wacom to MPa')
axis([0, maxW, 0 , maxP])

figure(2)
clf;
% plot(t,V*(1-exp(-t/tau)),'b')%w-->X norm
% hold on
% plot(t,-tau*log(1-t/V),'k')%X-->w denorm
y1=maxW*(1-exp(-tw/tau)); %norm
t_recover=-tau*log(1-y1/maxW); %denorm
plot(tw,t_recover,'.r')
grid on
xlabel('Pressure [MPa]'); ylabel('Pressure [MPa] (recovered)'); title('MPa to MPa (Normalization for Data Recovering)')
axis([0, maxP, 0 , maxP])
```

Table 4.17 -Exponential and logarithmic synthetic curve design and plotting.

The plot made at Table 4.17 results in Fig. 4.67 and Fig. 4.68; they match the desired design and also both functions invert perfectly.

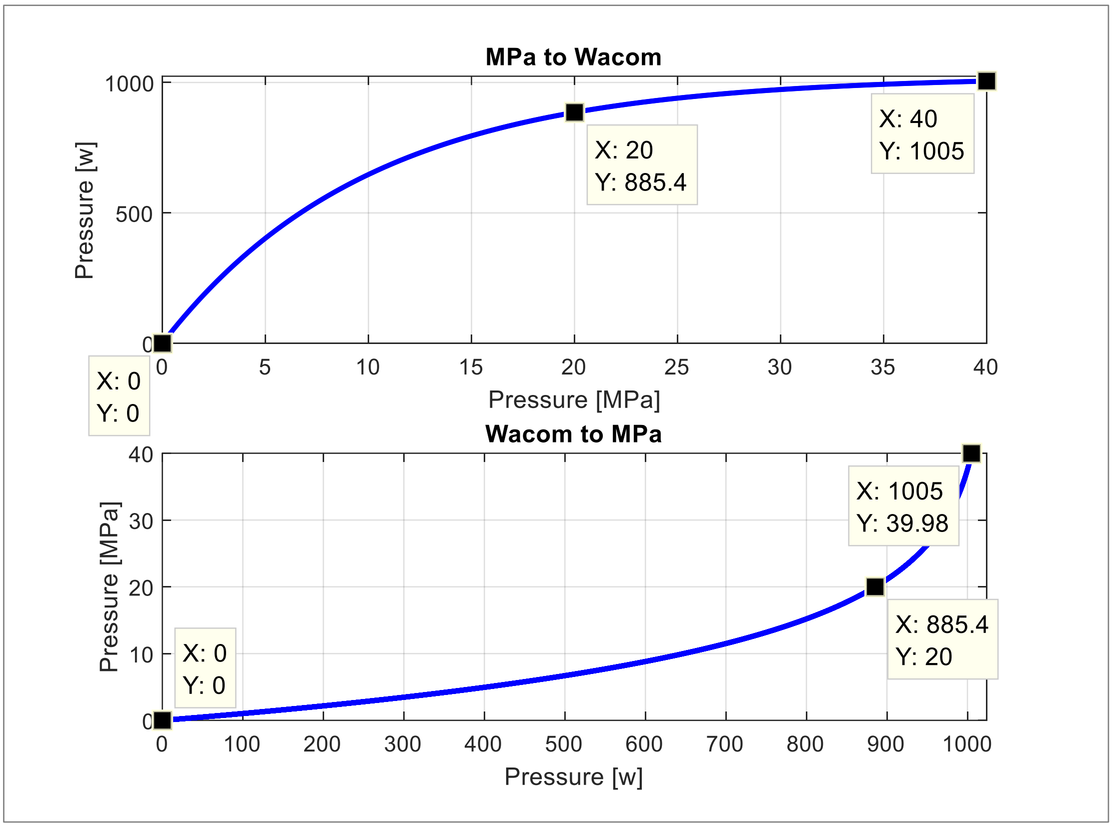


Fig. 4.67 - Figure (1) generated using the code from Table 4.17.

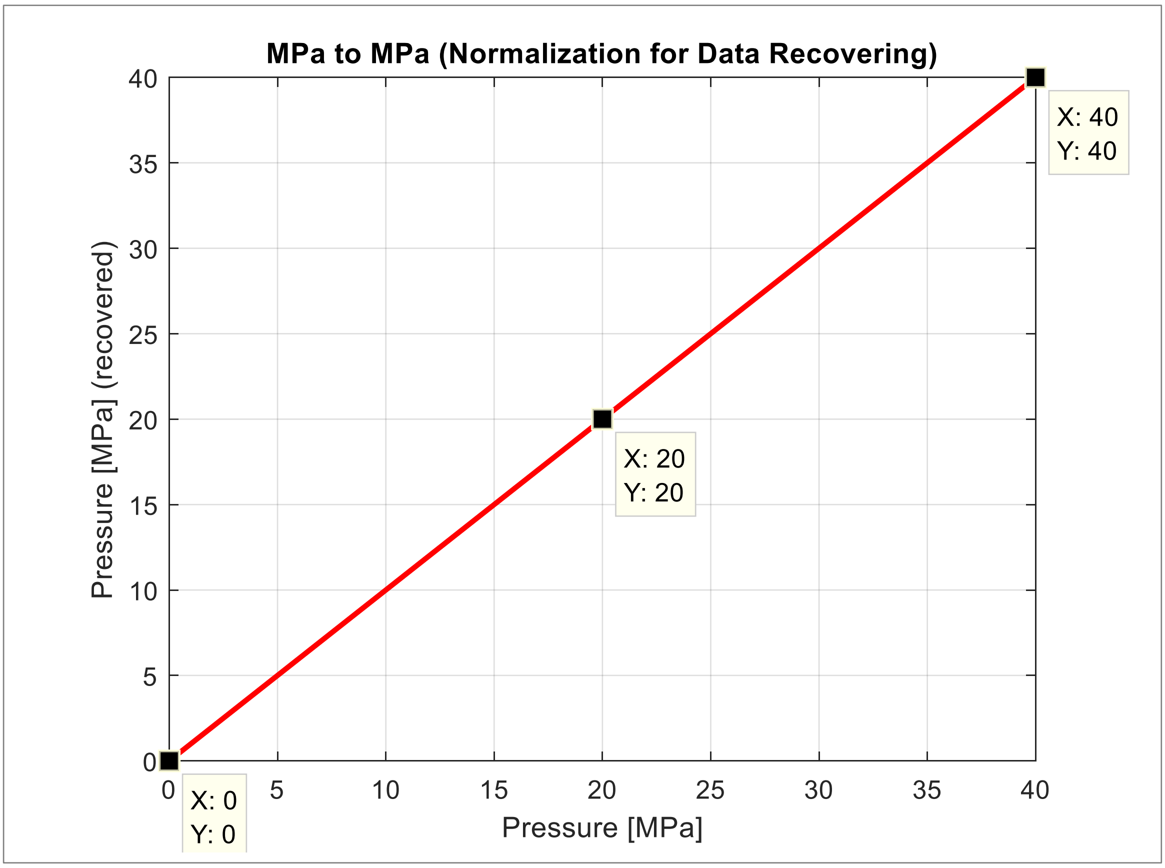


Fig. 4.68 - Figure (2) generated using the code from Table 4.17.

c) Example point representation test.

```
%% implementació exponencial-log (sense fitting)
clf
maxW = 1024;     maxP = 40;          tau=maxP/4;
pas = 0.05;      tw = 0:pas:maxP;    tp = 0:pas:maxW;

figure(1)
subplot(211)
plot(tw,maxW*(1-exp(-tw/tau)),'.b')
hold on
plot([0,20,maxP],maxW*(1-exp(-[0,20,maxP]/tau)),'*r')
xlabel('Pressure [MPa]'); ylabel('Pressure [w]'); title('MPa to Wacom')
grid on
axis([0, maxP, 0 , maxW])
hold off

subplot(212)
plot(tp,-tau*log(1-tp/maxW),'.b')
hold on
plot([0,500,maxW],-tau*log(1-[0,500,maxW]/maxW),'*r')
grid on
xlabel('Pressure [w]'); ylabel('Pressure [MPa]'); title('Wacom to MPa')
axis([0, 1100, 0 , 100])
```

Table 4.18 - Plot test using the designed synthetic exponential curve.

