Preliminary Commissioning and User Experimental Results for the TPS 31A1 Micro CT Endstation

Introduction

This article reports the commissioning results and user experimental status of the **TPS 31A1** projection X-ray microscopy (PXM) station up to the end of 2022. The PXM can provide high-speed computed tomography, fast X-ray imaging, high throughput, and high-energy resolution experiments, as shown in **Fig. 1**. The design of this system is described in NSRRC Activity Report 2021[1] and also in the additional reference papers.[2,3] This report focuses on the commissioning results and user experimental conditions of this year.

Commissioning for the First Half of 2022

During the first half of 2022, the research team conducted trial runs of **TPS 31A1**. The main task was to successfully introduce light into the experimental station. To accomplish this, the research team successfully tested the monochromator of the double multi-layer mirror (DMM) and double crystal (DCM). The test results were close to our expectations. The beam size at the experimental station is approximately 2 cm wide and 1 cm high. The output modes of this trial run included a white-light mode and single-light modes such as DMM and DCM. The beam size changes with energy and, as the energy increases, the footprint of the beam passing through the spectrometer in the vertical direction will decrease as a result of a variety of factors such as the angle of incidence and reflectivity. After testing, the DMM mode was found to be able to output an X-ray beam of up to 50 keV and the DCM mode able to output an X-ray beam of up to approximately 36 keV.

The research team also conducted testing of the white beam mode. The results revealed that the flux of the white light of this beamline is quite high, as was expected. Based on the design values, the estimated output of the white-light mode for the given output size should be approximately 500 W. However, because of the high heat, high radiation dose, and ozone generated by this mode, the experimental station's shield room requires further protection. The construction team is currently working on improving this.

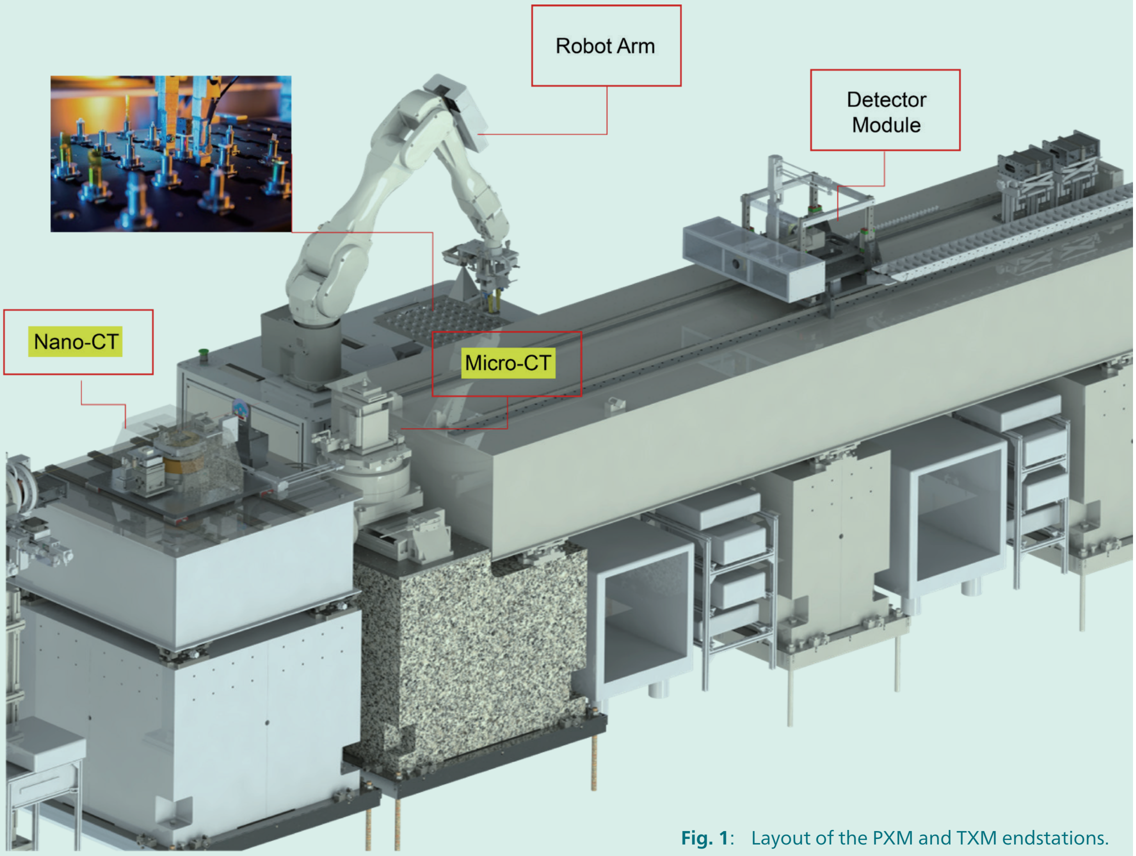

Fig. 1: Layout of the PXM and TXM endstations.

