
# Laser Assisted RObotic Surgery of the anterior Eye Segment

D 7.5 - Final release of integrated robotic platform

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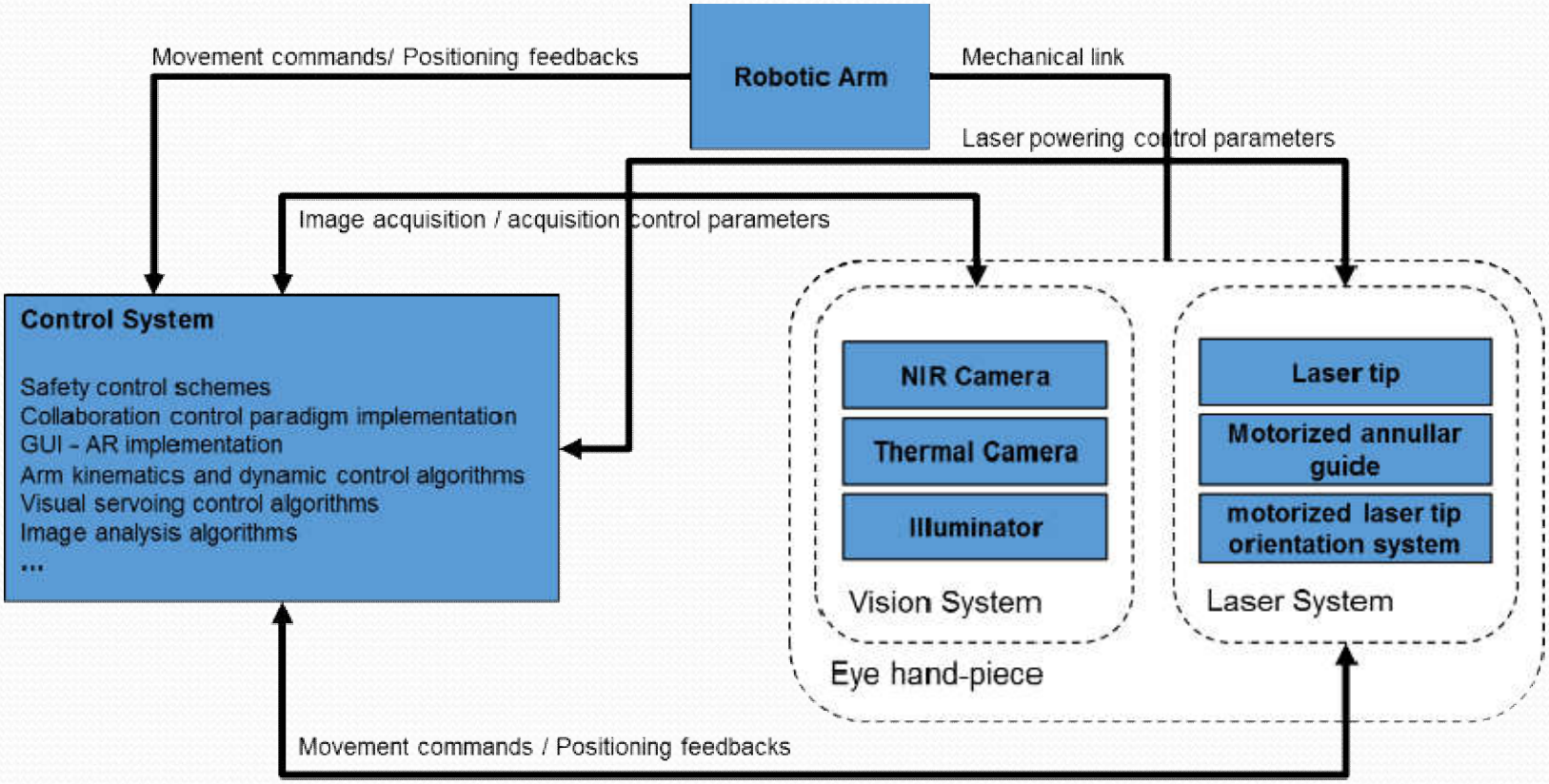
# Outline of the content

- Final status of the LA-ROSES system:
  - End-Effector subsystem: mechanical solution and laser motor handling implementation
  - Laser subsystem: laser motors control system and synchronization electronic circuit
  - Robotic arm solution
  - Vision system: HW components
  - LA-ROSES master controller system

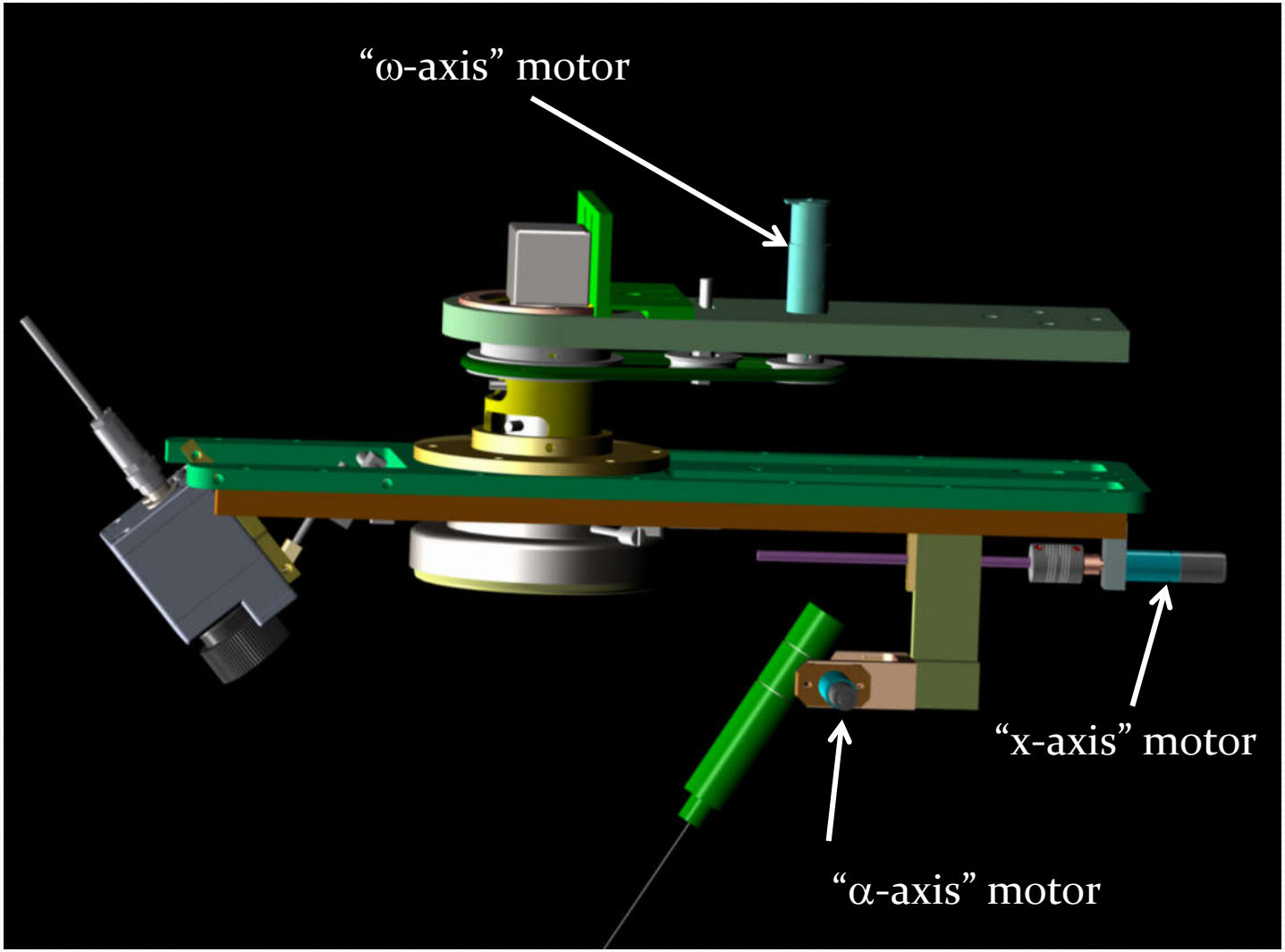
# End-effector status

- no force feedback implemented: with the new laser, there is no need to touch the cornea surface
- the use of a laser distance system eliminates also the sterilisation issues
- it is anyway necessary to know the distance (camera-cornea), but this can be done directly with a calibration of the camera and the kinematics of the system
- the end-effector was designed for a large set of configurations:
  - Laser working distance from 10 cm to 40 cm
  - Laser angle from 20° to 70°
- the measured resolution of the motors is below 0,1 µm