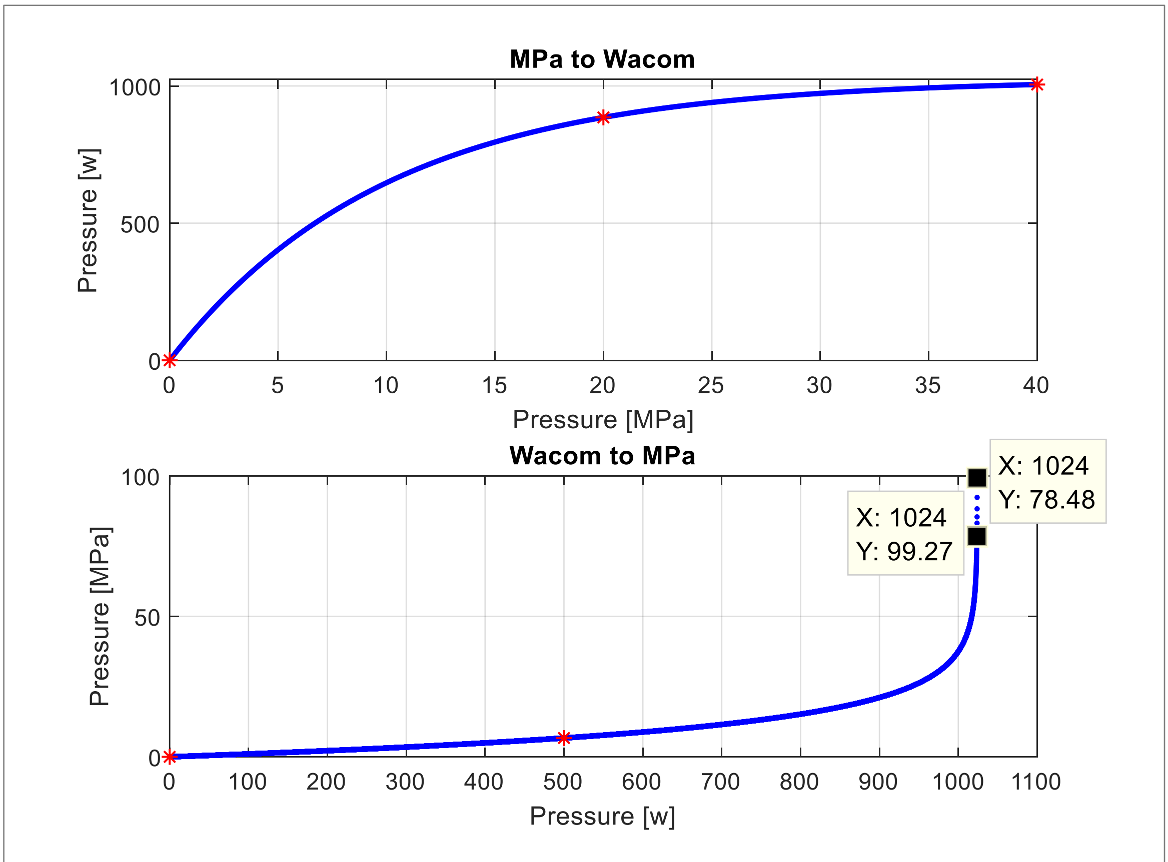


Fig. 4.69 - Some plot test using the synthetic exponential and logarithmic expressions, over the previously designed curves. From Table 4.18 code.

d) Curve appraising

The MPa-to-Wacom curve is monotonically increasing and its shape resembles the experimental one (see Annexe I). However, if a comparison with the available experimental measurements is performed (Table 4.19), the curve's values do not match any of the experimental curves (see Fig. 4.70).

```
%% comparacio exponencial amb mesures experimentals
clf
maxW = 1024; maxP = 40;
pas = 0.05;
tw = 0:pas:maxP;
tp = 0:pas:maxW;
tau=maxP/4;

figure(1)
plot(tw,maxW*(1-exp(-tw/tau)),'.b') %w-->X
xlabel('Pressure [MPa]'); ylabel('Pressure [w]'); title('MPa to Wacom')
grid on
axis([0, maxP, 0 , maxW])
hold on
%plastic
mpaP = [0.864 1.234 1.851 2.511 3.147 3.733 4.325 4.998 5.553 6.232 6.972 7.589 8.082 8.823 9.440 10.057 10.674 11.167 11.784 12.586 13.111 13.574 14.191 14.900 15.548 16.128 16.658 16.985 17.362 17.954 18.602 19.126 19.805 20.391 21.039 21.718 22.335 23.211 23.569 24.309 24.864];
wP = [164 225 286 383 414 484 526 532 590 638 650 665 685 740 751 760 773 784 796 812 828 833 852 863 888 891 904 907 917 918 924 935 940 952 961 967 991 997 1000 1005 1013];
plot(mpaP,wP,'.r')
%ink
mpaI = [2.698 3.679 4.905 6.254 7.382 8.768 9.871 11.098 12.508 13.611 14.899 17.057 18.516 19.865 21.030 22.073 23.532 24.648 27.161 29.430 30.043 31.968 33.047 33.722 35.745 38.259];
wI = [64 161 226 301 361 393 446 485 527 557 576 646 668 682 711 724 760 767 806 857 857 879 910 914 940 957];
plot(mpaI,wI,'.g')
hold off
legend('Synthetic exponential curve','Experimental mesurements (Plastic)','Experimental mesurements (Ink)')
```

Table 4.19 - Comparing the experimental measurements and the synthetic exponential curve.

Despite this, as the curve is quite centred between both data sets (see Fig. 4.70), it will give a try. The result of applying this logarithmic normalisation is quite good: see Fig. 4.71.

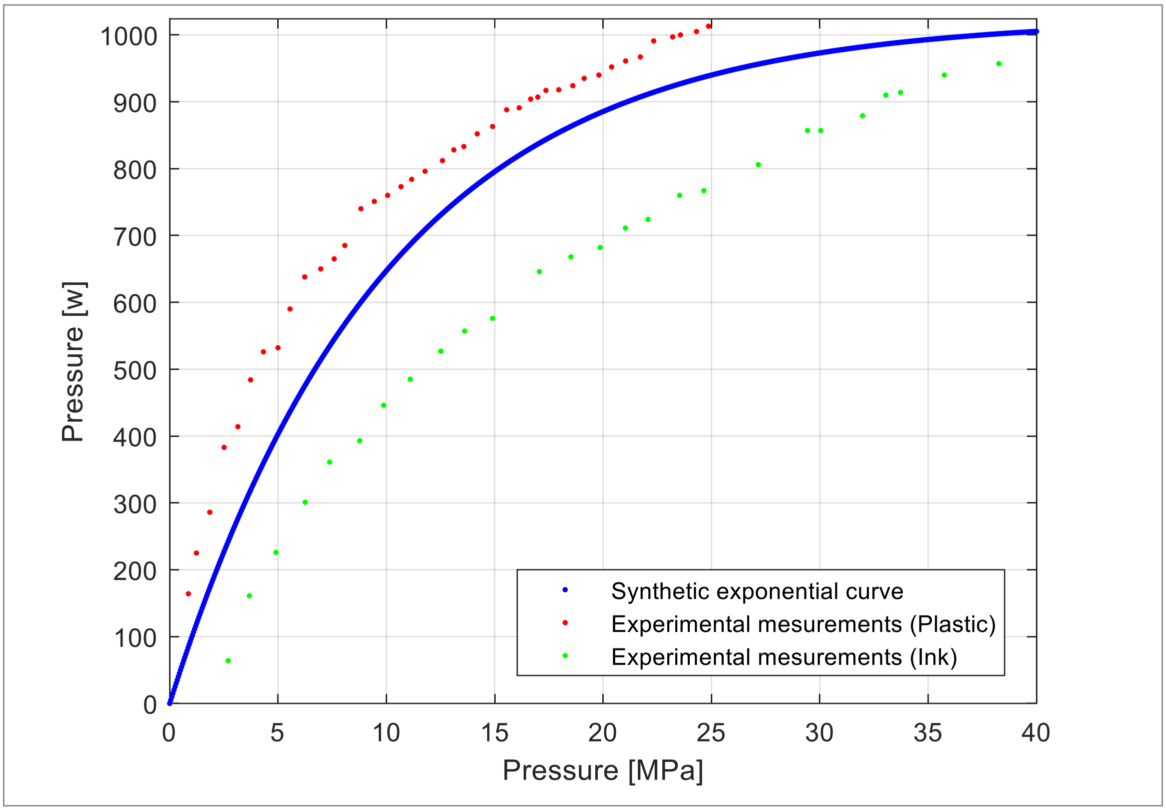


Fig. 4.70 - Plot showing the synthetic exponential curve and the experimental data. From Table 4.19's code.

