Applications of artificial intelligence in laser accelerator control system

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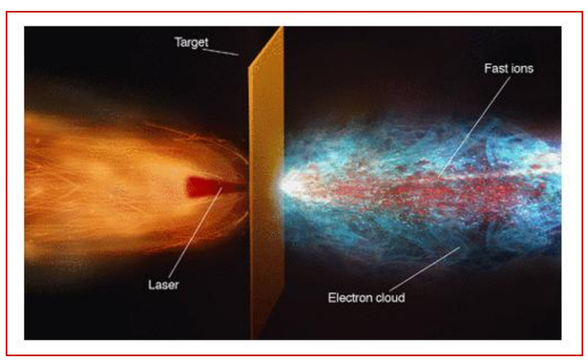

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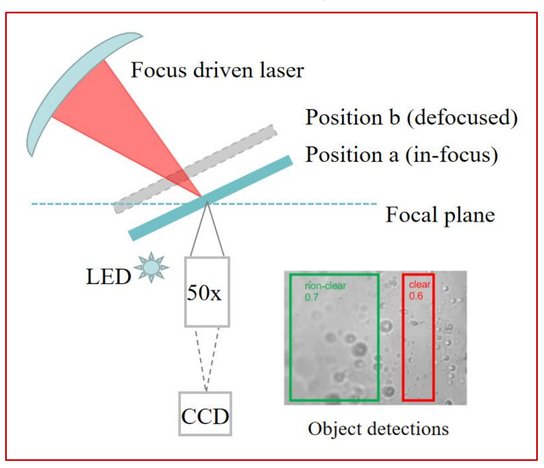
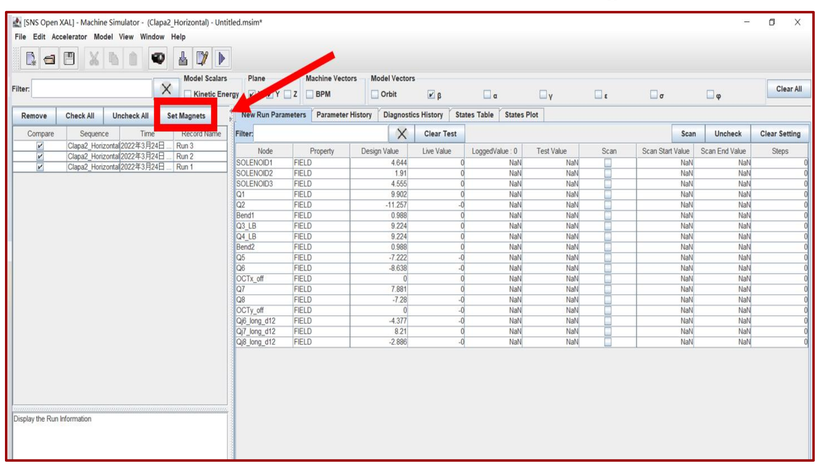
Target alignment by AI algothim



