Internship Report

Set up of a paper dust measuring camera system

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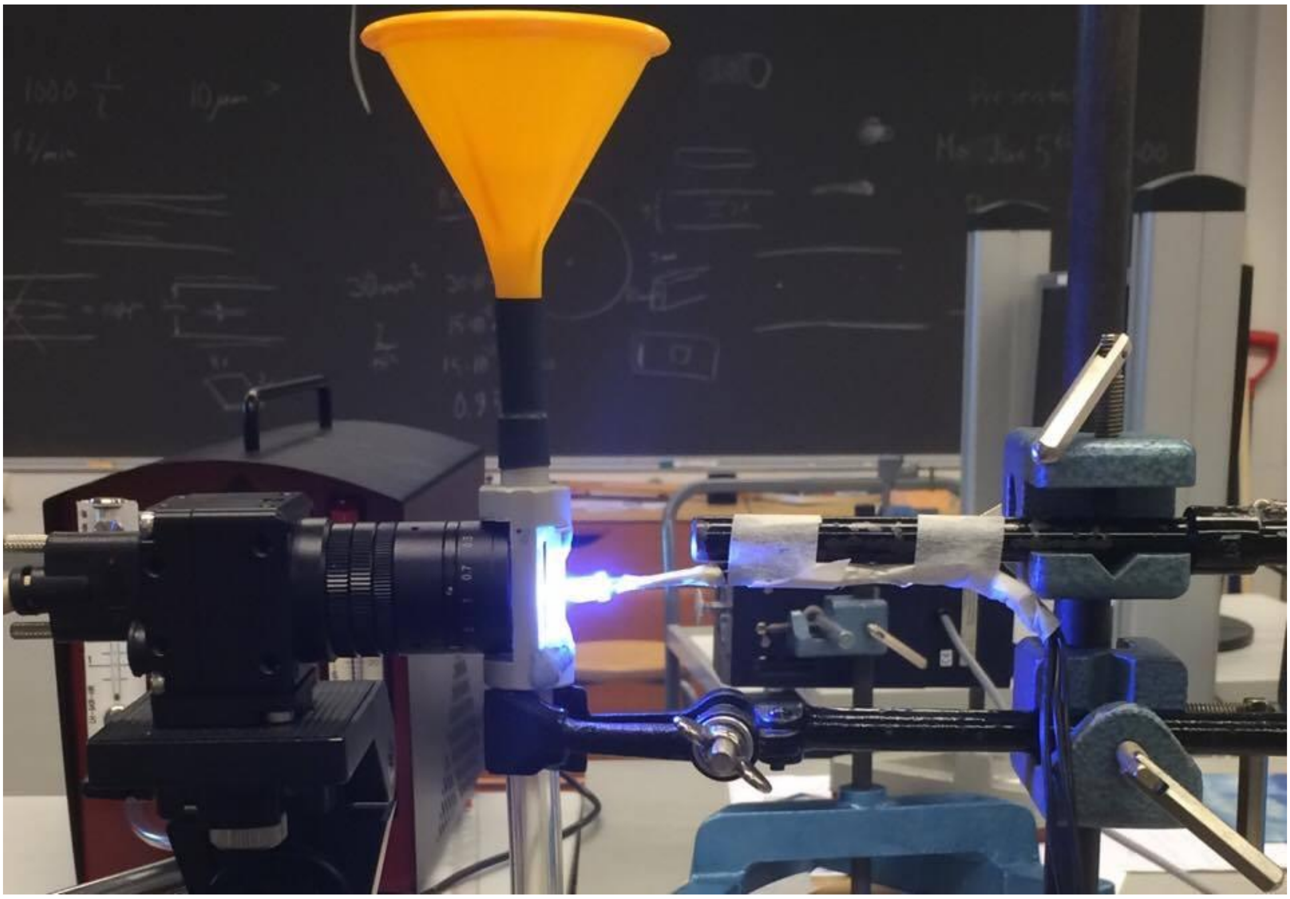

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Mr Benjamin GAUFRES, Senior Lecturer (France)

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I would also like to acknowledge my student partner Mr. Théo Jagueneau for all his investment in this project.
Moreover, i would like to present many thanks likewise to my French tutor Mr. Benjamin Gaufres for having supervised me from France during this work.

Finally, I would like to show all my appreciation for all the previous students and partners who have worked in this project making earlier prototypes, and for their thesis which have been very useful to me.

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Abstract

EN - The target of this project was to set up a new semi-fast camera with its controller in order to measure the amount of paper dust created during the printing process. Indeed, the printing industry is truly developed in Finland and requires a high quality of paper because the paper dust can break printers, interrupt the process and cause costly downtime. For that a new software controlling the camera must be mastered to detect the dust particles and protect printers. Different methods were exploited during this project. Firstly, the software Sysmac studio was used to control the camera. A lot of time was spent to study the connectivity of the controller and the Sysmac studio's user manual in order to master this new software. Nevertheless, this software has been left because it could not be used properly. Thus, a new software was used : the FZ-PandA included with the controller. A lot of data sheet study has been carried out and several tests and manipulations have been applied to master it.
A custom user manual was made to simplify the use of the software, the lighting has been set up and a final setup with a pump, to simulate a flow of dust particles, has been also created. It could be used to see microscopic patterns like hair and dust. However, due to quality of the system, the results were limited in accuracy. Indeed, moving dust particles could be detected but they could not be distinguished and count with sufficient accuracy because of the flow and the camera's frame rate. A more thorough development has been proposed to enhance measures by improving the cuvette, by increasing resolution of the camera, and the way to improve the frame rate.

FR - Une nouvelle caméra semi-rapide et un contrôleur ont dû être configurés afin de mesurer le taux de poussière créé lors du processus d'impression de papier. En effet l'industrie du papier est très développée en Finlande et nécessite un papier de très bonne qualité car l'accumulation de particules de papier peut endommager les imprimantes industrielles et causer de grosses pertes financières. Ainsi, un nouveau logiciel contrôlant la caméra doit être maîtrisé pour détecter ces poussières de papier.
Plusieurs méthodes ont été exploitées au cours de ce projet. Premièrement, le logiciel Sysmac Studio a été utilisé pour commander la caméra. De longues études de la connectivité du contrôleur et du manuel d'utilisation du logiciel ont été menées. Néanmoins, ce logiciel était inutilisable, c'est pourquoi un nouveau logiciel intégré avec le contrôleur l'a remplacé : le FZ-PandA.
Un manuel d'utilisation simplifié a été rédigé, l'éclairage et le montage final avec une pompe ont été mis en place. Des observations microscopiques (cheveux, particules de papier) ont été faites grâce au système mis en place. Cependant, la qualité du système n'a pas permis de compter ni même de détecter des particules en mouvement avec précision. Un développement plus approfondie a été proposé en améliorant, par exemple, la cuvette et la fréquence d'image de la caméra.

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Glossary

CMOS : Complementary metal oxide semi-conductor

CDD : Charged Coupled Device

The resolution : it determines the number of dots per unit area, expressed in dots per inch. The resolution thus makes it possible to establish the ratio between the number of pixels of an image and the actual size of its representation on a physical medium.

Frame rate : the frequency of an apparatus to produce consecutive images. It is often expressed in images / s (or fps).

Shutter speed : is the accumulated physical amount of visible light energy applied to a surface during a given exposure time.
To have a good image quality, the exposure time must be 10x greater than the speed of the event.

1 Introduction

In Finland, the paper industry accounts for a major export contribution of the country's industry and the global paper market is still growing these last years. Paper manufacturing always generates paper dust which can cause damage to printing equipment. Moreover, the paper industry tries to use more and more recycled paper to produce paper, between 5 and 10% of the composition of paper is recycled paper. This generates a challenge for approaching high-standard paper because recycled paper always involves a lot of paper dust.

Thus, measuring the paper dust during the printing process and paper manufacturing is a necessary work because nobody knows the limit of use of recycled paper without causing too much paper dust. It could allow to save millions of euros by increasing the use of recycled raw material for the paper production without breaking industrial printers that is why it is as interesting from an economic point of view as an ecological.

For 3 years French students from the University of Bordeaux, are working on new methods with the purpose to improve paper dust measures. A first dust collecting and measuring device was created but it is much too expensive and cumbersome for the market and it needs to be replaced. Thus, last year they have tried to replace the expensive Boulder counter but due to the limits of their measuring device (camera) they could not measure particles under 12*µm.* Therefore, we have studied a paper dust measuring camera with better characteristics which would be able to measure in real time the amount of dust present in a paper's surface.

