Applications of artificial intelligence in laser accelerator control system

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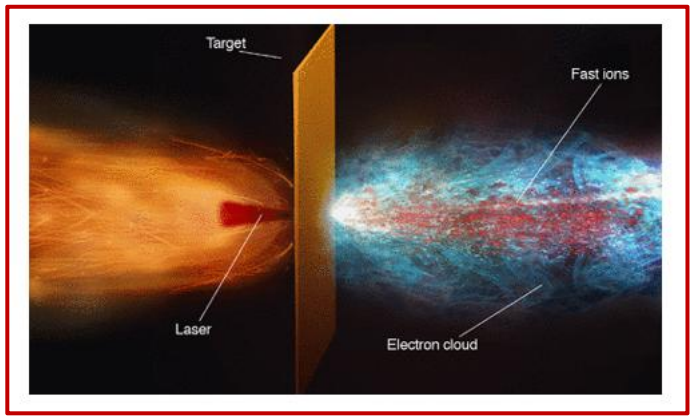
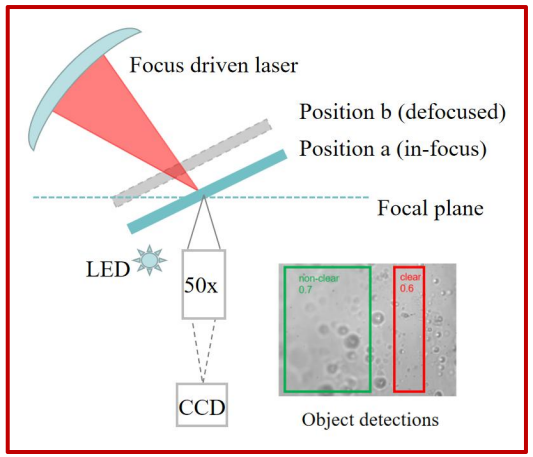
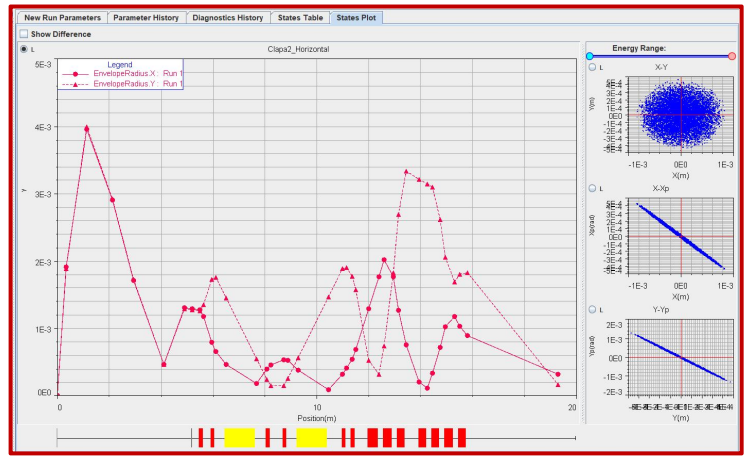


(Cite from *Rev. Mod. Phys. 85, 751, 2013*)