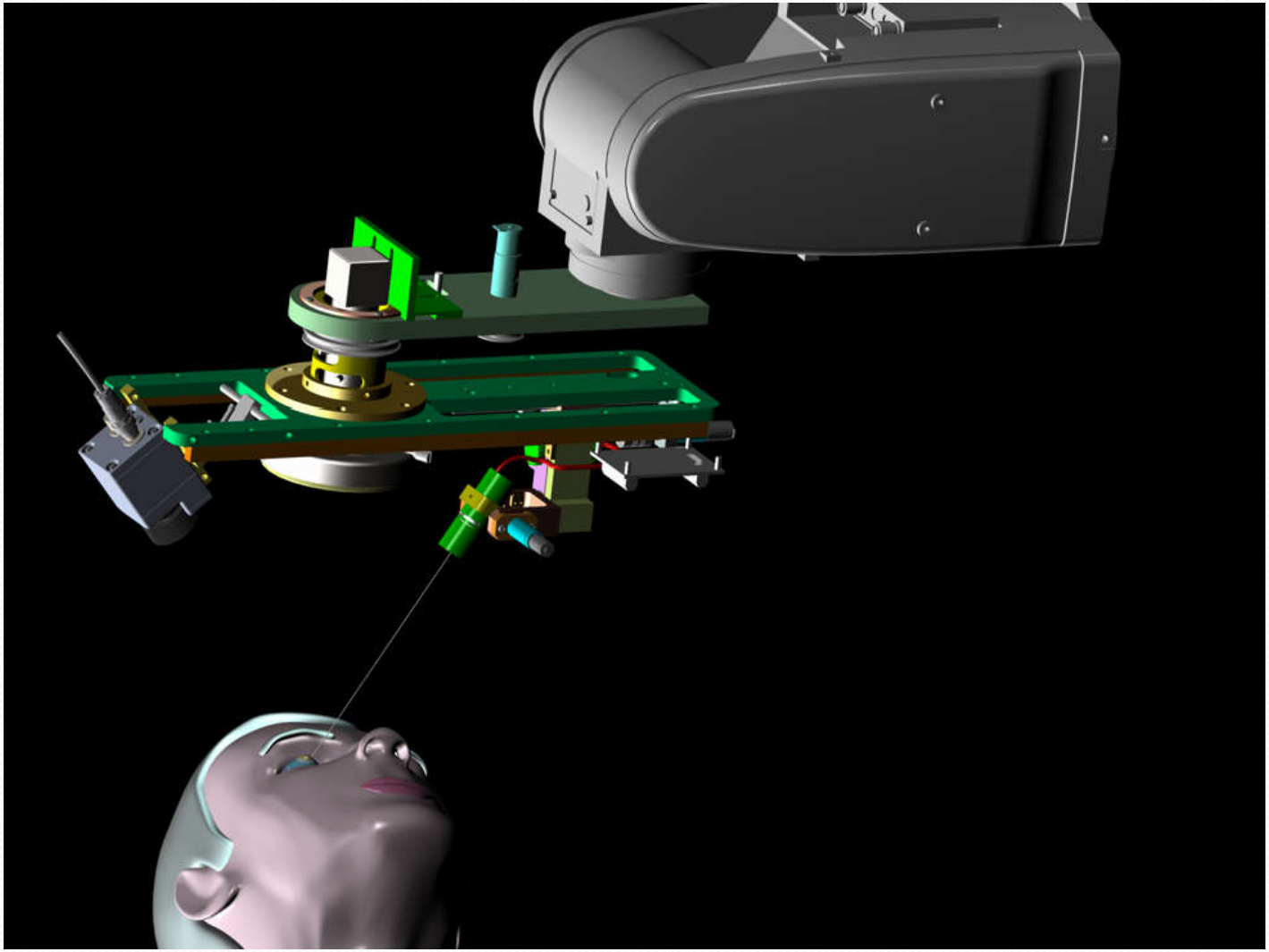
# LA-ROSES overall system diagram



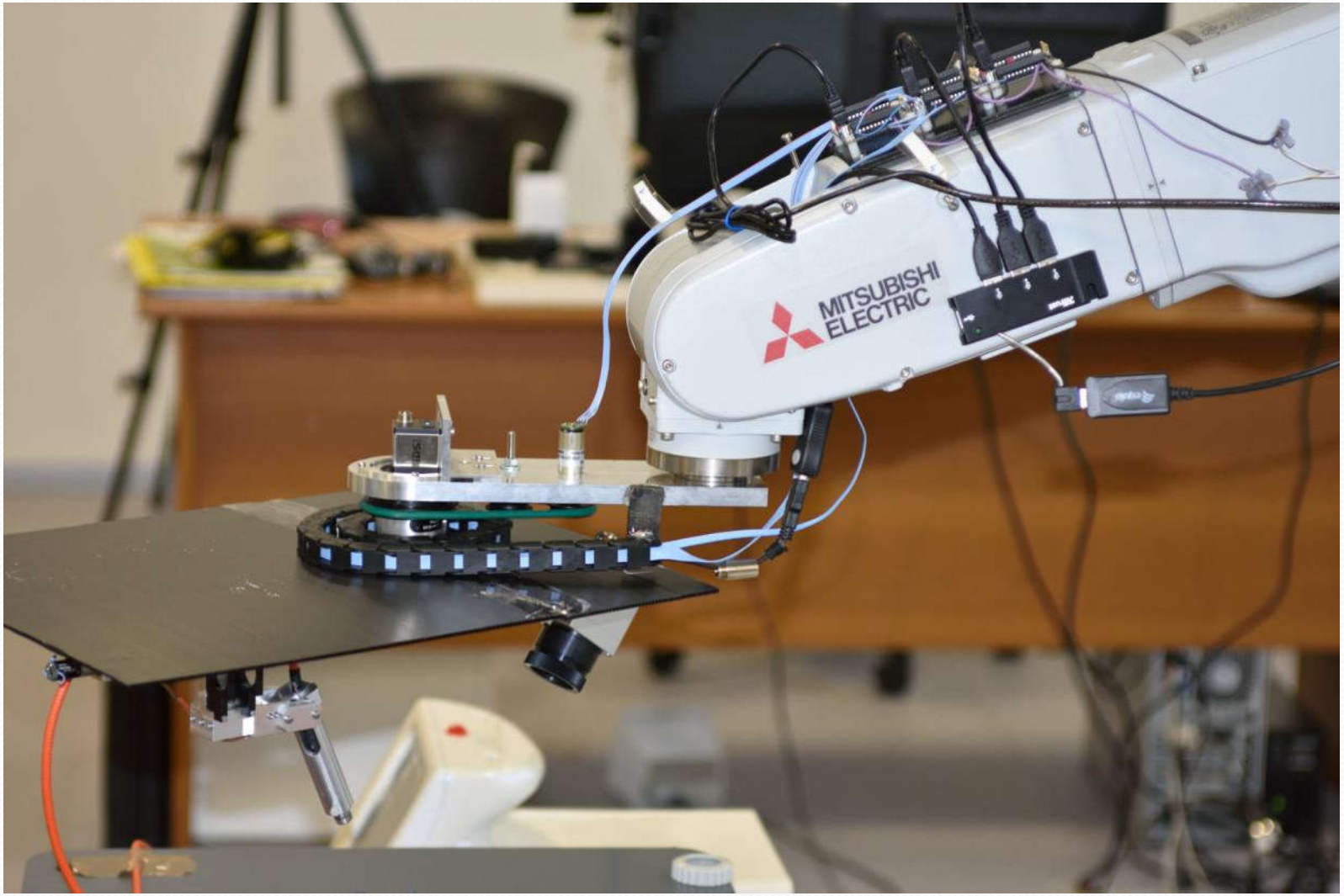
# End-effector Last release CAD



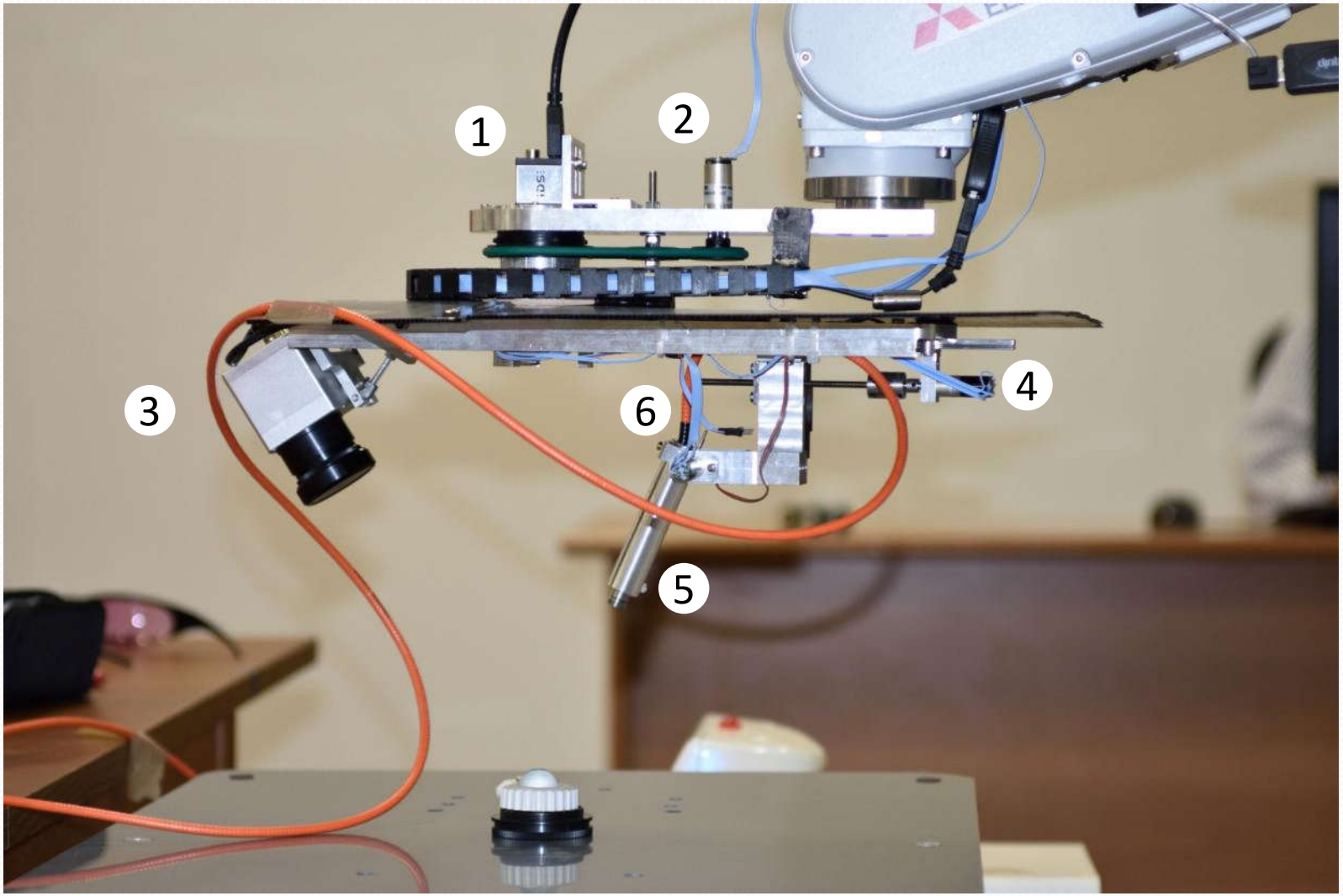
# End-effector cameras positioning



# Final version of the End Effector



# Final version of the End-Effector



# Legenda of the main components

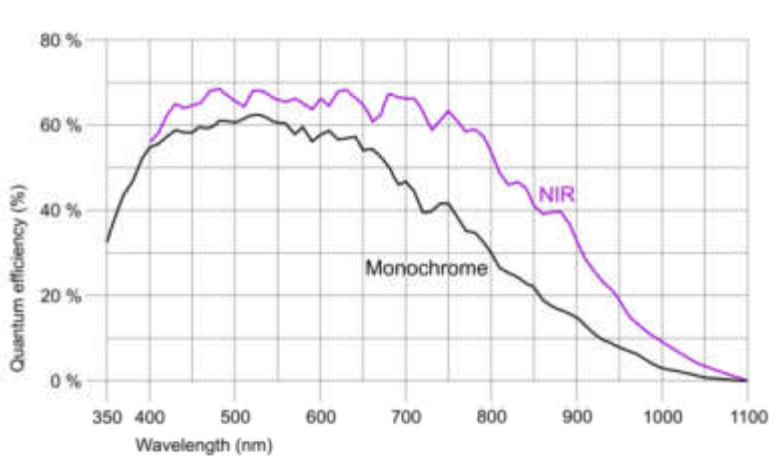
1. NIR camera
2. ω axis motor
3. Thermal camera
4. x axis motor
5. Laser
6. α axis motor

# The new robot: Mitsubishi RV-13FM


**Main features**

- 6-axis
- Repeatability: ±0,05 mm
- Payload: 13 kg
- Linear Workspace: 1094 mm
- Weight: 120 kg
- **real-time path control capability**

# IDS camera UI-3240CP-NIR-GL Rev.2




| Sensor | |
|---|---|
| Sensor type | CMOS Mono |
| Shutter | Global Shutter / Rolling shutter / Global Start Shutter |
| Sensor characteristic | Linear |
| Readout mode | Progressive scan |
| Pixel Class | SXGA |
| Resolution | 1.31 Mpix |
| Resolution (h x v) | 1280 x 1024 Pixel |
| Aspect ratio | 5:4 |
| ADC | 10 bit |
| Color depth (camera) | 12 bit |
| Sensor Size | 1/1.8" |
| Optical Size | 6.784 mm x 5.427 mm |
| Optical sensor diagonal | 8.69 mm (1/1.84") |
| Pixel size | 5.3 µm |

| LV3520 |
|---|
| 2/3" |
| 35mm |
| F2.0 |
| 14.4° x 10.8° |
| 0.2m |
| C-Mount |
| M 27 P= 0.5 |
| 34 x 36.535mm |

