ASIPP

Plasma Boundary Shape Reconstruction Using Visible Spectroscopy Diagnosis on EAST Tokamak

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- Motivation
- Algorithms for optical boundary reconstruction
- Real-time implementation
- Experiment Result
- Conclusion and outlook

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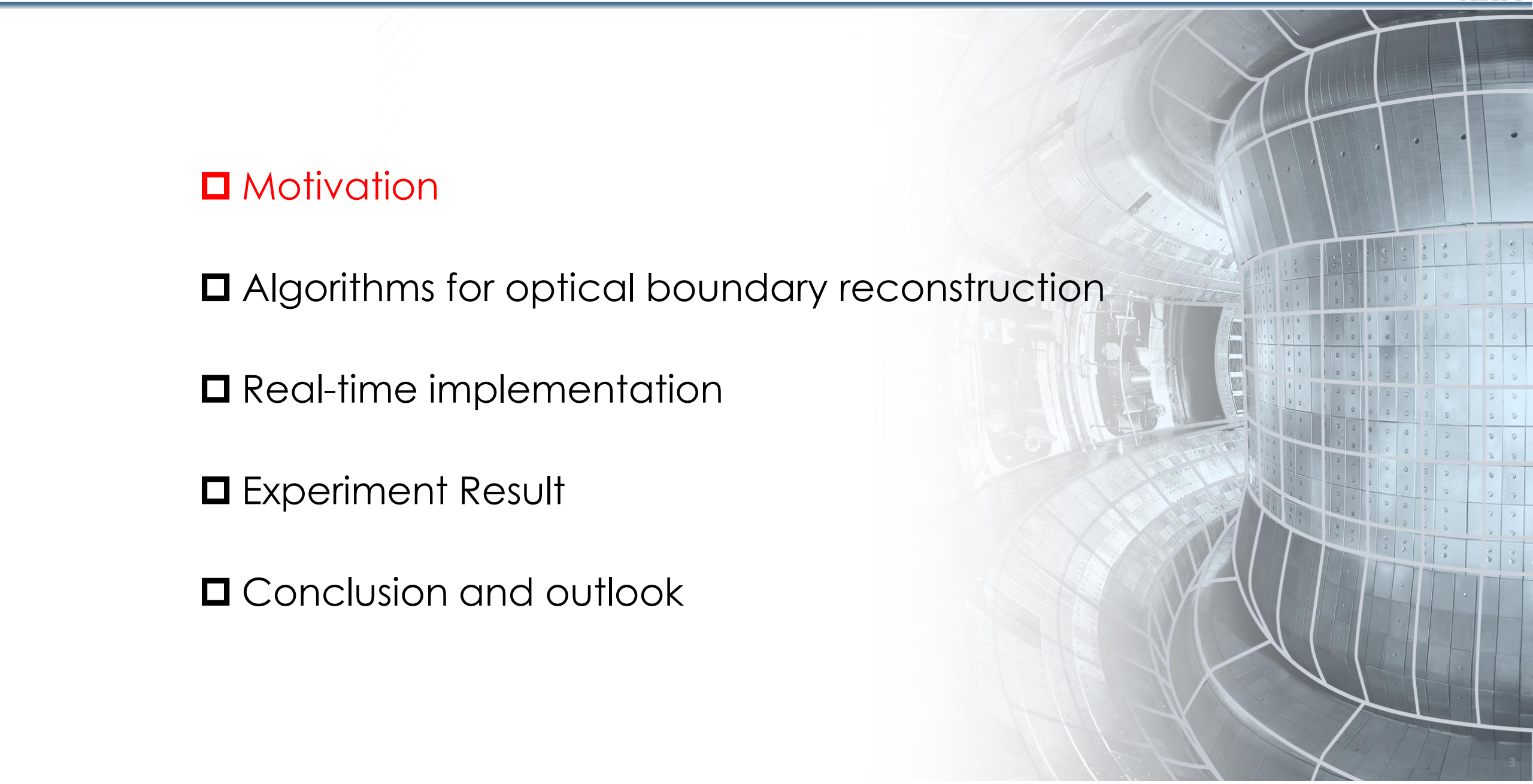
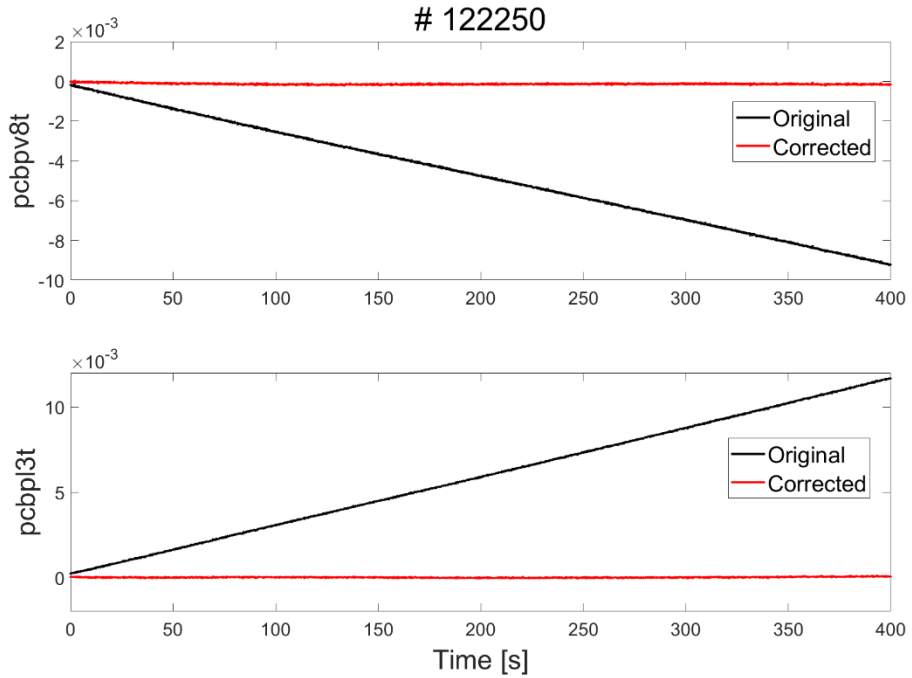


