Final Floc Size Measurement Research Report

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December 13, 2013

Abstract

This work presented preparations required to start developing and working on measurements related to floc size measurement. Literature was reviewed in order to find information about experiments setup and equipment. The camera we possessed was tested by pixel size measurement to evaluate its capacity. As it did not performed as expected, a new camera was then acquired. There was also the need to design a special cell through which flow would go so that good quality photos could be taken. The chosen solution was to have this flow cell adapted from a cuvette whose bottom was removed and sides melted and fused with a round tube with almost the same size so that the cell could be inserted into the system. Moreover, calculations of shear inside flow cell and camera properties were developed and further research done about software and connections options.

Introduction:

The development of a tool to measure flocculation size distribution in a non-destructive way is important to learn more about floc creation and possible breaking through the flocculation process. A digital camera will be used to create images of flocs passing through a thin flow cell made of a rectangular glass. This data will help to understand and potentially improve the flocculation system of AguaClara plants.

Literature review:

It is known in the literature that digital cameras have been successful in obtaining images of flocs and small particles and quantifying their size and distribution in a laminar or turbulent flow. Since flocs are fragile, the digital camera has proved to be an accurate non intrusive in-situ method.

A great number of cameras and devices can be used to capture images. One of the most employed was the AVT Firewire progressive scan with 1392x1040 pixels of resolution with a 2X objective lens.[1][2] This camera was able to measure flocs from 10 µm to 2.2 mm, capture images at a rate up to 17 frames per second and achieve a pixel size of 2.2µm/pixel. [2] Other paper also added that the AVT camera captured images at 10 Hz and has an interframing time of 40 µs.[3] The previous information is specially useful if further analysis of the flow field would be desired.

Another widely employed device is the Laser In-Situ Sizing and Scattering Trans-missometers (LISST-100X). It is a more powerful and complex device that can measure particles in a size range from 2.5 µm to 500 µm (Type C) or from 1.25 µm to 250 µm (Type B)[4]. Nevertheless, its complexity makes costs unfeasible for us.

A system assembly described by Kurmar et al. included a LED spotlight attached to a strobe controller coordinated by a computer program that triggered both the strobe and the camera at the same time. The strobe was implemented to

allow the capture of fast moving flocs by the camera. The validation of the camera method was done with the use of Coulter Counter solution of standard Polystyrene Latex with nominal sizes of nominal size of 10 µm, 20 µm and 30 µm.[1] The computer program ImageJ was an auxiliary image analyzing tool.

The steps to process the gray scale images of flocs are: noise reduction, thresholding the images to distinguish particles from background, applying an edge detection filter to identify in-focus particles, separating touching particles, and measuring geometric properties[2]. The thresholding process is done by selecting a minimum gray value above which all pixels are treated as particles. This process, however, cannot identify if a particle is in or out of focus. [2] Thus, an edge filter is required so that particles outside the plane that appear blurry and bigger will not introduce inaccuracies to the analysis. There are many different ways to implement an edge detection filter. More complex ones involve the use of a two-dimensional first-derivative Gaussian kernel in order to create gradient images [2]. A simpler treatment can be achieved by analyzing each pixel's neighborhood and detect the highest change in gray level. For the final step of measuring geometric properties, the individual floc size, d_f , can be easily calculate as

$$d_f = \sqrt{\frac{4A}{\pi}}$$

where A is the area of the particle.[2]. Keyvani et al. also showed that the fractal dimension of flocs can be calculated by conversion of 2D to 3D fractal dimension.

Methods:

Flow Cell Fluids Model

A flow cell is being designed to hold the flow while images are taken. A glass cell with a 2mm thick passage that is big enough to let the biggest floc pass through it will be used. The following equations specifies flow through a parallel plate:

$$u_{máx} = -\frac{1}{2\mu}\frac{\partial p}{\partial x}h^2 \quad [1]$$

$$\overline{V} = -\frac{h^2}{3\mu}\frac{\partial p}{\partial x} \quad [2]$$

$$\tau_{xy} = h\frac{\partial p}{\partial x} \quad [3]$$

where u is the fluid velocity, $\overline{V}$ is the mean velocity of the flow, μ is viscosity of water at 20ºC (1.002 $\frac{\text{mPa}}{\text{s}}$), p is pressure, and h is half of the distance between plates (1mm).

