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Simulating Pixels

Monte Carlo and Charge transport simulation in Medipix detector systems

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Simulating Pixels

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This is dedicated to...

ABSTRACT

This thesis is about...

SAMMANFATTNING

Den här avhandlingen handlar om...

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LIST OF PAPERS

This thesis is based on the following papers, herein referred to by their Roman numerals:

Paper I
  This is the title of my first paper
  D.Krapohl, H.-E. Nilsson, S. Petersson, S. Pospisil, T- Slavicek and G. Thungström, Journal of Instrumentation, 2011 . . . . . . **??**

Paper II

Paper III

Paper IV

Paper V

Paper VI

Paper VII

Paper VIII

Chapter 1

INTRODUCTION

Measuring and controlling the properties of a fog of water droplets has been the interest and focus of many studies during at least half a century. Applications range from atmospheric studies, aircraft safety to military and commercial applications.

Icing caused by freezing atmospheric water can be a significant problem in cold climates, affecting infrastructure such as wind turbines, power lines, and road and air traffic. With the increasing importance of electric power generated by wind, there is a renewed demand predictions of icing on wind turbines. Icing on the blades of a turbine lowers the efficiency, increases noise and may force the turbine to a complete stop [1-4]. Aircraft, power lines or any other weather exposed structure share this problem. Therefore big efforts have been made to create models for how the ice is formed [5, 6] and how it can be included in weather prediction models [7, 8].

This thesis is an exploration of a cost effective and robust method to measure atmospheric liquid water in order to predict icing on ground based structures.

The measurement method is based on digital image processing in a shadowgraph system using LED light as background illumination. A prototype instrument is built and initially tested using a fog chamber. It is calibrated using a micrometer dot scale with circular discs printed on a silicon glass. Polymer microspheres are also used for size measurement verification.

The instrument is constructed using standard components with the intent of viewing possibilities of low cost volume production. It may e.g. be used for real-time icing condition measurement, or remote meteorological data collection.

Following is a brief description of related work and an introduction to the attached papers.

1.1 Related Work

In 1970, Knollenberg [23] described an electro-optical technique to measure cloud and precipitation particles using a laser illuminated linear array of photo detectors. The photo detectors are used to make a two-dimensional image of the particles' shadows as they pass the light beam. Systems based on this technique are called Optical Array Probes (OAP) or two-dimensional imaging probes. Later development of this technique includes using image sensors to save gray scale images of the detected particles [17, 22].

Light scattered from a focused laser [15, 24] is one common technique to measure single particles. A laser beam is used to illuminate passing particles. When a particle is detected, its size is determined by comparing the variations in light with a pattern derived from the Mie scattering solutions [25].

The OAPs and the light scattering spectrometers each have some advantages over the other technique depending on the nature of the aerosol. Instruments for airborne use have been developed that combine several techniques into one single probe [26] for accurate measuring of LWC and MVD [16].

A similar but different optical technique for measuring water droplets is based on in line holography [27]. In principle this is a two-dimensional shadowgraph imaging system that use laser background illumination to create images of the diffraction patterns created by the passing particles. These patterns are measured to reconstruct images of the particles. This is a fairly calculation intensive process, but which may be one of the reasons why instruments based on this technique are not so common [28].

Sizing of the droplets using Mie spectrometry is a complex operation even for coherent light [29], and although it is possible to study Mie scattering from white light [30], the complexity, small droplet size range and sample volume makes it less attractive in this application. The optical resolution is usually too low. Therefore it is also difficult to determine the exact particle size and the usable depth of field for incoherent shadowgraph systems. The shadow from a particle can e.g. appear smaller or larger when out of focus.

Shadowgraph imaging of particles using incoherent illumination instead of laser has been tried e.g. in particle shadow velocimetry (PSV) [31, 32], or spray characterization [33]. Quantitative and comprehensive studies of other droplet measurement techniques exist [24, 28, 34].

