COMMAND AND CONTROL SYSTEM FOR LASER BEAM POSITION WITHIN TRANSMISSION LINE AT CETAL-PW

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CETAL-INFLPR laser facility (http://cetal.inflpr.ro/pw) aims to run at 45 TW with 10 Hz repetition rate and at 1 PW with repetition rate of 0.1 Hz, delivering pulses of 25 femtoseconds. Major issues are related to beam delivery on target, both spatial and temporal pulse structure being affected by complexity of beam transport system

The paper presents relevant aspects of concept, design, manufacture and tests for laser beam command and control system. It is an optoelectronic system for monitoring and control of laser beam within laser transmission line, aimed at eliminating the risks of destroying focal mirrors caused by parasitic focus.

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Keywords: control system, laser beam, monitoring software

1. Introduction

The experimental quest for the highest peak intensity has led to many developments in terms of increased energy, beam focus ability, temporal contrast and pulse delivery reliability.

Nowadays, state-of-the-art laser systems are targeting 10 PW peak power with energy of hundreds of joules with pulse duration below 20 femtoseconds (fs) One of the critical importance to any laser system, but especially for ultrafast laser systems [1] is proper optical alignment through transmission line from the starting point (initial oscillator) till target. These ultra-short pulses occupy a length scale of a few micrometers. Misalignment ultimately leads to temporal shifts of the pulses, which can drastically alter the results of ultrafast experiment such as pump-probe or four-wave mixing. A very clever alignment geometry using elliptical and parabolic mirrors was presented by MacFarlane [2] who showed that femtosecond timing can be preserved in a passive setup. A beam alignment device

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for ultrafast lasers consisting two quadrature photodiodes with feedback electronics was developed for small energy and simple setups [3]. A monitoring and control system strategy for the experiments was presented in [4] and however, high power for ultrashort (fs) lasers system, reports on the beam monitoring and alignment are rather scarce or unavailable.

CETAL-PW (Center for Advance Laser Technologies) laboratory is the newest department of National Institute of Laser, Plasma and Radiation Physics, (http://cetal.inflpr.ro/pw). The research activity is focused on the interaction of ultra-short high-intensity lasers with matter and, thus, of its application in: medicine, chemistry, space science. The laboratory is equipped with an extra high power petawatt laser system built on Ti:Sapphire technology. The system is a multistage amplifiers designed to amplify ultra-short pulses with the gain about 109 and repetition rate by 10 Hz for TW output and 0.1 Hz for PW output. [5].

Structure of CETAL-PW laser system consists in the main components mentioned next: petawatt laser; beam transport system; interaction chamber – where laser beam is focused onto the target. The functional blocks related to command and control of this complex system are related to: laser signal conditioning (Front-End); laser amplifiers in nominal regime (Amplifier 2); pulse generation of petawatt power (Compressor); laser radiation transmission onto the target (Mirrors M1,M2,M3,M4 and interaction chamber).

It is figure 1 that evidences the block diagram of CETAL-PW laser.

