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# Visualizing Breath using Digital Holography

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**Abstract.** Artist Jayne Wilton and physicists Peter Hobson and Ivan Reid of Brunel University are collaborating at Brunel University on a project which aims to use a range of techniques to make visible the normally invisible dynamics of the breath and the verbal and non-verbal communication it facilitates. The breath is a source of a wide range of chemical, auditory and physical exchanges with the direct environment. Digital Holography is being investigated to enable a visually stimulating articulation of the physical trajectory of the breath as it leaves the mouth. Initial findings of this research are presented. Real time digital hologram replay allows the audience to move through holographs of breath-born particles.

## 1. Introduction

The ability to observe organic patterns such as that created by the spent breath opens up opportunities through which to increase our understanding of communicational dynamics and the impact of the human breath. Making such dynamics visible expands our understanding of our interaction with our direct environment. Jayne Wilton works to make visible these dynamics using processes as diverse as camera-less photography and lithography. Collaboration with physicists Peter Hobson and Ivan Reid, who both have specialist experience of in-line digital holography, has facilitated an important engagement with previously inaccessible processes which has resulted in a greater technological empowerment of possible visual outcomes. In-line digital holography has not been used extensively in the making of art, so the collaborators are interested to investigate the potential for less traditional outcomes of this technique.

The creation of digital holograms of breathing patterns will allow the three-dimensional illustration and capture of the form and dynamics inherent in a range of direct and indirect communications: from the enigmatic sigh to the verbal articulation of core linguistic units or semantic primes. These holograms are played as a video, but additionally can be used interactively and navigated by the viewer so as to be able to engage with specific areas of the information captured. The three-dimensional coordinate data available from the replayed hologram images also facilitates the further potential development of the work into kinetic sculpture. The coordinates of each particle as suspended by the breath in the chamber allow the constellation to be recreated in different formats and scales and using different media.

## 2. Use of Digital In-Line Holography

The visualizing of breath using digital in-line holography is challenging due to the issues of the relative scale of the human breath in relation to the recording area of the hologram which is, for collimated beams, limited by the sensor area. In this collaborative project a number of approaches, including the use of spatial filtering [1], are being used to record the human breath.

## 2.1. Hologram Recording System

*2.1.1. Continuous-wave laser.* The use of holography to capture vapour bubbles is well documented and a digital hologram recorded and replayed in our laboratory is illustrated in figure 1. Bubbles clearly can be containers of breath, yet the investigators are currently also exploring the impact of breathing into an air chamber rather than through a liquid. A variety of methods have been examined ranging from breathing into a cloud generated by liquid nitrogen and breathing into a chamber of fine particles to allow the holographic visualisation of the trajectory of the spent breath.