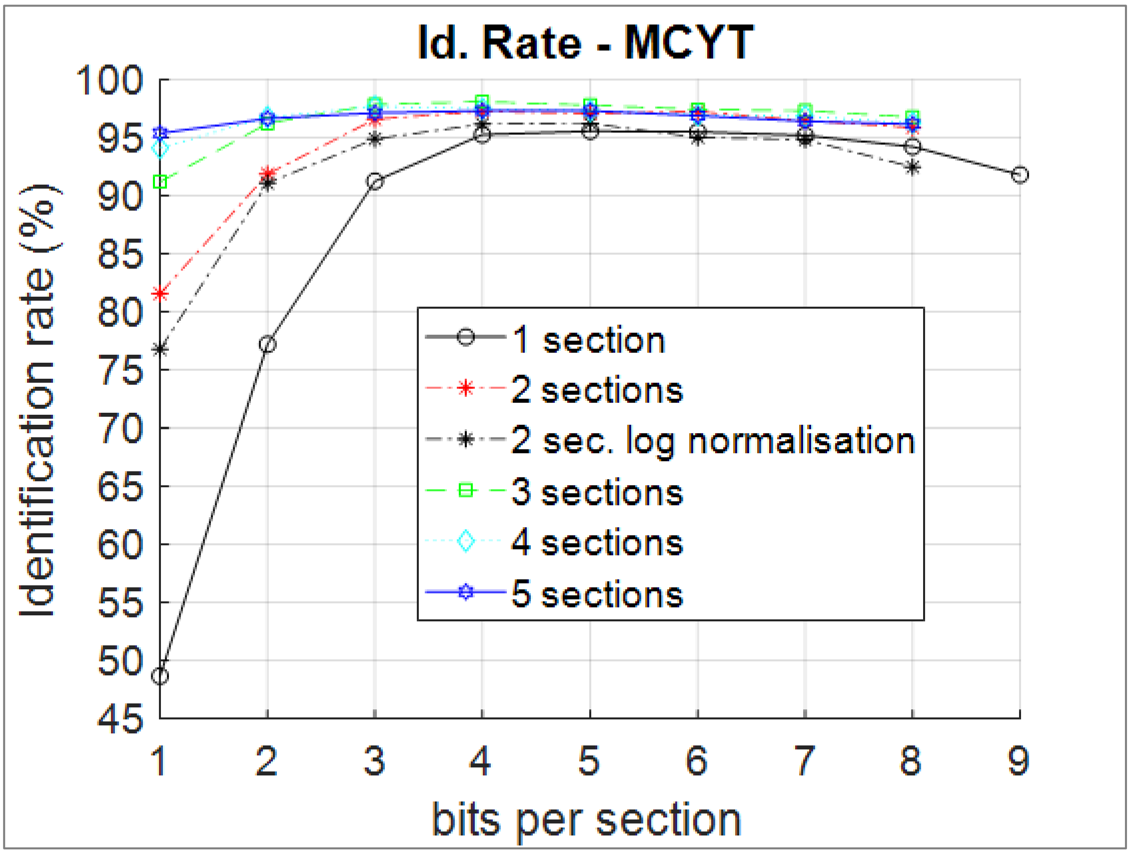


Fig. 4.71 - Result of using the logarithmic normalisation

4.3.6 Technical specs fulfilment for Activity 2 (2.1 & 2.2).

The part of the solution corresponding the Activity 2.1 is especially designed for the writing material (TSR-ii) and it could be adapted to other material. It features the use of mock-up material so the adjustments and launching pose no risk to the material (TSR-iii). Once the whole assembly is set, carrying out the experiments to get new data should be straightforward (TSR-iv). In addition, as the moving solution consists of a robot, closed-loop with a sensor, experiments with repeatability can be conducted (TSR-vi). Lastly, using a collaborative robot would make the project attractive (TSR-vii).

On the other hand, with respect to Activity 2.2, the quality of the results has been assured in each experiment, making several verifications (TSR-v); the procedures and changes have been documented so they can be repeated or modified freely (TSR-vi); they use the same algorithms and data that the original publication did, so the results are able to be compared with the original ones (TSR-i & ii). This part of the solution cannot damage the material.

Regarding the gender perspective (TSR-viii), the machines and equipment used during the development of this project (see §3) are “neutral” regarding gender perspective. The digitising material is generic for men and women as well; it is also the same for right and lefthanders.

4.4 Activity 3

Hereunder, Table 4.20 contains the results of the tests performed at §4.3.

Test	Bits per section							
	1	2	3	4	5	6	7	8
Original	81.5758	91.8788	96.6061	*97.2727*	97.0909	*97.2727*	96.4848	95.8788
	0.2001	0.1029	0.0570	0.0379	0.0320	0.0299	0.0304	0.0308
4.3.2 c	80.9091	92.9697	96.6667	*97.1515*	97.0303	96.9697	96.8485	95.6970
	0.1980	0.1027	0.0552	0.0381	0.0331	0.0295	0.0294	0.0304
4.3.3 b	81.7576	92.4848	96.9091	97.0303	*97.2727*	96.9697	96.4242	95.5758
	0.1984	0.1026	0.0550	0.0380	0.0334	0.0295	0.0292	0.0309
4.3.3 c	69,3333	86,8485	92,4242	93,7576	94,1818	94,1818	*94,3030*	92,7273
	0,2462	0,1667	0,1105	0,07971	0,06406	0,05557	0,05338	0,05384
4.3.3 **d**	79,0909	91,6970	95,2727	96,0606	*96,5455*	96,1212	95,6364	94,6667
	0,2280	0,1420	0,09357	0,07082	0,05627	0,04811	0,04397	0,04445
4.3.4 a	68,4242	88,4848	93,9394	*94,3636*	93,8788	92,1818	88,7879	85,1515
	0,2507	0,1532	0,09996	0,08353	0,07652	0,0730	0,07348	0,07581
4.3.4 c	38,1212	54,1818	*60,1818*	56,7879	53,5152	51,8182	48,9091	46,1212
	0,2149	0,1437	0,1118	0,1065	0,1125	0,1126	0,1159	0,1155
4.3.4 d	45,9394	66,3636	72,3030	*69,7576*	62,6667	57,6364	52,9091	48,9091
	0,2270	0,1416	0,1014	0,0909	0,0925	0,09613	0,1022	0,1051
4.3.4 e	80,8485	92,9697	96,7273	*97,2121*	96,9697	*97,2121*	96,6061	95,7576
	0,1982	0,09923	0,05501	0,03865	0,03173	0,03052	0,02893	0,03071
4.3.5 d	76,7879	91,0909	94,9091	96,1818	96,2424	95,0303	94,8485	92,4848
	0,2224	0,1272	0,08127	0,06486	0,05374	0,04809	0,04503	0,04745

Test	Reference - description
Original	No normalisation - `CBMS2.mat`
4.3.2 c	Non normalising curve on look-up table (plastic). [19] "corba_MPa_w4"
4.3.3 b	Non normalising polynomic curve (plastic). [20] "corba_MPa_w5" - `CBMS2poly_verif1x1.mat`
4.3.3 c	Polynomial curve normalisation to MPa (plastic) - "corba_MPa_w5" - `CBMS2poly.mat`
4.3.3 d	Polynomial curve normalisation to MPa - "corba_MPa_w5" – 39.75 factor - `CBMS2poly39_75.mat`
4.3.4 a	Polynomial normalisation for ink-pen – "corbaINK_w_MPa" – `CBMS2poly_INK5.mat`
4.3.4 c	Mismatch test (Wacom(ink) – Wacom(plastic)) - `CBMS2mismatch.mat`
4.3.4 d	Mismatch normalised - `CBMS2mismNORM.mat`
4.3.4 e	Remake of the original computation ("Wacom" ink) using the new algorithms
4.3.5 d	Normalisation with logarithmic curve - `CBMS2loglog2.mat`

Table 4.20 - Activity 2.2 results summary. Blue rows: identification rate (%); White rows: DCF.

[19] At files referred as: "Conversió sense conversió amb taula (mod)"
[20] At files referred as: "Poly verificació 1x1" or "nova corba amb correcció"

From Table 4.20, it can be seen that, in general, when a normalisation is applied, the identification rate decreases and the DCF increases. The identification rate is affected even when a linear normalisation (such as the verification ones) is applied, and some “noise” is detected (see the “Remake” curve at Fig. 4.73)

Another remarkable fact is that even though the database corresponds to ink-pen data, the results using the plastic-pen normalisation were comparably good. The worse performance of the ink-curve could be due the fact that the experimental measurements only got to 957 pressure levels. The quality of the experimental data could affect the normalisation performance.