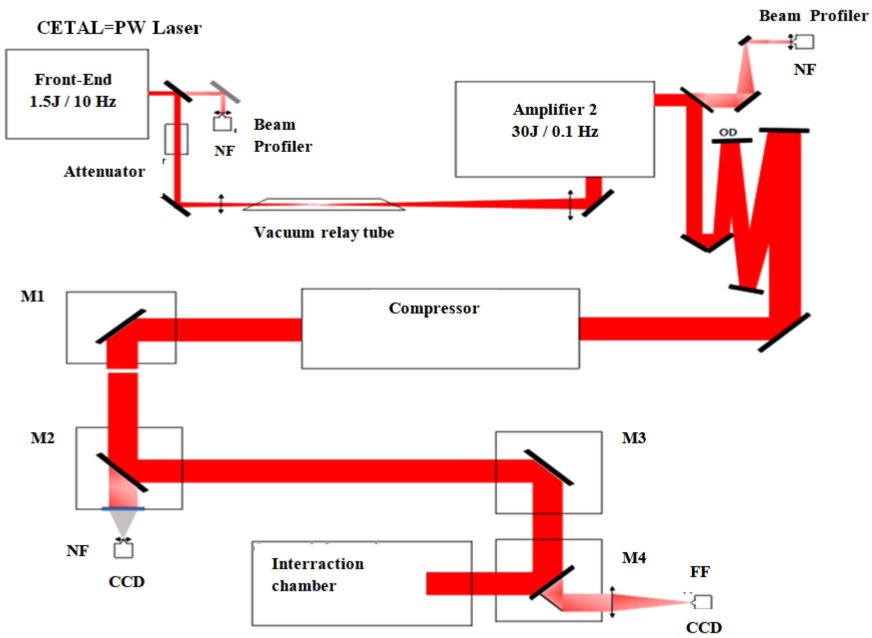


Fig. 1. Block diagram of CETAL-PW laser

The significance of notations in Fig. 1, as well as in figures to be presented next (figure 3, figure 5) is the one that follows.

- "NF" represents the Near Field CCD cameras – short focal lens, aimed to characterize the position of laser beam.
- "FF" stand for Far Field CCD cameras – long focal lens (1,000 mm), for characterization of the angle of laser beam.
- "OD" is the deformable mirror, whose role is to correct the front of laser beam.
- "Attenuator" is the optical attenuator - controllable from 2% to 100% (a rotating half-wave plate and double polarized extinction plates), needed for low energy optical alignment.
- "M1","M2","M3" and "M4" represent the dielectric mirrors, for beam-transport.
- "Front-End" is the laser signal conditioning - it is made of a femtosecond pulse generator with specific amplifier and contrast booster, a temporal stretcher to 500 ps pulse duration, specific amplifiers.
  At the end of "Front-End" the laser pulse is characterized by: 1,5J (energy); 500 ps length and 10 Hz repetition frequency.
- "Amplifier 2" is the nominal amplifier stage to 30J energy needed for obtaining 1PW laser peek intensity.
- "Compressor" is the femtosecond reconstruction pulse stage.
  It has an inverse low from the stretcher and generates 25 fs pulse length. The efficiency of this stage is around 82% so, output energy is 25J at 25 fs and the peak power is 1 PW.

Propagation within the system of laser beam is done by its amplification with optical telescopes so that the energy density on surface its kept below value (limit) corresponding to destruction of component elements, 150mJ/cm^2. This is why the laser beam diameter varies as follows: 12 mm at exit from Front-End block; 60 mm at the exit from Amplifier 2 block; 160 mm at the entry in Compressor block. From this point forward, laser radiation is transmitted into the interaction chamber, by vacuum, through pipe with inner diameter of 240 mm.

The control of laser beam position in this propagation is done in several points, by three Near-field cameras, that uniquely determine position, and one Far-Field camera, that uniquely determines radiation direction. The optical path for propagation of laser radiation is 84 m long, measured from Front-End exit up to Interaction chamber entrance. While this complex laser system works, it has been proved that it is crucial to have an accurate propagation of laser radiation. In fact, any mirrors micro-displacement caused by thermal variation within Front-End or, mirrors major displacement in vacuum system, caused by air extraction, generate wrong position of the laser beam and, consequently, parasitic focusing points (due to pipes of transmission system).

The parameters of the laser beam will be almost unchanged during this propagation (energy, pulse duration, frequency etc) but a misalignment can generate major mirror failure like the one evidenced in figure 2.

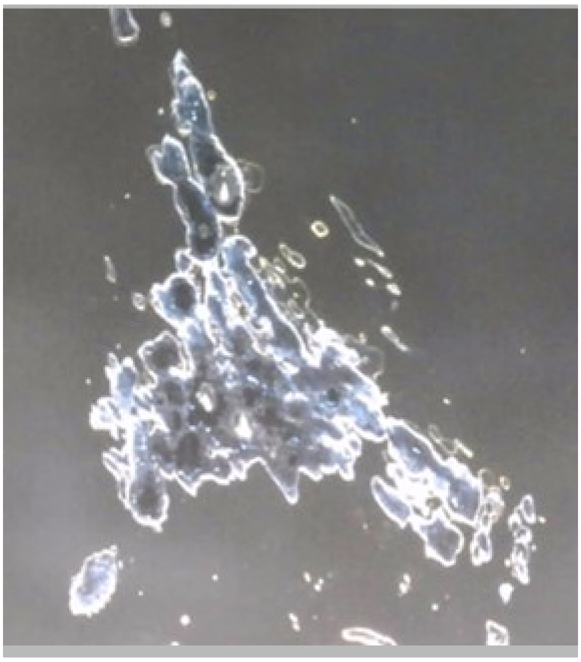


Fig. 2 Mirror with multiple parasitic focusing points

All the aspects mentioned above, stand for the need of eliminating risks of destroying mirrors by parasitic focus. For this reason an innovative optoelectronic system for monitoring and control of laser beam within transmission line has been designed and developed, as to be presented next.