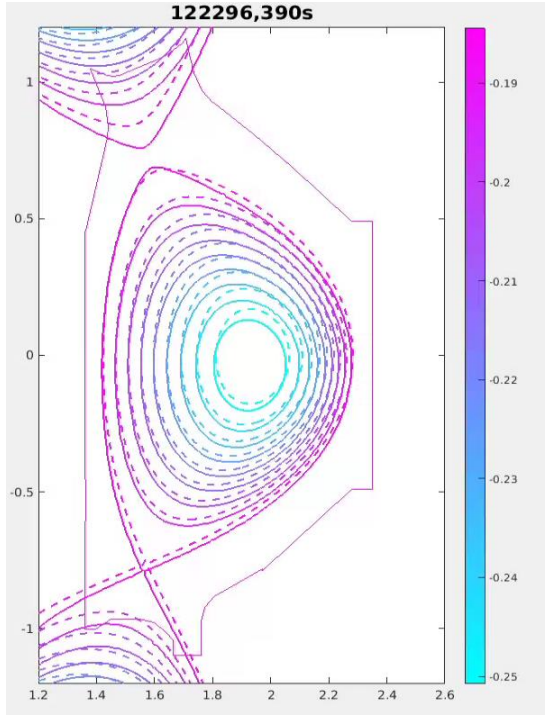
Motivation

At present, shape reconstruction based on magnetic diagnostic has several challenges:

- Weak magnetic sensor signal in case of steady-state discharge.
- Unavoidable integrator value drifts for long pulse.
- Degradation of magnetic sensor material cause by Neutron and γ irradiation



Integrator signal drift after 400s operation



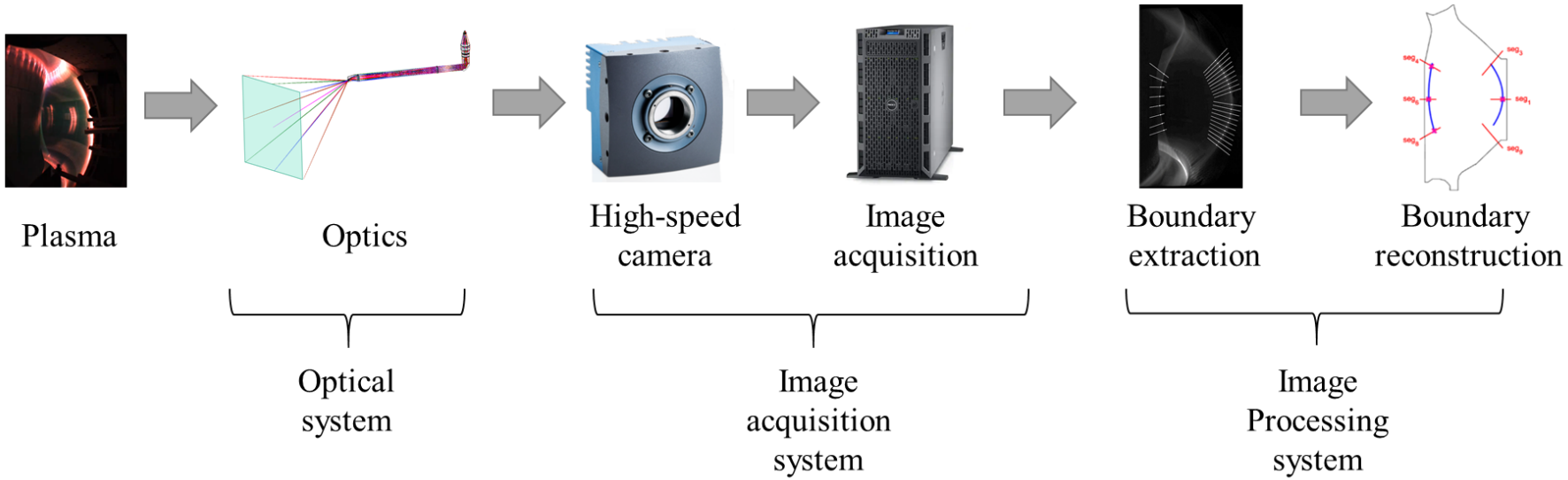
Shape reconstructed with uncompensated signal inversion at 390s

Motivation

Optical-based reconstruction method have some advantages over magnetic measurement methods:

- Signals are unaffected by the complex electromagnetic environment of the tokamak
- Easier to maintain as a port diagnostic

Optical-based reconstruction method can be a supplement to electromagnetic measurement to achieve higher shape reconstruction accuracy or serve as a potential alternative to plasma shape reconstruction



