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Visualization of Ink Fluidity in Inkjet Imaging Process Using Method of Optical Coherence Tomography

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Abstract

In order to enhance the performance of the inkjet printer, it is important to be able to appropriately control the ink fluidity in the imaging process. For examples, it is useful to know how the ink fluidity changes when inside the inkjet head or when adhering to the media. As a method that can be used for this judgment, it was attempted to use method of optical coherence tomography was attempted. It is clarified that the fluidity distribution and its time change inside the ink can be visualized by optical measurement and signal analysis. It will bring way to know if the control condition of ink fluidity is appropriate.

Background and Purpose

In order to achieve high speed, high image quality and high reliability in the inkjet process, it is important to successfully control the fluidity of ink during the imaging process. For example, when paying attention to the viscosity of the ink, it is desirable to keep the ink in the head within an appropriate low viscosity range in order to cause the ink to fly from the ink jet head without trouble. On the other hand, after the flying ink droplet adheres to the medium, it is desirable that the ink quickly has a high viscosity range in order to avoid mixing of adjacent ink droplets and disturbing the image. In this way the ink is controlled to change viscosity significantly during the imaging process.

In an inkjet system using an aqueous pigment ink, in order to keep low viscosity of the ink inside the inkjet head, a cap is attached to prevent evaporation of the ink solvent during non-operation, or refresh operations are periodically performed during operation. By doing this, it is possible to fly ink droplets with the target size and speed at all times. On the other hand, the flying ink droplets wet and spread after adhering to the medium to form ink dots. In order to increase the viscosity of the ink droplets quickly, the treatment liquid may be applied to the medium in advance. The treatment liquid contains a coagulant for agglomerating dispersed particles such as pigment particles contained in the ink and agglomerates the dispersed particles by acting on the ink droplets to increase the viscosity of the ink droplets.

Verifying such ink state changes will help to optimize the imaging process for inkjet systems of various applications. However, it is not easy to grasp the fluidity of the ink directly during the imaging process. To date, fluidity of ink in the inkjet head has been estimated by observing the movement of the meniscus in the vicinity of the nozzle [1]. In this method, it was impossible to grasp the fluidity inside the inkjet head. Also, observing the speckle pattern of the laser beam irradiated on the ink droplet on the medium, it has been known to grasp the phenomenon of lowering fluidity [2]. In this method, the fluidity distribution and its change in the thickness direction of the ink layer were unclear.

The purpose of this research is to visualize temporal change of fluidity of ink during inkjet imaging process. As a result, it can be confirmed whether or not the ink fluidity is changing aimed as intended.

Visualizing Method and Experimental Setup

In order to confirm that the ink viscosity was not changed or changed as intended in the imaging process, we attempted to visualize the state change of the ink using method of optical coherence tomography (OCT). By irradiating measuring light to a measurement object such as ink, OCT can acquire scattered light intensity distribution in the thickness direction in a non-contact and non-destructive manner. By analyzing the temporal change of the scattered light intensity distribution, it is possible to estimate the flow state of the measurement object and its change.

When the pigment ink is irradiated with the measurement light, a part of the light penetrates into the ink and is scattered by the pigment particles, so that scattered light is generated at each position on the light ray. Based on the principle of the low coherence interferometer, by acquiring the scattered light intensity generated at each position with time, it is possible to acquire the temporal change of the scattered light intensity distribution generated in the ink.

A schematic diagram of the experimental system of OCT used for measurement is shown in fig.1. As a light source, a broadband light source having a center wavelength in the near infrared region was used in order to make it easy for light to reach the inside of the ink. The interferometer is configured so as to divide this light into the signal light irradiating the ink and the reference light to be applied to the mirror, and combines the return lights. The coupled return light is detected by the spectrometer and if scattered light is generated in the ink, spectral interference signals having a fringe spacing corresponding to the position are overlapped. The coupled return light is detected by a spectroscope, and if scattered light is generated in the ink, a signal in which spectral interference signals having a fringe spacing corresponding to the position are superimposed is obtained. Replacing the interference fringe spacing with the position information in the space by performing inverse Fourier transform on the detected spectrum, the scattered light intensity distribution in the ink is obtained.