Kuhn et al (2012) described a method to characterize ice particles by Fourier shape descriptors (Granlund 1972). The system uses a microscope-like technique to achieve a high resolution level, in the order of one micrometer. Perhaps this method can be used also for larger scale objects like snowflakes. The system described by Kuhn et al has a field of view of 200x150um and a depth of field of approximately ten micrometers.

— Chapter 2 —

THEORY

2.0.1 Forming of Ice

Apart from being a rather complex phenomenon in itself, icing on wind turbines is forming differently from the ice accretion on an aircraft airfoil. First since the turbine is stationary it cannot stop icing, or de-ice by moving to a different condition. Same conditions may also continue for days or weeks. Secondly the turbine blade moves concentrically making the tip of the blade the fastest, and occasionally highest moving part. The remote and exposed position of icing makes it difficult to detect ice directly when it is initially formed (Matthew C. Homola, Nicklasson, & Sundsbø, 2006).

2.0.2 Liquid Water Content and Median Volume Diameter

The liquid water content (LWC) and the water droplets median volume diameter (MVD) are essential input parameters to predict or model icing. The MVD is given at the point where half of the total volume of liquid content in a fixed air volume consists of droplets with diameters larger and the other half has smaller diameters. For estimation of icing, the MVD has been shown to be a good indicator (L. Makkonen, 1992).

Although there do exist methods to measure these properties, they are scarcely ever measured at a planned or existing wind turbine [9, 10]. Measuring them accurately and frequently would be an advantage for the planning of new wind mill farms or for the application of anti-icing arrangements on existing power stations. It may be of particular interest as input to weather prediction models by which both LWC and MVD can be computed [7, 8]. In combination with information about the aerodynamic properties of the wind turbine, it can give more accurate predictions of icing or even result in better design of wind turbines and anti-icing methods.

While icing caused by large supercooled droplets, with diameters from approximately 50 μm to exceeding 1000 μm, is often considered severe due to its shape and quick build-up, icing may occur even with droplets as small as 5 μm [11-13]. In most cases, though, icing is caused by cloud droplets measuring between 10 μm and 30 μm in diameter [10, 12]. Although optical imaging and other techniques for measuring aerosol properties is continuously improving, the choice of instrument is still very much dependent on the application's requirements [14-17]. An instrument for measuring icing parameters for wind turbines should be able to detect supercooled cloud droplets from five micrometer and determine an accurate measure of the LWC. Since measurements are needed in multiple remote locations it should also be affordable, reliable, have low power consumption, and ideally be possible to place near the highest point of the turbine [18].

2.1 Optical Properties

Instruments based on Mie calculations of light scattering have the issue of dealing with aliasing in the sample bin resolution, leading to spikes in the size distribution (Evaluation of the Forward Scattering Spectrometer Probe-Baumgardner 1990, Spiegel Zieger 2012).

2.1.1 Light Spectrum

In visible light, water is almost transparent. This means that the imaginary part of the refractive index, i.e. the absorption, is very small, while for some higher and lower wavelengths it increases with a factor of almost ten power to ten (Segelstein, 2011). This fact is used in two-color lidar measurements (Westbrook, Hogan, O'Connor, & Illingworth, 2010).

The real part of the refractive index for water is much more stable, approximately 1.34 at 455nm light (Hale & Querry, 1973).

A spherical lens in the form of a droplet will scatter almost all of the light that reaches the droplet from different directions. Some of the light will also be absorbed, albeit the absorption of a single water droplet is negligible due to its small volume and because water absorb very little in the visible spectrum.

The combined effect of scattering and absorption is the extinction (Bohren & Huffman, 2008). Due to this combined effect, clouds look nontransparent from a distance. Measuring extinction is possible in aerosols e.g. by using Raman LIDAR (Ansmann, Riebesell, & Weitkamp, 1990).