2. Concept of command and control system

Avoiding destruction of mirrors placed within transmission line of laser beam, is possible by designing an optoelectronic system, with extra components (when referring to the already existing one) for unique determination of laser radiation position, that is space position and propagation angle.

2.1. Control system for laser beam alignment

The block diagram of laser beam system, with new optical components is presented in Fig. 3. Monitoring the laser beam source is done by two cameras type, as follows:

- Near-Field type cameras, where displacement is proportionally seen on CCDs (regular video cameras);
- Far-Field type cameras, with very long focal length, where on CCD is pointed the focal spot of monitored laser beam.

Its displacement is proportional to beam angle.

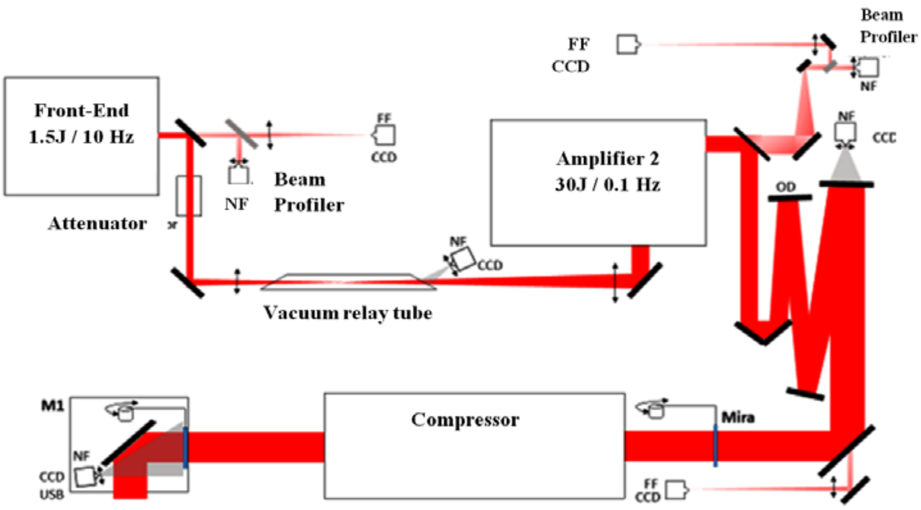


Fig. 3. Block diagram of laser with new optical components

Explanation of the aspects mentioned follows next:

- at the Front-End exit, there is a Far-Field type CCD camera, with focal length of 1000 mm - by its correlation to initial Beam-Profiler camera, a complete characterization of laser beam is done;
- at the entry in Amplifier 2, there is a Near-Field type camera for monitoring the beam at the exit of telescope vacuum tube –wrong position of the beam at this point gets to burning of tube's exit part;
- at the exit of Amplifier 2 there is a Far-Field CCD camera, with focal length of 1000 mm – by its correlation to initial Beam-Profiler camera, a complete characterization of laser beam is done;
- at the entrance of Compressor (within telescope for beam magnification from 60 mm, up to 180 mm), there is a binom of Near-Field and Far-Filed.

In real conditions, when laser beam diameter gets to 160 mm, the Near-Field type cameras are not fit for use, as it is not possible to notice dispalcements of milimeters.This is why, it has been considered fit a new solution, that of using a mira, as shown in Fig. 4. This mira enables to pass through only one part of the beam and to clear evidence the center of laser beam.


Fig. 4. Mira used for clear evidencing laser beam center

2.2. Control system for beam transmission

The block diagram of beam transmission system, with new optical components is presented in Fig. 5.