Optical-based reconstruction method workflow

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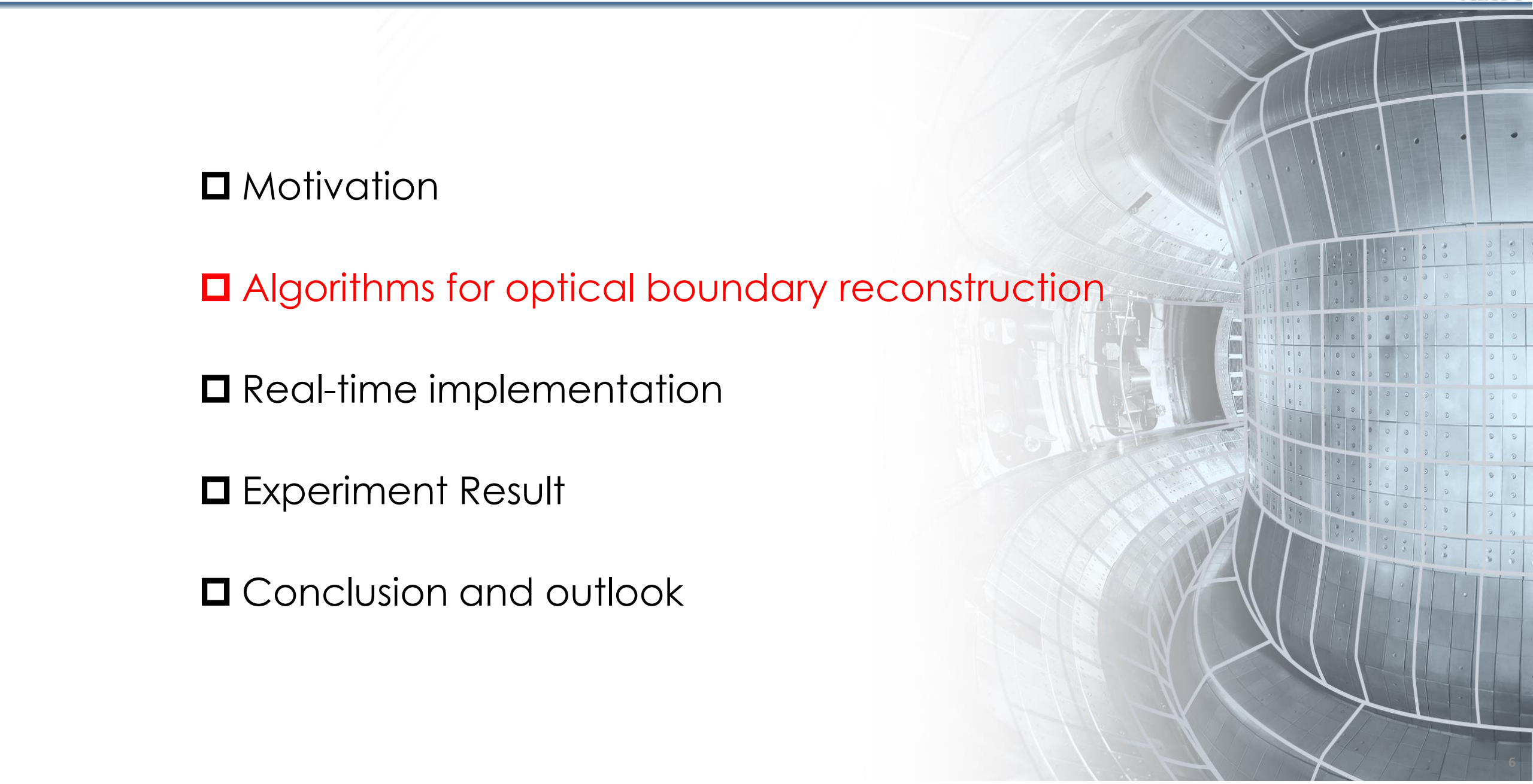
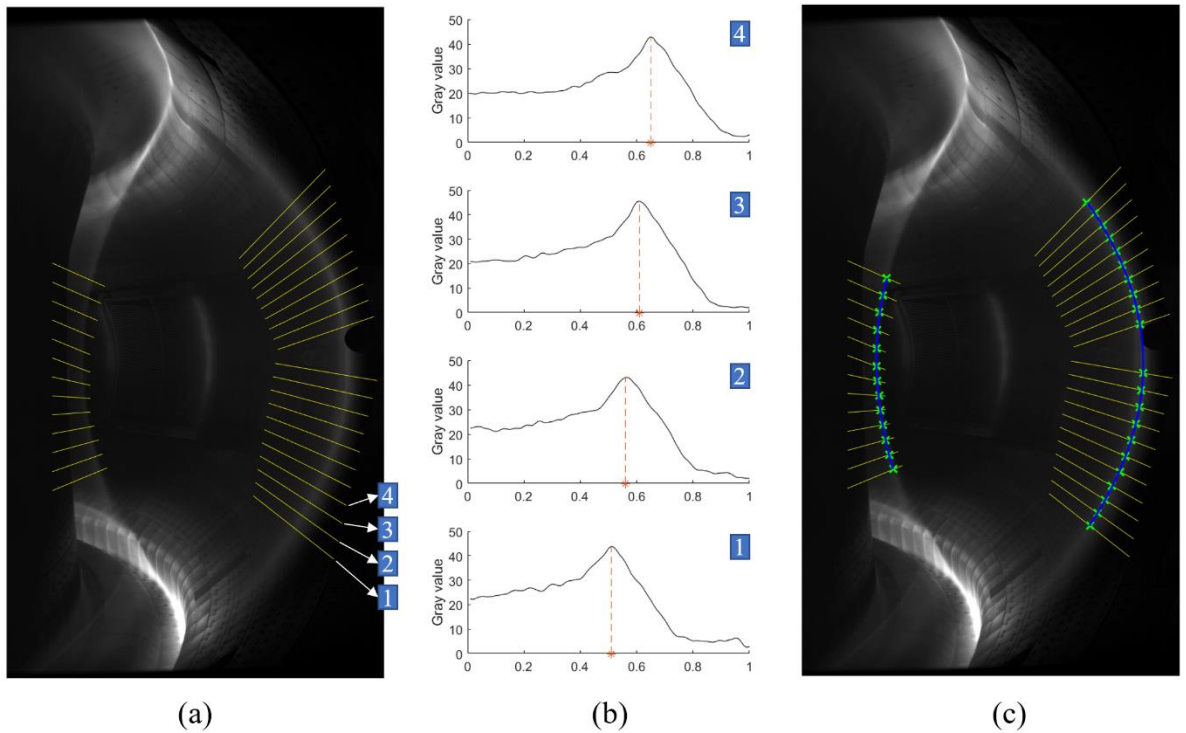


Algorithms for optical boundary reconstruction

➢ Edge Extraction Algorithm

According to the characteristics of plasma boundary, an algorithm has been designed to extract the plasma boundary from the image based on the grayscale feature

① Select characteristic line segments
② Calculate the gray value of line segments
③ Apply Gaussian smoothing to line segments
④ Identify the highest gray value points on each line segment
⑤ Fit the detected points using a curve



The flow of the boundary detection algorithm

Algorithms for optical boundary reconstruction

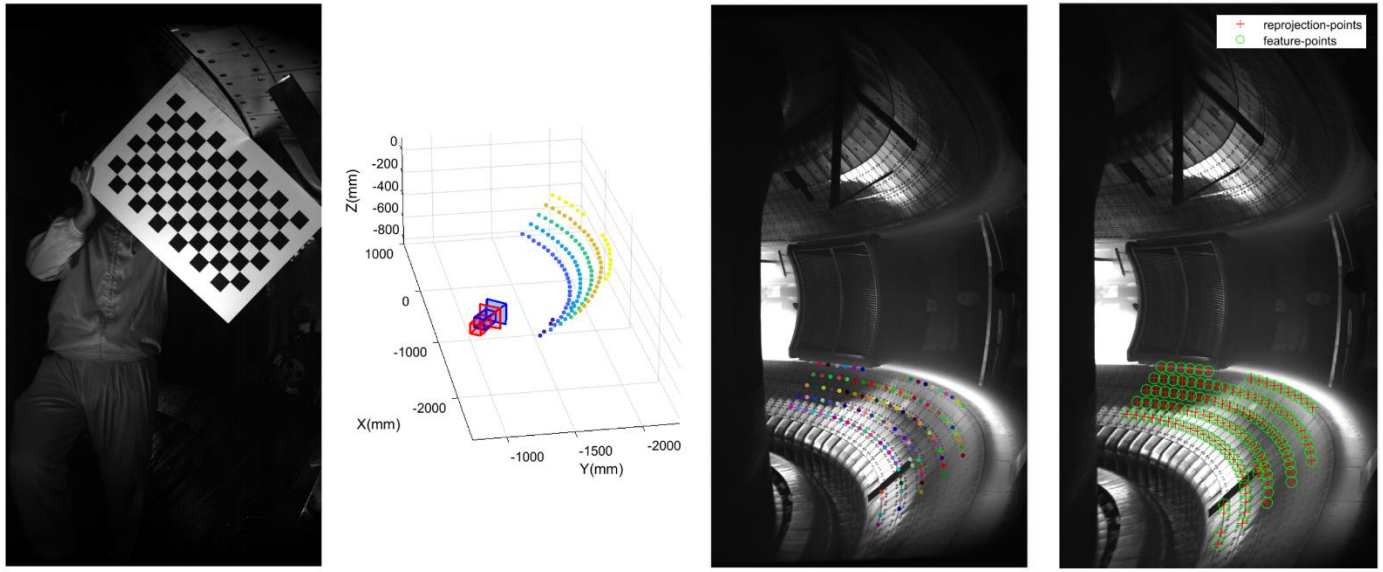
➢ Boundary Reconstruction Algorithm

1. System Calibration Algorithm

① Calibrate the intrinsic parameters with Zhang's method
② Collect images with clear feature points
③ Match the image feature points with the vacuum chamber feature points
④ Calculate the extrinsic parameters
⑤ Jointly optimize the intrinsic parameters , extrinsic parameters to minimize the mean reprojection error