At WD of about 200mm we have an optical/camera resolution of 40 um/pix

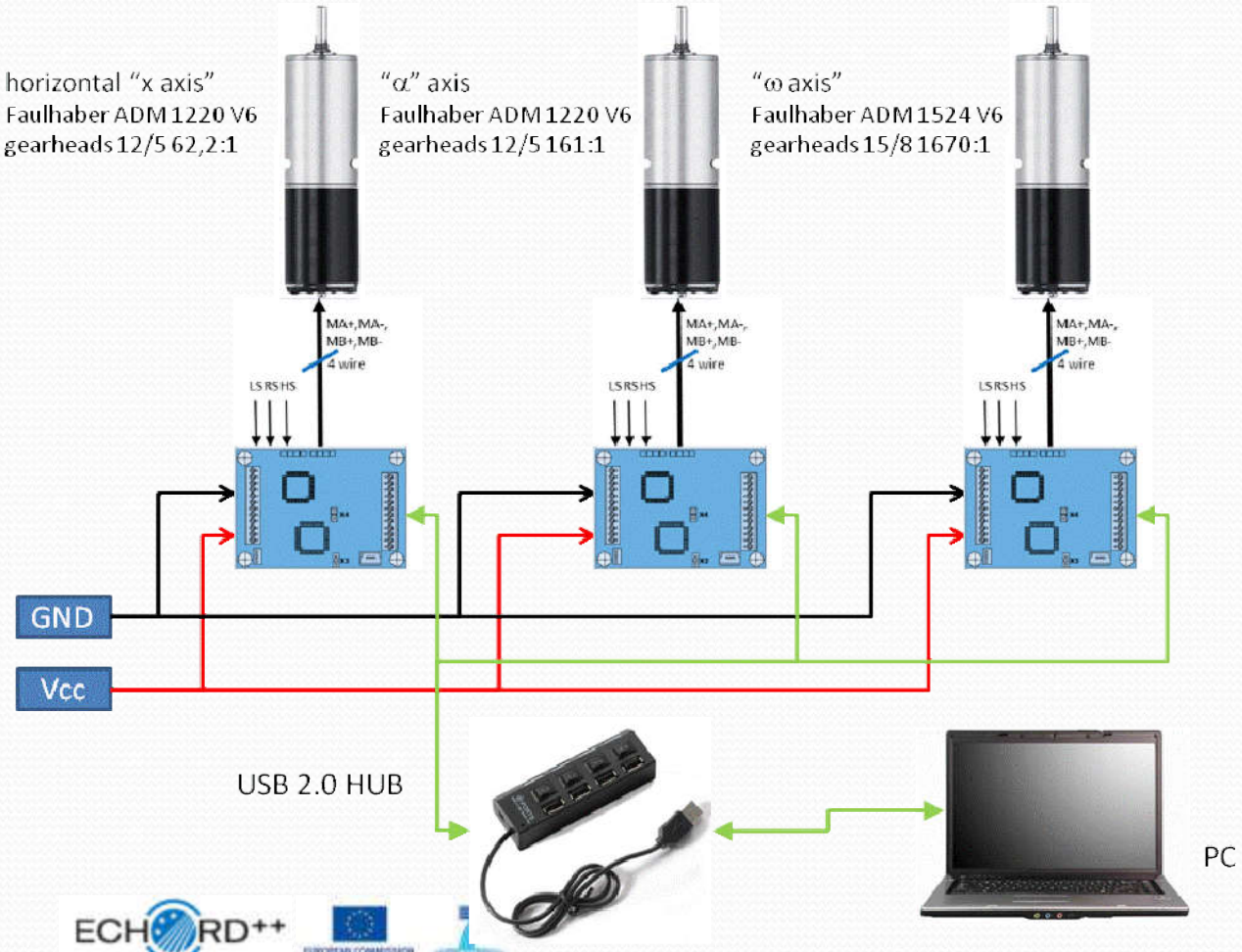
# Thermal Camera

- Dimensions: 46 x 56 x 90 mm
- thermal sensitivity: 40 mK
- thermal image recording in real time at up to 80 Hz
- weight: 320 g incl. lens
- detector with 382 x 288 pixels
- usable at ambient temperatures of up to 70 °C without the need for additional cooling

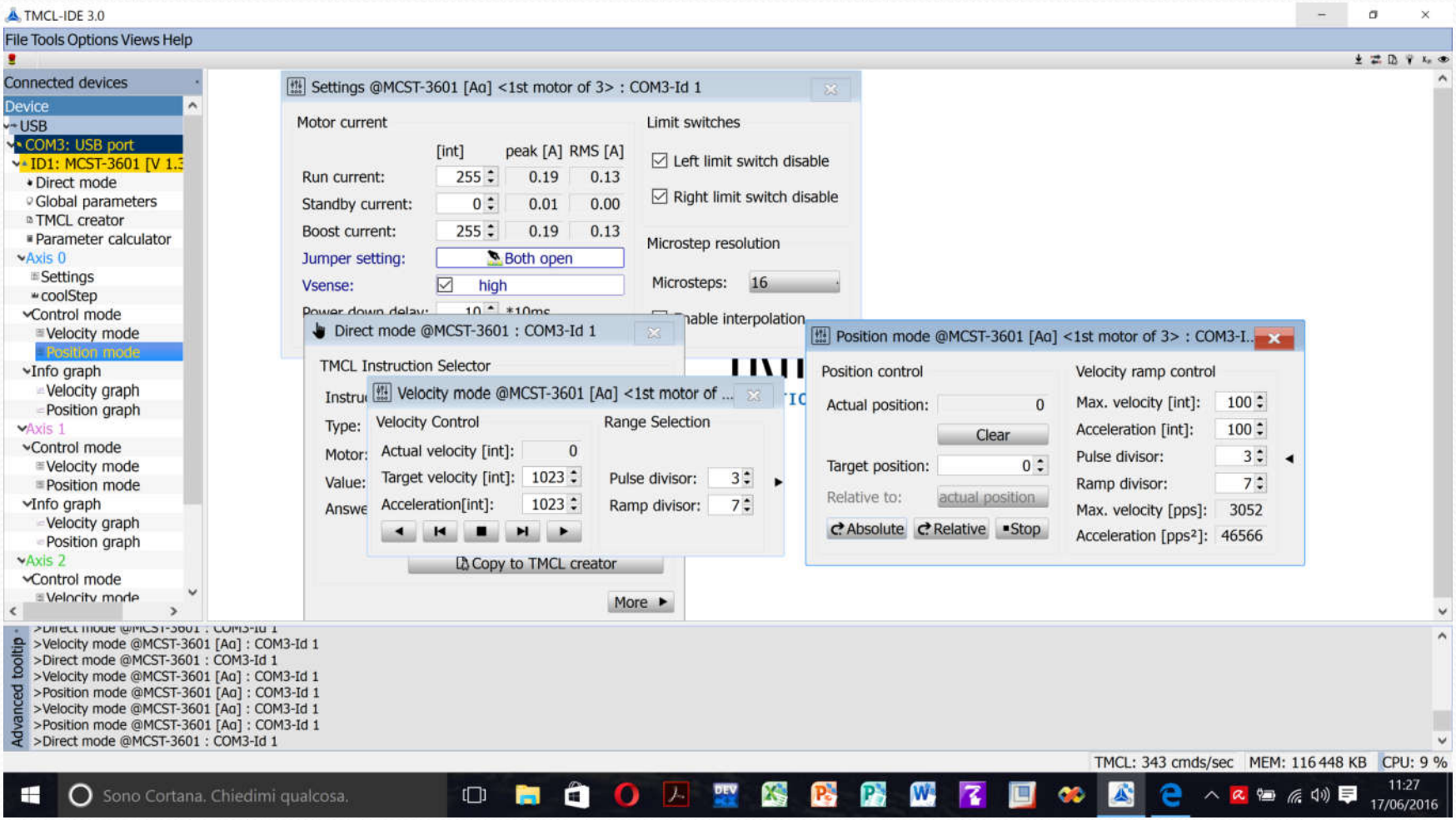
optris® **PI 450**
**INFRARED CAMERA**

# Motor driver control Unit

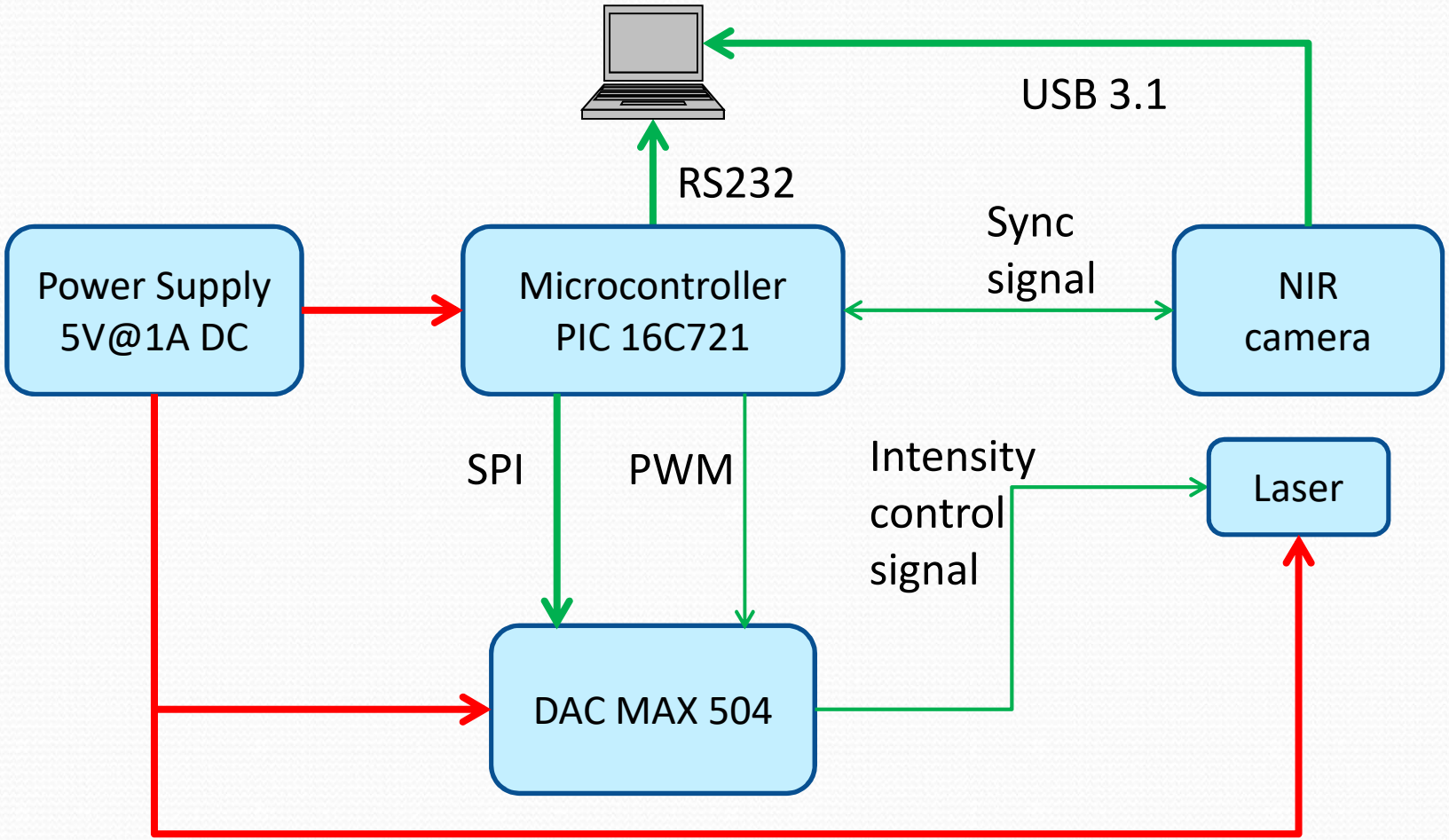
To simplify the motor control all selected motors are driven by the same type of control unit: the Faulhaber the MCST 3601 .