The maximum velocity gradient so that flocs do not break can then be calculated:

$$G = \sqrt{\frac{\eta}{\nu}} \quad [4]$$

where ν is the kinematic viscosity of water at 20ºC (1mm^2.s^{-1}) andη is estimated as a maximum of 10$\frac{\text{mW}}{kg}$.

G can then be obtained as 100s^{-1}. Since G is the maximum shear force that does not break a floc, Equations 3 and 4 can be set equal to each other and the derivative of pressure with respect to x can be obtained:

$$G = h\frac{\partial p}{\partial x} \quad [5]$$

$$\frac{\partial p}{\partial x} = \frac{G}{h} \quad [6]$$

The derivative allow us to obtain $\overline{V}$,the maximum velocity that do not break the flocs:

$$\overline{V} = -33.267\ \frac{m}{s} \quad [7]$$

Camera Properties

Some cameras and lenses were evaluated to be used in the project. Different aspects have to be considered before choosing the camera with the best set of lenses. Further calculations can be done to achieve camera resolution and accuracy. The following formulas were taken from Edmund Optics website[5]:

$PMAG = \frac{Sensor\ Size_{H\ or\ V}}{FOV_{H\ or\ V}}$

where PMAG is the Primary Magnification FOV is the Field of View, H stands for horizontal and V for vertical and SenSize is the sensor size in mm. The vertical FOV we desire is around 2mm so that particles as big as 1mm can be easily captured. Taking into account the monitor size, the system magnification and resolution can be calculated.

$System\ Magnification = PMAG \cdot \frac{Monitor\ Size_{Diag}}{Sensor\ Size_{Diag}}$

$Camera\ Resolution = \frac{1}{1.33} \frac{2 \cdot Sensor\ Size_{H}}{TVL_{H}}$

$System\ Resolution = \frac{Camera\ Resolution}{PMAG}$

where *Diag* stands for Diagonal, TVL is the TV Line specifications. the factor 1.33 was used take into account the sensor's ratio of 4:3. Both expressions for resolution have their results calculated by units of length.

$Measurement\ Accuracy = \frac{Pixel\ Error \cdot FOV_{H\ or\ V}}{Number\ of\ Pixels\ in\ Image}$

where Pixel Error is the error associated with each pixel. It is important to highlight that FOV and the accuracy have the same units at the equation above.

The following section applies the previous equations to the camera specifications in order to obtain more information about the camera's capability. Since TVL_H does not depend on the camera, it will be set as 570 for calculations.

Flea3 Monochrome GigE

This camera's specifications are the following:

Sensing Area, H x V (mm)	4.8 x 3.6
Pixels (H x V) (µm)	1288 x 964
Pixel Size, H x V (µm)	3.75 x 3.75
Pixel Depth	8 to 24 bit

This camera and this system had a resolution of 12.7 µm and 7.0 µm, respectively. The measurement accuracy obtained was of 6.23 µm.

AVT Guppy F-033

This camera's specifications are the following:

Sensing Area, H x V (mm)	4.8 x 3.6
Pixels (H x V) (µm)	658 x 494
Pixel Size, H x V (µm)	7.4 x 7.4
Pixel Depth	8 bit

This camera and this system had a resolution of 12.7 µm and 7.0 µm, respectively. The measurement accuracy obtained was of 12.15 µm.

AVT Guppy Pro F-031

This camera's specifications are the following:

Sensing Area, H x V (mm)	3.6 x 2.8
Pixels (H x V) (µm)	656 x 494
Pixel Size, H x V (µm)	5.6 x 5.6
Pixel Depth	12 bit

This camera and this system had a resolution of 9.5 µm and 6.8 µm, respectively. The measurement accuracy obtained was of 12.15 µm.