mean reprojection error:

$$\frac{1}{n}\sum_{n}^{i=1}\left\|m_i-\hat{m}\left(A,k_1,k_2,R,t,M_i\right)\right\|$$



(a) (b) (c) (d)

Calibration process

Algorithms for optical boundary reconstruction

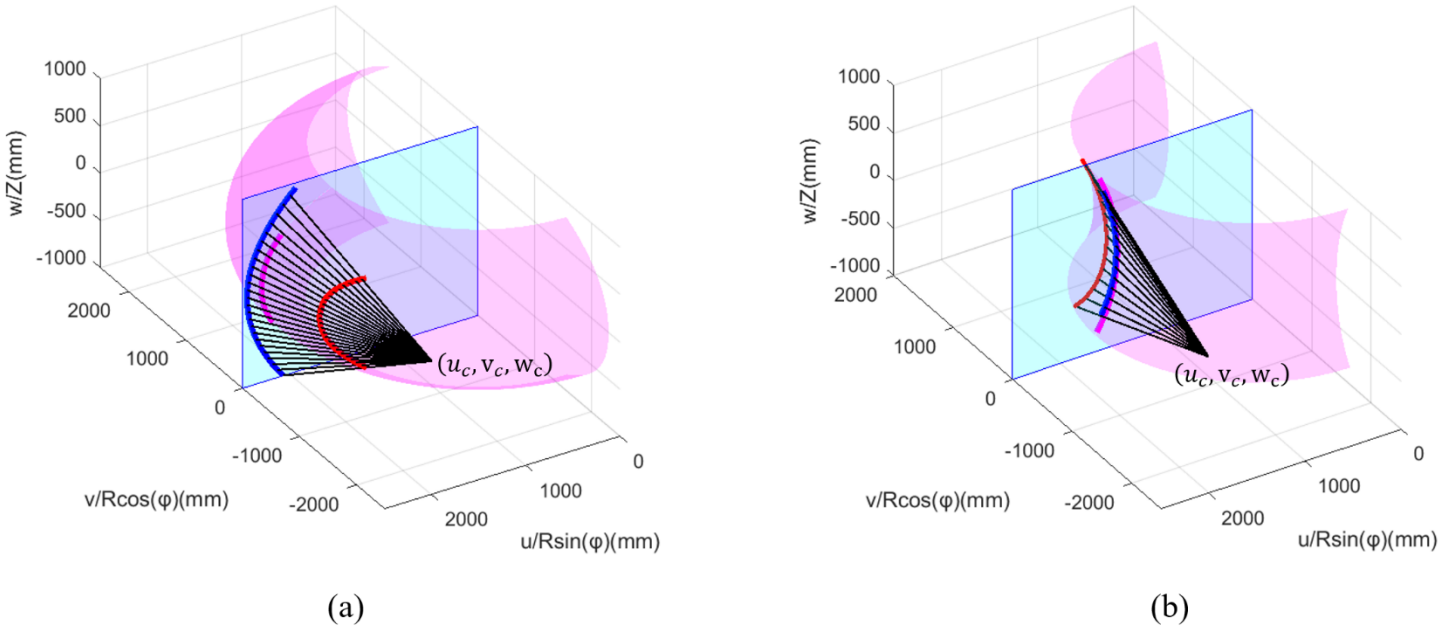
➢ Boundary Reconstruction Algorithm

2. Coordinate Mapping Algorithm

By exploiting the geometric relationship between the tangent line and the projection plane to map 3D coordinates, the coordinates of the 3D plasma boundary surface can be obtained through geometric calculations

Coordinate Mapping Process:

$$\begin{cases} tan(\varphi) = \dfrac{(v_e - v_c) - \dfrac{dv_e}{dw_c}(w_e - w_c)}{u_c} \\ R_e = \dfrac{u_c u_e}{u_c cos(\varphi) + (v_e - v_c) sin(\varphi)} \\ Z_e = w_c + (w_e - w_c)\dfrac{u_c - R_e sin(\varphi)}{u_c} \end{cases}$$



The 3D diagram of the coordinate mapping algorithm
(a) Low-field side. (b) High-field side.