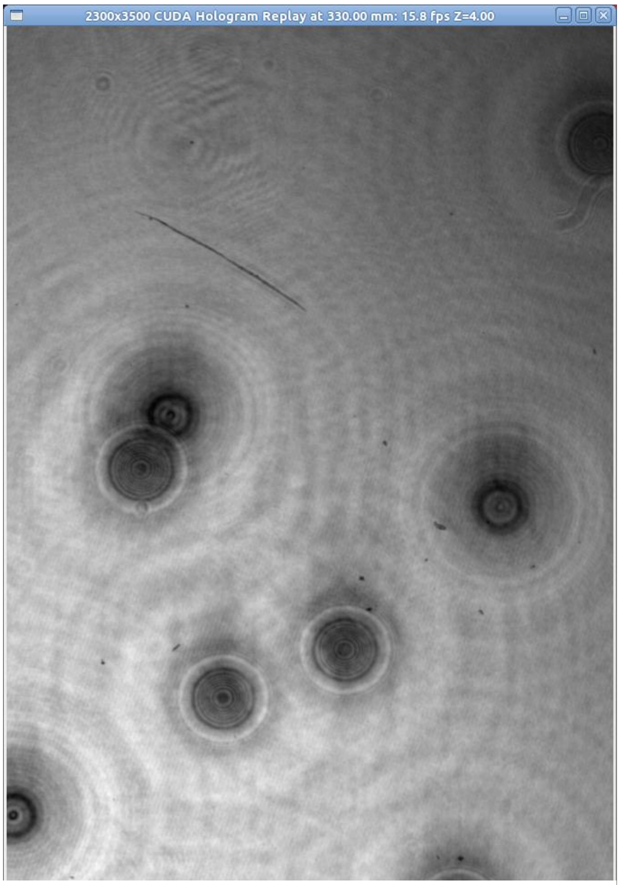


**Figure 1**. Replayed plane from a digital hologram of bubbles recorded using a continuous-wave red HeNe laser. The diameter of the bubbles is approximately 0.7mm.

*2.1.2. Pulsed laser.* In-line digital holograms were recorded using a fast pulsed green laser and a 36×24 mm$^2$ CCD camera (figure 2 and figure 3). The laser is a custom doubled Nd-YAG from Elforlight Ltd, model number LP3-10-532. This produced single longitudinal-mode pulses with a wavelength of 532 nm, duration of 2 ns and an adjustable energy of a few millijoules. The beam was then attenuated using a Newport 935-10 high-power variable attenuator and reflected, using a BK7 wedge, towards a beam expander telescope. The expanded beam then traverses a tank with BK7 flat windows and the resulting hologram is recorded using an ATMEL Camelia 8M CCD camera (Figure

2). The resulting holograms from the camera have 3500×2300 10 micrometre square pixels and are recorded with 12 bits of grey-scale information.

The holograms are replayed using the recently developed HoloMovie software that runs on NVIDIA GPU [2]. Our general approach to reconstruction is based on the convolution method [3] and can be summarised as follows:

- Numerically multiply the (zero-padded) hologram by a complex amplitude reference wave (in the case of collimated beam in-line holography the reference wave is 1+0i).
- Perform a 2D discrete Fast Fourier transform (FFT); real-valued data is transformed to complex-valued data.
- Multiply the result by a transfer function in the frequency domain based on the Rayleigh-Sommerfeld equation. The transfer function depends on the wavelength and the distance of the desired depth plane from the recording plane.
- Perform an inverse 2D FFT to generate the reconstructed image for a single depth plane. Extract the magnitudes, remove the zero-padding and normalise intensity.