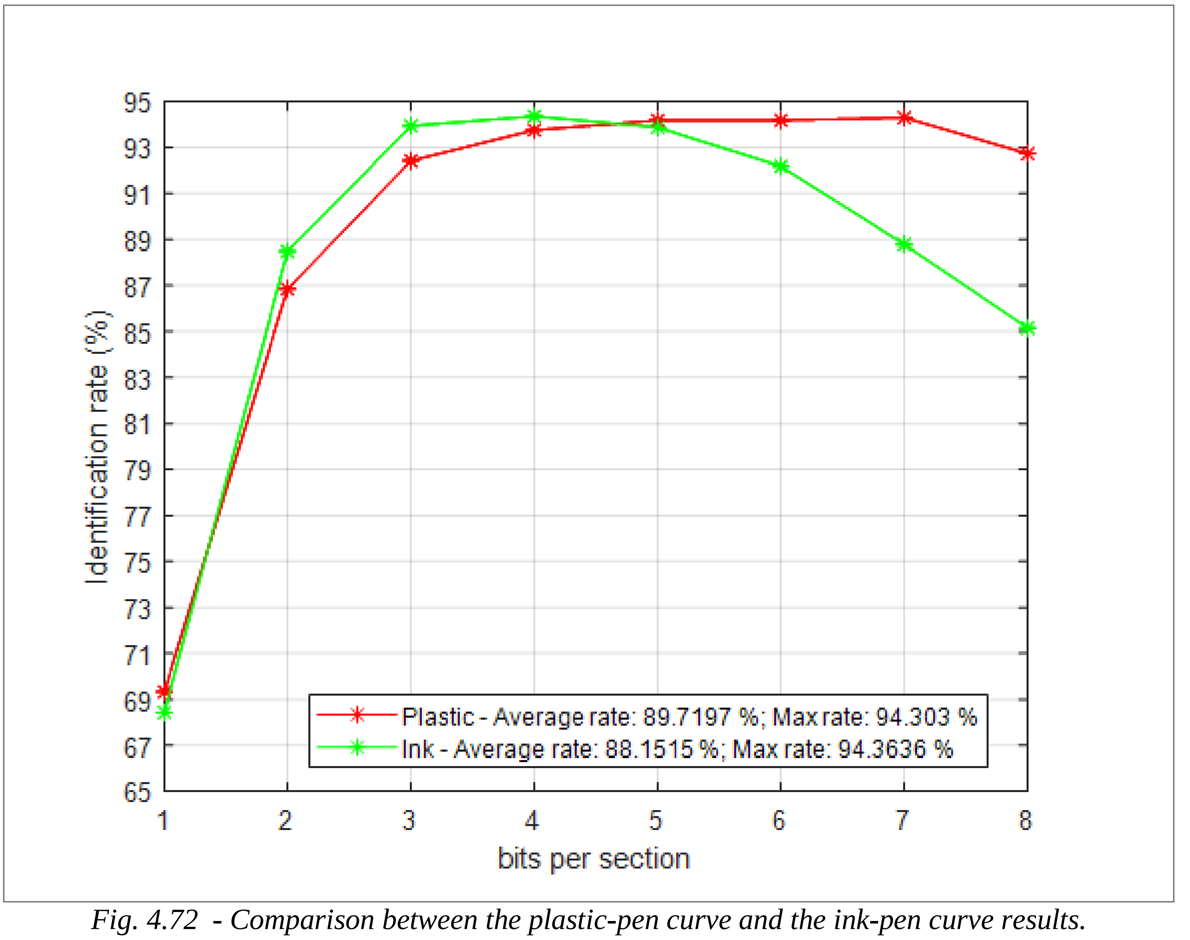


Fig. 4.72 - Comparison between the plastic-pen curve and the ink-pen curve results.

Furthermore, the normalisations applied by polynomial curves that were calculated got better results than the normalisations using look-up table. Given there are not known computation restrictions, the polynomic normalisation would be preferred.

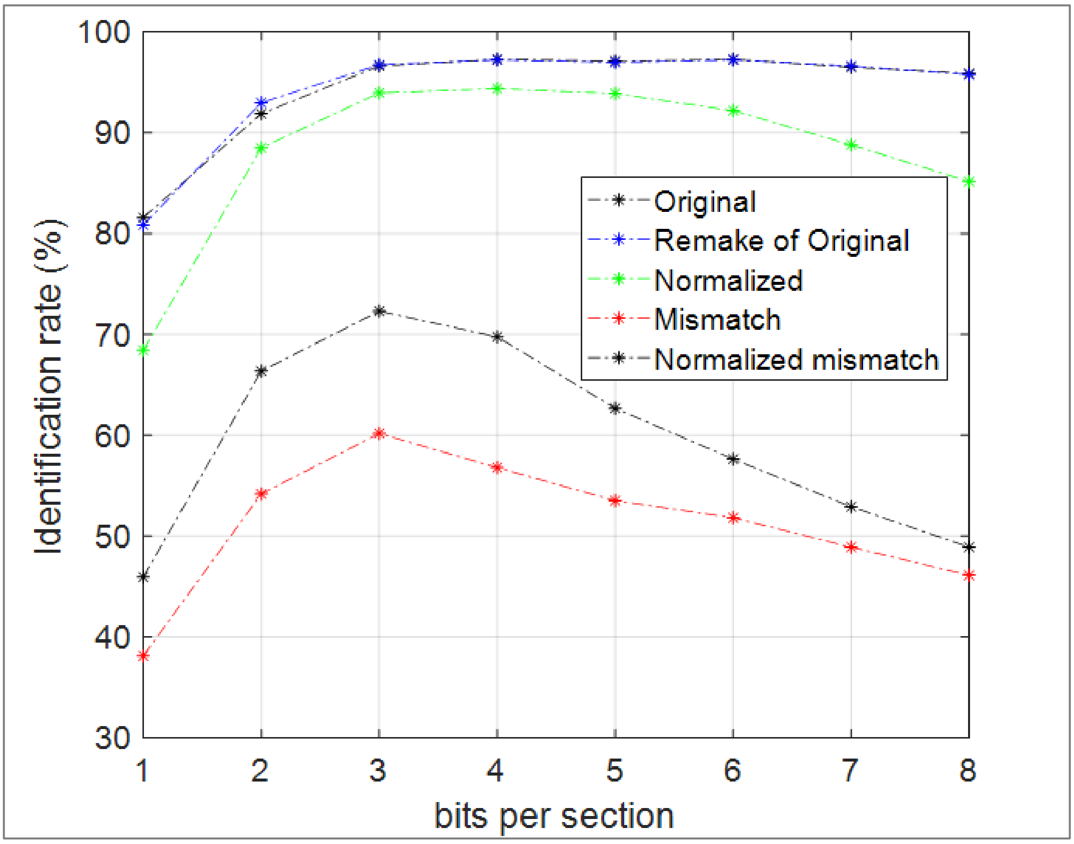


Fig. 4.73 – Plot that compares the results obtained along §4.3.4.

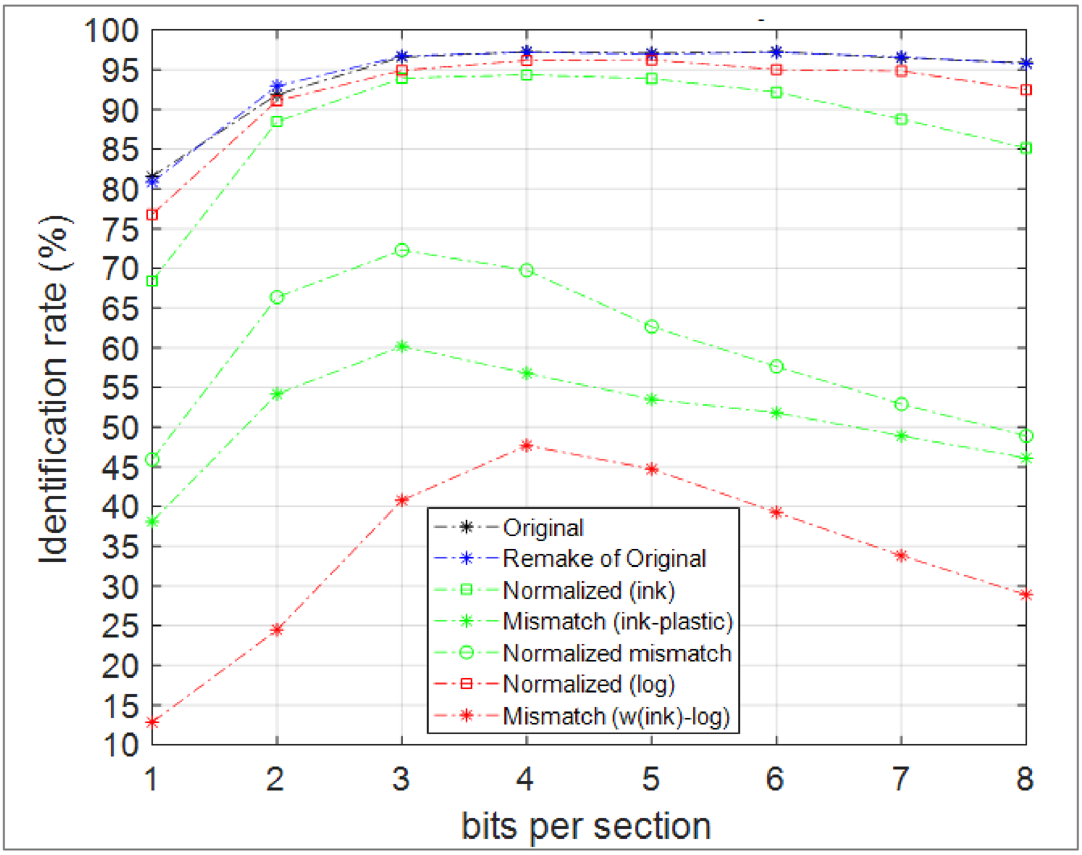


Fig. 4.74 - Comparation of the mismatch test and the logarithmic normalisation, among others.