Virtual Beamline Tuning

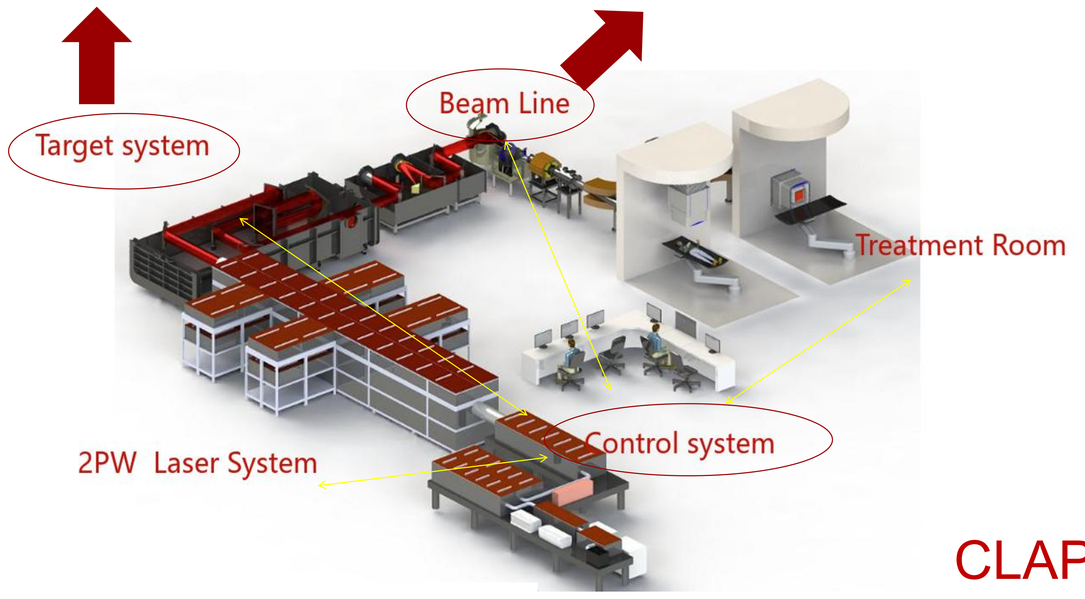


Laser-plasma accelerator its control system:

- TV/m acceleration gradients, a compact accelator.
- The LPA control system requires stability and efficiency.
- CLAPA-II, a new laser-driven proton therapy facility.

Applications of AI in control system:

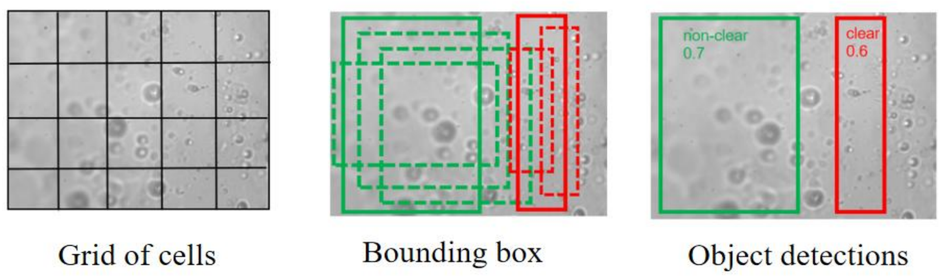
- Target system alignment:
  - ✓Object detections algorithm (YOLO)
  - ✓Data collection, evalution,an inference
- Camera monitoring (by YOLO) in safety interlocking system
- Virtual beamline tuning
  - ✓GPU-accelerated multi-particl algorithm
  - ✓Genetic optimization algorithm



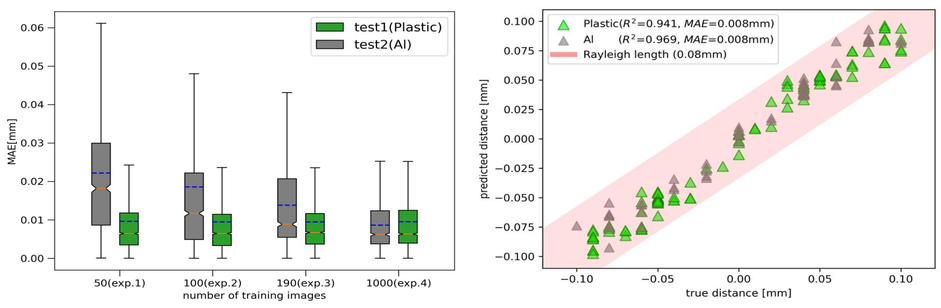
CLAPA-II

Application1: Real-time object detection in LPA

- A fast and precise algorithm,YOLO
  - ✓The position of clear and non-clear areas depends on the imaging position of the target.
  - ✓Using deep learning network to detect the clear area.
  - ✓How does YOLO(You only look once)work?



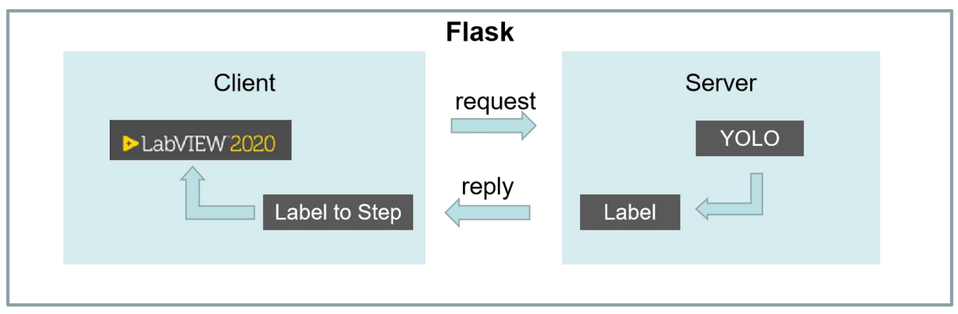
- Workflow
  - ✓Data collection and annotation labels
  - ✓Transfer learning: 40mins, ~200 images, 400 epochs
  - ✓Test results: Mean absolute error of 8 μm (~ 0.1 Raleigh length for a 5 μm laser spot)