Dispersed particles such as pigment particles contained in the aqueous pigment ink undergo Brownian motion in the solvent. The degree of Brownian motion is represented by the diffusion coefficient by the Einstein-Stokes equation and has the following relation.

$$D = \kappa T / 6\pi\eta d \quad (1)$$

where D is diffusion constant, κ is Boltzmann's constant, T is absolute temperature, η is viscosity of solvent and d is particle size. The high diffusion coefficient of ink means that the movement of particles is fast and the fluidity of the ink is high, and the low diffusion coefficient means that the movement of the particles is slow and the fluidity is low. When the viscosity rises due to the evaporation of the solvent of the ink or the pigment particles aggregate and the apparent dispersion particle diameter increases, the fluidity of the ink decreases. On the other hand, when the measurement light is irradiated to the ink whose position of the particle is fluctuating, the position where the scattered light is generated also fluctuates. Each particle in the ink generates scattered light while changing its position. And some of them, as backscattered light, returns to the incident direction while optically interfering with the scattered light generated by neighboring particles. Therefore, the fluctuation frequency of the scattered light intensity distribution in the ink observed with the OCT becomes higher as the position fluctuation of the scattering particle becomes faster, and becomes shorter as the position fluctuation of the scattering particle becomes slower. In order to grasp the distribution of the fluidity in the ink layer by utilizing this relationship, measurement as follows will be performed. Measurement light is made incident on the ink layer, and scattered light intensity in the ink layer by OCT Obtain temporal change of distribution. For each position in the ink layer, the fluctuation frequency of the scattered light intensity is analyzed. If the scattered light intensity seems to fluctuate frequently, the fluidity of the ink is relatively high, and conversely, if the fluctuation of the scattered light intensity is slow, the fluidity of the ink is relatively low.

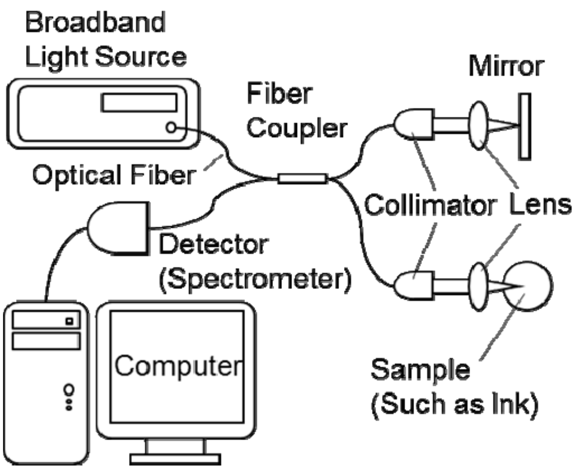

***Fig.1** Outline drawing of experimental setup using optical coherence tomography*

Experimental Result

The fluidity of the ink in the inkjet head and the fluidity change of the ink adhered to the pretreated medium were visualized.

Visualization of Ink Fluidity in Inkjet Head

Fig.2 shows an outline drawing of experimental setup for visualizing ink fluidity in the vicinity of nozzles in the inkjet head. And guides the collected measuring light to the inside of the inkjet head through the nozzle hole. The interior of the head is filled with an aqueous pigment ink, and if scattering particles are present, scattered light is generated. Fig.3 shows an example of tomographic images of ink and inkjet head acquired by scanning the measurement light in the direction of the nozzle array by OCT. The image lateral direction is horizontal to the nozzle surface, and the image longitudinal direction is vertical to the nozzle surface. The tomographic image is colored so as to change in order of black, yellow and red as the scattered light intensity becomes higher.

Since the inkjet head is made of a metal, the inkjet head reflects light on its surface, and the scattering light intensity distribution has a high peak in the nozzle surface. At the position where the measuring light is incident on the nozzle hole, strong reflected light such as occurs at the nozzle surface is not observed, and weak reflected light can be seen. It is inferred that the weak reflected light seen near the nozzle surface is reflected light generated at the meniscus surface. In the upper part of the meniscus, there is a region that generates scattered light, and it can be confirmed that the nozzle is filled with ink. On the further inner side of the ink layer is the inner wall of the head, and strong reflected light can be seen. Therefore, among the regions in the vicinity of the nozzles in the head, the fluidity of the ink filled from the nozzle surface to the inner wall can be grasped.