The DCM mode provides a source for stable and clean images, as well as higher-energy resolution. However, the X-ray intensity provided by the DMM mode is approximately 20 times stronger than that provided by the DCM mode, which is in line with the calculations.

The research team conducted experiments using both DCM and DMM and found that, by using the beam provided by DCM, it was possible to achieve approximately 20 ms per image, whereas by using the beam provided by DMM, it was possibly to achieve approximately 1 ms per image. Using DCM mode, it was also possible to complete full-resolution X-ray tomography, including 1440 projection images of 2560 × 2180 pixels and two reference images with the same pixel resolution. This was tested using a weak absorption sample and found to reach approximately 2/3rds of the maximum counts of the detector. To take a complete tomography data set requires a certain degree of overhead for speeding up the rotation stage, slowing down the stage, removing the sample, and taking the reference images. This process takes approximately 75 s to complete, or an average of 50 ms per image. To achieve the aforementioned resolution for a tomography scan, currently the DMM mode takes approximately 45 s to complete. The average time per image is approximately 31 ms, which is significantly different to the previous time of 1 ms per image. The main reason for this is that the currently used light detector (Andor Zyla) has a maximum frame rate of only 100 images per second. Therefore, if using a faster detector (such as NAC-ACS1 m60) is expected to improve the current time of 45 s to approximately 2 s without reference images.

Automation Integration of the Experimental Station

The sample automatic exchange system[4] of the experimental station is built on the automatic loading of multiple samples on a sample tray and the use of a robotic arm to place the sample holders on the sample tray onto the test position of the experimental station, as shown in **Fig. 2**. To fully automate the process, the research team first places the sample holders on the pre-designed sample tray and uses an automated program on a 2D contour measuring instrument to locate the samples in 3D space. After the samples are positioned, the tray is placed into a conveyor box (magazine) located in the experimental station and then placed onto the test position by the robotic arm. An online video can be found *via* the reference.[5]

At this time, the three-dimensional positioning data on the 2D contour measuring instrument will be transmitted to the computer controlling the experimental station, which enables the tomography scan to be performed directly without consuming valuable time for beamline alignment.

In this automated system, the sample tray is a 5 × 8 sample space and each conveyor box can hold eleven trays. The system contains two transport boxes and the system can store up to 880 sample seats. Currently, the estimated time for each sample is up to one minute minus the time for the robotic arm to pick it up, which is approximately 1.5 minutes. Therefore, a storage capacity of 880 samples can last for approximately 24 hours. If it remains possible to simultaneously use the 2D contour measuring instrument to make measurements, then it will be possible to continue to perform tomography scanning work.

Processing of the Tomography Data

Due to the fast pace of the experiments, the system's corresponding data storage system is 1.0 PB and each set of data was calculated at approximately 10 GB, which is sufficient for approximately 100,000 sets of data. With 500 sets of data per day, this is approximately 200 days, or almost one year of data storage capacity.

After the data was acquired, a self-made program was used to perform the tomography reconstruction. For a full data set of 1440 projection images of 2560 × 2180 pixels, it takes around two minutes to complete the reconstruction calculation for a typical personal computer. Thus, this program can be installed on a general user's

Fig. 2: (a) Schematic drawing of the automatic sample loading/unloading system. (b,c) Photographs of the automatic sample loading/unloading system.