Moreover, the mismatch test show that a real mismatch situation would ruin the algorithm performance if no measures are taken. However, even though the normalisation of the mismatched case does improve, the result is not good enough to be used. See comparisons in Fig. 4.73 and Fig. 4.74.

To finish, in tests from §4.3.2-b and §4.3.3-d, it is observed that magnifying the normalisation with a determined factor affects the algorism performance in a great manner. Selecting a factor that keeps the normalisation in the original range (0-1024) is by far the best normalisation: Fig. 4.48; Table 4.20, row “4.3.3 d”. Also, the normalisation using the logarithmic curve performs almost as good as this one, moreover, it is perfectly invertible and needs less parameters.

5 Feasibility analysis

5.1 Environmental Feasibility

This is a research project, an intellectual exercise that involves computing with regular computers, the use of several mechanical lab machines (robots mainly), the use of digitising writing material and the making of some tools to adapt the pens and tablets to the robots. Most of this material is available at the university. This implies the use of household electricity.

The development of this project will not disturb the people around: it will not produce noise pollution, it will not produce particles, radiations nor wastes that could pollute neighbour air, ground or ecosystems. The knowledge resulting in this research can benefit research groups from the university or abroad.

5.2 Technical Feasibility

In a research project, the technical feasibility is not 100% because, when working with problems that were never solved before, a lot of complications, delays and unexpected issues can occur. However, the content of this preliminary report and the context where the project is developed lays a solid foundation for its success.

5.3 Economic Feasibility

This project is not intended to provide an economic profit because it will not produce products nor services to be sold. The investment will be the following (see details at the annexed document “Economic analysis”).

Final Budget		
Total from Chapter I	10560,00	€
Total from Chapter II	0	€
Total from Chapter III	933,33	€
TOTAL	11493,33	€
IVA 21%	2413,60	€
TOTAL BUDGET	**13906,93**	**€**

Table 5.1 - Final budget.

Even though there were no cost materials (the practical part could not be developed), the pricing of such material referenced at the Technical solution’s section (§2.1), where they have been selected. This information can be used when this part is put in practice.

6 Scheduling

Before the scheduling development, an analysis of available time has been done. This project is planned to be realised in 400 hours[21] of work: they have been allocated as shown below.

1 Project		Days		Hours/day		Hours		
		Type 1	Type 2	Type 1	Type 2	Type 1	Type 2	Total
1r Trim. 2020	January	18	6	2,5	3	45	18	63
	February	20	9	2,5	3	50	27	77
	March	10	4	2,5	3	25	12	37
2n Trim. 2020	April	20	8	4	3,5	80	28	108
	May	20	10	4	3,5	80	35	115
Total Preliminar Report hours			14-feb -20		88,5			
Total hours 1st Trim.			31-mar-20		177			
Total Mid project Report hours			24-apr-20		270			
Total Final Projecte hours			10-jun-20		400			

Table 6.1 - Work time arrangement

Now, the detailed tasks are described:

1. Definition of the project: its aim, intention, purpose, object and scope.
2. Beginning of information and background research. This will set an important part of the project's theoretical basis.
3. Definition of the technical solution to conduct the project. Technical specs.
4. Scheduling of the project.
5. Beginning of the Activity 1 (defined at §4.1).
6. Beginning of the Activity 2 (defined at §4.2).
7. Writing and editing the document for the preliminary report.
8. Upgrade of information and background research to fulfil information needs. Inclusion of Activity 1's
9. Detailing of the technical solutions; modifications, if needed.

[21] The TFG consists of 16 ECTS. As each ECTS equals the employment of 25 hours: 16 ECTS*25 h/ECTS = 400 h

10. Continuation and finishing of Activity 1: complete functionality of software, functions and databases.
11. Adjustment of the project schedule to correct deviations. Justification of those deviations.
12. Continuation of Activity 2: realisation of first tests.
13. Beginning of Activity 3 (described at §0): analysis of the results of the first tests realised in Activity 2.
14. Writing and editing of the document for the mid project report: inclusion of new information, progresses and results achieved until that point.
15. Upgrade of the Background section with new information collected.
16. Adjusting of the scheduling and deviation analysis.
17. Finishing of the Activity 2: realisation of last tests.
18. Finishing of result analysis (Activity 3). Draw of conclusions and findings.
19. Writing and editing of the final report document.

Note that even there are specific task for the document edition

#	Task name	Duration	Start	Finishing	Prec.	Resource
1	Project definition	10 h	08/01/20	11/01/20		OBR
2	Info. & Background research	36 h	11/01/20	25/01/20	1	OBR
3	Technical solution definition	6 h	25/01/20	27/01/20	2	OBR
4	Scheduling	3 h	27/01/20	28/01/20	3	OBR
5	Activity 1	16 h	28/01/20	03/02/20	4	OBR
6	Activity 2	4,5 h	03/02/20	05/02/20	5	OBR
7	Writing & Editing - Preliminary report	18 h	05/02/20	12/02/20	6	OBR
8	Info. & Background research - upgrade	12 h	12/02/20	15/02/20	7	OBR
9	Technical solution definition - detailing	14 h	15/02/20	19/02/20	8	OBR
10	Activity 1 - continuation	64 h	19/02/20	31/03/20	9	OBR
11	Project scheduling - adjusting	4 h	31/03/20	01/04/20	10	OBR
12	Activity 2 - continuations	58,5 h	02/04/20	23/04/20	11	OBR
13	Activity 3	7 h	23/04/20	25/04/20	12	OBR
14	Writing & Editing - Mid project report	18 h	25/04/20	30/04/20	13	OBR
15	Info. & Background research - 2nd upgrade	12 h	30/04/20	03/05/20	14	OBR
16	Project scheduling - final adjusting	3 h	03/05/20	04/05/20	15	OBR
17	Activity 2 - finishing	27 h	04/05/20	11/05/20	16	OBR
18	Activity 3 - finishing	63 h	11/05/20	27/05/20	17	OBR
19	Writing & Editing - Final report	24 h	27/05/20	01/06/20	18	OBR

Table 6.2 - Summary of scheduled tasks.

Those tasks are arranged in a Gantt diagram that serves as a schedule control tool. See pages bellow.