Target alignment by AI algorithm



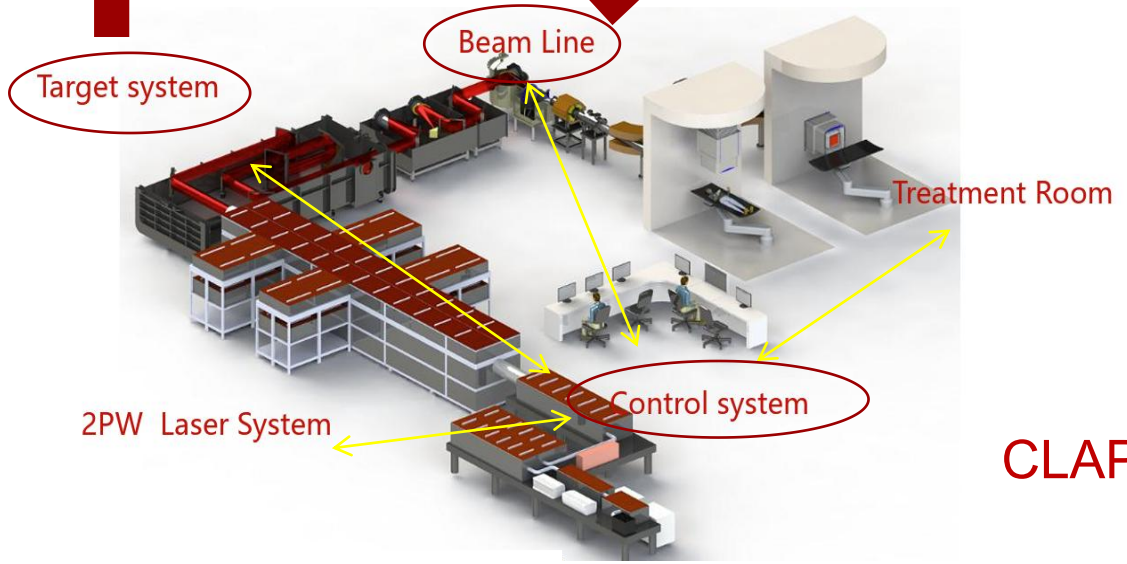
Virtual Beamline Tuning

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, and inference
- Camera monitoring (using 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

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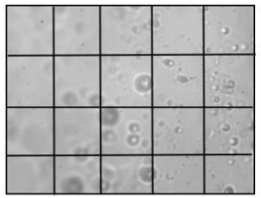
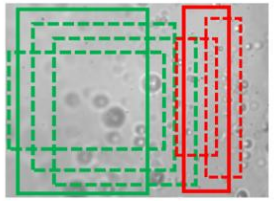
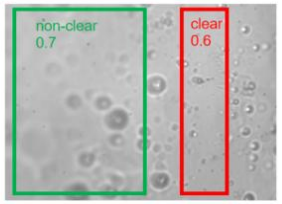
- A fast and precise algorithm,YOLO
  - ✓ The position of clear and non-clear areas depends on the imaging position of the target.
  - ✓ Using deep learning network to detect the clear area.
  - ✓ How does YOLO(You only look once)work?



Grid of cells

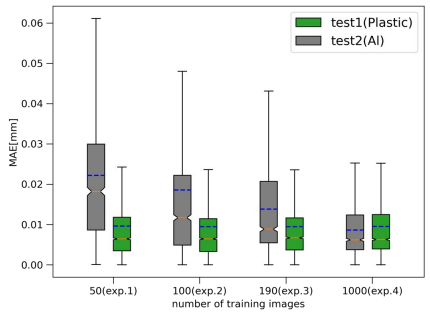


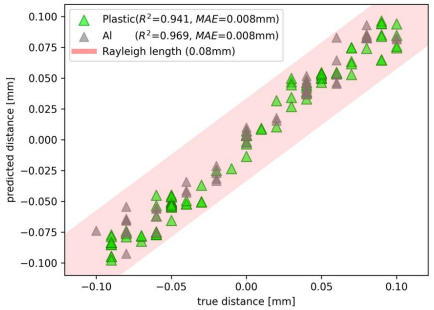
Bounding box



Object detections

- 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) .