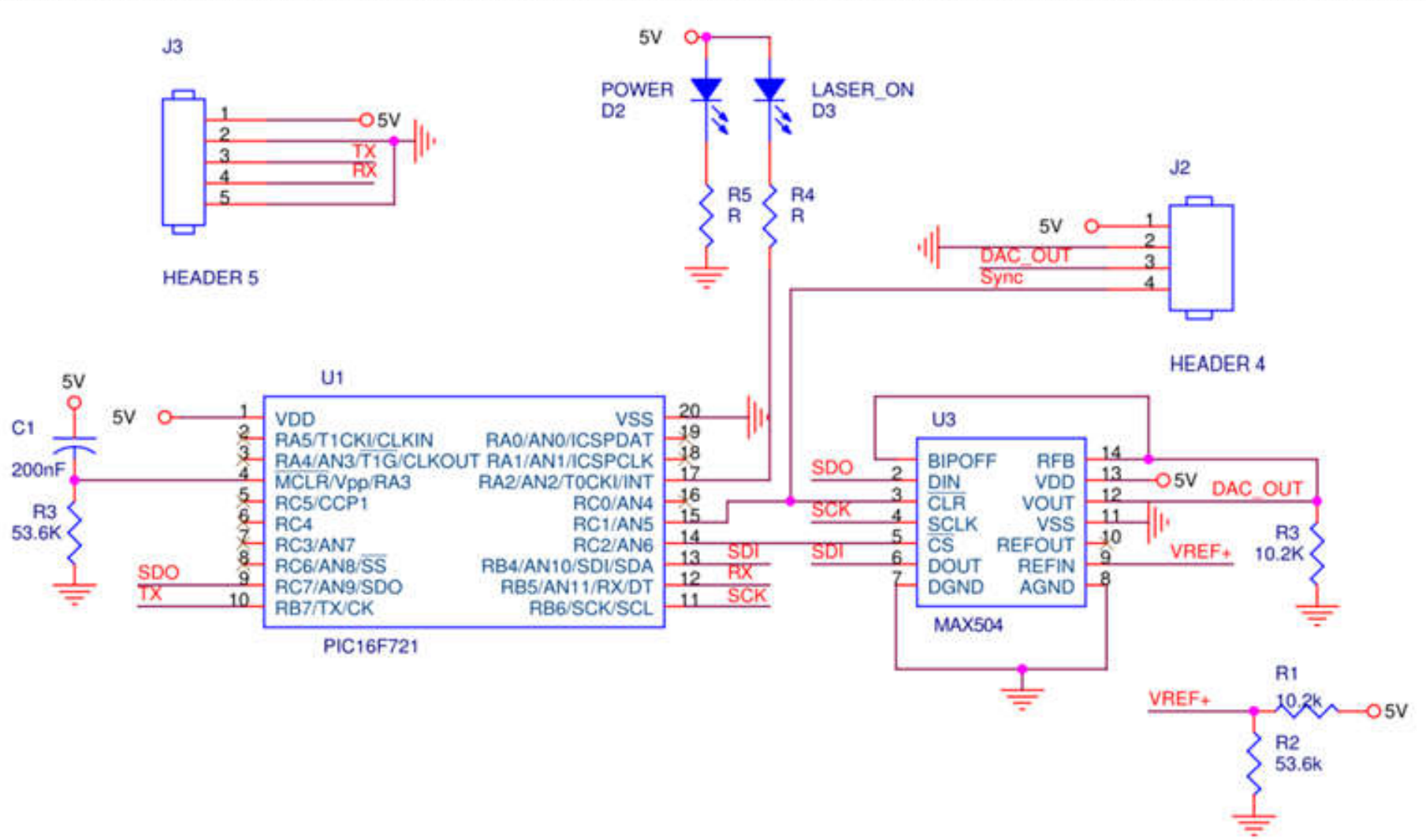
# Faulhaber IDE for setting motor's motion parameters for laser movement



# Laser control unit functional diagram

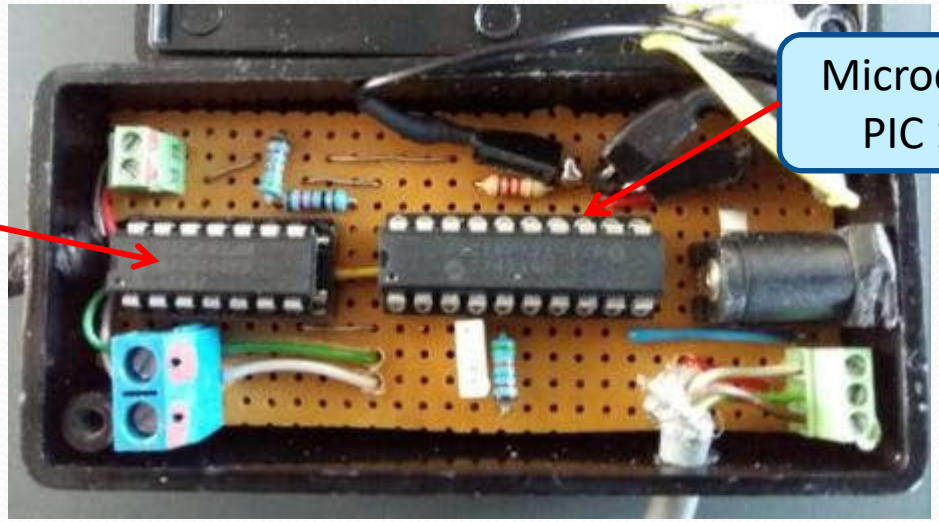


# Laser control unit schematic diagram

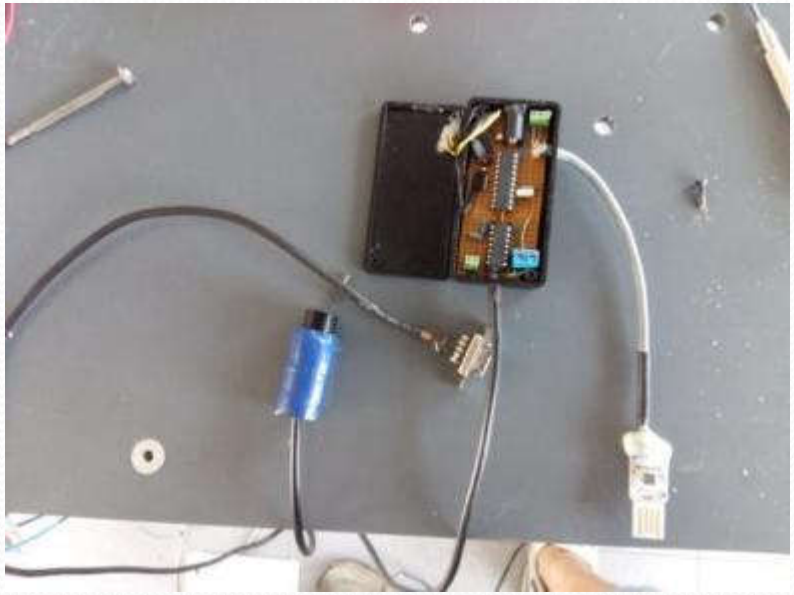


# Laser control unit prototype realization

DAC MAX 504

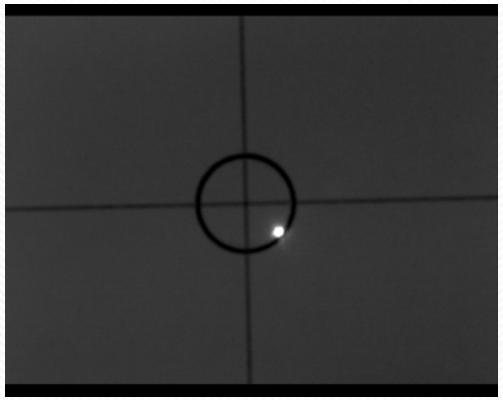


Microcontroller
PIC 16C721



# Laser movement control system development

- For a *safe* development of the entire system a low cost and low power (1 mW) laser is used:
  - visible wavelength at 690 Nm
  - acquirable by NIR camera
  - low power emission (1 mW)