- Linear transform to montor movement
  - ✓Detection labels convert to montor moving steps.
  - ✓Clear area is found / only non-clear area is found

$$L = K_1 (0.5\text{-}x) \;/\; L = K_2 w \cdot \mathrm{sign}(0.5\text{-}x)$$

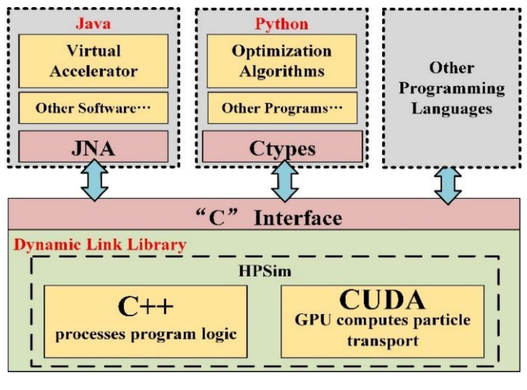
- Inference and
  - ✓Client-server mode based on the FLASK framework

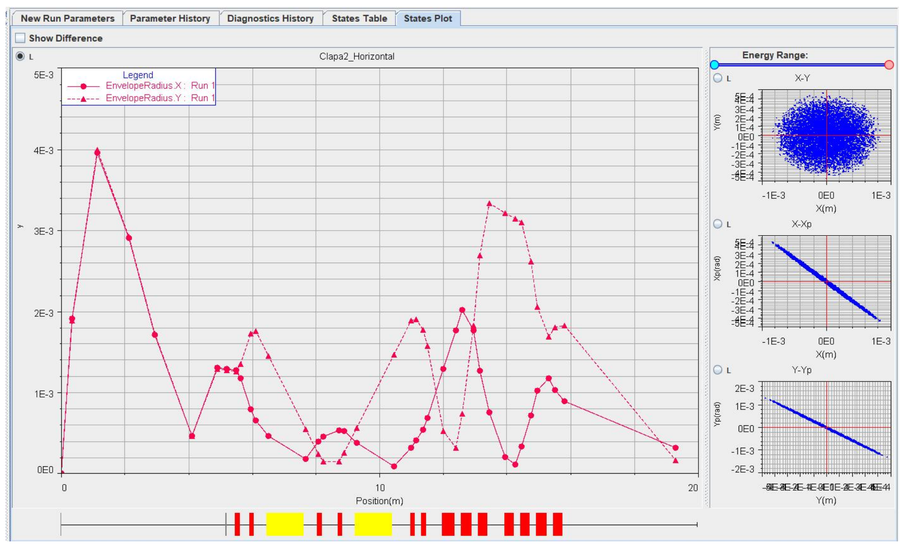


- Other applications[1]
  - ✓The YOLO algorithm is also integrated into the safety inter-locking system for anti-tailing.
  - ✓Detecting human's entry when LPA is runing.
  - ✓Easily deployable on edge mobile devices.

Application2: Virtual accelerator for beamline

- GPU-accelerated multi-particle beam transport simulation algorithm
  - ✓Based on "HPSim".
  - ✓Transfer Matrix-based methods.
  - ✓A single simulation takes a few hundred milliseconds.
  - ✓Provide interfaces for Java, Python, and other programs to call.





- Optimization of magnet parameters in the beamline.
  - ✓Combining GPU-accelerated simulation algorithms and genetic optimization algorithms.
- Development of virtual accelerator software
  - ✓Based on "OpenXAL".
  - ✓Crucial for real-time beam transport simulations, beam tuning, and operation adjustments of accelerators.
  - ✓Enhance beamline diagnostics, providing a virtual diagnostic framework.
  - ✓Beam transport visualization.
  - ✓Conversion between physical quantities and control quantitie.
- Future work
  - ✓Implementing complex control algorithms in the virtual accelerator.
  - ✓Applying artificial intelligence algorithms to beam tuning.

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