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ISS ソーレ係数測定実験における干渉縞の自動解析手法

Automatic Analysis Method of Interference Fringes in Soret Coefficient Measurement on the ISS

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1. Introduction

An interferometer enables non-contact measurement of temperature and concentration changes in a solution and used for Soret coefficient measurement [1)] on the ISS. In the measurement, it is important to automatically and precisely unwrap the huge amount of intermittent phase time series converted from the captured interference fringe intensity to obtain the phase change. However, it was observed phenomenon of discontinuous phase changes in the time direction, hopping [2)], which is hindered the unwrapping automation. In this study, we proposed an automatic analysis method to correct hopping as follows: subtracting the amount of phase difference due to hopping from the phase after the frame with the hopping to reproduce the original continuous phase time series. However, the characteristics of hopping themselves, such as spatial distribution, the rate of change, and the amount of phase difference, have not been reported. The objective of this study is to confirm the characteristics of hopping and to establish a valid automatic analysis method to correct hopping. To confirm the validity, we compared the correlation coefficients of phase changes with and without hopping of interference fringes observed at almost the same time using two different wavelengths lasers in the ISS measurements.

2. Experimental and Analysis Procedures

The interference fringe intensity in about 30 experimental runs including *Run* #2-16 of the Soret-Facet Mission were analyzed, which were observed using a two-wavelength (532 and 780 nm) Mach-Zehnder interferometer in the "*Kibo*" of ISS as described in a reference paper [1)]. Here, *Run* #No. is the identification number of the run. The obtained interference fringe intensity was processed through the Gaussian filter and converted to phase $\phi(X,n)$ using spatial phase analysis [3)], where X and n are the vertical position and frame number of the interference fringes, respectively. At first, the number of frames with hopping were manually detected and the phase differences between neighboring two frames with and without hopping were calculated. The proposed hopping correction method was then applied as follows to obtain the corrected phase $\phi(X,n)_{corr}$: **1st)** unwrapping $\phi(X,n)$ spatially to obtain a spatially smooth phase $\phi'(X,n)$, **2nd)** calculating the phase differences between neighboring two frames as $\delta\phi'(X,n) = \phi'(X,n) - \phi'(X,n\text{-}1)$, **3rd)** averaging $\delta\phi'(X,n)$ at all analysis positions X as $\delta\phi'(n)_{mean}$, **4th)** detecting frame numbers n_{hop} at which $|\delta\phi'(n_{hop})_{mean}| > \delta\phi'_{thr}$ where $\delta\phi'_{thr}$ is a threshold value of 0.5, which is a value that exceeds the noise as mentioned in Sec. **3**, **5th)** subtracting $\delta\phi'(X,n_{hop})$ from the phase at the frames after n_{hop} at each analysis position as $\phi'(X,n \geq n_{hop})_{corr} = \phi'(X,n \geq n_{hop}) - \delta\phi'(X,n_{hop})$, and **6th)** wrapping $\phi'(X,n)_{corr}$ spatially to obtain $\phi(X,n)_{corr}$. The value of $\phi(X,n)_{corr}$ was then unwrapped in the time direction to obtain the phase change.

3. Results

In *Run* #2-16 as an example, continuous phase time series $\phi(X,n)$ was obtained at 532 nm while two discontinuous phase changes were observed at 780 nm as shown in **Fig. 1** (a) and (b). The hoppings occurred uniformly in the observation field of view and finished within one frame. Manually detected frame numbers with the hoppings were n = 600 and 632. The average value of the phase differences due to the hoppings in the X-direction was 0.66 and -0.73 rad, respectively. At both wavelengths, the value of $|\delta\phi'(X,n \neq n_{hop})|$ at $n \geq$ about 250, concentration change region, were about 0.4 rad at most even with a large noise. The value of $|\delta\phi'(X,n_{hop})|$ was larger than 0.4 rad at almost all analysis points. The amount of phase difference due to the hopping was found to be at least larger than the noise. Through the **1st** to **4th** processes, only $|\delta\phi'(600)_{mean}|$ and $|\delta\phi'(632)_{mean}|$ at 780 nm exceeded the threshold value of 0.5 rad and n_{hop} = 600 and 632 were detected. The values of $\delta\phi'(600)_{mean}$ and $\delta\phi'(632)_{mean}$ were 0.66 and -0.73 rad, respectively. The automatically detected values of n_{hop} and $\delta\phi'(n_{hop})_{mean}$ were consistent with the manually detected ones. This result revealed that the **1st** to **4th** processes were valid. Through the **5th** to **6th** processes, a continuous phase time series at 780 nm was obtained as shown in **Fig. 1** (c).

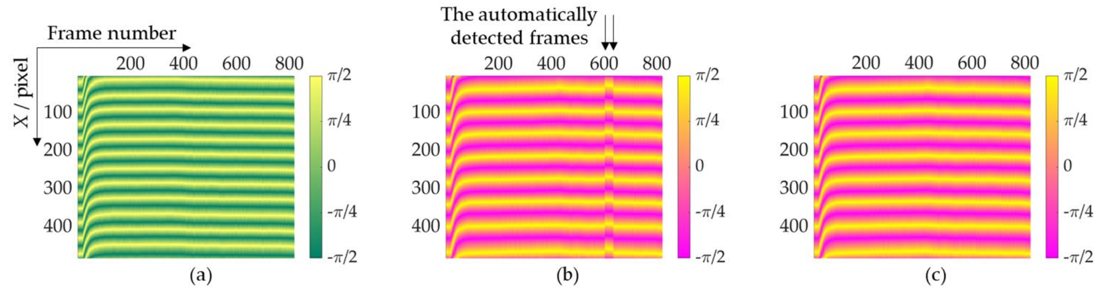

Fig. 1 The phase spatio-temporal images in *Run* #2-16 at (a) 532 nm, (b) 780 nm with hopping, and (c) 780 nm applied the hopping correction method: frames were taken every 6 s for the first about 0.6 h of the 9 h-experiment, and every 66 s thereafter.

4. Discussion

At both wavelengths, since the interference fringe movements were observed at almost the same time in the same solution, it is considered that there is a positive correlation between the phase changes at both wavelengths. The correlation coefficients of the phase changes between two wavelengths of the concentration change region at the same analysis positions were calculated for the *Run* #2-16. The averaged correlation coefficient in the X-direction after applying the hopping correction method was dramatically larger than that before applying the method. Furthermore, the proposed hopping correction method was applied to the phase of all runs where hoppings occurred, and the averaged correlation coefficients became larger for most runs. The correlation coefficients of the runs corrected for hopping were comparable to those of ones without hopping. This result revealed that the **5th** to **6th** processes were valid.

5. Conclusion

We analyzed the interference fringes of the ISS measurements and compared the correlation coefficients between two wavelengths of the phase changes with and without hopping, and found the followings. The hopping occurs uniformly in the observation field of view and finishes within one frame, and the amount of phase difference is larger than the noise. A valid automatic analysis method to correct hopping is as follows: spatially unwrapping the phase converted from the interference fringe intensity, detecting the frames where the averaged phase differences between neighboring two frames exceed the threshold, subtracting the phase differences at the detected frames from thereafter frame phase at each analysis position, and spatially wrapping the obtained phase.

References

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