2.2 Materials

2.2.1 LED Light Source

LEDs can sometimes be used with currents far above the specifications, as long as the pulse length is short and the duty cycle is low enough to permit the heat generated to be transported away between the pulses. Using the LED above specifications may though affect the efficiency and aging of the LED. LED emittance also depends on the temperature. Depending on the capacitance of the diode, the rise time may limit the current, although there exist some techniques to shorten the LED pulses (Tanaka, Umeda, & Takyu, 2011; Veledar et al., 2007).

2.3 Image Segmentation

Edge detection can be done in several ways. The simplest method is to use a threshold at a fixed level and define the edge as the transition between above and below that threshold (Gonzales & Woods, 2002). Other techniques use different methods to measure the gradient of the change in intensity (Canny, 1986; Marr & Hildreth, 1980)

2.4 The Impact

Makkonen and rotating cylinders...

The icing process is complex and the result depends on a combination of the aerodynamic shape of the structure or airfoil, the velocity of the air and its contained water, the temperature, the mixing of snow and water, the concentration of liquid water and the droplet size distribution. The figure below illustrates the difference between large and small supercooled droplets passing an aerodynamic profile.

A particle's eagerness to follow the flow or collide depends on several factors, like the flow velocity, the size of the obstacle, the density and drag coefficient of the particle. This relationship is known

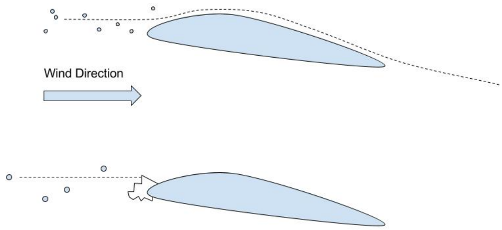

Figure 2.1: Supercooled water droplets on collision course with an aerodynamic profile.

in fluid mechanics as the Stokes number (Stk). Small droplets or particles with Stk « 1 may continue with the airflow around the profile, while large droplets or particles with Stk » 1 due to their inertia collide with the structure. A supercooled droplet colliding with a structure would likely freeze on the impact.

All droplets or particles approaching an obstacle are affected by the change in pressure and wind direction surrounding it, a fact which complicates measuring the concentration of particles in unaffected air. Measurement probes working by extraction of air using a mechanical air pump would expect a loss of particles with large Stokes numbers. Ideally the measuring device would affect the flow as little as possible.

Measuring particles from aircraft is complicated by the high air speed. The sample is affected by the change in pressure surrounding the aircraft and by particles hitting parts of the probe, splintering or changing direction. (ref) An instrument fixed to the ground on the other hand is affected by the wind speed relative to the ground. This means that it needs to be directed in the direction of the wind. Particles may also enter the measurement zone from different directions depending on their Stokes number, which has been shown to have a large impact on the measured liquid water content (ref).

— Chapter 3 —

METHODS

3.1 Starting Studies

Infrared and Visible Light We describe the measured droplets as spherical lenses made of pure water at a constant temperature, surrounded by air. For simplicity we assume that the refractive index of air is equal to one.

3.1.1 Laser Light

3.1.2 Image Noise

3.1.3 Light Sensitivity Measurement

3.1.4 Speed of Light Flash

3.2 Design Considerations

We describe the measured droplets as spherical lenses made of pure water at a constant temperature, surrounded by air. For simplicity we assume that the refractive index of air is equal to one.

3.2.1 Optics

We assume that the optical silhouette of a droplet is comparable to a dot having equal diameter and being printed on a silicon glass. It is not a new concept and has at least once been proved experimentally for coherent light, by comparing with beads of glass and water droplets of known sizes (Korolev, Kuznetsov, Makarov, & Novikov, 1991). The shadow image of water drops of any size will be defined mainly by the diffracted component, as long as the distance between the drop and the lens is much larger than the drop diameter. Only in a small bright spot in the middle will the refracted component be large