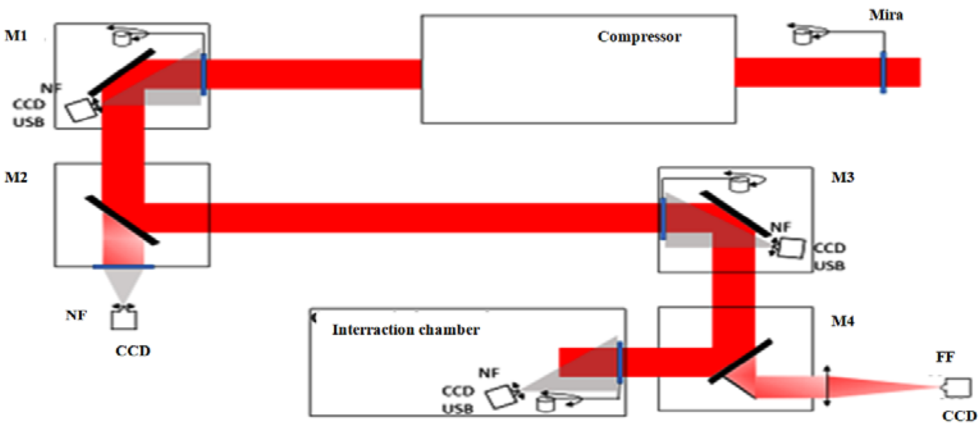


Fig. 5. Block diagram of transmission system with new optical components

In the former (initial) system there is implemented a Near-Field type control at mirror M2 and a Far-Field type control at mirror M4. For this system, mathematically results in four unknown double variables (angles of mirrors M1, M2, M3 and M4) of a two equations system. Geometrical dimensions of each of the four mirrors are 320 x 230 mm. They are positioned in vacuum and, implicitly, the air extraction causes changes of their position.

In order *to solve the delicate problem of mirror displacement*, there has been considered an innovative solution based on screens mounted on a rotational system, in front of the mirrors and on Near-Filed type cameras monitoring the beam by screens transparency. Thus, it is generated a well determined system for laser beam position within the whole transport system.

The screens are made of teflon plates, due to teflon fit properties like: high melting tenperature; low gas permeability rates; good transparency rate. The system used for screen rotation is goniometer STANDA, type 7R150V, with main characteristics: rotation up to 360°; angular speed: 8 rot / min; angular resolution: 2 arc/min; radial load: 1.7 kg; vacuum operation. The video cameras are Microsoft USB Cam 3000HD with HD resolution, self-focusing and vacuum operation.

3. Prototype of system components

The new system's components had to be designed and, further, developed under strict conditions, meaning no mechanical change of the existing CETAL-PW laser components was allowed. That is why, customized solutions had to be considered for manufacturing, mounting and assemblying the required components. The solution for mounting the mirrors M1 and M3 is presented in Fig. 6, where one can notice, both 3D model and manufactured subassembly.