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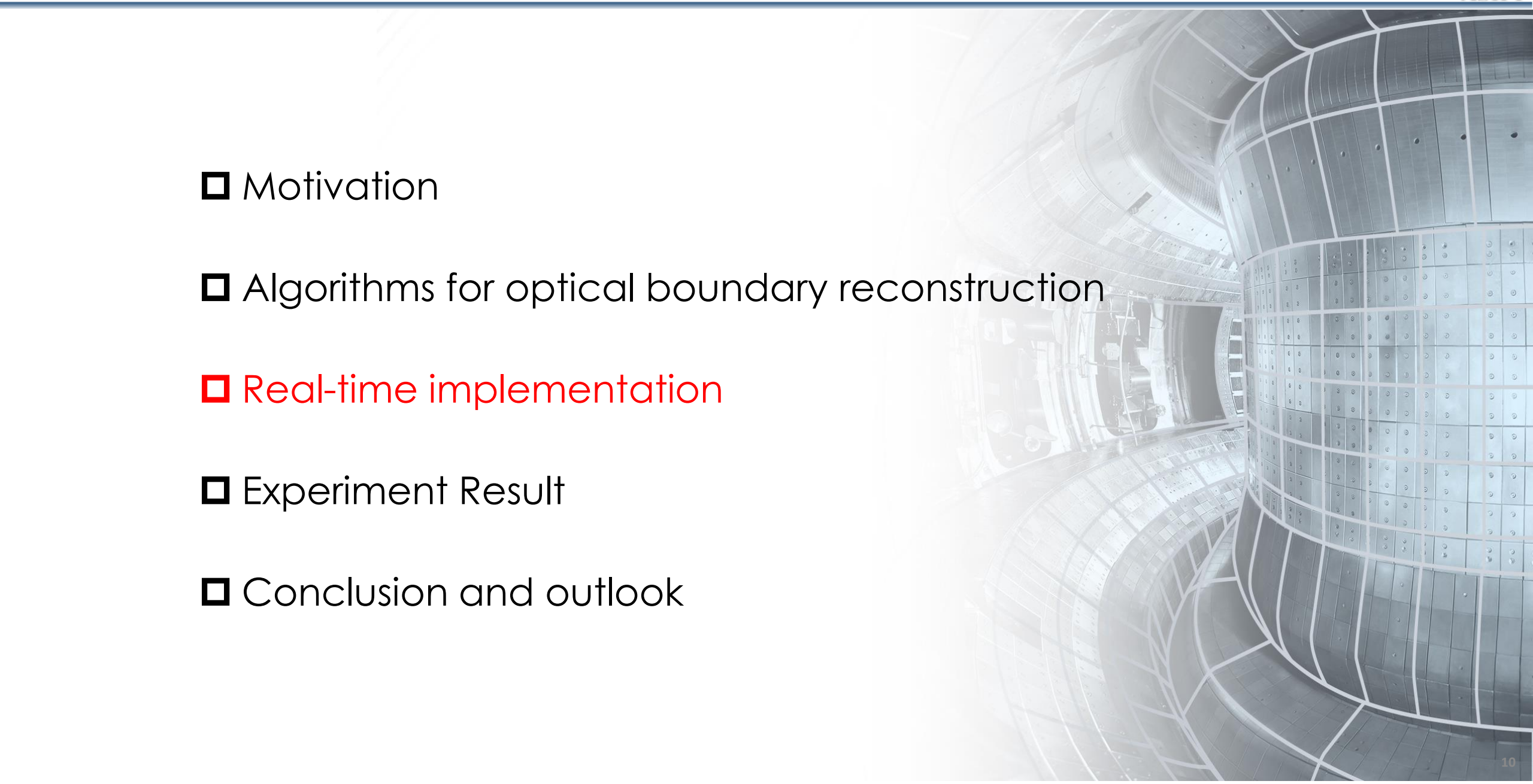
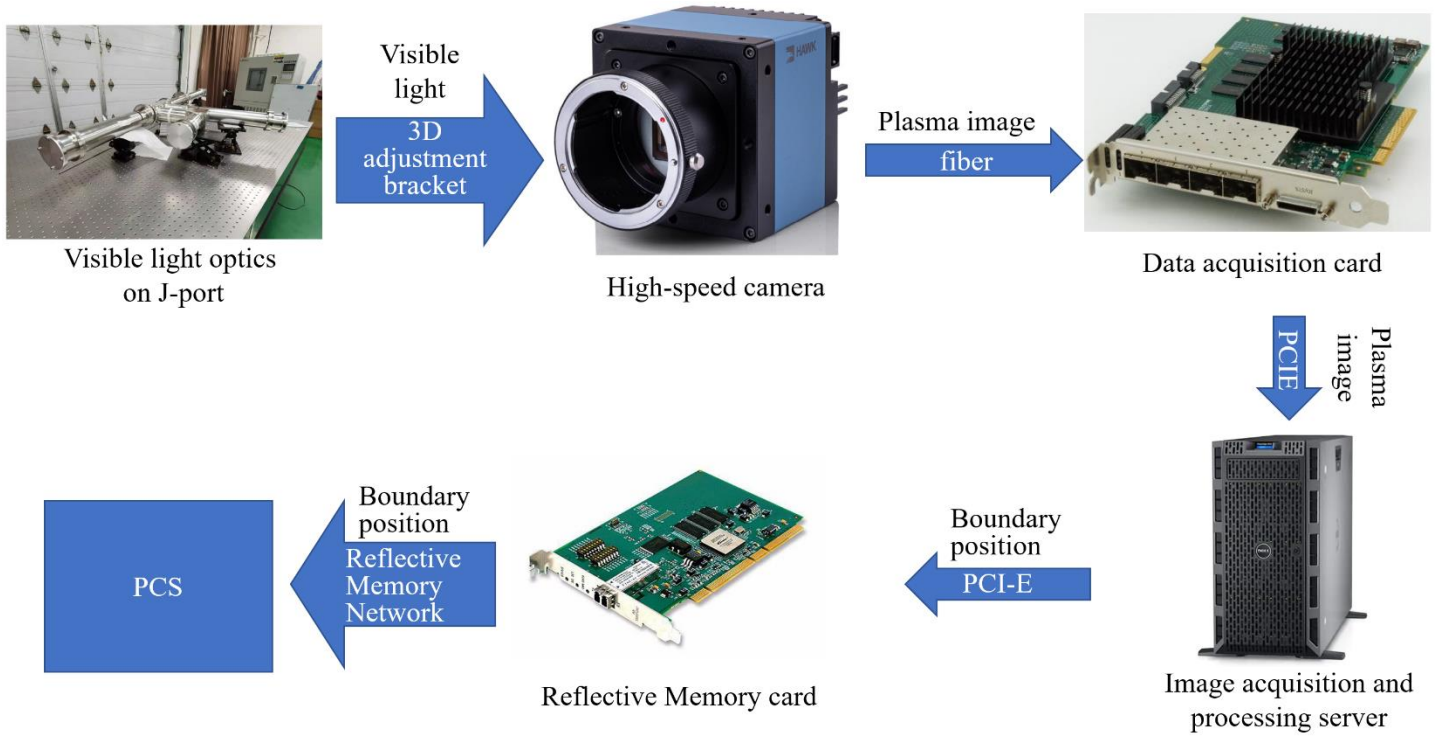


Real-time implementation

➢ Hardware implementation

The hardware of the optical reconstruction system is composed of visible band optics, a high-speed camera, a data acquisition card, a server, and a reflective memory card