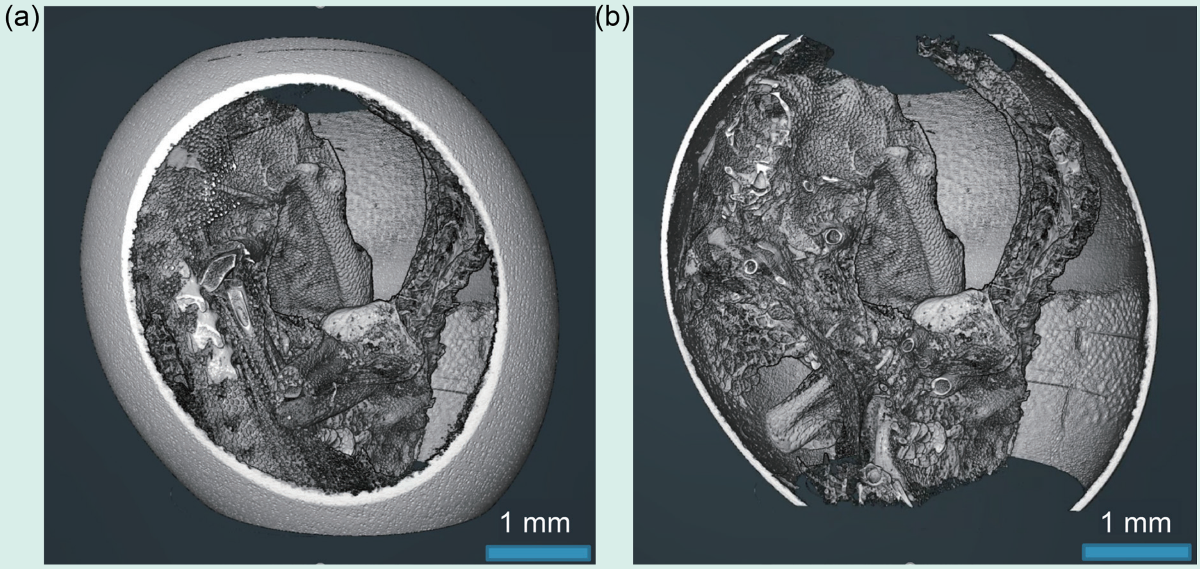

Fig. 3: 3D rendering of an unhatched gecko egg. (a,b) Two different virtual slices.

computer. In this program, the rotation center can be found *via* a semi-automatic process and ring artifacts can be removed automatically. The reconstruction data has been transformed into a suitable format for 3D rendering programs such as Amira (Thermo Fisher Scientific Inc.) and 3D slicer[6] and one rendering is shown in **Fig. 3**.

Commissioning for the Second Half of 2022

In the second half of 2022, this beamline was made available for 30% of its time for use by users with many applications in various fields such as materials, biology, energy, geology, and the environment. The experiments are classified as general experiments and *in situ* experiments. General experiments can use general sample holders and adopt an automatic alignment method, whereas *in situ* experiments depend on the preparation status and use the script provided by the experimental station to perform action programming and then automatically perform measurements according to the experimental conditions.

The PXM has served more than eight research groups, provided over 100 beam shifts, and already produced its first user paper[7] in November 2022. Additionally, the high-quality images obtained from the experimental station were used by award winning participants in the "2022 Taiwan Microscope Image Contest" held by Olympus Corportation.[8]

Summary and Future Work

This article reports on the progress of a new high-speed tomography experimental station developed at the end of 2022, including the trial run and user experiments. The automation and integration of the PXM endstation, including an automated sample changing system and its data storage and calculation capabilities, have greatly improved the efficiency and accuracy of experiments conducted there and also reduced the time needed for experimentation. By the end of 2022, the PXM endstation had served eight research groups, provided over 100 beam shifts, and produced its first user paper in November of 2022. The research team will continue work in 2023 on the development of the environmental cell, white beam mode, big data processing, and the TXM endstation. (Reported by Gung-Chian Yin)

References

1. G.-C. Yin, NSRRC Activity Report **2021**, 106 (2022).
2. G.-C. Yin, Y.-F. Song, B.-Y. Chen, C.-Y. Lee, M.-Y. Hsu, C.-L. Liao, C.-C. Chiu, M.-H. Lee, C.-Y. Liu, C.-F.Chang, C.-C Wang, L.-C. Chiang, J. Phys.: Conf. Ser. **2380**, 012119 (2022).
3. M.-Y. Hsu, C.-Y. Lee, H.-S.Fung, B.-Y. Chen, G.-C.Yin, J. Synchrotron Radiat. **29**, 888 (2022).
4. C.-Y. Lee, G.-C. Yin, B.-Y. Chen, M.-Y. Hsu, Synchrotron Radiat. News **34**, 4 (2021).
5. TPS BL31, Youtube, January 16 (2023). https://www.youtube.com/@tpsbl31/videos
6. A. Fedorov, R. Beichel, J. Kalpathy-Cramer, J. Finet, J-C. Fillion-Robin, S. Pujol, C. Bauer, D. Jennings, F.M. Fennessy, M. Sonka, J. Buatti, S.R. Aylward, J.V. Miller, S. Pieper, J. Magen. Reson. Imaging **30**, 1323 (2012).
7. L.-W. Kuo, T.-Y. Chen, D. Brown, J. Si, T.J. Meng, H.S. Sheu, Y.-F. Song, G.-C. Yin, Contrib. Mineral. Petrol. **177**, 111 (2022).
8. Olympus Corportation, 2022 Taiwan Microscope Image Contest, October 11, (2022). https://olympusomic.tw/online-expo/