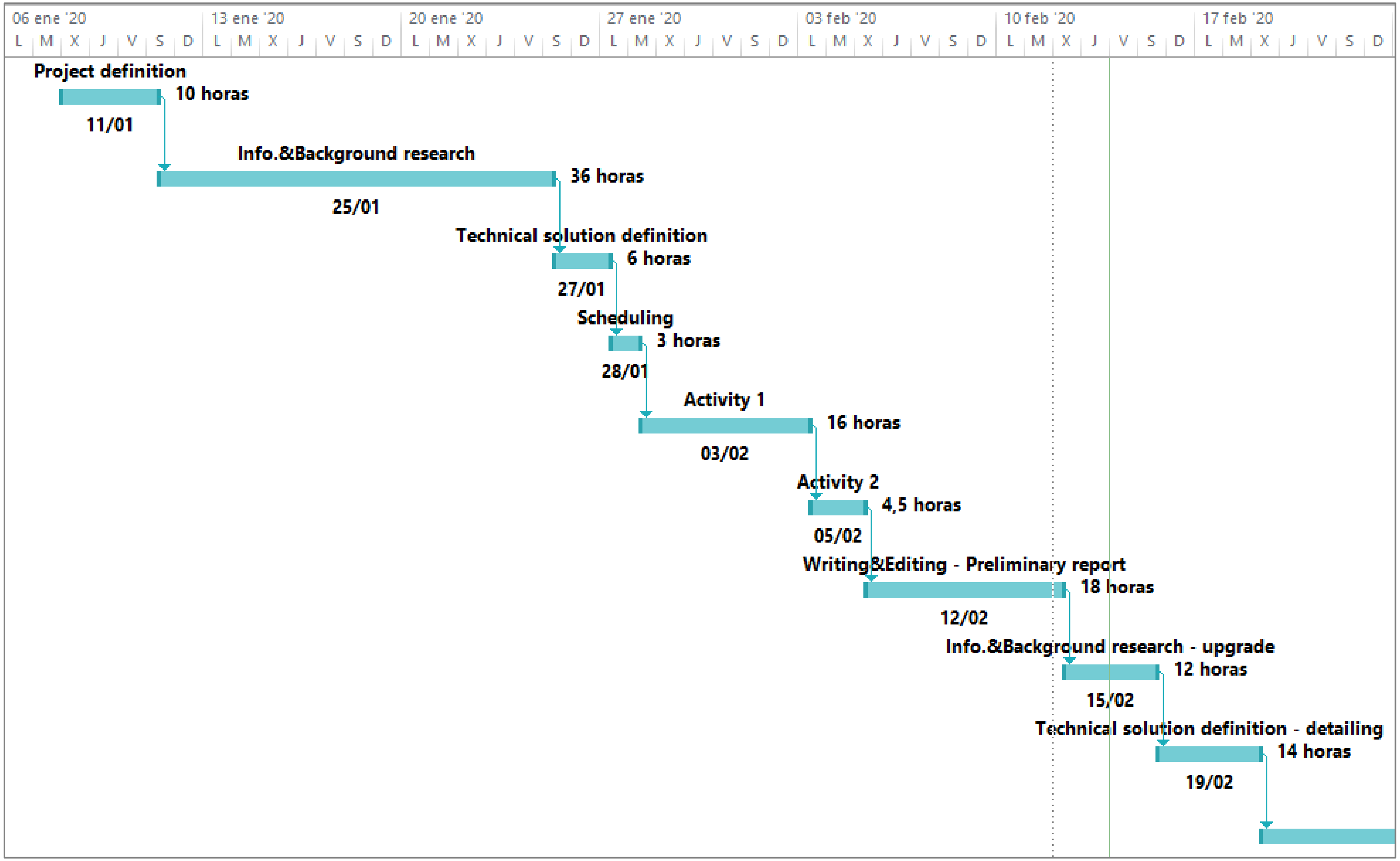


Fig. 6.1 - Gantt diagram of the project's schedule (1/4).

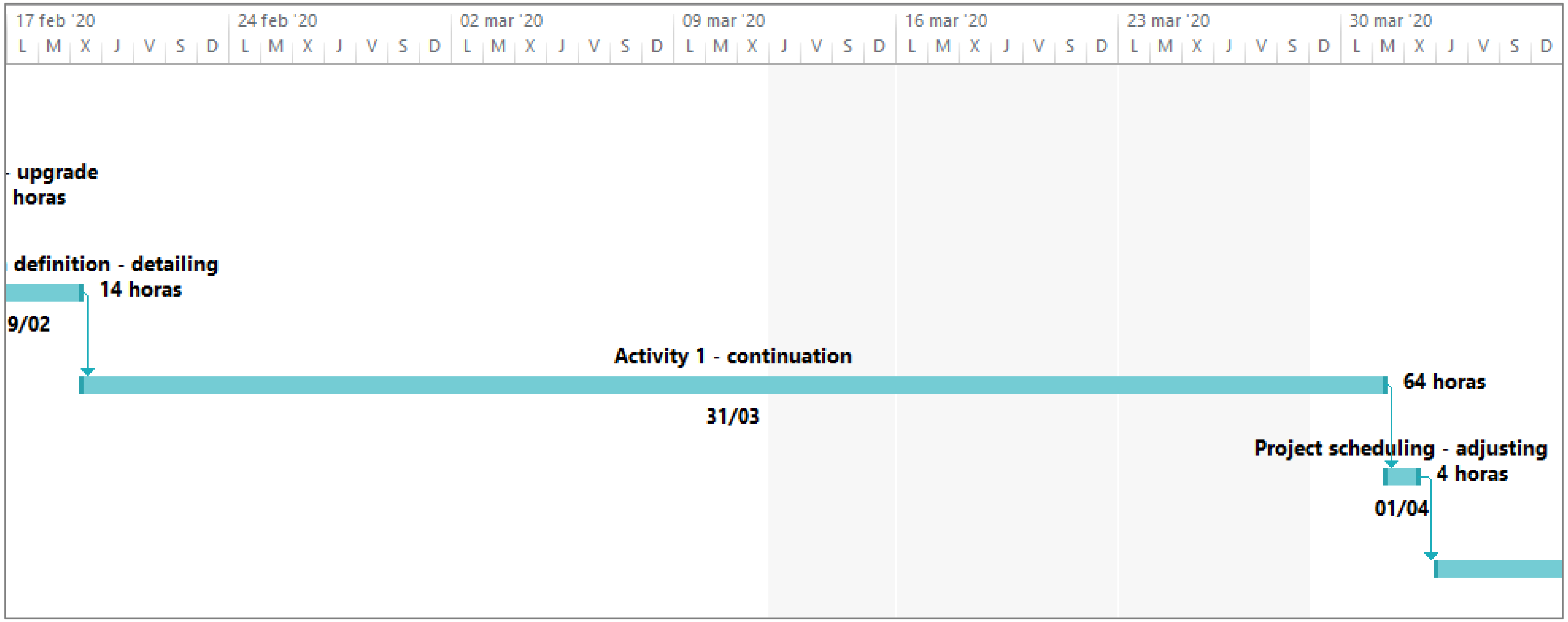


Fig. 6.2 - Gantt diagram of the project's schedule (2/4).

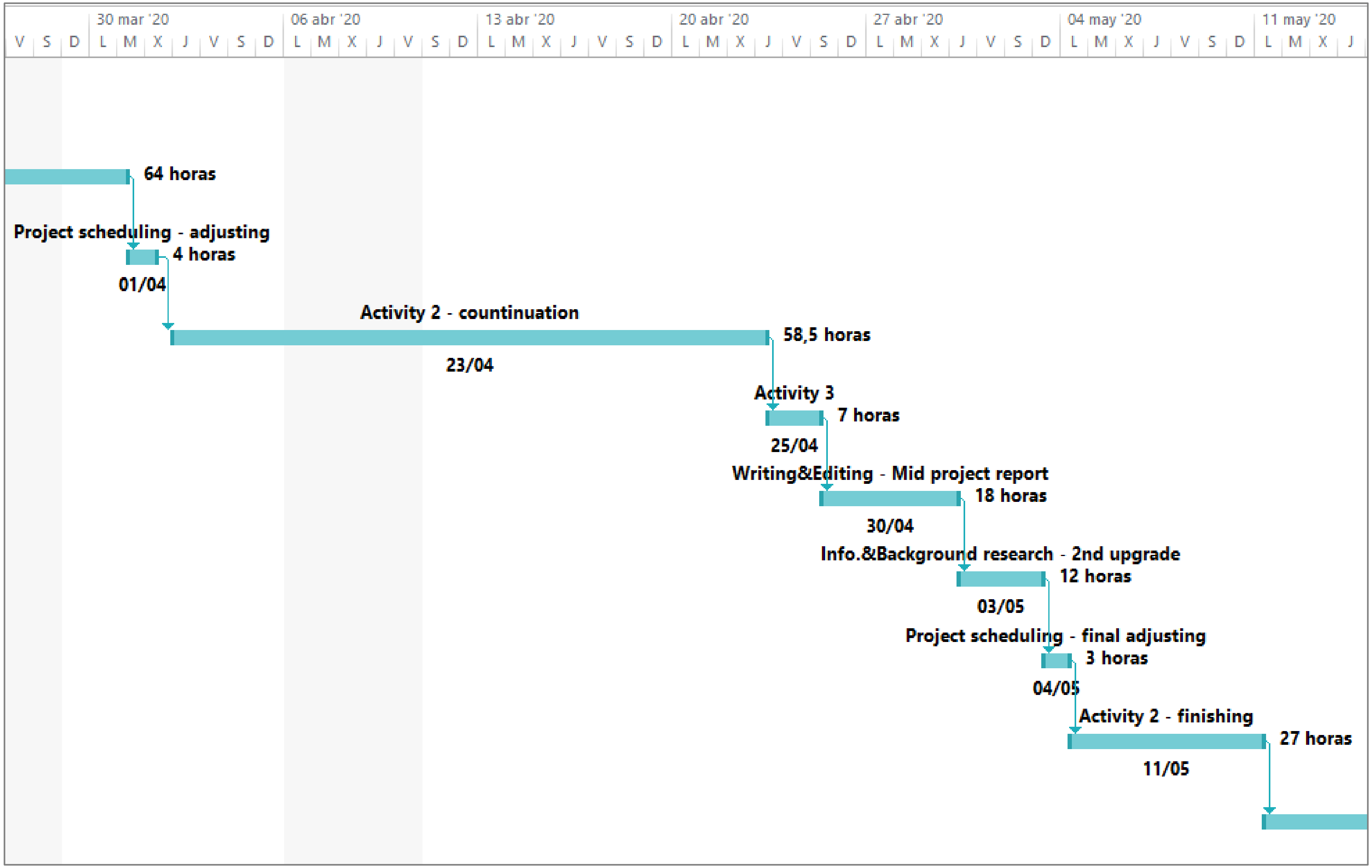


Fig. 6.3 - Gantt diagram of the project's schedule (3/4).