The objective of our project is to set up a semi-fast camera and its controller in order to capture pictures of paper dust particles in motion, between 5µm and 100µm, with a speed of 7m/s. It can be widely exploited to bring advantages to not only the process of reducing paper dust but also to paper quality-control.

For that we work on two softwares, then we setted the lightening and the software to control the camera, we tested the camera to verify its characteristics. We did macroscopic test and then we have continued with microscopic measurements to observe particules and then we realized the final test with a pump to simulate a flow of moving dust particles

2 Situation

2.1 Finland

Figure 1 : Map of Finland

The republic of Finland (Suomen tasavalta in Finnish) is a northern European country surrounded by Russia, Norway, Sweden and the Baltic Sea. It has an area of 338 424 km² for 5.5 million inhabitants (2015), which represents 5 times the French population. The major part is located in the southern region where there is the capital, **Helsinki**.

Its history is closely linked to Sweden : they were the same country for 5 centuries from 12th to 19th century.
Then, in 1809, the country became an autonomous Grand Duchy of the Russian Empire. It was after the Bolshevik Revolution and a civil war that Finland obtained its independence, in 1917. Finland joined the European Union in 1995, and the Eurozone in 1999. It is part now of the Schengen Space.

Figure 2 : Finland's Flag

Despite its climate, -35°C during winters to 35°C during summers, the country is considered as one of the best place to live and study in the world with one of the best educational system in Europe.
It has low corruption and crime rates, that's why Finnish sense of security is one of the highest.

Due to the quality of their education most of them speak good English, and they are also very welcoming so it is very easy for a foreigner to integrate.
It is important to know that Finland is covered at 75% by forests, it is the most forested land of Europe. We can easily understand why the wood industry is so developed in Finland, the wood exploitation represented 5% of the Gross Domestic Product (GDP) in 2010.

2.2 Tampere

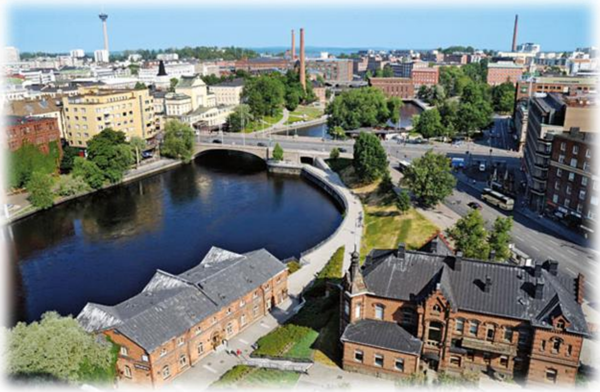


Figure 3 : City centre of Tampere

Tampere was founded in 1775 by Gustav III of Sweden.

Tampere is a Southwest-city of Finland, located at 170km North of Helsinki. It is the second urban area with 364 000 inhabitants living in an area of 4977km², the first one is obviously Helsinki with more than 1.300 million inhabitants. The two cities are separated by 170km

The city is surrounded by 2 lakes joined by rapids which allows electricity production with some barrages.

Figure 4 : Hydraulic Barrage

Indeed, the city was developed as a market place and around this hydraulic power. It has known an important economic development since the industrial revolution during the 19h century

Tampere is known for its important universities, they are attempting a union of the 3 university of Tampere, just as the University of Bordeaux, cumulating 40 000 students. You can also find 2 000 exchange students at Tampere

2.3 Tamk

Figure 5 : Overview of a reduced model of Tamk

Tampere University of Applied Sciences (In Finnish: ***Tampereen ammattikorkeakoulu***, TAMK) was founded in 1996, so it is a really young university

It has 10,000 students studying six different educational fields in technology, business, culture, health and social welfare services.

Finnish universities concentrate on academic and scientific research whereas universities of applied sciences such as Tamk are more oriented to working life. Their task is to conduct research and development which supports instruction and regional development.

3 Organization

At the beginning of the project, it was important to understand the requirement and have a clear vision on the topic. That is why we studied several theses on the same topic, from Hamk (a second university of Tampere) and Tamk and the last year project which consisted of replacing an expensive measuring device by a camera in order to capture paper dust. Our project is a continuation of that last one, with a way better camera that Tamk bought for its higher characteristics.
This project consisted of measuring a flow of moving paper dust with this new camera.
People involved with me were Mr. Jagueneau, my student partner, Mr. Arvela, my tutor and Mr. Pitkänen, the technician laboratory. We had 2 mechanical labs at our disposition for all our measurements and our experiments.

We decided to divided our work in different step in order to enhance our work.
The first phase of the work was to start the software and learn how to master it in order to control the camera. In the same time, I was working in the lighting of the measuring system. The second phase was to proceed to macroscopic measures first, to test the software settings, then to microscopic measures to test the limits of our camera. The final phase was implement the final setup which consisted of simulating flowing dust with a pump and building an accurate vision system using the apparatuses from laboratory.

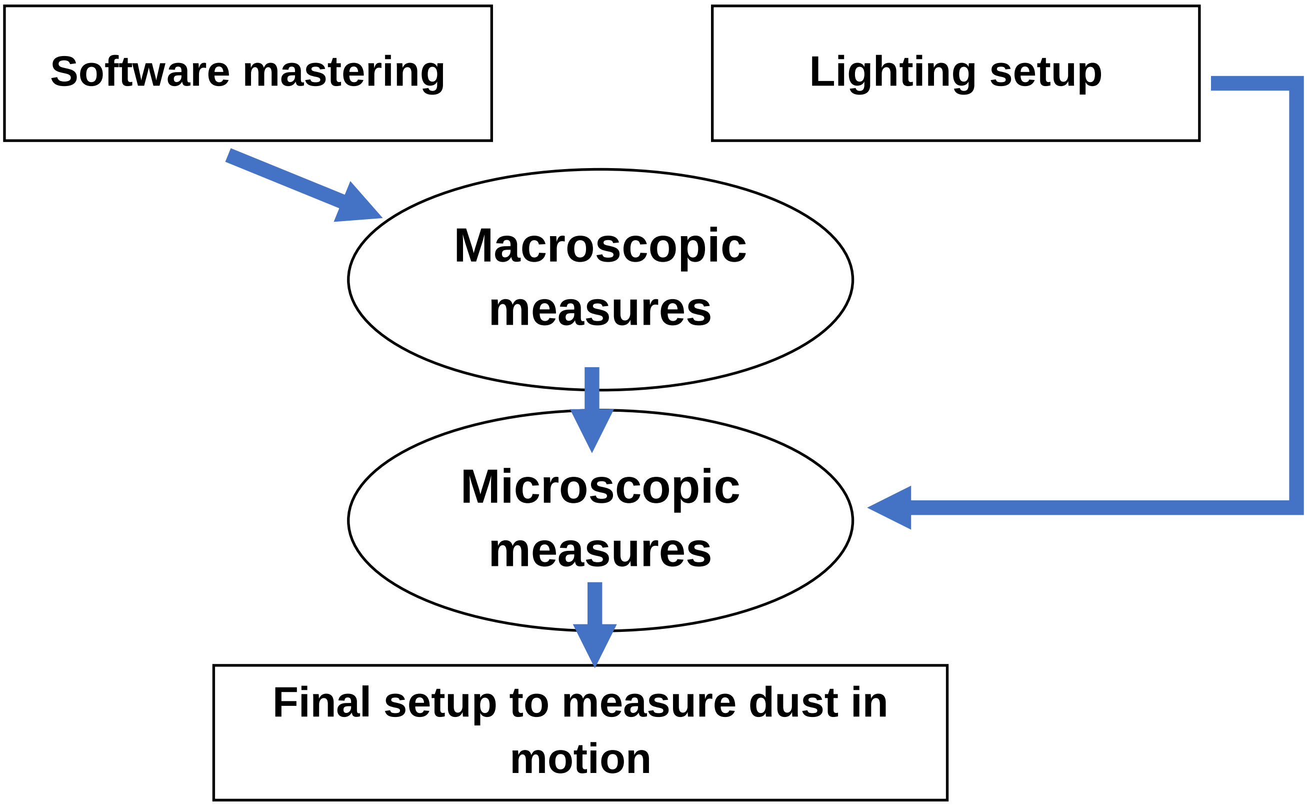
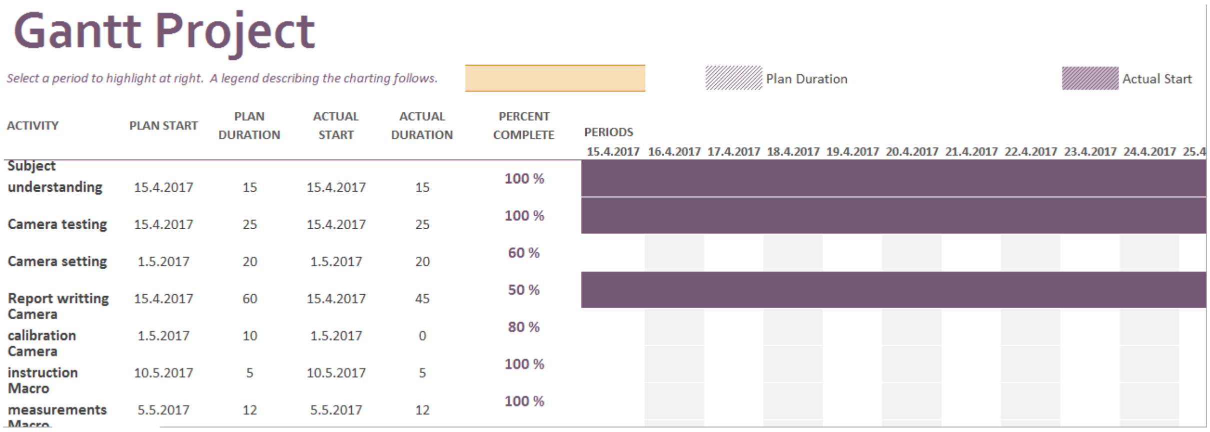