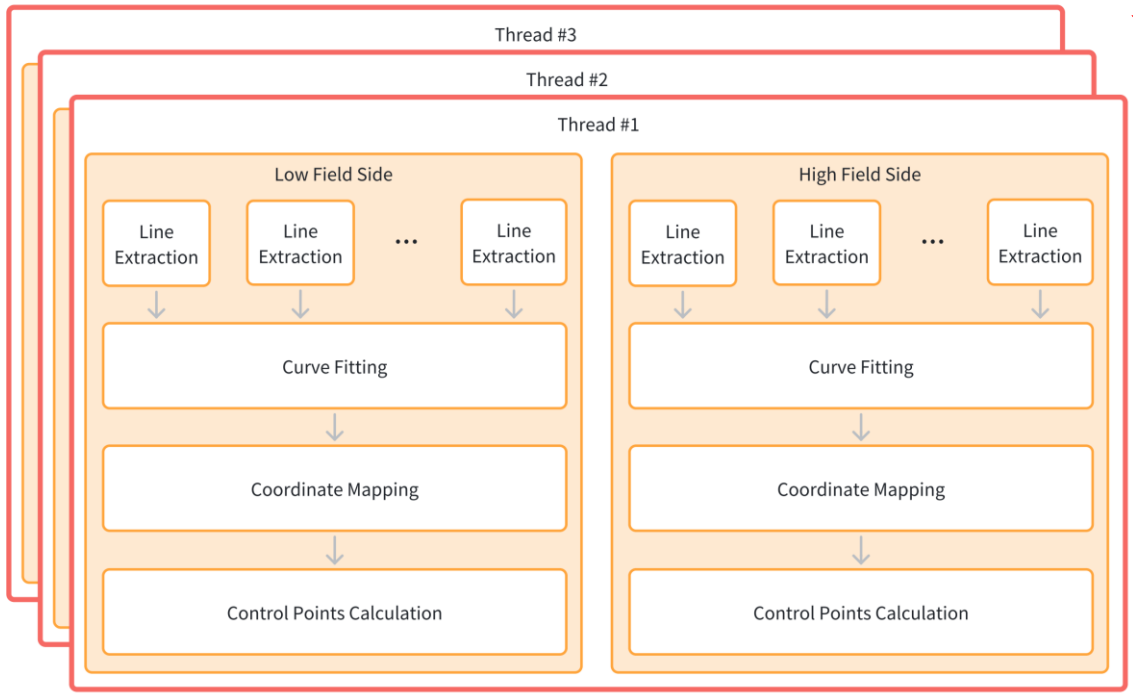


The hardware workflow of the real-time optical plasma boundary reconstruction system

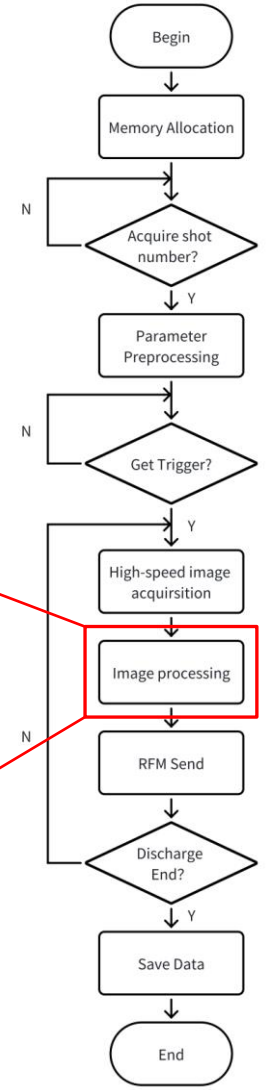
Real-time implementation

➢ Software implementation

- The software for real-time optical reconstruction is deployed on the EAST
- A thread pool is used for multi-threaded simultaneous computation.