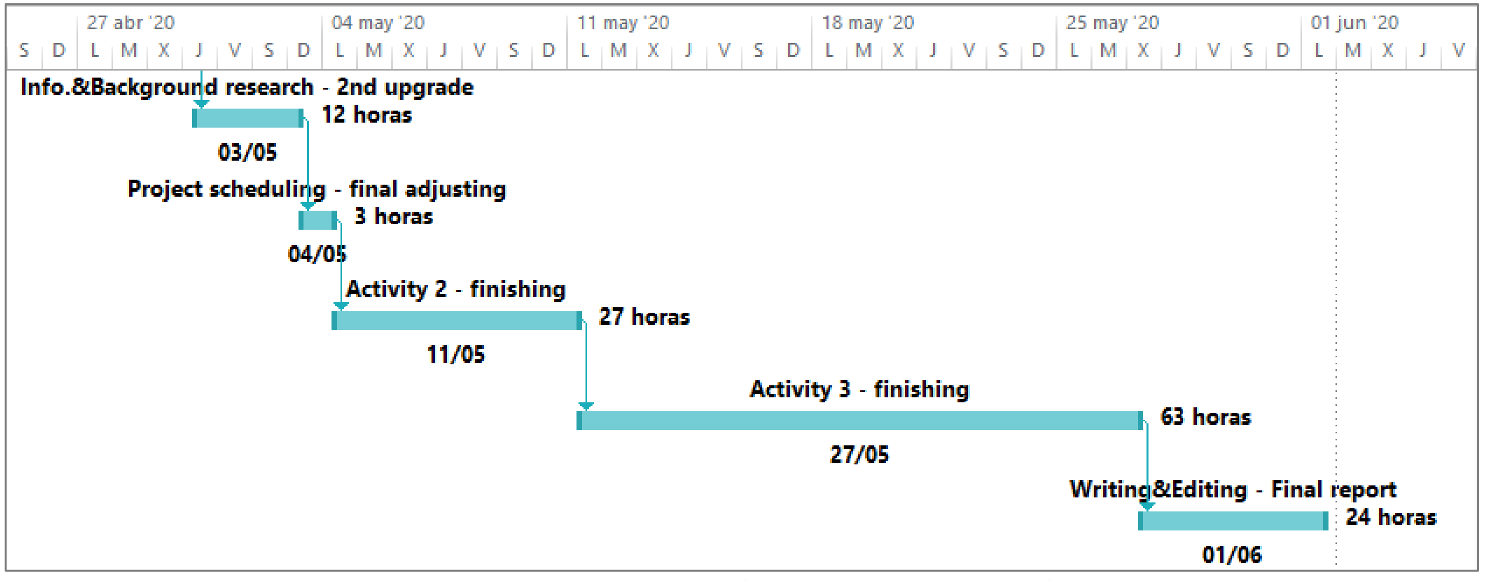


Fig. 6.4 - Gantt diagram of the project's schedule (4/4).

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6.1 Schedule adaptation after Mid Project report.

#	Task name	Duration	Start	Finishing	Prec.	Resource
1	Project definition	10 h	wed 08/01/20	sat 11/01/20		OBR
2	Info.&Background research	36 h	sat 11/01/20	sat 25/01/20	1	OBR
3	Technical solution definition	6 h	sat 25/01/20	mon 27/01/20	2	OBR
4	Scheduling	3 h	mon 27/01/20	tue 28/01/20	3	OBR
5	Activity 1	16 h	tue 28/01/20	mon 03/02/20	4	OBR
6	Activity 2	4,5 h	mon 03/02/20	wed 05/02/20	5	OBR
7	Writing&Editing - Preliminary report	18 h	wed 05/02/20	wed 12/02/20	6	OBR
8	Info.&Background research - upgrade	12 h	wed 12/02/20	sat 15/02/20	7	OBR
9	Technical solution definition - detailing	14 h	sat 15/02/20	wed 19/02/20	8	OBR
10	Activity 1 - continuation	64 h	wed 19/02/20	tue 31/03/20	9	OBR
11	Project scheduling - adjusting	4 h	tue 31/03/20	wed 01/04/20	10	OBR
12	Activity 2 - continuation	58,5 h	thu 02/04/20	thu 23/04/20	11	OBR
13	Writing&Editing - Mid project report	7 h	thu 23/04/20	sat 25/04/20	12	OBR
14	Mid project report delivery		mon 30/03/20	fri 24/04/20		university
15	Activity 3	18 h	sat 25/04/20	thu 30/04/20	13	OBR
16	Info.&Background research - 2nd upgrade	12 h	thu 30/04/20	sun 03/05/20	15	OBR
17	Activity 2 - finishing	27 h	sun 03/05/20	sun 10/05/20	16	OBR
18	Activity 3 - finishing	63 h	mon 11/05/20	wed 27/05/20	17	OBR
19	Writing&Editing - Final report	24 h	wed 27/05/20	mon 01/06/20	18	OBR
20	Final report delivery		wed 10/06/20	fri 12/06/20	14	university
21	Exposition preparation	¿	mon 15/06/20	mon 15/06/20	19	OBR
22	Project exposition period		wed 01/07/20	wed 15/07/20	20	university

Table 6.3 – Tasks of the Mid Project Report scheduling modification.

As well as with the first version of the scheduling, a Gantt diagram is attached.

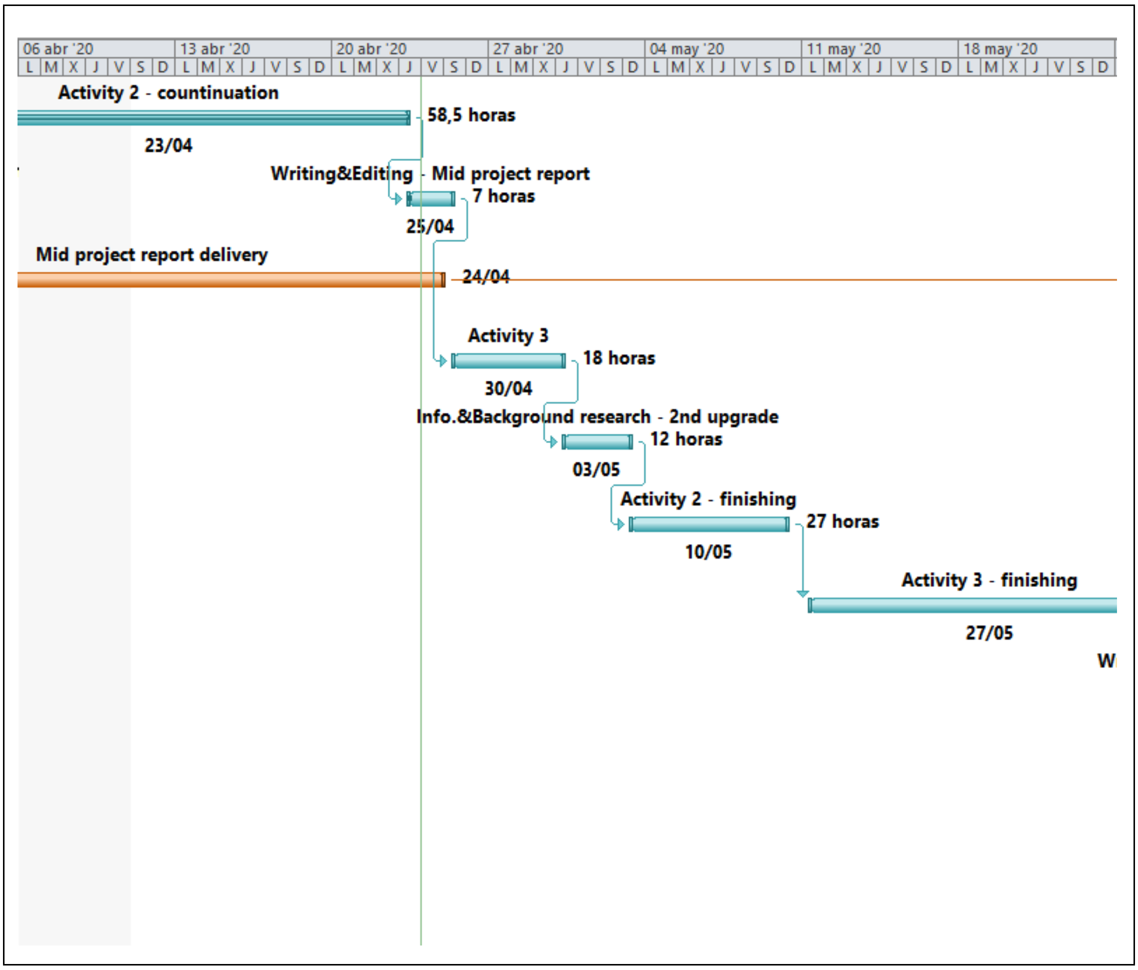

Fig. 6.5 - Mid Project Report scheduling modification Gantt diagram (1 of 2).