Figure 6 : Five phases of the project

Finally, we decided with our tutor to not work on the processing image part and the dust particle counting because of time issue.

To proceed we decided to share our work with Mr. Jagueneau. Our tutor was guiding us with some instructions, while my partner split the work for two each week and giving me tasks to do. He was charged to work on the calculous and the theoretical part while I was doing the practical part, working on technical issues like the lighting of the system, the set-up of experiments. I also made and worked on the Gantt diagram by keeping it up to date. By the way it was an important task because we had a lot of meetings to plan : such as our daily meetings with our tutor or like meetings with a project group from Hamk working on a flash light system, almost two times per month. It has clearly allowed to establish a chronological hierarchy of our work and to enhance our organisation.


Gantt Project

Select a period to highlight at right. A legend describing the charting follows.

Plan Duration | Actual Start

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	PERIODS 15.4.2017	16.4.2017	17.4.2017	18.4.2017	19.4.2017	20.4.2017	21.4.2017	22.4.2017	23.4.2017	24.4.2017	25.4
Subject understanding	15.4.2017	15	15.4.2017	15	100 %											
Camera testing	15.4.2017	25	15.4.2017	25	100 %											
Camera setting	1.5.2017	20	1.5.2017	20	60 %											
Report writting	15.4.2017	60	15.4.2017	45	50 %											
Camera calibration	1.5.2017	10	1.5.2017	0	80 %											
Camera instruction	10.5.2017	5	10.5.2017	5	100 %											
Macro measurements	5.5.2017	12	5.5.2017	12	100 %											
Macro																

Figure 7 : Gantt diagram of the project

At our arrival, we had to do a presentation of our university and the French educational system. At the end of our project we also had to do a final presentation of our work about the aim, methods and results in front of students and senior lecturers from Hamk in order to share our results. I was asked to do the powerpoint support for each presentation.

4 Equipment

4.1 Camera and Lens

Figure 8 : Sideview of the camera

In measuring system, camera plays an extremely important role to the quality of measure which is linked to the quality of the camera. Indeed, technical features must be studied to choose and work with a new camera without being narrowed during experiments.
In this project, an industrial semi-fast camera was exploited, made by OMRON. This camera is used to take pictures of rapid moving targets, like dust particles in motion, and that without or little blurring effect. We mainly studied paper and kaolin particles, so the camera has to be enough accurate.

Model	FH-SM	FH-SC
Image elements	CMOS image elements (1/3-inch equivalent)	
Color/Monochrome	Monochrome	Color
Effective pixels	640 (H) × 480 (V)	
Imaging area H x V (opposing corner)	4.8 × 3.6 (6.0 mm)	
Pixel size	7.4 (μm) × 7.4 (μm)	
Shutter function	Electronic shutter; Shutter speeds can be set from 20 μs to 100 ms.	
Partial function	1 to 480 lines	2 to 480 lines
Frame rate (Image Acquisition Time)	308 fps (3.3 ms)	

Figure 9 : Camera features

This is a CMOS camera while the previous camera last year was a CDD camera, it means that it has a CMOS captor which allows to reduce the size of the camera, so to gain some place, and it is less sensitive to noising dust. The CMOS captor also allows a best acquisition speed and it is more resistant to glare than the CDD captor which is expensive in comparison to the CMOS.

The model of our camera is FH-SC, the only difference with the FH-SM model is that this camera is a color camera which means it can captures and displays color images.

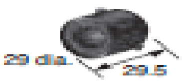
Model	3Z4S-LE SV-1214V
Appearance/ Dimensions (mm)	
Focal length	12 mm
Aperture (F No.)	1.4 to Close
Filter size	M27.0 P0.5
Maximum sensor size	1/3 inch

Figure 10 : Lens features

Rings
2x1.8mm
1x1.4mm

Figure 11 : Frontview of the lens

Figure 12 : Printed rings

The size of detected paper dust particles is around 5 and 100 micrometers, which meant the focal length of the lens should be short.

The camera was delivered with an optical lens of 12 mm. The lens allows to control the aperture and the focus.

The rings of the lens are used to decrease the focal length. We also created custom rings to do several tests with a 3D printer.

4.2 The controller

Figure 13 : Frontview of the controller

The controller is also made by OMRON, it is the FH-50 model which allows fast and precise measurements among various applications.

It is a FH standard controller 2-core, NPN/PNP at the output 2 cameras, so it enables to capture 3D pictures with 2 cameras. All its connections are explained in a scheme in appendix. This controller can be used to control the camera and perform image processing specified by setting created by users and it shows result of measurements.

It includes a software, that we will see farther, for inspection and measurement combinated with our camera that can capture high-sensitivity and high-resolution images. It provides high-speed and high-precision measurement and analysis without complex programming. The controller needs 24 Volt powered by a direct current generator.

4.3 Cuvette and dust measuring devices

Figure 14 : Frontview of two cuvettes and their features

The cuvette is a device used for dust measuring, the camera is placed above the transparent part, at the contact of the surface and after that a flow of dust particles is created, then they are passing through the cuvette where they can be observed. We first work with the biggest cuvette for calibration measurements but we changed to the second one cuvette, because as it is thinner the camera is able to measure a higher part of dust particles passing through.

I also used different dust sensors in order to carry out measurements of dust particles and analyse their dispersion depending on their size.

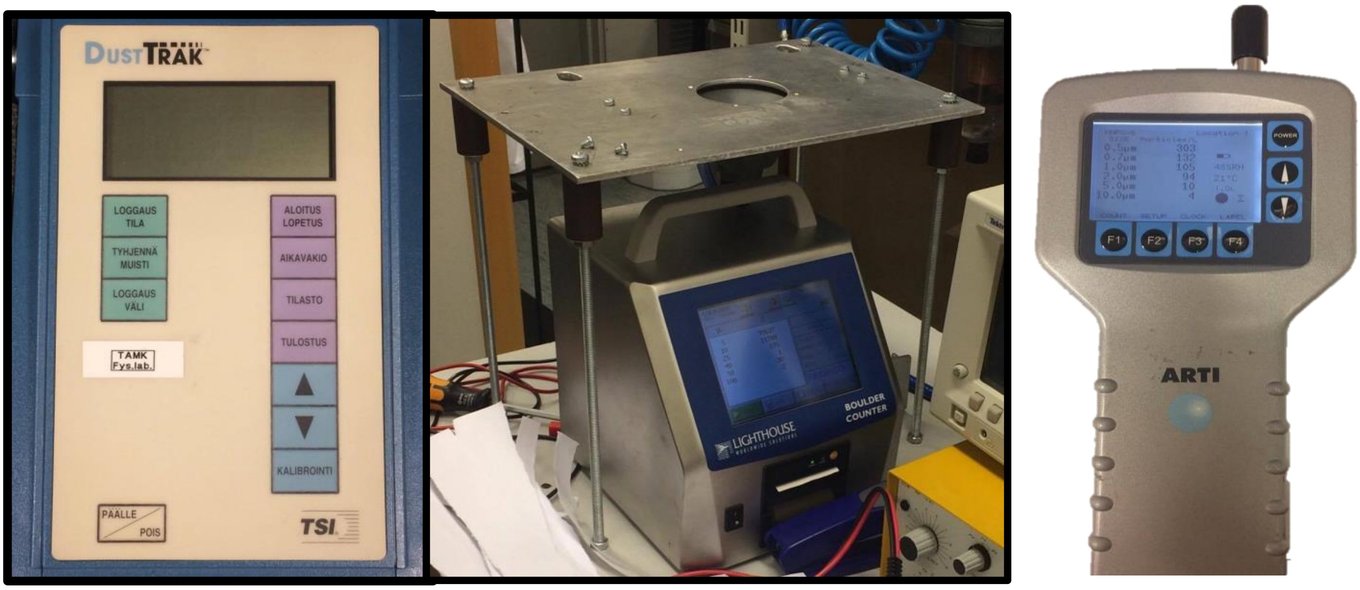


Figure 15 : Pictures of a dust sensor, the Boulder counter and a handheld particle counter (left to right)