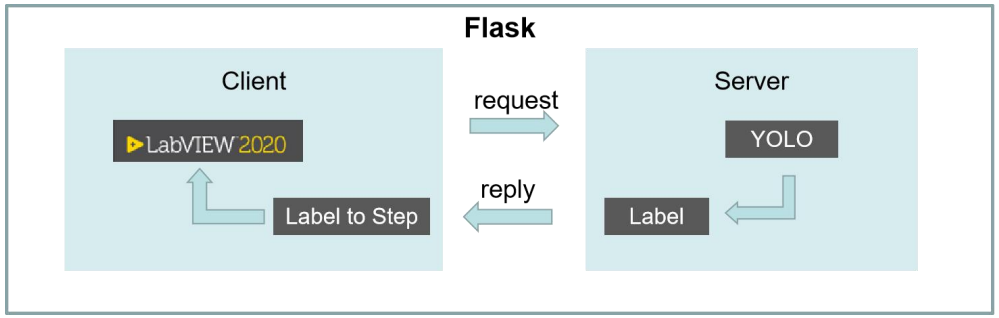




- Linear transformation of labels
  - ✓ Detection labels converted to montor moving steps.
  - ✓ Clear area is found / only non-clear area is found

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

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



- Other applications
  - ✓ 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

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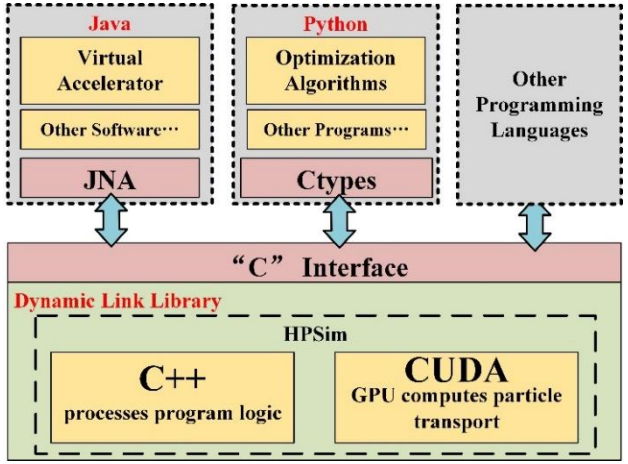
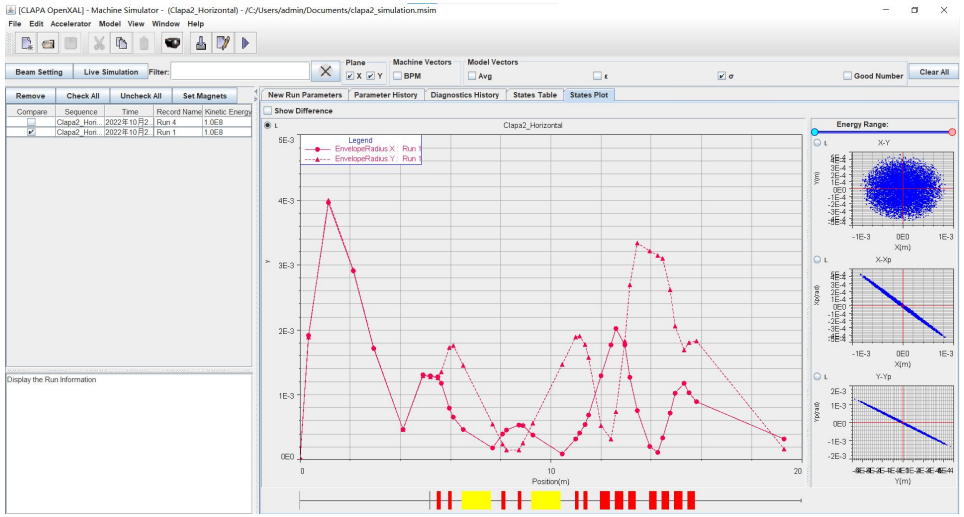
- GPU-accelerated multi-particle beam transport simulation algorithm
  - ✓ Based on “HPSim”
  - ✓ Transfer Matrix-based methods
  - ✓ A single simulation takes a few hundred milliseconds.
  - ✓ Provide interfaces for Java, Python, and other programs to call.



- 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 quantities.



- Future work
  - ✓ Implementing complex control algorithms in the virtual accelerator.
  - ✓ Applying artificial intelligence algorithms to beam tuning.