The parallel structure of the image processing module



The flow chart of the software for boundary reconstruction

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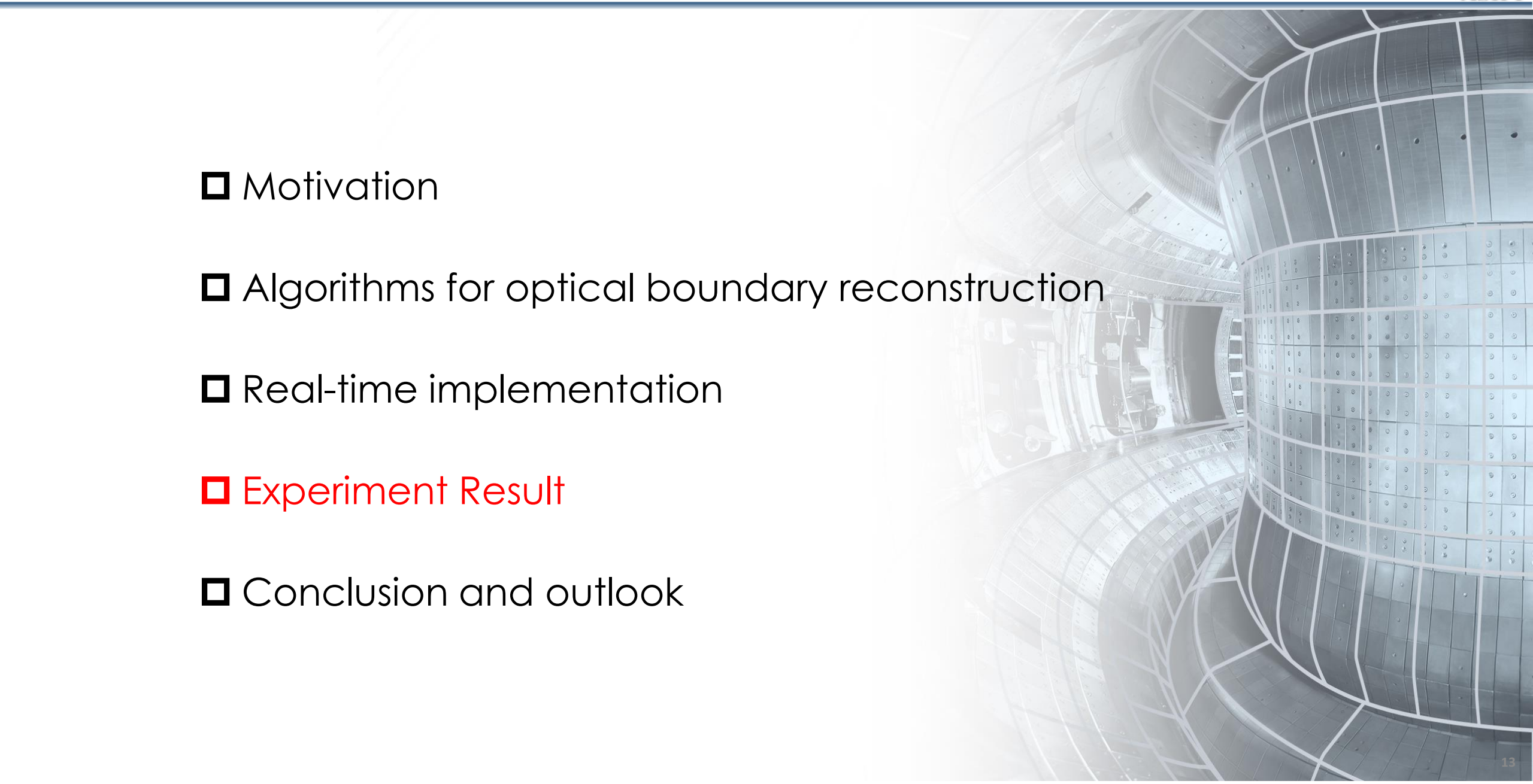
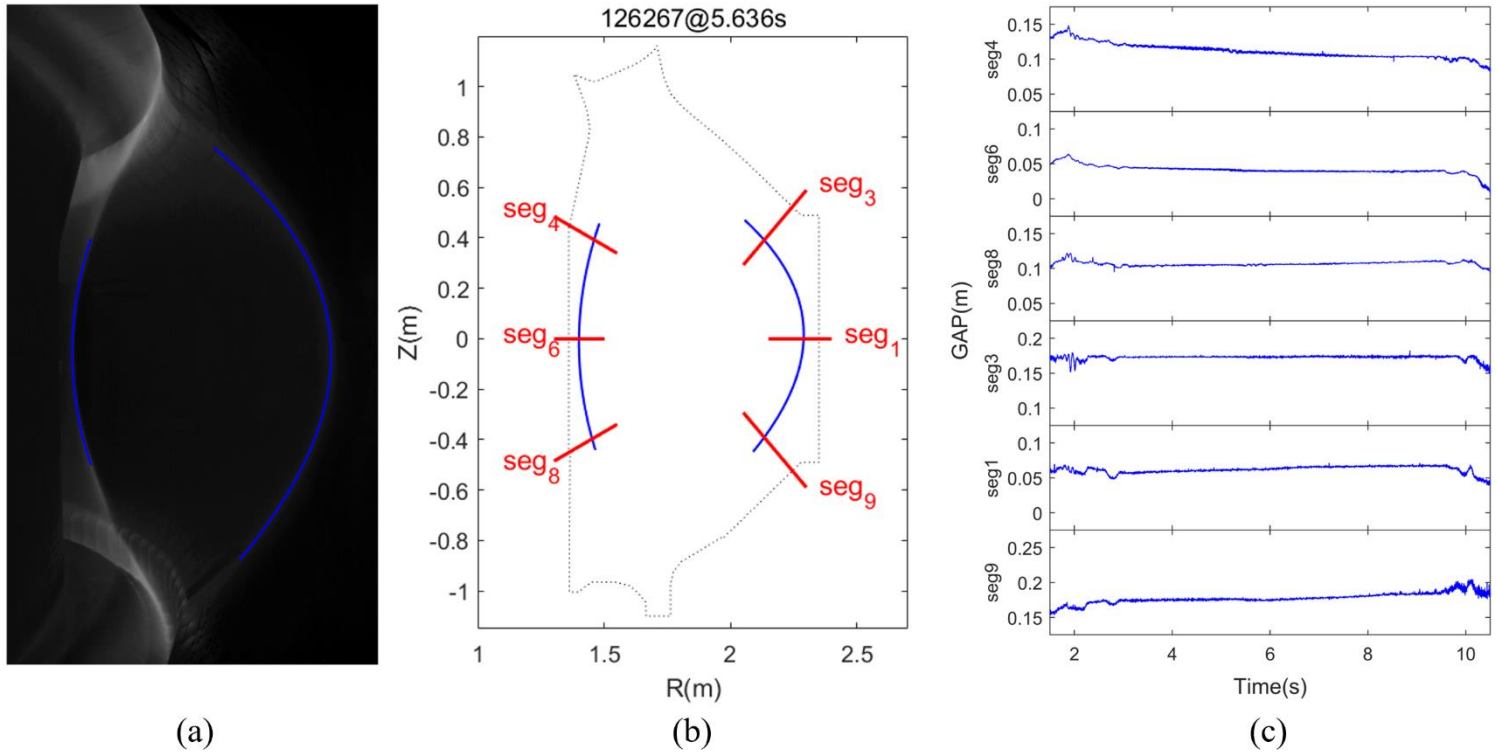


Experiment Result

➢ Reconstruction Result (Normal discharge)

- The Z-axis coordinate ranges for the low-field and high-field boundaries become identical due to the mapping process
- There are intersection points with six shape control segments
- The change curve of the shape control points over time can be obtained based on optical reconstruction

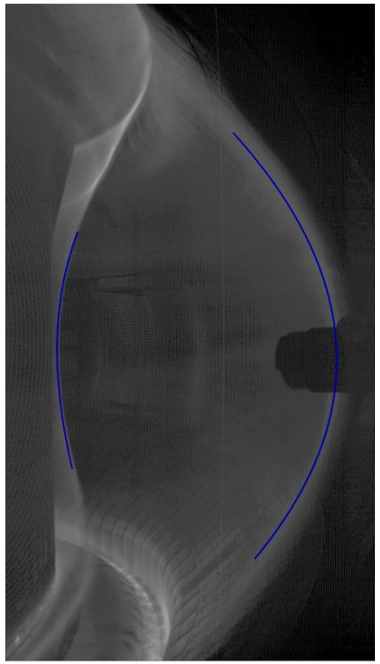


The reconstruction result of Shot#126267

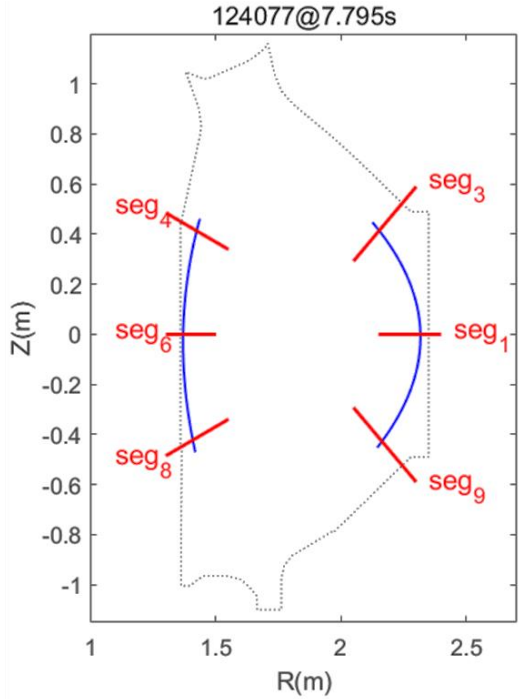
Experiment Result

➢ Reconstruction Result (Impurities behavior)