Fig.4 shows the temporal change of fluidity at each position in the area from the nozzle surface to the inner wall. Fig.4 (1) shows the change in fluidity of the ink A, fig.4 (2) shows the change in fluidity of the ink B, which are measurement results of aqueous pigment inks of different types. The horizontal axis of the graph indicates the elapsed time since the measurement was started after refreshing the nozzle, and the vertical axis of the graph indicates the distance from the meniscus of the filled ink. And the graph is colored so as to change in order of blue, green, yellow and red as the fluctuation frequency of the scattered light intensity becomes lower. In other words, the closer the display in the graph is to red, the lower the fluidity. It can be seen that the area of the ink A having a slightly low fluidity is enlarged from the nozzle side as time elapses. On the other hand, in the ink B, it can be seen that the region with extremely low fluidity is enlarged from the nozzle side with the lapse of time. Since the regions with low fluidity are enlarged from the nozzle side in any of the inks, regarding the thickening phenomenon caused by the decrease of the volatile solvent in the ink due to the evaporation from the nozzle, it is considered that the depth direction distribution of ink fluidity and the change with time of it in inkjet head has been visualized.

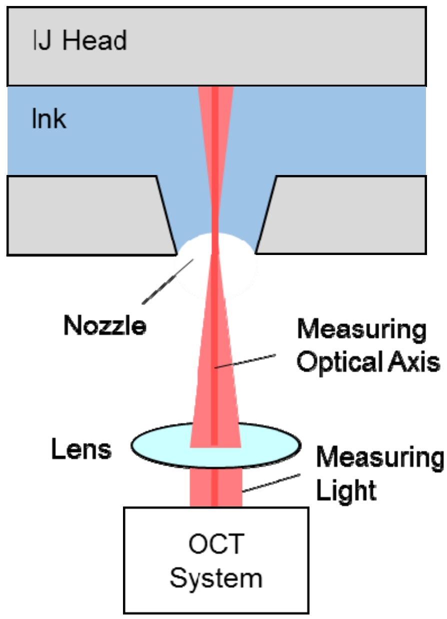

***Fig.2** Outline drawing of experimental setup for visualizing ink fluidity in the vicinity of nozzles in the inkjet head*