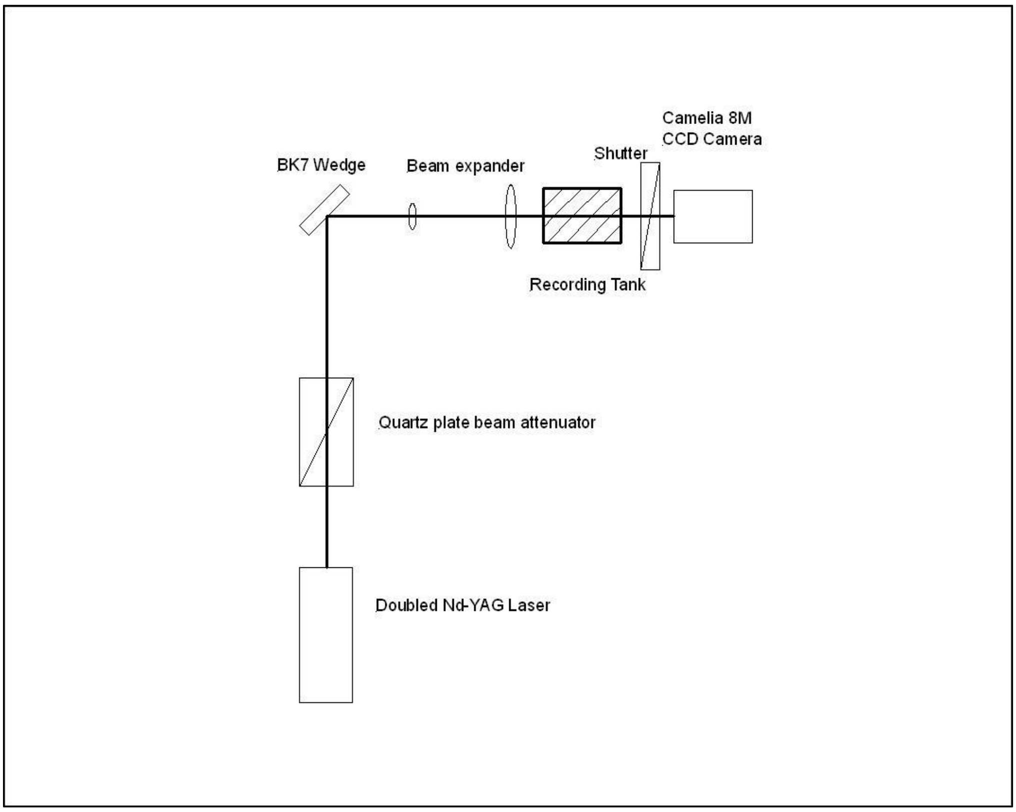


**Figure 2.** Diagram illustrating the optical set up for pulsed laser in-line digital holography set up.

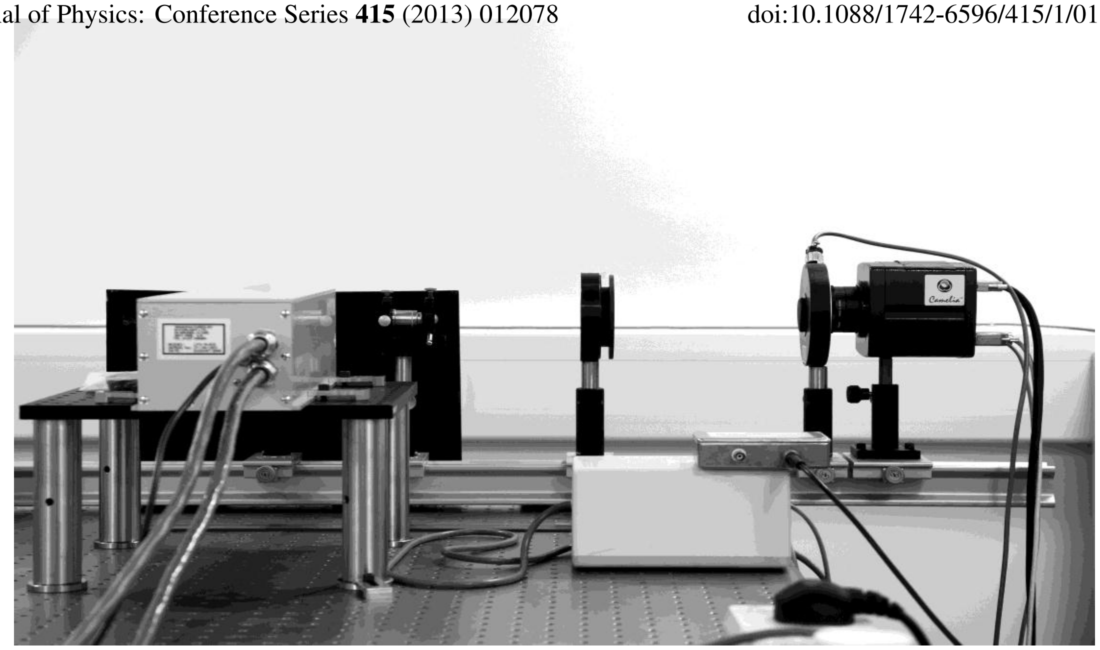

**Figure 3**. The configuration of the optical equipment. From left to right: the pulsed laser, the beam expander, the shutter and the camera. The variable attenuator has been removed in this picture for clarity.