Flow Cell Model

The design of the flow cell includes the use of square glass tubes. There are mainly two types of glass used on the fabrication of square tubes. The first if borosilicate glass which has good optical properties at the visible spectrum, low refractive index and dispersion, and good chemical resistance. The second type is clear fused quartz that features, aside of the borossilicate properties, a very low coefficient of thermal expansion and good optical properties in the UV region of spectrum. Although the last material has better properties, none of the extra properties are absolutely necessary for our experiment. This way, borosilicate glass was the chosen material as it is less expensive and meets our needs.

The preliminary idea that is still being considered to make the transition from round to square glass tubes is to melt the sides of the glass in order to generate a circular pattern and attach into the input and output tubes. By considering that there is no energy dissipation on contraction, the use of a cell with a smaller size then the input tube is wiser. Thus, there is no risk of breaking the flocs at the entrance of the flow cell if our cell is narrower then the input tube. The tubing diameter is considered in a preliminary way to be of half an inch (1.27cm), which constraints our square tube size to a maximum of 0.35 in (9 mm). It may be difficult to melt down the square tube edges to a bigger sized circle and it could lead to usage of a larger square tube. Then, our square tube would have a minimum side size equal to the diameter of tubes which is half an inch (1.27cm).

A model was already sent to a glass shop at Olin Hall, Cornell. We expect that it will be possible to use a cuvette as a rectangular cell and have its bottom removed and sides melted to fit circular tubes in it.

Pixel Size Measurements

There was a camera at our disposal that could be useful to perform our tasks. Some measurements were run in order to check if this camera was appropriate.

	MP	Start pixel	End pixel	Distance from Lens (cm)	µm/pixel
Basler with 8mm lens	1.1	152	436	20	14084,51
Basler with 75 mm lens	1.1	68	424	100	280898,88
Web Cam	1.8	100	556	13	28508,77
iPhone	5.7	589	2343	10	5701,25

Table 1: Pixel size measurement results

The first and easier way to get this information is through pixel size measurements.

The camera we possessed was a Basler scA640-70fc with resolution of 658 pixels x 492 pixels and pixel size of 7.4 µm x 7.4 µm as the camera's specification. Lens of 8 mm and 75 mm were also available for use with the camera. Two other ordinary cameras were also tested to be used in comparison: a web cam and a cellphone's camera.The experiment was conducted by taking photos of a ruler and measuring how many pixels were between a distance of 4 cm.The results are in 1 below.

Even though the Basler had less megapixels of resolution, it performed better than the web cam. Even so, our camera had worse results mm/pixel than the iPhone due to the huge difference in resolution.

Software and connections options

The connection and software processing also have to be analyzed when choosing a camera. There are a few options that differ in transmission and processing speed, CPU load and availability. Some of them can be found listed below.[6]

Gigabit Ethernet and GigE Vision have a reasonable speed of 100 MB/s, a standard interface on different types of hardware and support long cables up to 100 m, but have limitations with CPU load.

USB 3.0 is a high speed connection with 350 MB/s speed and a standard hardware interface. It also has plug and play functions, low CPU load and can supply power to device as well.

FireWire is an older type of interface with more limitations. Due to its surpassed technology, it possesses a low speed up to 64 MB/s and a decreasing hardware and software support. However, this interface is still has a low CPU load and signal latency.

Camera Link can achieve the highest speed up to 850 MB/s and can also power up the device. Although it has become a standard interface, it still has limitations due to its high complexity.

Future Work

For the next steps we should order the camera and lenses we found that have the necessary resolution and focus and work on getting the flow cell done with the use of a cuvett. We should be careful with camera resolution since phenomenon as optical aberrations may lower this property. These aberrations are deviations from mathematical models used to make the camera and lens. The use of a back or front light is another point that needs to be debated and tested.

As a future work for the next group, camera installation and calibration are the first tasks. Calibration can be done with standard sizes particles. LabVIEW programming could be done in parallel so that images could start being analyzed as soon as they are ready. The main goal is to find the floc size distribution of the flocculated flow.

References

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