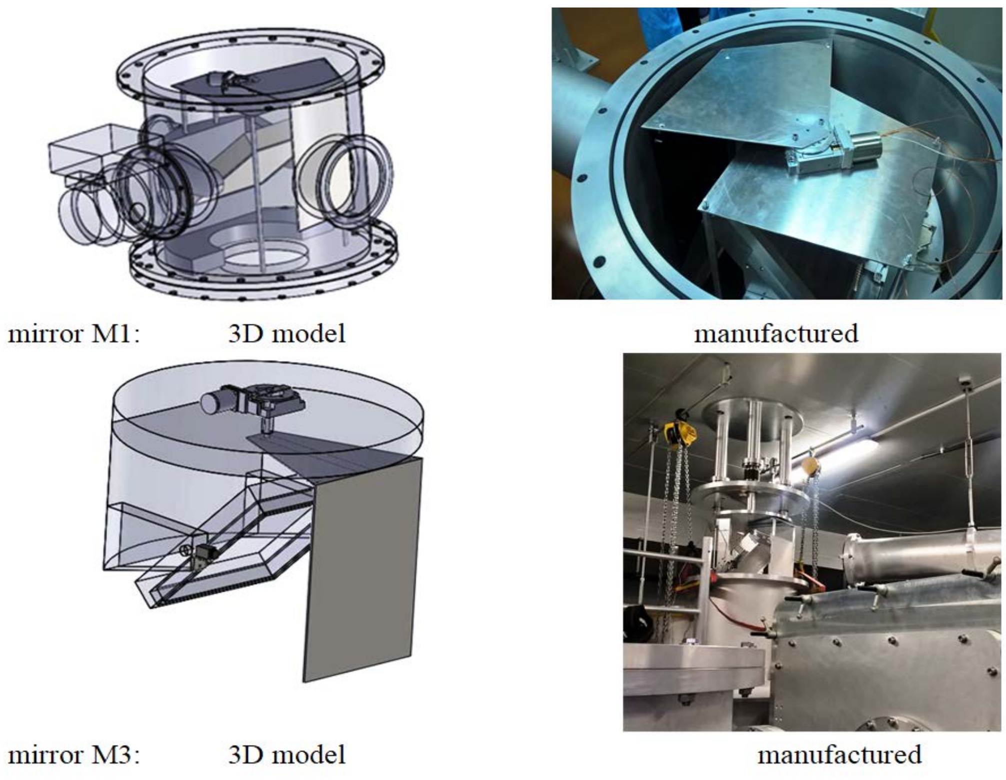


Fig. 6. Subassemblies for mounting mirrors M1 and M3

4. Software for command and control

The monitoring, command and control software has been developed in Python 2.7 for stepper motors drivers control; in OpenCV for webcams control and in GTK 3.0 for designing the GUI Interface. Its concept is that of control zones separation as follows.

- Laser zone – controls and monitors the position of mira and laser beam at the output from the compressor with video stream of the Far-Field and the Near-Field CCD.
- Transport zone – controls and monitors the screens and video cameras of mirrors M2, M3 and M4, as well as the interaction chamber.

The advantage of implemented hardware system is that enables operation in two distinct modes, presented next.

- “Align” mode – correlated to operating the mira. By using curtains in front of mira, there is ensured its protection, avoiding damages caused by parasitic focus on the surface.
- “Optical Quality” mode – it is analyzed the profile of laser beam on each screen (without using mira) and it is enabled the detection of reflection defects for transmission mirrors. The sooner the detection, the better implementation of solutions for repairing mirrors surface at early stages.

Graphical interfaces are developed in GTK and shown in Fig. 7.

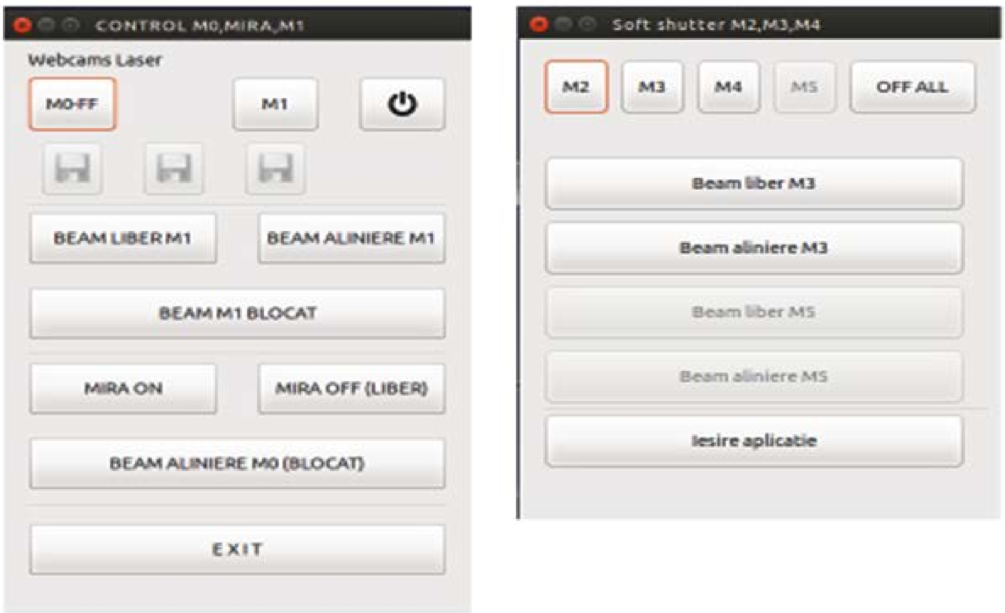


Fig.7 . Graphical interfaces for hardwae system

The monitoring software correctly computes laser beam center position for near-field captures, far-field captures and should have the ability to command the shutter position and mirrors in order to correct the deviation. In this stage, the system is capable to adjust position for individual mirrors and to correlate identified misalignments for multi-element modules and proceed to the system global alignment using global procedures based on computed algorithms on beam transport line – see Fig. 8.