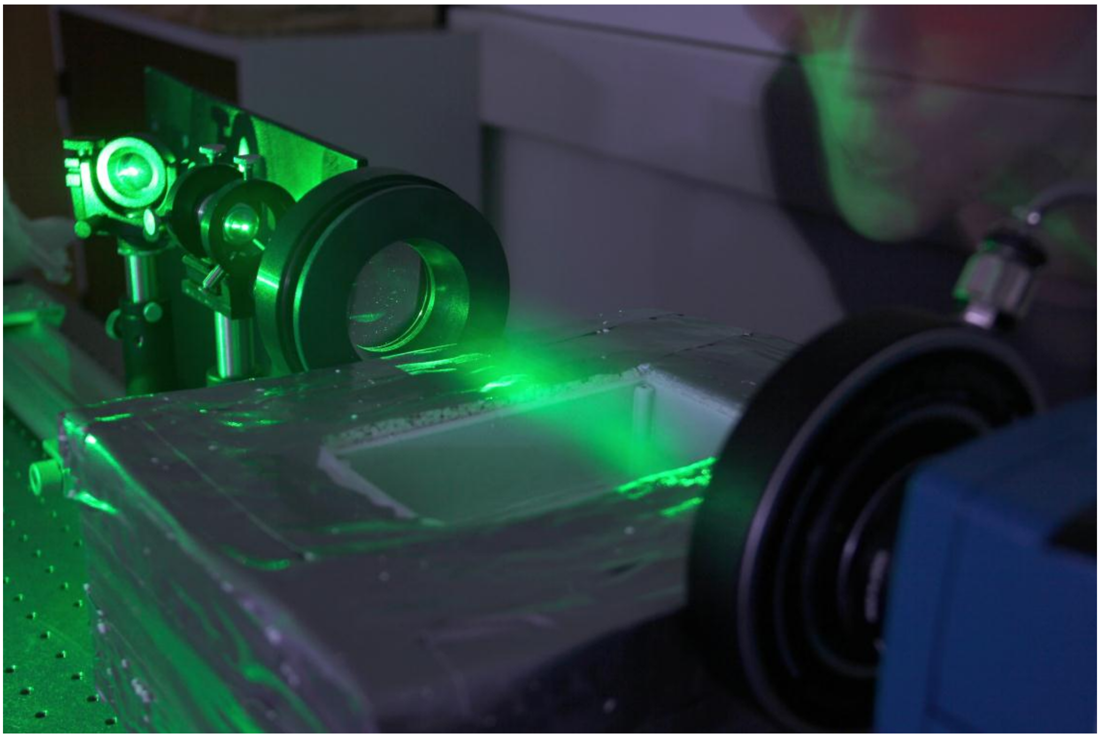

**Figure 4.** Recording a digital hologram of breath over liquid nitrogen.

*2.1.3. Using a pulsed laser to record the dynamics of breath.* Current investigations centre on the breathing of small particles such as seeds into a chamber. The subsequent holograms capture their trajectory within the vessel. A range of air-borne seeds were tested due to their aerodynamic properties. Initially poppy seeds were used. However the 1mm diameter of these seeds was too large to allow a significant cluster to be recorded. The investigators then progressed to digitalis seeds which, with a diameter of 0.4mm, allowed for a greater cloud of seeds to be recorded in the hologram. Breathing gestures such as the sigh were performed into the chamber and recorded as holograms (figures 5-7).