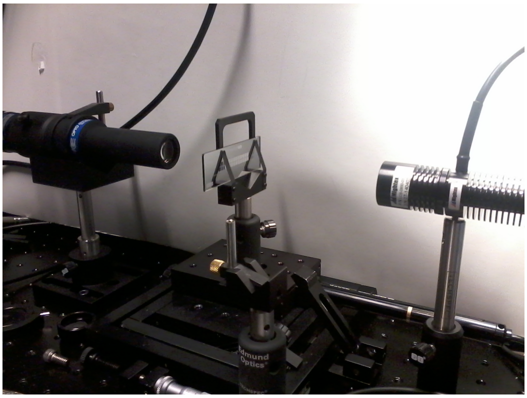

Figure 3.1: Figure showing the experimental setup with a dot micrometer scale as test object mounted on a translation stage.

enough to be visible in a shadowgraph system (Korolev et al., 1991; Wendisch & Brenguier, 2013).

3.3 The Shadowgraph System

The system consists of a monochrome digital image sensor with a telecentric lens and a collimated LED illumination.

Calibration of true droplet size and measuring range both depends on the measured size of the droplet shadow and the amount of light used for exposure. It is possible to predict both the precision of the measured size and accuracy for measurement of droplet size.

A value of both MVD and LWC can be derived from a series of images and since the number of measured droplets will depend on the concentration, the accuracy and precision will depend on the number of samples from the total population of droplets.

Many existing instruments suffer from errors caused by the instrument itself during sampling, e.g. when droplets get stuck on the inlet [19], or shatters into smaller droplets [20]. An instrument should be designed in order to affect the free flow of particles as little as possible [16]. Therefore we also investigate the illuminative power required to get a good exposure with the tested system at a targeted maximum wind speed of 50 m/s.

We used a stage micrometer scale for characterization of the system and simulation of water droplets. This characterization holds true given that the optical silhouette of a droplet is comparable to a dot having equal diameter and being printed on a silicon glass. It is not a new concept and has at least once been proved experimentally for coherent light, by comparing with beads of glass and water droplets of known sizes [21]. The shadow image of water drops of any size will be defined mainly by the diffracted component, as long as the distance between the drop and the lens is much larger than the drop diameter. Only in a small bright spot in the middle will the refracted component be large enough to be visible. [21, 22]. Using the results of this study, a weather protected prototype may be built to perform a comparative study.

The design using a weakly collimated LED that illuminates an area slightly larger than the field of view makes the system quite insensitive to misalignment of the camera and the light source. Temporal or permanent changes in light intensity caused by a minor misalignment can be automatically compensated for by continuous measurement of the total exposure level. If the level of exposure is increasing or decreasing, the length of the light pulse is changed correspondingly. The light intensity can also be affected by dirt on the front glass of the housings.

Spatial dissimilarities in the light intensity that are not caused by noise we can compensate for by calculating the local average intensity of the background around each measured droplet. The size of a droplet is then based on the intensity dip caused by the shadow compared with its local background.

making a flat-field correction. This is done by constructing an average image by the last 20 images and using this as a

3.4 The Fog Chamber

The fog chamber is needed partly for practical reasons since natural fogs tend not to occur just when we are ready to test. It gives an indication of how the instrument will behave in a real measurement. It is also a verification of the instrument's water ingress resistance. The chamber has a frame made of 30 mm aluminum profiles, fitted

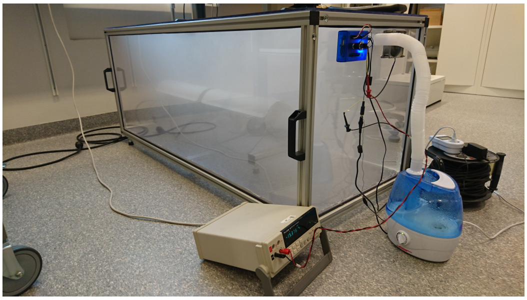

Figure 3.2: Fog chamber with connected droplet generator (blue container) and a multimeter used for fan power measurement. A Beaglebone Black microcontroller (blue box) is used for fan speed regulation.