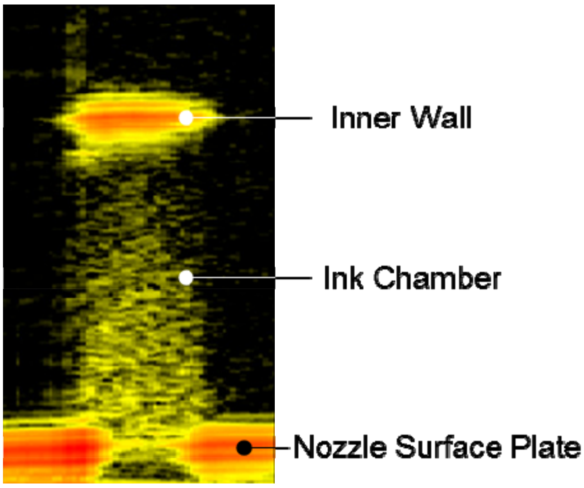

Fig.3 *example of tomographic images of ink and inkjet head*

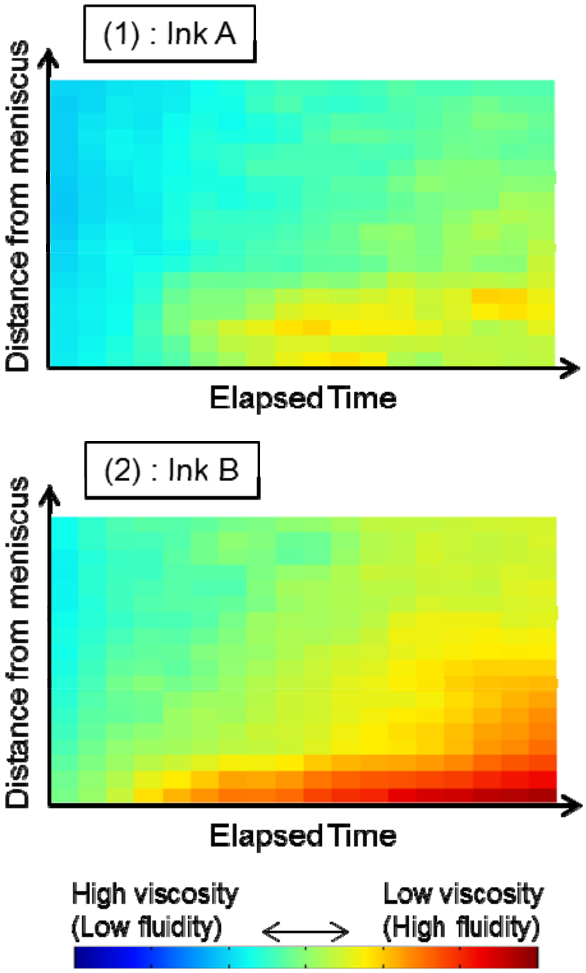

Fig.4 *Graphs which shows temporal change of ink fluidity at each position in the area from the nozzle surface to the inner wall of inkjet head*

For example, it can be estimated that the fluidity of the ink in the vicinity of the nozzle is liable to decrease in a short period of time compared to the ink A in the ink B. With this information, it is possible to decide the timing and the operation amount for discharging the ink in the thickened region in the nozzle or causing the operation to recover the fluidity. In addition, it is possible to design or select an ink which does not lower flowability even if evaporation of the ink solvent proceeds from the nozzle hole.

Visualization of Ink Fluidity on the Medium

Fig.5 shows an outline drawing of experimental setup for visualizing the fluidity of ink adhering to pretreated media. The medium was irradiated with the focused measuring light, and the ink was adhered to the vicinity of the irradiated part by using an inkjet head. The attached ink droplet spreads over the medium. The measuring light is incident on the medium at an angle. The reason for this is to avoid detecting strongly reflected light occurring on the surface of the ink droplet and to observe the thin ink layer in an enlarged manner.

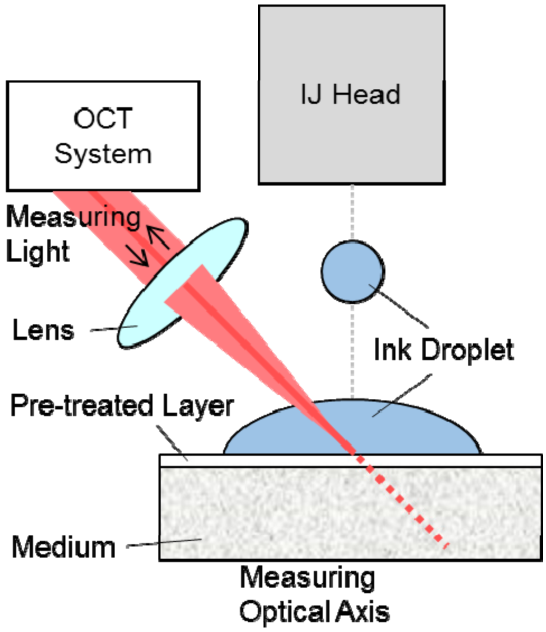

Fig.5 *Outline drawing of experimental setup for visualizing the fluidity of ink adhering to pretreated media*

Fig.6 shows the temporal change of the scattered light intensity distribution occurring in the ink C when the ink C adheres to the medium coated with the pretreatment liquid containing the different amount of flocculant. The amount of flocculant is increased in the order of fig.6 (1), (2), (3), (4). The horizontal axis of the graph indicates the elapsed time from immediately before ink adhesion. The vertical axis indicates the position on the measuring optical axis, which may be read as the position in the thickness direction of the ink layer. Supplemental lines are attached to the fig.6. The dashed blue line means the boundary between air and ink, or the boundary between ink and media. That is, in any of the figures, it is understood that the ink layer is reduced in height by spreading, evaporation or the like after adhering to the medium. The yellow dotted line is added to the position considered to be the dispersed. In the region closer to the medium than the yellow boundary between the region in which the particles contained in the ink aggregate and the region in which the particles are dotted line in the ink, it is considered that the coagulant contained in the applied pretreatment liquid diffuses into the ink and agglomerates the scattering particles to lower the fluidity. This is because the fluctuation frequency of the scattered light intensity is low in this region, and in fig.6 it is a streaky image in the time series direction. It can be seen that the fluctuation frequency of the scattered light intensity is short and the state of high fluidity continues in the region not affected by the coagulant, that is, in the region away from the medium rather than the yellow dotted line. in the region considered not influenced by the coagulant, the fluctuation frequency of the scattered light intensity gradually decreases as the elapsed time progresses, and a streaky image is formed in the time series direction. This is presumed to have been caused by viscosity increase or solidification due to evaporation of the ink solvent or the like.