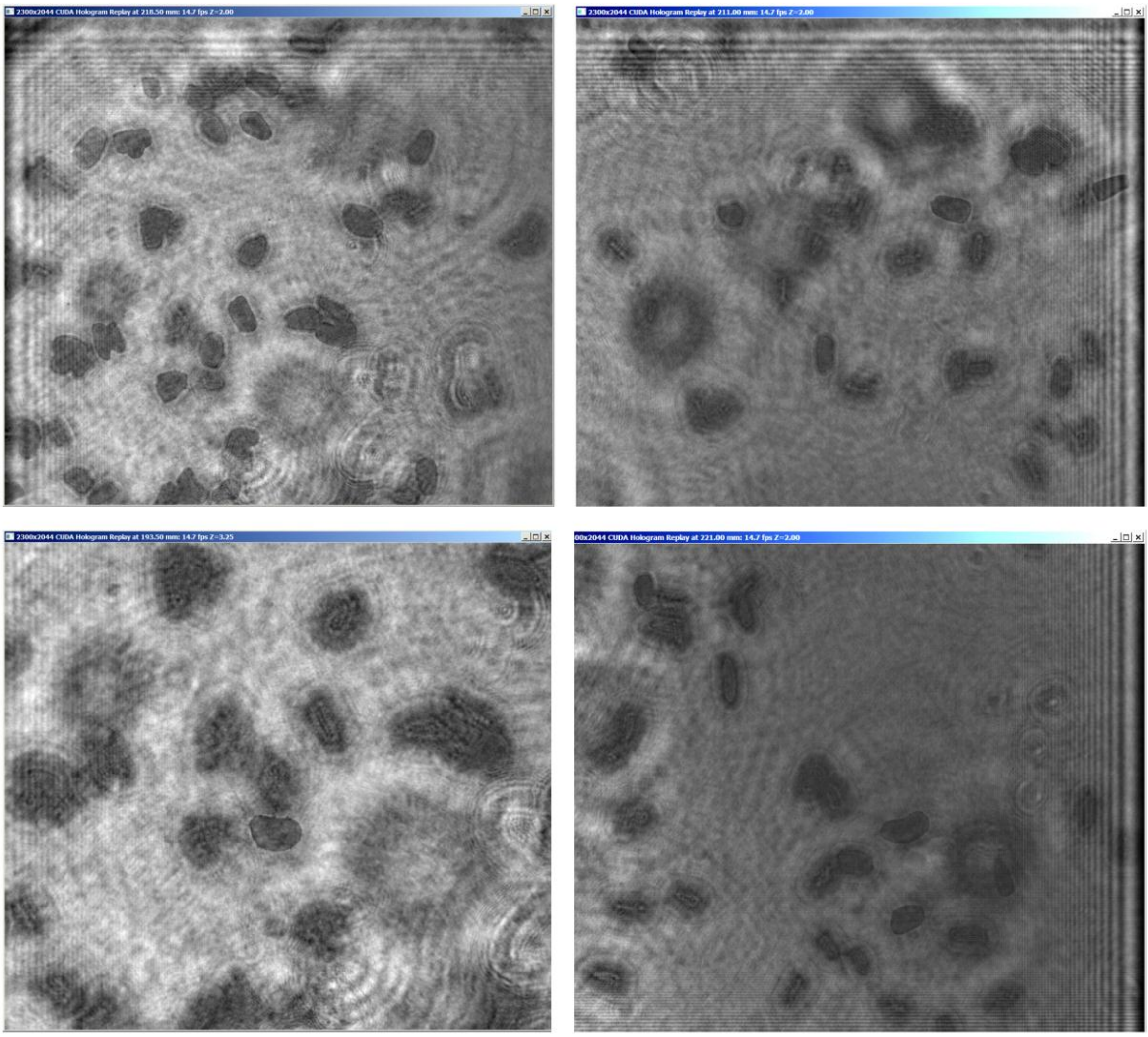

**Figure 3.** Series of images extracted from hologram replay of breathing gestures.

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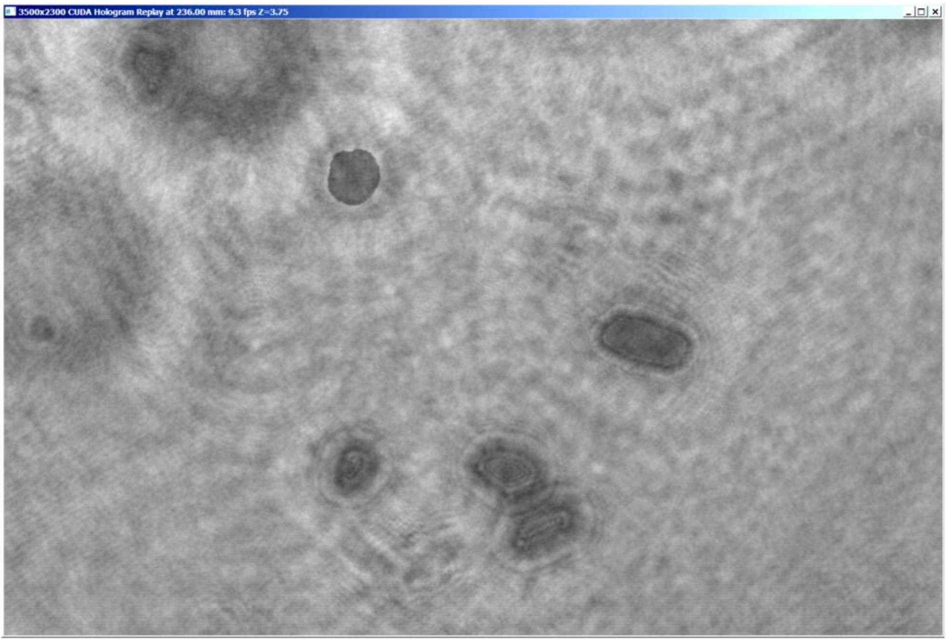
## 3. Hologram Replay.