After many experiments I decided to only use the 2 last measuring devices because the first one, the DustTrak, was not enough accurate, probably due to its sensor which has suffered from age, because It has given incongruous values.They allow to measure dust between 0.5 to 100µm.

4.4 Kaolinite

Figure 16 : Bottle with Kaolinite

Kaolinite or China clay, is one of the most widely occurring minerals. Its consumption is still increasing since it gives distinct and desired properties such as runnability, decent coverage as ultra low weights, and print quality. It is intrinsi-cally valuable due to platy particle shape, good colour (white or near white) and relatively easy to be processed to fine particle size. Most of the kaolin clay particles have a size range from 0.3 to 5 µm. We have used it has a substitute of the dust paper, because they have similar characteristics.

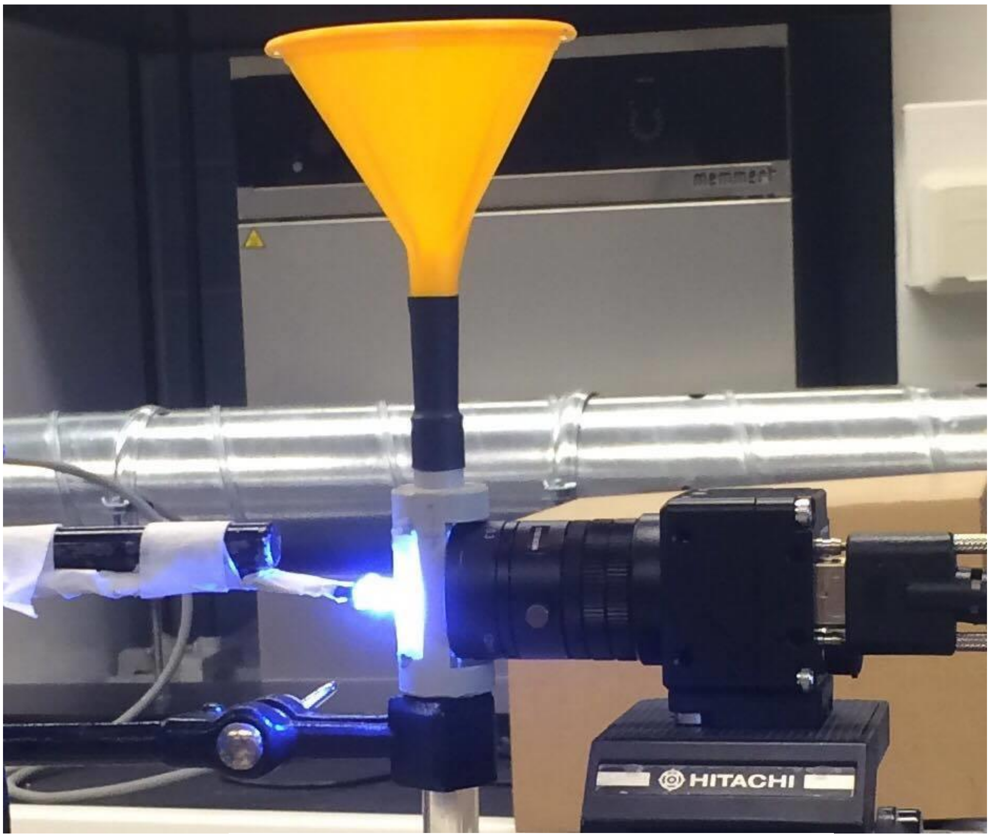


Figure 17 : Final lighting system

5 Lighting system

Lighting system is an important aspect of our measuring system. Depending on the source of light, pictures' quality can be highly influence. That is why a light source was made for illuminating the whole region of interest. An issue appeared : if the illumination intensity is too high, the object will become smaller but if the intensity is too low, there will be points in the background which have the same intensity of the particles and cause noise to the final result. Thus, the intensity must be alterable.

The best way to light the cuvette when the camera is at the contact is to light it from behind the cuvette. The setting of the illumination intensity has been really annoying. Indeed I decided to put 2 LED because of their characteristics : they have a omnidirectional light and our tutor enjoined me to use white light only.
They were powered by a direct current voltage generator. They have a nominal current of 75mA, this is the limit for correct use, if the limit was exceeded the LED would be getting warmer until the melting of plastic wires and If ever this happens there would be a short circuit and finally LED could burn.

Led needed around U1 = 5.5V to reach 75mA in the circuit but a blank piece of plastic was needed at the back of the cuvette because the LED were too bright to do correct measures. However, this led to another problem, now the brightness is too low to proceed to measure. That is why I decided to increase the electrical power without changing the current, in order to stay below the 75mA limit, by adding just a small resistance of 100 Ω in the circuit, indeed as U=R.I if the resistance increases the voltage would increase also and the circuit current won't change while the electrical power would increase, because the voltage and the power are linked by this equation : P=U.I. I have obtained U2 = 13V with this method.

The power before the resistance was P1 = U1 x I = 5.5 x 75 x (10^-3) = 0.4125W whereas when I added the resistance it came P2 = U2 x I = 13 x 75 x (10^-3)
P2 = 0.9750W

However the DC voltage generator was not enough accurate to know exactly the current value of the circuit, that is why I added an ampermeter in series, in order to control the current precisely.

The illimunation setup was adequated until the final experiment with the pump, because we have changed some parameters which have influenced on the illimunation intensity (like the shutter speed and the aperture) and involved darker observations. There was still a need to increase the power, but it was too late to change the resistance for an higher one, so we had to exceed the limit of 75mA, to have enough illumination intensity it was necessary to go near of 100mA and 18V which correspond to P3 = 18 x 100 x (10^-3) = 1.8 W.

Our tutor ask me to study a lamp of 1W and 3V. However even if the range of illumination was better we could not change the power, so we can't set the intensity depending on the parameters of the camera. What is more 1 watt fixed is not enough to proceed to the final experiment with the pump the LED were definitively better.

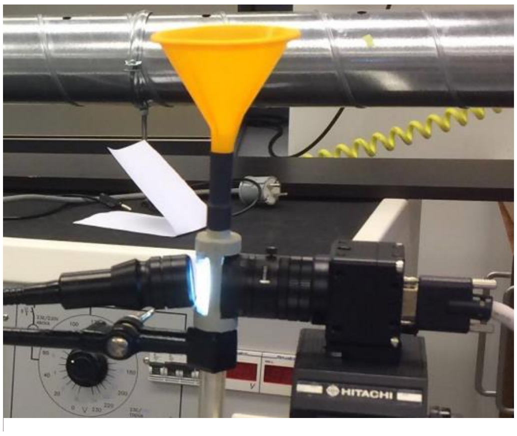


Figure 18 : Setup of the lamp experiment

In order to protect the LED it would be preferable to change these LED for more resistant LED or to increase the circuit impedance in order to reach 1.8 W without burning LED.

Finally the illumination system must be controlled by the software of the conrtroler because it eliminates the needs of power supply for lights and lighting cables, saving space and wiring at the same time. The software needs to be studied and setted to improve the lighting system by switching lights and controling brightness of several light sources directly with the controler without external device.