with transparent 6 mm polycarbonate walls on all sides using rubber sealing strips. The droplets are produced using an ultrasonic fog generator pushing the droplets to the chamber through a flexible tube approximately 30 mm in diameter and 500 mm long. Next to the fog inlet, there is a dry air inlet with a speed adjustable fan. See Fig. 7. On the back of the chamber there is a similar sized outlet for air and moisture.

$$E' \quad \hbar\omega' \quad \frac{\hbar\omega}{1 \quad \frac{\hbar\omega}{m_e c^2}(1 - \cos\theta)} \tag{3.1}$$

3.5 Hybrid pixel detectors

cite Medipix paper

?? shows a hybrid pixel detector.

Rember to write more text here...

— Chapter 4 —

DISCUSSION

4.1 Starting Studies

Infrared and Visible Light
    Laser Light
    Image Noise
    Light Sensitivity Measurement

4.1.1 *Speed of Light Flash*

4.1.2 *Aerodynamics*

Many existing instruments suffer from errors caused by the instrument itself during sampling, e.g. when droplets get stuck on the inlet (Spiegel et al., 2012), or shatters into smaller droplets (Cohen, 1991). At higher wind speeds, there may be an effect of particles shattering and bouncing on the supporting structure making up the instrument (Field, Heymsfield, & Bansemer, 2006). An instrument should be designed in order to affect the free flow of particles as little as possible (D. Baumgardner et al., 2011).

4.1.3 *Optics*

Using a high power LED instead of laser reduces the interference effects used in e.g. holography (Henneberger et al., 2013), but since it is a monochromatic source, interference may not be completely ruled out. The coherence length, provided a Gaussian spectrum, can be approximated by Eq. 12 (Akcay, Parrein, & Rolland, 2002): $equation12l$

LEDs can sometimes be used with currents far above the specifications, as long as the pulse length is short and the duty cycle is low enough to permit the heat generated to be transported away between the pulses. Using the LED above specifications may though affect the efficiency and aging of the LED. LED emittance also depends on the temperature. Depending on the capacitance of the diode, the rise time may limit the current, although there exist some techniques to shorten the LED pulses (Tanaka, Umeda, & Takyu, 2011; Veledar et al., 2007).

check these facts

4.2 Droplets and Ice Interference

Droplets that are very close are likely to coalesce, thereby decreasing the number concentration at a rate that appears to increase for larger droplets and more complex droplet size distributions (Bordás, Hagemeier, Wunderlich, & Thévenin, 2011).

Due to the small depth of the measurement volume, i.e. the measuring range compared with the field of view, the likelihood of finding two droplets very close in the image is very low due to the low number concentration of droplets we are measuring.

A solution is to make a measurement of the droplet's circularity and add this as selection criteria for the measurement. This solution also works as a filter for ice or snow particles.

4.3 Icing

the risk of icing increases with increasing wind speed (Lasse Makkonen, 2000)

Calibration of true droplet size and measuring range both depends on the measured size of the droplet shadow and the amount of light used for exposure. It is possible to predict both the precision of the measured size and accuracy for measurement of droplet size.

A value of both MVD and LWC can be derived from a series of images and since the number of measured droplets will depend on the concentration, the accuracy and precision will depend on the number of samples from the total population of droplets.

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The design using a weakly collimated LED that illuminates an area slightly larger than the field of view makes the system quite insensitive to misalignment of the camera and the light source. Temporal or permanent changes in light intensity caused by a minor misalignment can be automatically compensated for by continuous measurement of the total exposure level. If the level of exposure is increasing or decreasing, the length of the light pulse is changed correspondingly. The light intensity can also be affected by dirt on the front glass of the housings.

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making a flat-field correction. This is done by constructing an average image by the last 20 images and using this as a

— Chapter 5 —

CONCLUSION AND OUTLOOK

5.1 Conclusion

This is the title of my first paper

D.Krapohl, H.-E. Nilsson, S. Petersson, S. Pospisil, T- Slavicek and G. Thungström