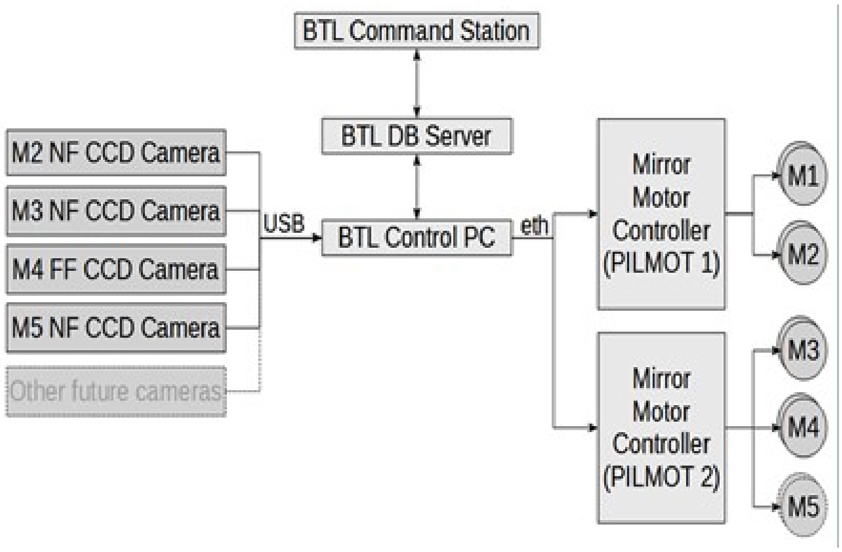
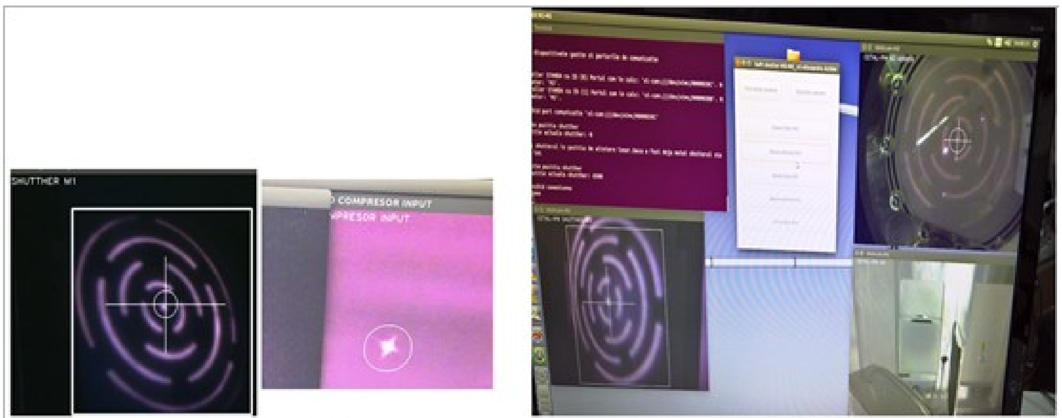


Fig. 8. Beam transporter line (BTL) monitor and alignment system architecture

Application of the developed software for command and control of CETAL-PW laser is evidenced in figure 9.



a. for mirror M1 b. for mirrors M2, M3 and M4

Fig.9. Control image for laser mirrors

The significance of notations is as follows:

a. – control image for mirror M1, with positioned mira and Far-Field camera;

b. – control image for mirrors M2, M3 and M4.

5. Conclusions

CETAL-PW laser facility should be open for users and for better system security, stability and reliability it should be functional with as less human intervention on the alignment of the laser beam as possible.

The laser beam alignment trough the transport tubes is also critical, since small misalignments on the long transport line tubes might tilt the beam and produce reflections on the beam pipes. Such reflections could further generate bad focusing points on the optical mirrors and destroy them.

In order to monitor the beam alignment a set of CCD cameras and a set of motorized shutters windows (for forming the beam image) were installed on each reflective mirror on beam transport. A software was developed in Python2.7, OpenCV and GTK 3.0 for command and control the webcams, step motors driving mirrors and shutters using GUI controls

Further development aims the analysis on laser spot for determining energy distribution within laser beam (spatial profile) and the study of laser mirror state by comparing the propagation of spatial profile within transmission line (beam-transport).

R E F E R E N C E S

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