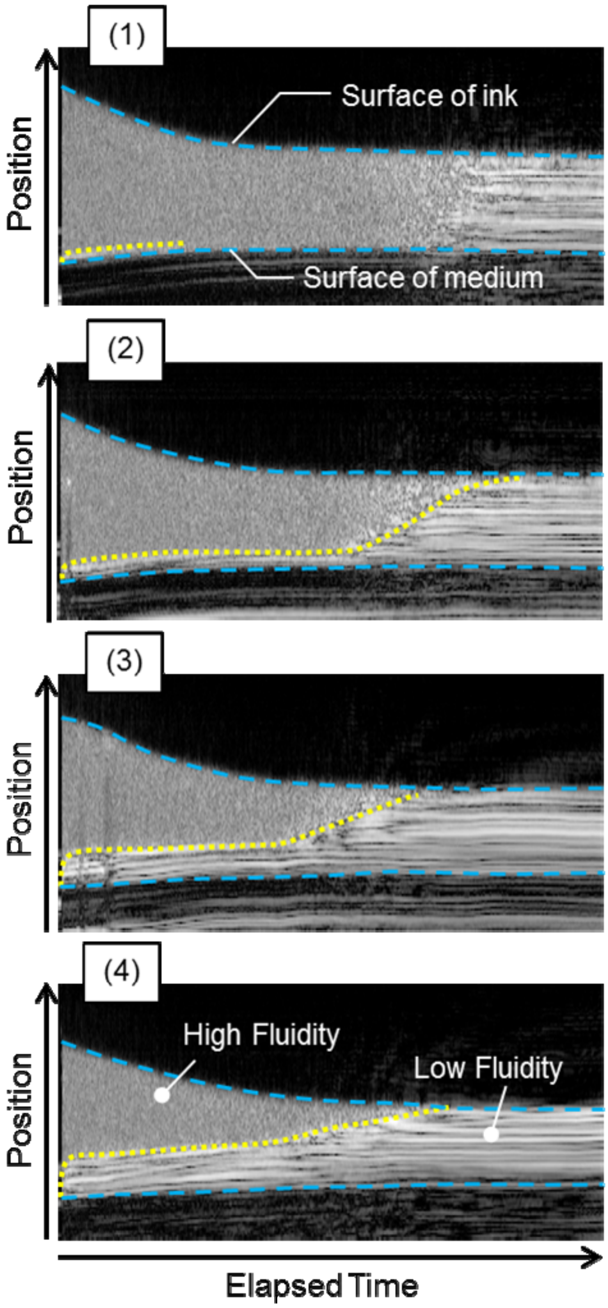

Fig.6 *Images which shows temporal change of the scattered light intensity distribution occurring in the ink when the ink adheres to the medium coated with the pretreatment liquid containing the different amount of flocculant.*

The larger the amount of the coagulant contained in the pretreatment liquid applied to the medium, the thicker the agglomerate layer formed in the attached ink becomes. This means that the larger the amount of flocculant that can diffuse into the ink, the faster it can reach the position away from the media. Based on such information, it is possible to estimate the amount of flocculant or time necessary for sufficiently lowering the fluidity of the adhered ink droplets.

Conclusion

By using method of OCT, it was possible to visualize the change in fluidity of the aqueous pigment ink at two places in the imaging process. By estimating the fluctuation frequency of the particles in the ink based on the temporal change of the scattered light intensity distribution acquired by the OCT, it was possible to quantitatively grasp the fluidity of the ink. In the inkjet imaging system, its performance is enhanced by adding a function of maintaining high ink fluidity for a desired period of time and a function of lowering ink fluidity at desired timing. It is expected that the present technology can grasp process conditions and ink characteristics suitable for enhancing the performance of inkjet printers.

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Author Biography

Yoshihiro Harada obtained his masters in quantum engineering at the Nagoya University in Japan in 2009. In the same year, he joined to Ricoh Company, Ltd. He has been engaged in the development of optical measurement and evaluation technique for inkjet imaging process using knowledges he has been learning since he was in university.