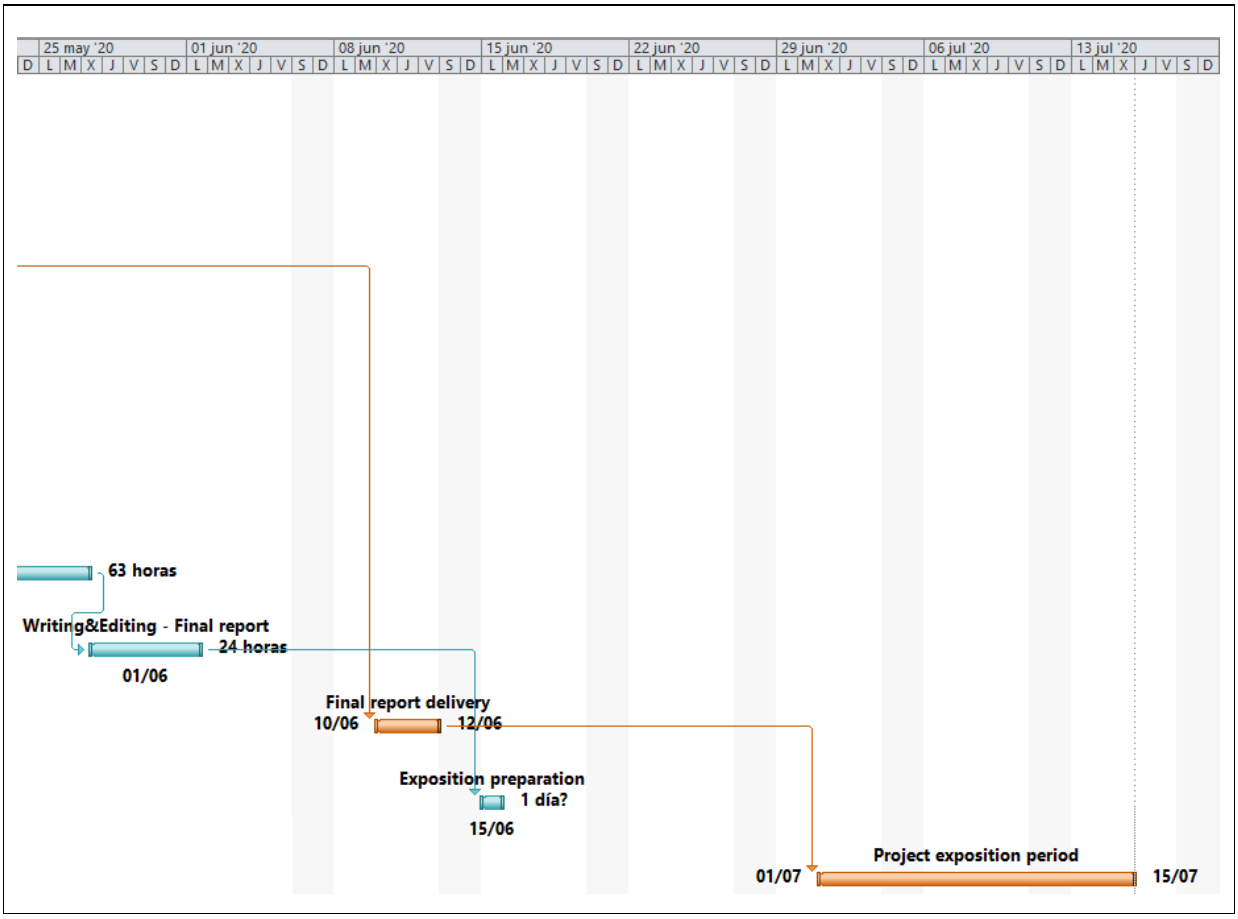

Fig. 6.6 - Mid Project Report scheduling modification Gantt diagram (2 of 2).

7 Project Closing

7.1 Deviations.

7.1.1 Schedule deviations

In this project there have been two major deviations. The first one was the closing of the labs to the Covid-19 events. This left no option but eliminating the practical part that required the labs. Instead, a detailed procedure of how it would have to be developed in the future was included in the memory.

The second deviation was an error that was committed at the beginning of the normalisation development. The documentation of the MCYT database does not specify that the signature samples were obtained using an ink-pen, although they were. For this reason, the normalisation was developed for plastic-pen samples. The error was noticed while discussing a plastic-vs-ink pen crossed-test with Professor Marcos. The former results were saved as additional information, though.

Finally, the report delivery deadline was moved from 10th – 12th June to 1st – 3rd July. The “extra” time was used to carry out additional tests and verifications.

7.1.2 Budget deviations.

As the lab part was not put in practice, the components were not bought which supposed a budget saving.

7.2 Strengths and weaknesses of the project’s result

The main strength is that some good normalisations have been accomplished, two of them maintaining the algorithm performance especially well. Getting a linearization of the pressure sensor was the aim of the project and it has been accomplished while fulfilling all the technical specifications. Some mismatch scenarios have been tested, which is difficult with signatures because they cannot be acquired simultaneously with different sensors.

Also, even though it could not be put in practice, a testing methodology for digitising tablets has been established. Besides, the documentation of the algorithms is a plus, especially regarding future works following this project's direction.

The main weakness of the project is not having been able to develop the practical part which, despite not being in the specifications, would have made the whole project more solid. In addition, the mismatch normalisation results have a good room for improvement.

7.3 Future work line.

The first thing that can be done, at the reopening of the labs, is to put in practice the part that could not be executed in this project (Activity 2.1). Next, using the resulting data in the normalisation to see if it can be improved.

This would allow, testing whether the pressure sensitivity of the signature device is affected by the device ageing or worn could be an interesting experiment as well.

Regarding the normalisation methods, it is been observed that the magnification could be a clue to get better performances, so this could be a good work line. The matter of using a logarithmic curve, which is perfectly invertible and has just two parameters, can be deepened as well. Moreover, it is been proved that the normalisation can improve the performance in mismatch situations, but the results must be enhanced.

Further work would be using the normalisation in real biometry application

7.4 Other knowledge

For everyone who may continue this research, and especially those who do not have experience in this field or this kind of projects, as I did, I will give the following advice:

- From my experience, I would say that the best way to manage time in a project like this one is starting the practical part as early as possible and looking for the background information on the go.
- Having a detailed documentation of the functions, contents and procedures of the project will save time and mistakes. Those who inherit the project will be grateful.

- In a project like this, where you have to change files and save results several times, writing down everything that is done (such as in a logbook) is a good practice. My advice is making a folder for each test where the results and a description are saved; and save a copy of the algorithm at the moment of performing such test in a .txt file too. Making a beautiful results document (with plots and code captures) takes time and you may have to keep changing it all the time. You will be more effective if you add the information to the project's memory once you have solid results, and you will be able to transmit a more global idea of them too.
- Also, in a research project is not very useful to time a schedule (it is difficult to set a time for a development), but defining an actuation plan with some activities or steps if very helpful in order to have a general vision of what will be done.
- Regarding the information references, in a research project this has a bigger importance than in a typical engineering project, since it will usually require more information referencing. In my mind, the more effective strategy to document is listing the information and the sources altogether, and afterwards, sorting the information parts together with its reference.

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