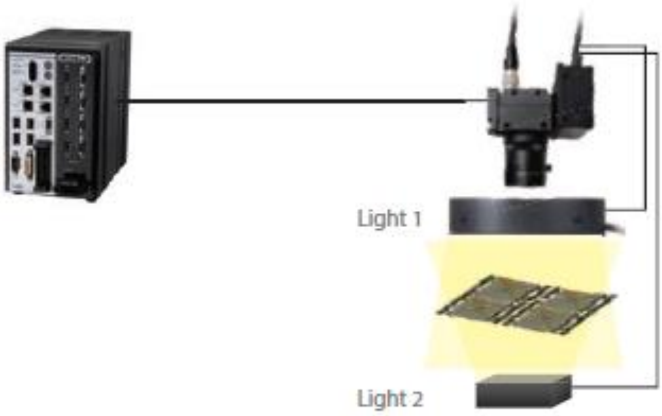


Figure 19 : Example of a lighting system controlled by the Omron controller

6 Software

6.1 Sysmac studio

Figure 20 : The Sysmac Studio board

The Sysmac Studio provides one design and operation environment for configuration, programming, simulation and monitoring of a measuring camera system. It was the first software of the project, it was not included with the controlled so we had to install it with a trial version of one month. We have studied it a lot and tried to master it during one month. For that we have read hundreds of datasheet pages in order to control this software but we were blocked since the beginning because of the connection between the software and the controller, indeed we connected directly the controller to a computer where the software was installed with a Ethernet cable, the software was able to recognize the controller with its own IP address but when we tried to connect to the controller we could not and an error message appeared all the time, always the same.

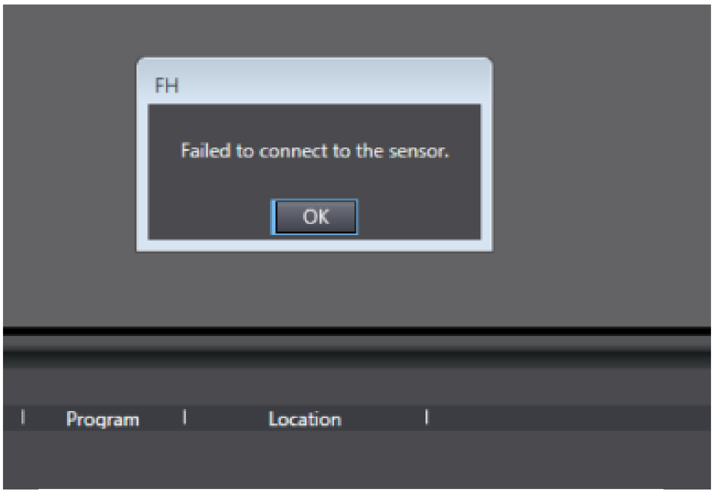


Figure 21 : Sysmac Studio error message

We tried without succes to fix this problem for several weeks contacting OMRON to help us, trying new settings or to change the Ethernet cable putting an USB adaptator. Finally OMRON advised our tutor to use another software using the controller like a computer and connecting a screen, a mouse, and a keyboard directly on the controller and to use the softwared included with it.

6.2 FZ-PanDA

The OMRON software uses the controller to process measurements of objects that are imaged with the semi-fast camera. It allows a lot of application with its interface buttons called “processing units” which correspond to a particular action like logging an image, detecting a square shape, detect defects etc. This software enables to group those processing items (or units) and this combination is called a "scene" and scenes can be easily created by combining processing items that are suited to the measurement purpose from the list of processing items provided on the Edit flow menu where scenes can be created and modificated.

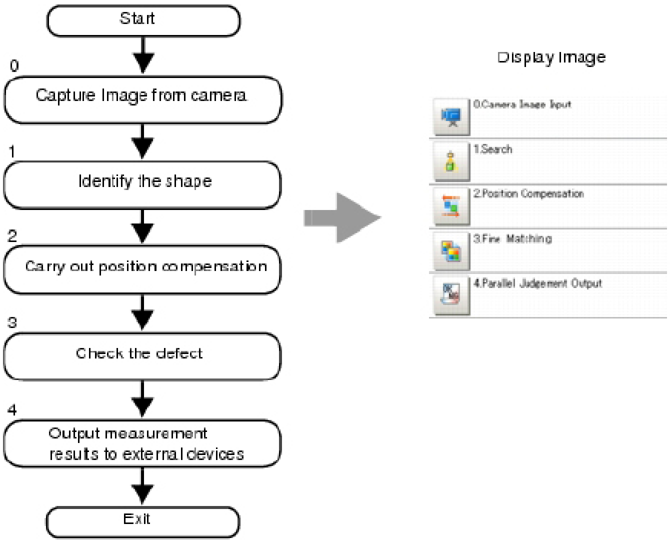


Figure 22 : Scene examples

Several scenes can be created and saved, then it is easy to switch between each scene created during experiments, and for each scenes differents set up can be chose and that is really interesting, it allows to save a lot of time.

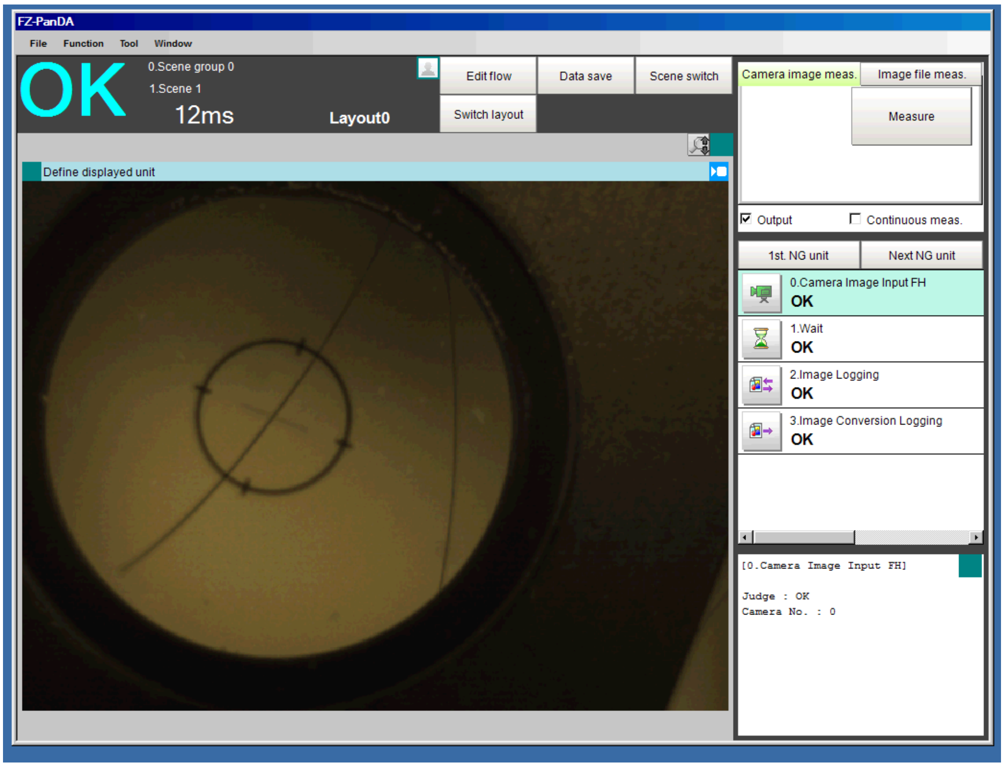


Figure 23 : FZ-PanDA’s boarding overview

7 Macroscopic measurements

In order to test the new software and to try to control the camera we proceed some physics test. For that we test the fall of a tennis ball near to a ruler to measure the distance. We did that experiment with our camera and a standard webcam .

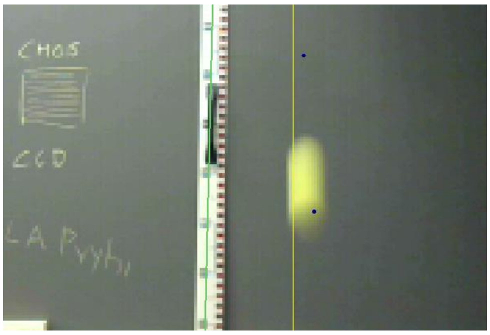


Figure 24 : Tennis ball measure with

Figure 25 : Tennis ball measure with the camera

It has enabled us to observe that with our camera we don't observ the blurr effect during the fall of the ball while with the webcam we can clearly see that it is not sharp at all, due to the speed acquired by the ball and the low frame rate of the webcam (around 20fps). However we also could observe that the frame rate of the camera was far from the 308 fps expected.

That's why we decided to do a frame rate test to calculate the real frame rate of the camera.