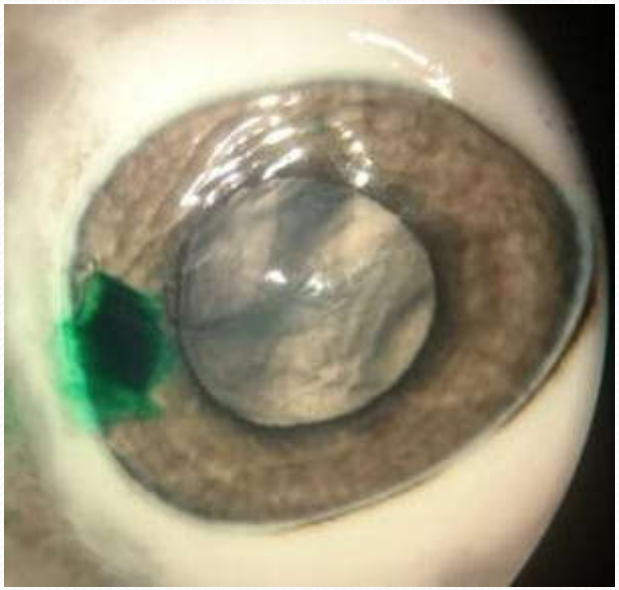
| Parameter | RS stock no./Value | | | | Units |
|---|---|---|---|---|---|
| | 213-3562 | 213-3590 | 213-3584 | 213-3607 | |
| *Nominal wavelength* | *635* | *670* | *635* | *670* | *nm* |
| *Maximum power output* | *1* | *0.8* | *3* | *3* | *mW* |
| *Typical power output stability (@20°C)* | *<3* | | | | *%* |
| *Typical power output temperature dependence* | *15* | | | | *µW/°C* |
| *Operating voltage* | *+4.5 to 5.5* | | | | *Volts* |
| *Typical operating current at minimum voltage* | *65* | | | | *mA* |
| *Typical operating current at maximum voltage* | *68* | | | | *mA* |
| *Power supply rejection ratio (50Hz-100kHz)* | *1* | | | | *%/V* |
| *Mean time to failure (MTTF) @30°C* | *4,500* | *20,000* | *4,500* | *20,000* | *Hours* |
| *Connections* | *2 pin socket (Pre wired plug supplied)* | | | | |
| *Red lead* | *+ve supply* | | | | |
| *Green lead* | *0* | | | | *Volts* |

ECHORD++

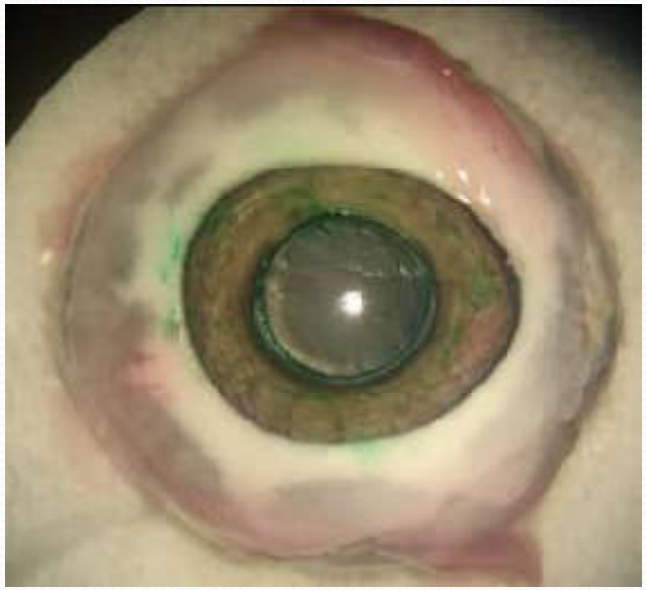
LA ROSE

# Osela Laser tests: welding effect

- Ex vivo tests in porcine eyes
- Different cut shapes

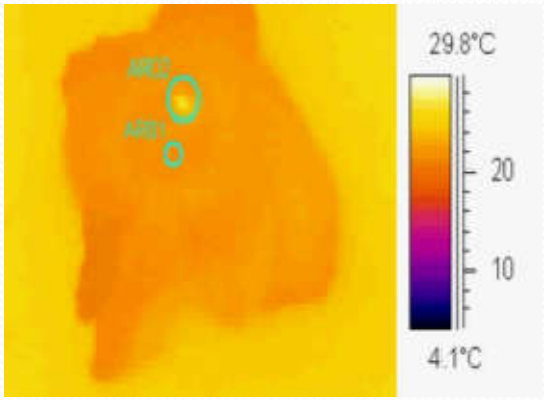


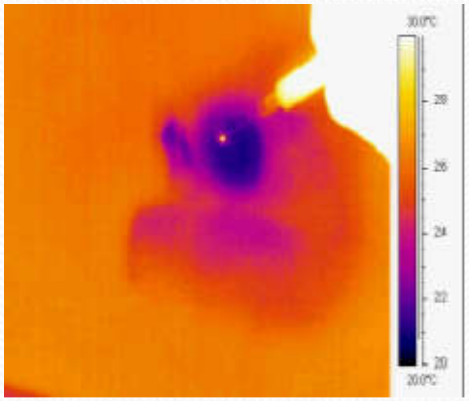
Surgical cut (parallel to lamellar planes- simulating lamellar keratoplasty)
ICG staining

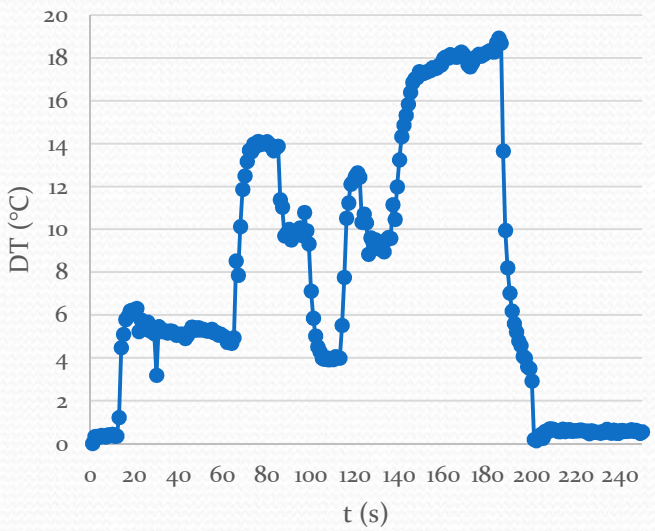


Surgical cut (half depth- simulating PK)
ICG staining

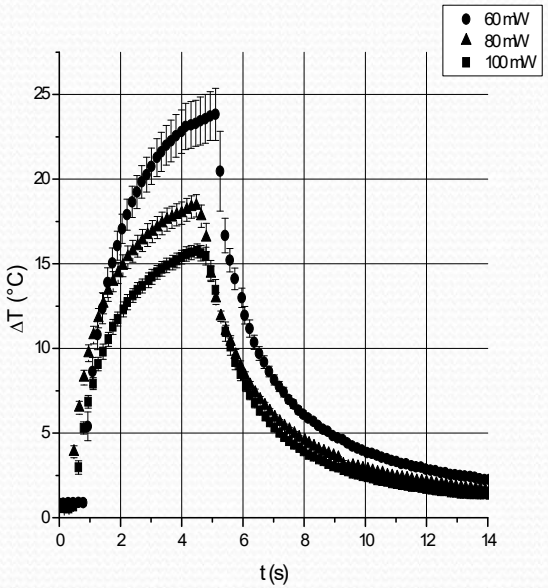
# Comparison with old tests (manual laser, fixed target)






New «robotic» laser (moving)