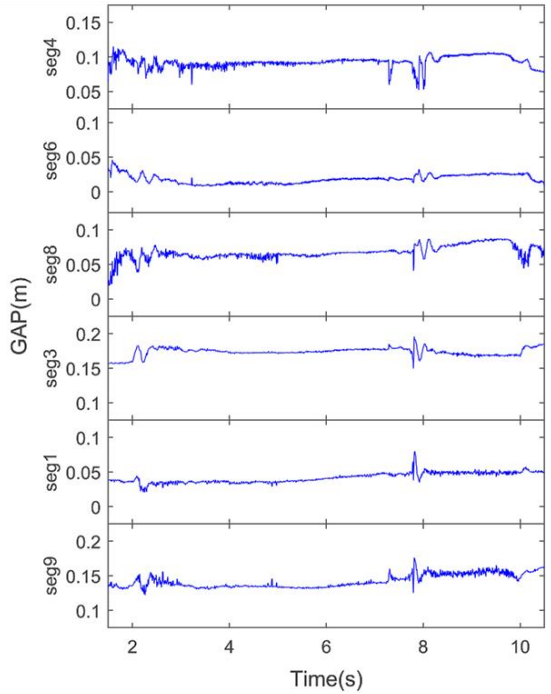
- [Fast response] Impurities entered the plasma, causing the radiation signal to rise and the boundary shape to change slightly
- [Good robustness] Fast-moving probe obscures part of the boundary but does not affect the result, verifying the stability of the reconstruction algorithm



(a)

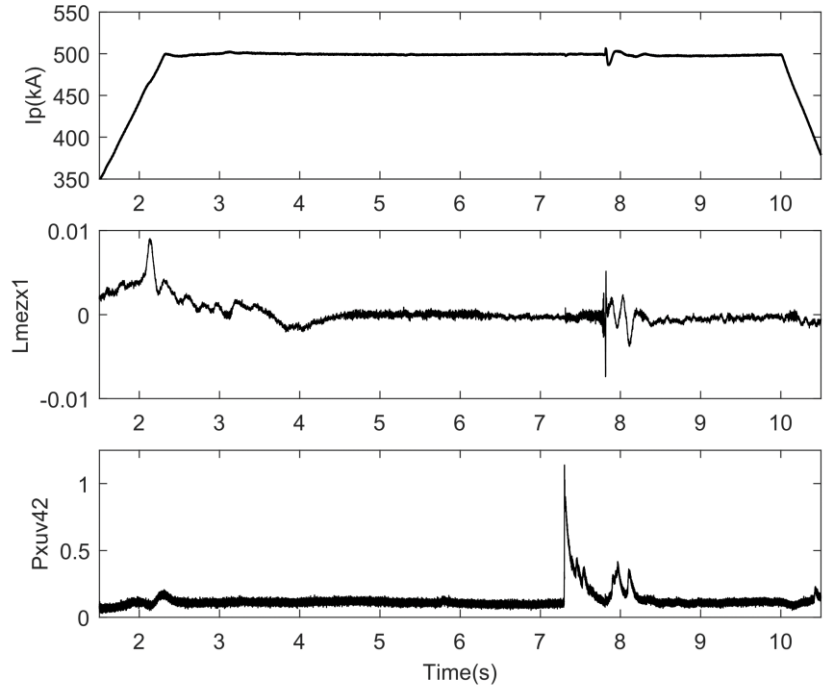


(b)



(c)

The reconstruction result of Shot#124077



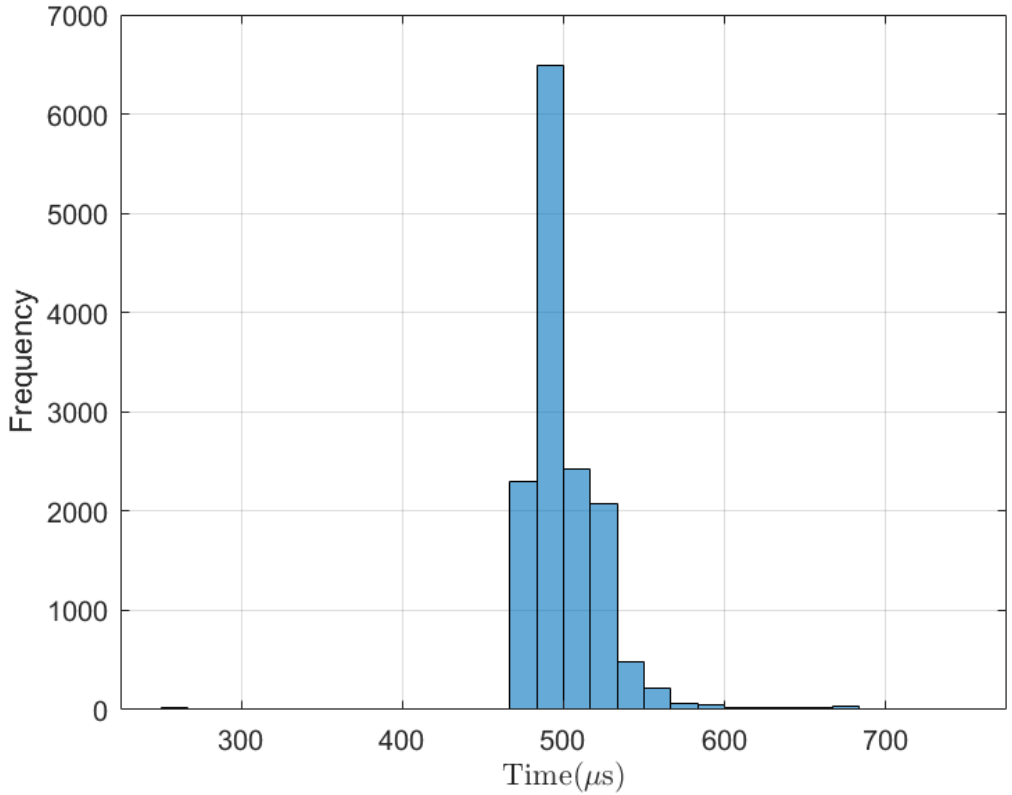
Plasma current (Ip), Z_error (Lmezx1), and radiation (Pxuv42) signals for Shot#124077

Experiment Result

➢ Algorithm time response

- Maximum image processing algorithm time consumption does not exceed 700 μs
- Overall system delay is less than 1840 μs

Category	Max time(μs)
Image acquisition	980
reconstruction algorithm	700
RFM transmission	50
Total	1840



The time consumption of the image processing algorithm for Shot#126382

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Conclusion and outlook

➢ Conclusion

- Implemented an optical boundary shape reconstruction system on EAST Tokamak
- Verified the feasibility of boundary shape reconstruction based on an optical method

➢ Outlook

- Use optical reconstruction system to correct the shape reconstruction drift based on electromagnetic measurement and achieve a higher shape reconstruction accuracy
- Carried out experimental verification of control the plasma shape through optical reconstruction

Thank you !