For that we have measured the rotation of speed per minute of a rotating motor equiped with a bright point with an optical tachometer using the light reflection method which consists in emits a light that will be reflected by the bright point and returns to the measuring equipped with a receiver. The speed is measured in rpm by counting the frequency at which the beam is reflected. Then have we measured the same motor at the same speed with our camera. The problem was that we don't know how we capture a video or transform measure series into a video directly with the software. Thus, we had to save all the measures and use WindowMovie Maker to transform them into a video by accumulating them and put a low delay between each image (around 50µm) then Mr. Jagueneau (I can advise you to analyzed it and calculated a frame rate of 32fps which is third times lower than the real speed of the rotating motors : 7250 rpm measured with the tachometer which is equivalent to 120 fps.

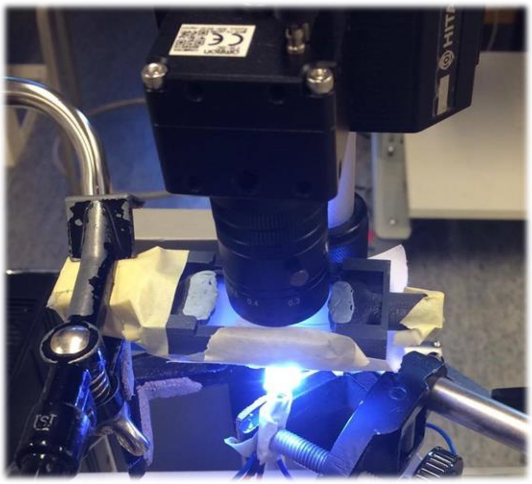
Figure 26 : Rotation speed measurement

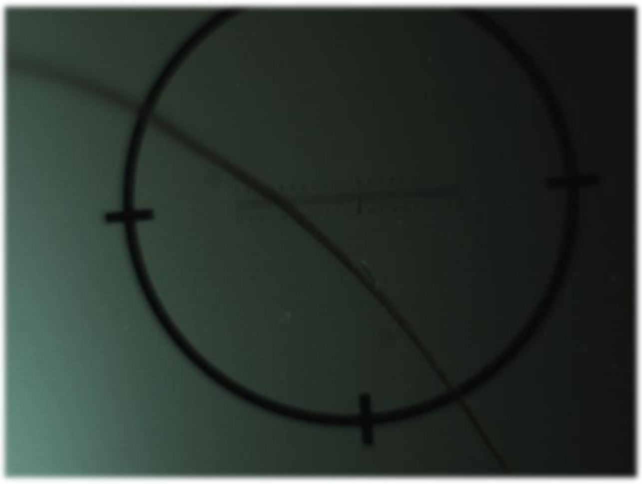
Though, we discovered a challenging problem the camera's frametare was ten times lower than the frame rate expected of 308 fps. That is why we contacted OMRON again, because even with new settings we could not increase the frame rate. After several discussions we could finally increase this amount from 32 to 50 fps thanks to OMRON's instructions. They advised us to reduce the number of line to be read, in other words the size of the image shown on the screen, to reduce also significately the shutter speed and to change the calibration setting from sampling to "Specify point". We tried a new frame rate test and this time we had 50 fps instead of 30, but this is still ridiculous regarding our expectaions.

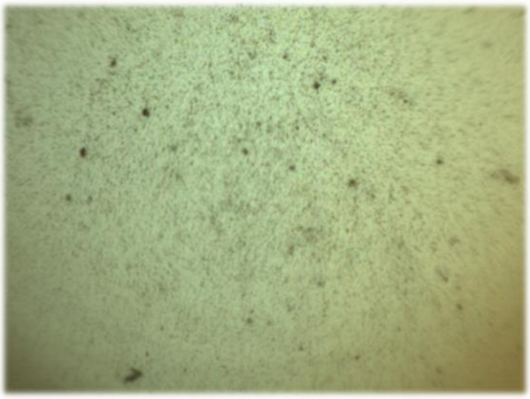
8 Microscopic measurements

We did not spend a lot of time in this part, the objective was to be able to measure hair then dust particles without motion/flow. It was a usefull part because we could learn more on the limits of the camera, like the smallets visible particle that we could measure : 14.5 µm, calculated by our tutor during test with a real microscope.

Figure 27 : Miscrocopic experiment with the setup, a hair image and dust particles observation







We could proceed to microscopic measures without any problem below 14.5 µm. During this step we studied the effect of the shutter speed and the aperture on the resolution and the illumination intensity. We could observe that the resolution was increasing when the aperture was decreasing but for the illumination intensite it was the opposite it decreases with a lower aperturer and also when we decrease the shutter speed. The aperture was modifiable with the lens, we could read 4 coefficients named K : 1.4, 4, 8, and 16 corresponding to a denominator of a fraction : $\frac{F}{K}$ and F corresponds to the fixed focal length : 12mm here. Indeed this fraction correspond to the maximum focal length aperture depending on the factor K, when K increases the aperture decreases. It will be an important point for final measures. If we take 1.4 the maximum aperture of the focal length would be 12mm/1.4.

9 Final setup

As we could observe stationnary dust particle we were ready to include a pump to our system in order to creat a flow of dust particules and measures particles in motion.
To proceed we have to create the best way to collect the paper dust, we also have to protect the pump with a dust filter and calculate the flow in liter per minute. Once again Mr. Jagueneau work on the calculation part while I started trial measurements. I tried some setup to the final experiment, and with my tutor Mr. Pasi Arvela we decided to put the cuvette at the vertical for a mechanical reason : there will be fewer particles that stick to the walls, that accumulates and which can be a source of error.
When my partner finished his part, he joined me to work with me. He determined that the pump must generate a maximum flow of 0.9 L/min to be able to see and capture dust particles in motion. Above this limits we could not measure it with the quality of our system.

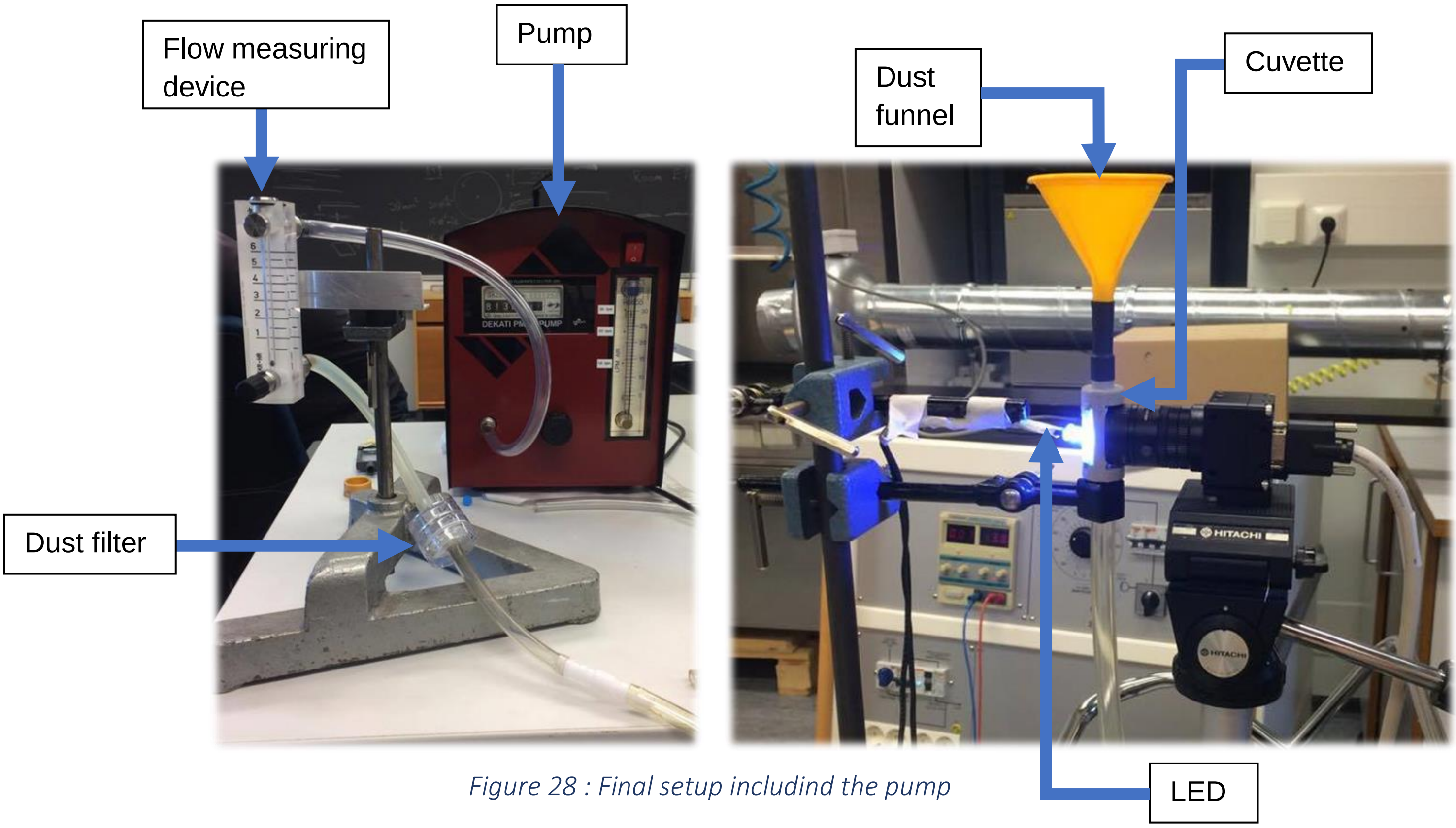


Figure 28 : Final setup includind the pump

To proceed, we firstly tried to do measurements using Kaolinite which imitates paper dust characteristics, using the pump to creat a 0.9L/min flow.