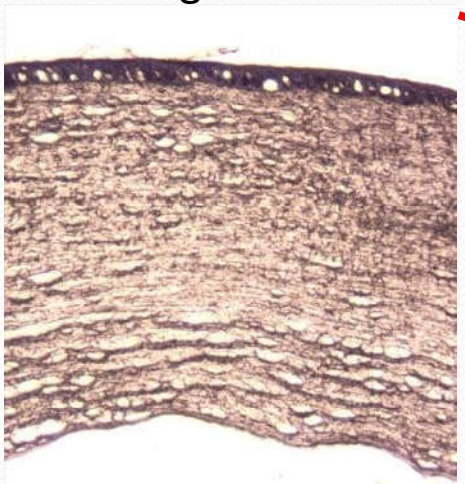



Old manual laser(static)

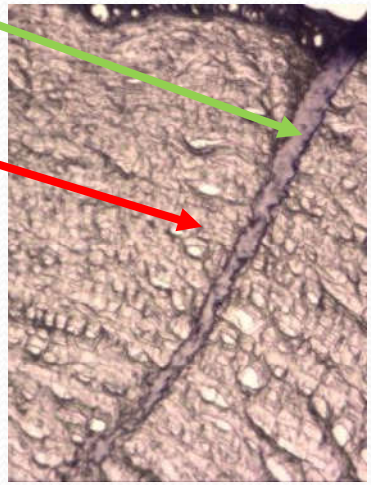
# Laser source tests: H&E evidence of welding effect

Welded stroma

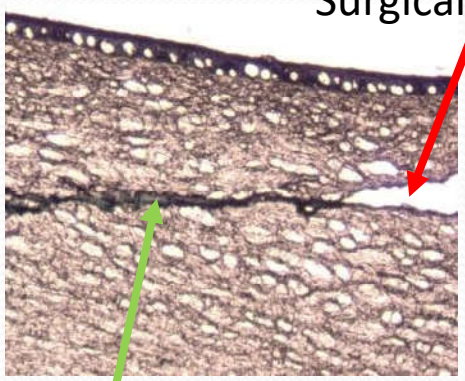
Surgical cut walls (PK)



Healthy cornea



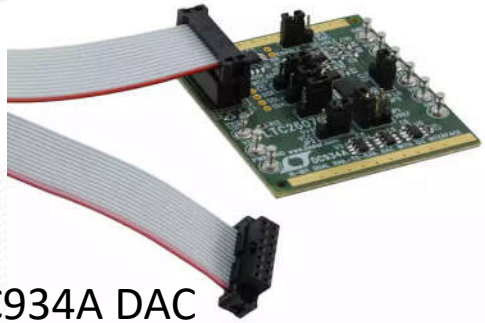
Surgical cut (ALK)



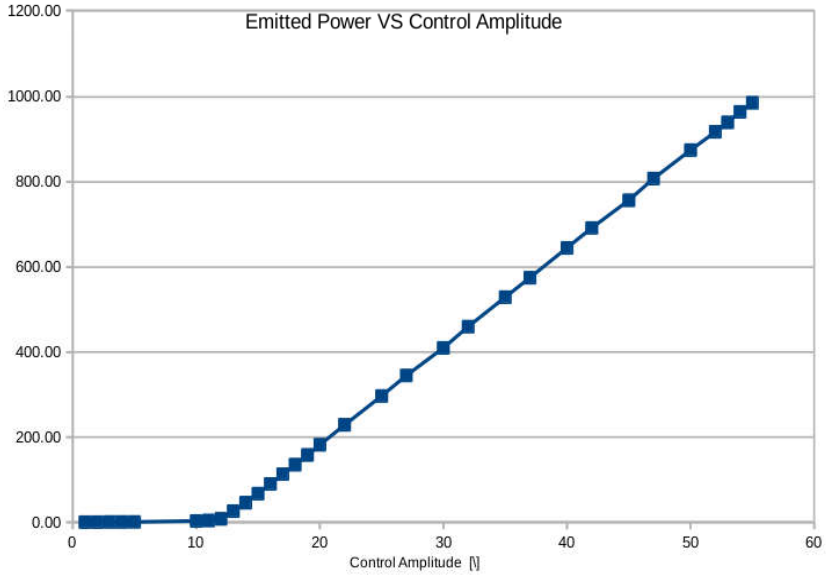
Welded stroma

# Laser output characterization- Thorlabs laser

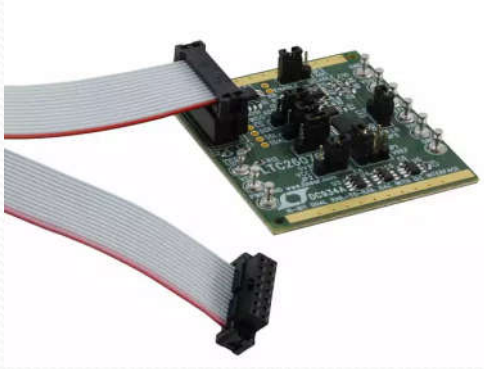
L808P1000MM multimode
1W 808 nm laser diode
LDC220C constant
current/power laser driver +
support & lens