The captured data is then processed using specially developed code, HoloMovie, running on NVIDIA GPU (Reid, Nebrensky & Hobson 2012[2]). Our software allows for an interactive involvement with the audience who can navigate through the depth of the replayed hologram and therefore explore the dynamic forms created by the breath. Figure 6 shows some of the dynamics available to be explored by the viewer from navigating the hologram.



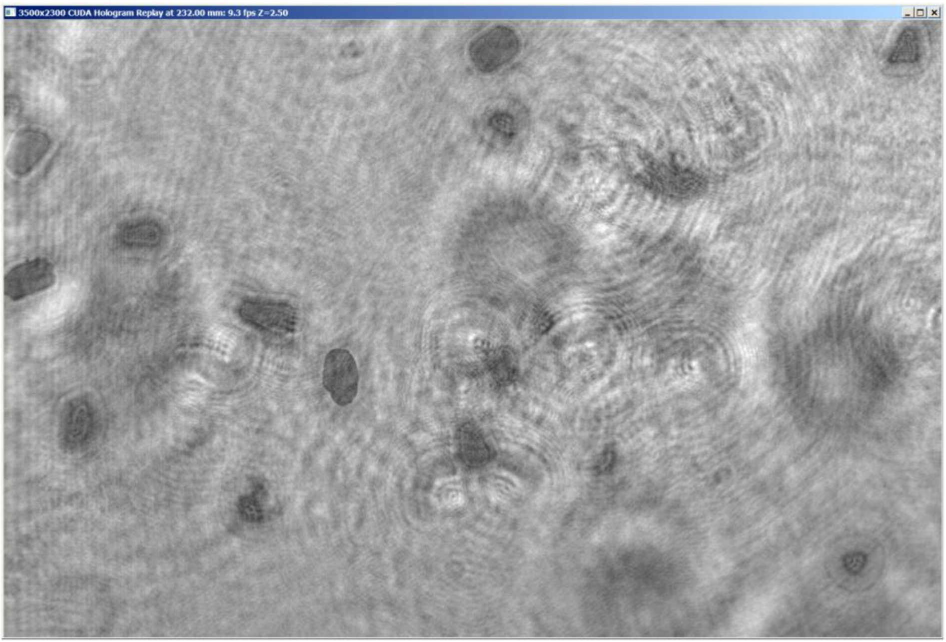




**Figure 4.** Images obtained from navigating through the holographic field.

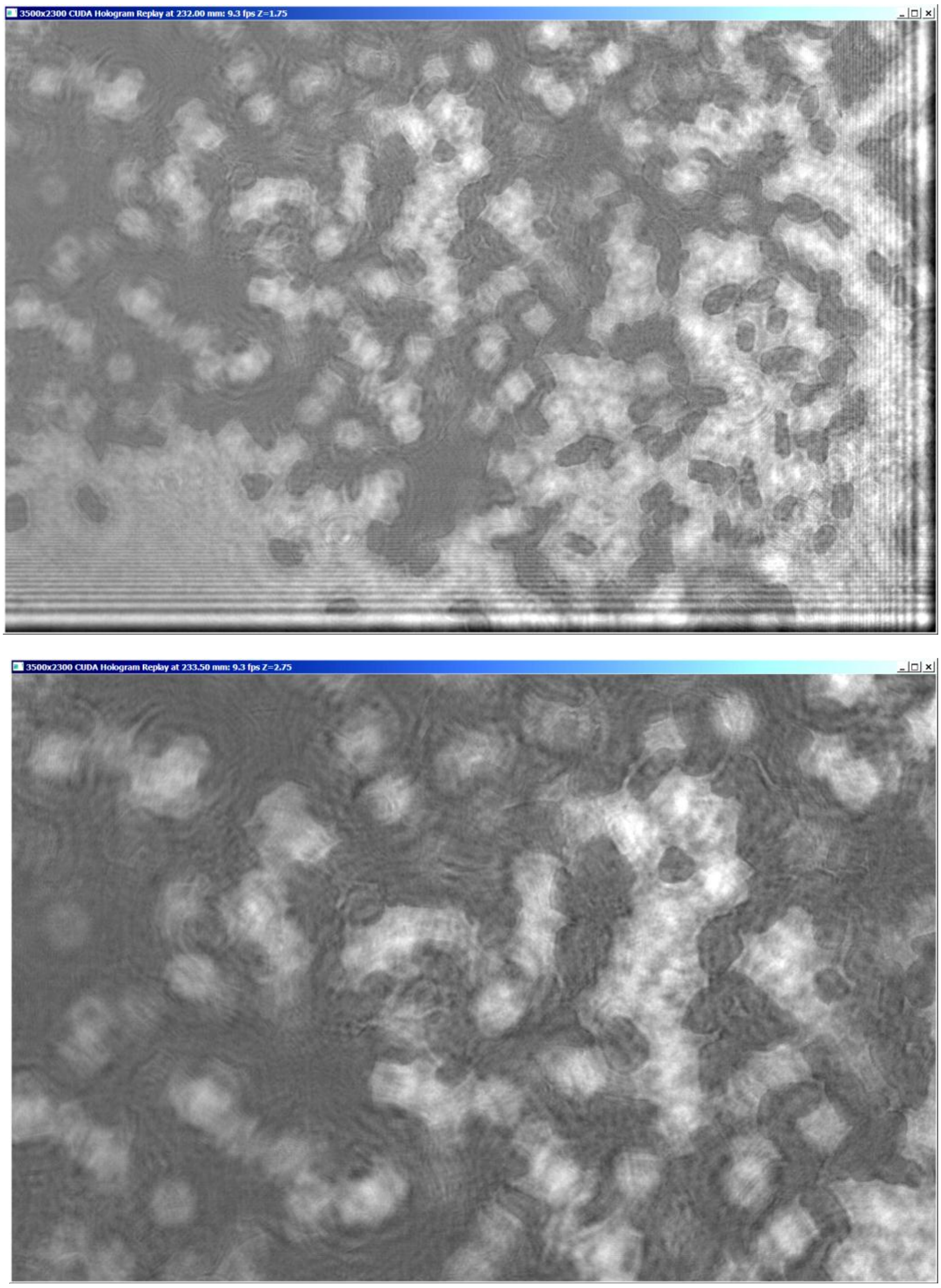



**Figure 7.** The intense fields of seeds evoke the movement of their initiating force.

## 4. Conclusion

This paper presents the first stages of investigating the use of in-line digital holography for the creation of imagery to facilitate the visualization of breath. The work is the starting point for further projects using data derived from the data capture, but the images themselves are also considered of interest. The use of seeds to render the air movement within the chamber gave an interesting view of the dynamics at play. Digitalis seeds allowed a denser cluster to be recorded on the hologram than poppy seeds and therefore allowed a more meaningful analysis of the breathing dynamic recorded. Scientifically the resulting holograms of denser clusters of seed would be seen as sub optimal. However artistically the results are of interest both aesthetically and because of information provided on the force of the expiration. The results also provide the starting point for a range of further investigations.

The collaborators will continue to explore ways of extending this initial investigation including the expiration of differing density fluids into fluid filled tanks and the creation of a schlieren field captured holograpically. At the current stage of development this work has demonstrated the ability of in-line holography to record valuable information about the movement of the breath. It is interesting to note that for the purposes of application to art we are recording interesting images with a much higher total object area to beam area ratio than would typically be regarded as usable for most scientific applications [4]. However further investigations are needed to fine tune techniques to enable comparison of dynamic breathing forms

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