But I quickly realized that the quality of our system was maybe too low to see those very thin clay particles, indeed all our expirements failed. So I decided to realise differents tests to study the size of the particule of Kaolinite.
For that I used dust measuring devices presented in the equipment part and I tested the standard conditions without paper dust, then I tried with the Kaolinite and finally I started again with real teared paper. The Boulder counter has a range from 5 to 100µm whereas the particle counter has a smaller range from 0.5 to 10µm. Finally the 0.5 to 10µm was useless because our camera can't do measure below 14.5 µm, however they confirmided the trend : most of the particles are located in the smallest size columns.

Particles sizes (in µ)	5	10	25	40	50	100	total
Air 1	358	122	5	0	1	0	486
Air 2	546	228	7	0	1	0	782
Kaolinite 1	53281	6370	8	0	2	0	59661
Kaolinite 2	1590	257	3	0	0	0	1850
Teared paper 1	99637	11708	175	1	30	2	111553
Teared paper 2	90085	12996	188	3	41	2	103315

Figure 29 : Table of the dispertion of dust particles depending on the size

With this table I could deduce the dispertion of the dust particles depending on their size, the major part of particles are lower than 10 µm with 89% of thel lower than 5 µm and 10.5% of them lower than 10 µm for the Kaolinite and for teared paper. We can observe an incongruous measure because of the value difference between the test 1 and the test 2 for the Kaolinite it could be explained by the fact that I did the first Kaolinite measure just after the teared paper test, and it has polluted the first test. But the most important is the global view : for teared paper we still have hundreds of particles higher than 25 µm. Therefore, I decided to tear paper above the dust funnel with the hope to observe and measure some dust particles in motion.

Hopefully it worked, we achieved one of our main goal : measuring paper dust in motion.
Depending on the settings we could observe some dust particles in motion, for instance with a flow of 0.9L/min an aperture with K = 4 and 20µs of shutter speed we could not observe it.

It worked only for these two settings :

- a flow of 5L/min an aperture with K = 16 and 2000µs of shutter speed.

- a flow of 5L/min and an aperture with K = 4 and 20µs of shutter speed.

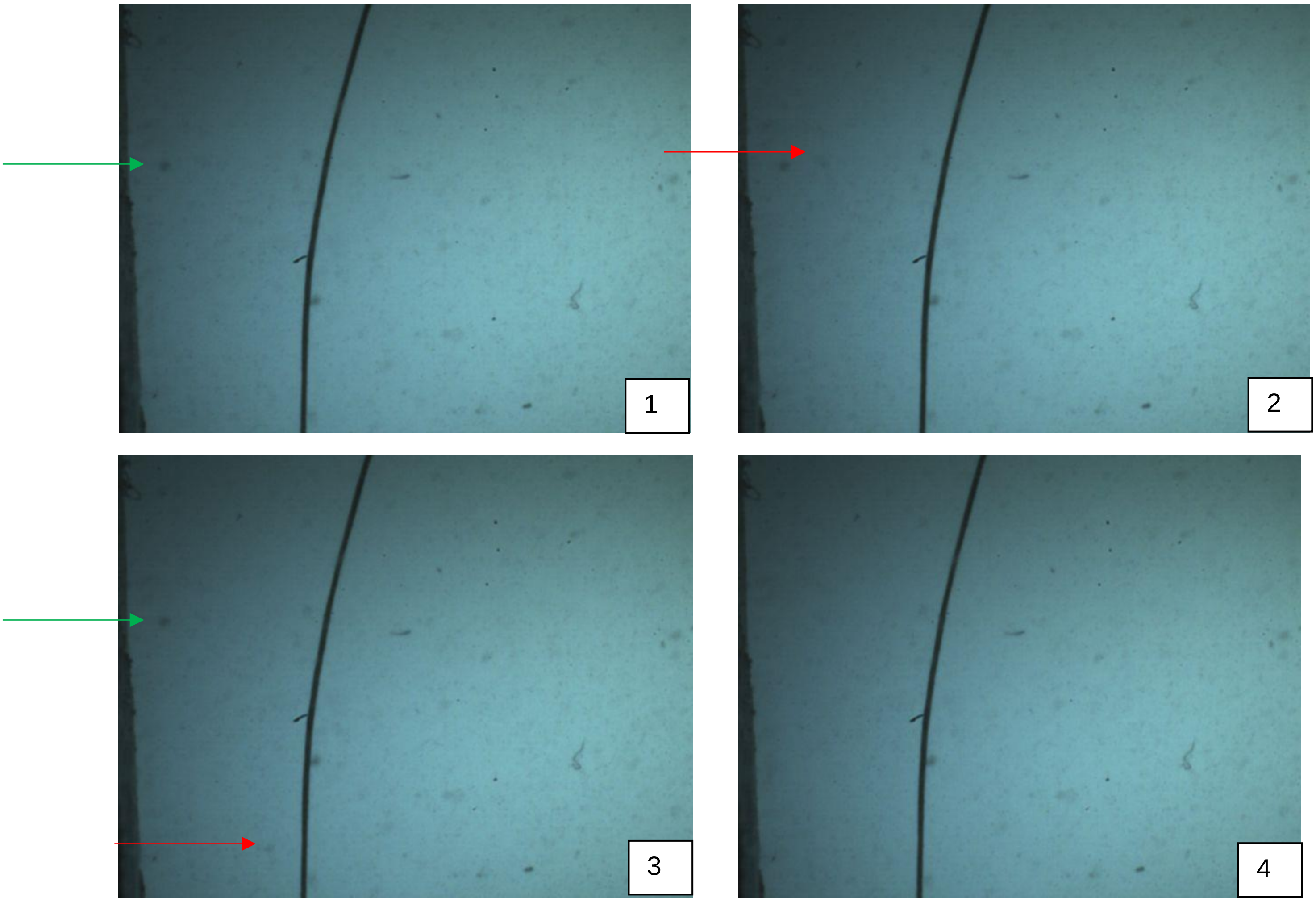


Figure 30 : Result of the last experiment

In the figure 30 you have two colored arrow which show 2 different particles moving for a flow of 5L/min an aperture with K = 16 and 2000µs of shutter speed.
It is really hard to see with these stationnary images, with a video or thanks to image processing it could be more visible.
Only few hundreds are observable that explains the low amount of particles. We could not study it and go further, try other settings or even do image processing because of the time.
We did also a last test measuring the field of vision but it was the same we could not dot calculous or use it for the same reason.For that we did 5 measures of hair for each coefficient K of aperture : for the first measure we positioning the camera at the maximum of sharpness then we went up and down to find the limit before the apparition of the blurr effect and finaly again we went up and down to determine the uper and low limit when the hair started being half visible. With a measuring device at the top of the camera which enables to determine small height variation.

aperture value	16	8	4	1,4
1/2 visible	0	1.92	0.95	1.17
upper limit	0	0.5	0.2	0.23
maximum sharpeness	0	0	0	0
down limit	0	-1.03	-0.6	-0.4
1/2 visible	0	-2.44	-1.25	-0.91
upper down limit difference	0	1.53	0.8	0.63
1/2 visible difference	0	4.36	2.2	2.08

Figure 31 : table of measures to determine the field of vision

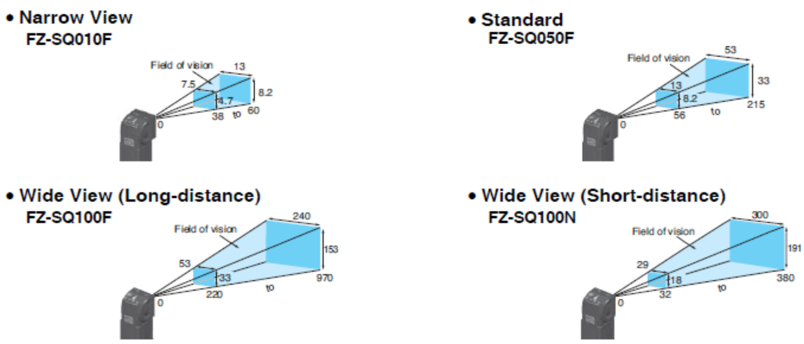


Figure 32 : Pictures showing several fields of vision

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10 Conclusion

During this project, I have suffered a lot of problems. The most important issue was the Sysmac Studio software which blocked us during one entire month. However, this problem was just hiding other ; communication problems (with the OMRON industry), material problems such as the differences between the characteristics expected from the datasheet and the real features.

For me it was also difficult because of the literature work. We had to read 800 pages just for the user manual of the FZ-PanDA software and again 800 hundred more pages for its refer manual. And with the previous software it was almost the same. I also have to admit that the theoretical level was important, even if our tutor didn't ask us to do the processing part I tried to study the user manual in order to try some processing methods but it was a real failure. What is more the measuring and testing process was really difficult, indeed we had to analyse hundreds of pictures for each experiment.

In spite of all these annoyances we finally found a solution for the software and we could use properly the controller. Finally, the lighting system was finished and we established a final setup with a pump and we could, thanks of that, measure dust particles in motion for the first time with a Tamk camera, we achieved the main goal of our project, in other words we have setted and used our paper dust measuring camera system and we could do measuring paper dust in motion. However due to quality of the final set up and the camera's real features we still can't measures dust particle below 10µm which represents 99% of the paper dust particles and due to the time lost on the first software we could not analyse our final results and start the image processing in order to count the particle rate. This project can be widely exploited to bring advantages to not only paper quality-control but also the process of reducing paper dust, but it requires to improve the frame rate of the camera and also its resolution to see smaller particles.

11 To go further

A lot of improvements can be deployed to enhance our paper dust measuring system such as the work on the illumination system and control it with the software of the conrtroler in the idea of automating it. What is more the illumination intensity must be increased to reach at leats 1.8 Watt

With the dust tunnel it is obvious that we don't collect enough particles, it has to be changed just as the cuvette, a new one must be customized and tailored for our specific camera and lens, it must have the same size than the lens in order to improve the field of view and to cover all the cuvette.Moreover, dust particles stick to inside walls of the cuvette which is a source of error and inconvenience during the analyses, a method to remove the dust or that prevents dust to stick inside should be studied.

The pump and the flow have to be studied again, in order to reduce the size of tubes and have a smaller set up and also to calculate the real flow in L/min because we could observe dust motion for 5L/min and not for 1L/min so I think that there is a mistake somewhere.

12 References

[1]:FH-FZ **Users Manual**, **Cat. No. Z340-E1-07**, Version 5.30, OMRON Corporation, June 2014

[2]: FH-FZ **Refer Manual**, **Cat. No. Z341-E1-06**, Version 5.30, OMRON Corporation, June 2014

[3]:Operation Manual For Sysmac Studio, Cat. No. **Z343-E1-04**, OMRON Corporation, 2014

[4]:FH **Series DataSheet, Cat. No.Q197-E1-06A-X,** OMRON Corporation, 2014

[5]: "Improvement of a paper dust measuring collecting device by 3D printing", Alexis Chaudet, Tampere, 2015

[6] "Detection of Lint Using Machine Vision", Thesis presented for the degree of Master of Science in Energy Engineering Technology, 2016-2017 Spring Semester, Benjamin Filtjens.

[7] Sysmac Studio, Cat. No.**181E-EN-08**, OMRON Corporation, 2014

[8] "Programming of a LabVIEW interface for the creation of a measuring paper dust collecting device", Willian Moine, Tampere, 2016

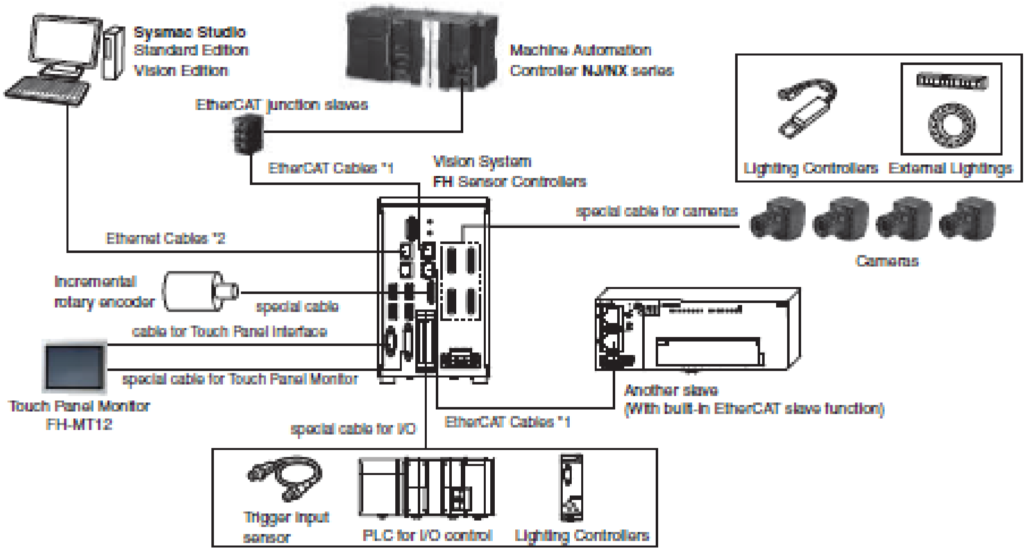
13 Appendix

Appendix 1 : Connections for the controller

System configuration

EtherCAT connections for FH series

Example of the FH Sensor Controllers (4-camera type)



*1. To use STP (shielded twisted-pair) cable of category 5 or higher with double shielding (braiding and aluminum foil tape) for EtherCAT and RJ45 connector.
*2. To use STP (shielded twisted-pair) cable of category 5 or higher for Ethernet and RJ45 connector.

Appendix 2 : OSPW5111P maximum ratings and characteristics of LED

OptoSupply

5mm Deluxe Power White LED
OSPW5111P

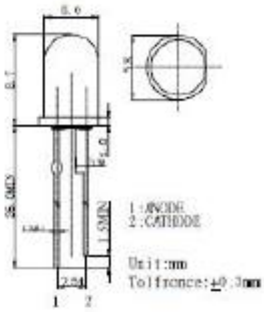
Features

- Deluxe Power LEDs
- 5o Standard Directivity
- Superior Weather-resistance
- UV Resistant Epoxy
- Water Clear Type

Applications

- Automotive Dashboard Lighting
- Back Lighting

Outline Dimension

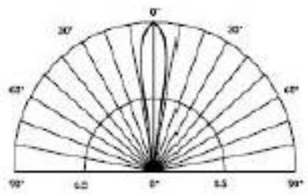


Absolute Maximum Rating (Ta=25℃)

Item	Symbol	Value	Unit
DC Forward Current	I_F	100	mA
Pulse Forward Current*	I_{FP}	150	mA
Reverse Voltage	V_R	5	V
Power Dissipation	P_D	500	mW
Operating Temperature	Topr	-30 ~ +80	℃
Storage Temperature	Tstg	-30 ~ +100	℃
Lead Soldering Temperature	Tsol	260℃/3sec	-

*Pulse width Max.10ms Duty ratio max 1/10

Directivity



Electrical -Optical Characteristics (Ta=25℃)

Item	Symbol	Condition	Min	Typ	Max	Unit
DC Forward Voltage	V_F	I_F=75mA	3.0	3.6	4.2	V
DC Reverse Current	I_R	V_R=5V			10	μA
Luminous Intensity	Iv	I_F=75mA	30000	40000	50000	mcd
Chromaticity Coordinate *	x	I_F=75mA	0.27	0.30	0.33	
	y	I_F=75mA	0.28	0.31	0.34	
50% Power Angle	2θ1/2	I_F=75mA		15	-	deg

LED & Application Technologies

VER A.0

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