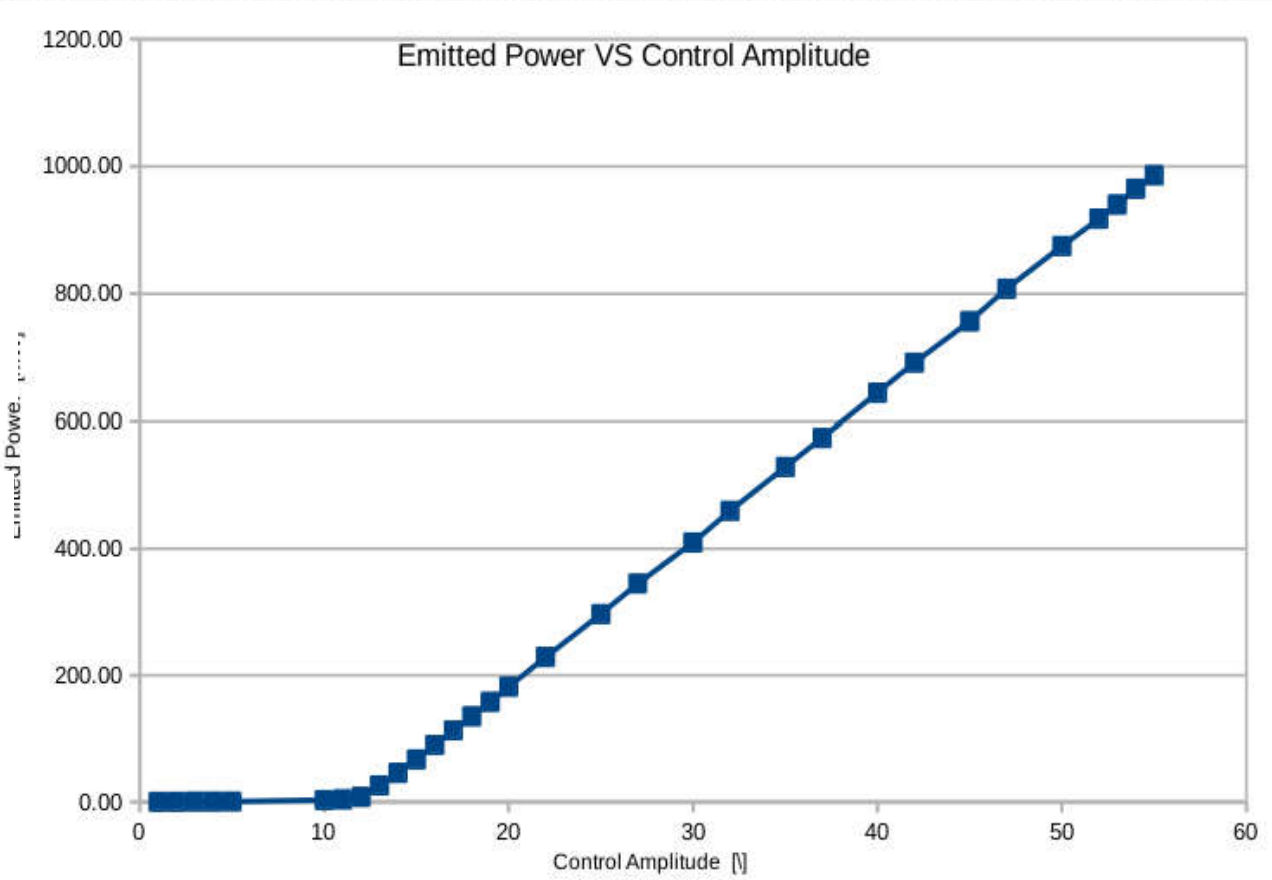


Arduino controller + DC934A DAC
Highly linear response



# Laser THORLABS

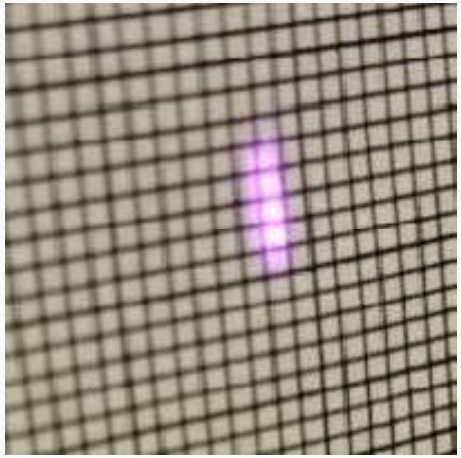


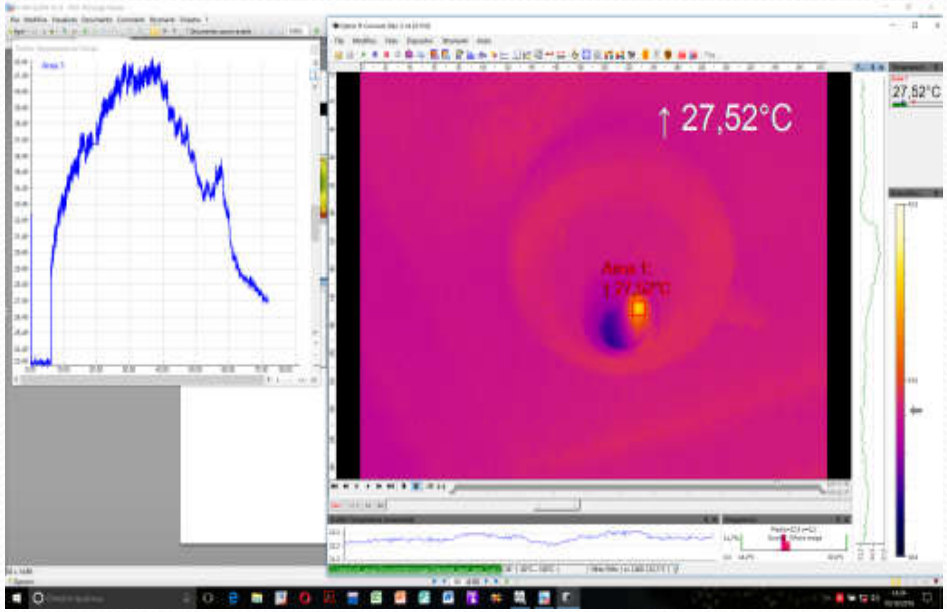


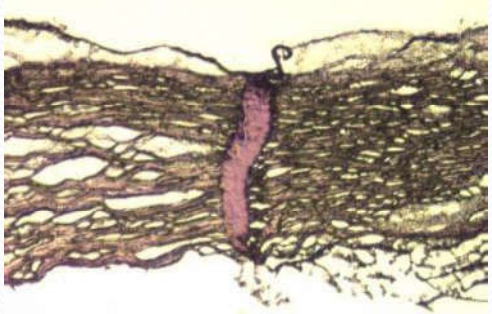

Arduino controller + DC934A DAC

Highly linear response

# Laser output characterization

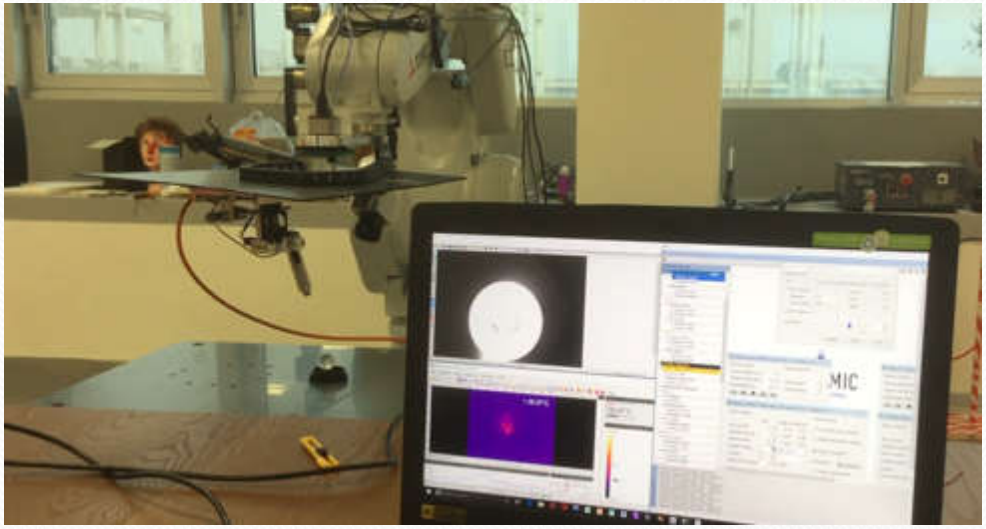




Ex vivo tests demonstrating effective welding

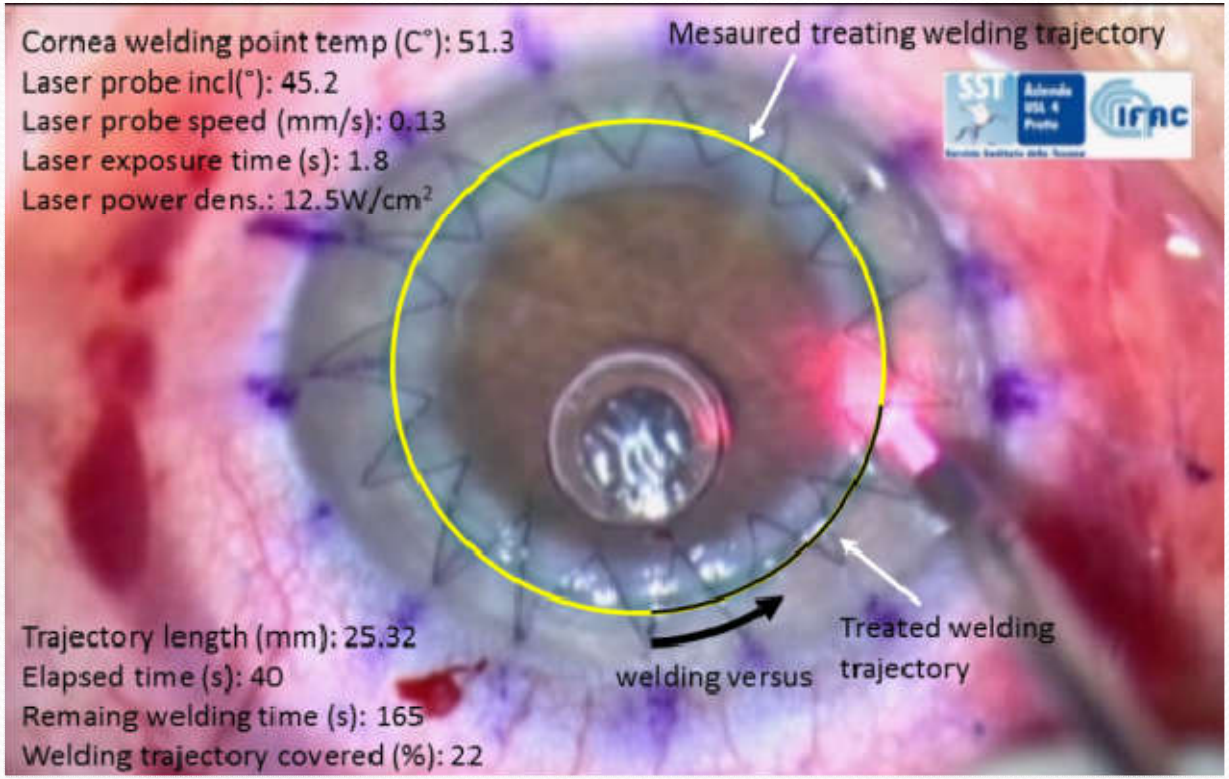
# Laser spot optimization



# The control system

The robotic platform will provide a graphical user interface (GUI) allowing the surgeon to operate from a remote console. The surgery procedure will start enabling the control system of the robotic arm to adjust the position and the orientation of the suturing end-effector just above the patient's eye.

The laser module will be autonomously positioned by the robotic arm by using a Visual Servoing (VS) control scheme



# LA-ROSES robotic platform control strategy definition

**Welding trajectory detection**

The control system will detect and calculate the welding trajectory; then all the system parameters related to the welding process will be proposed to the surgeon check, before enabling the start command.

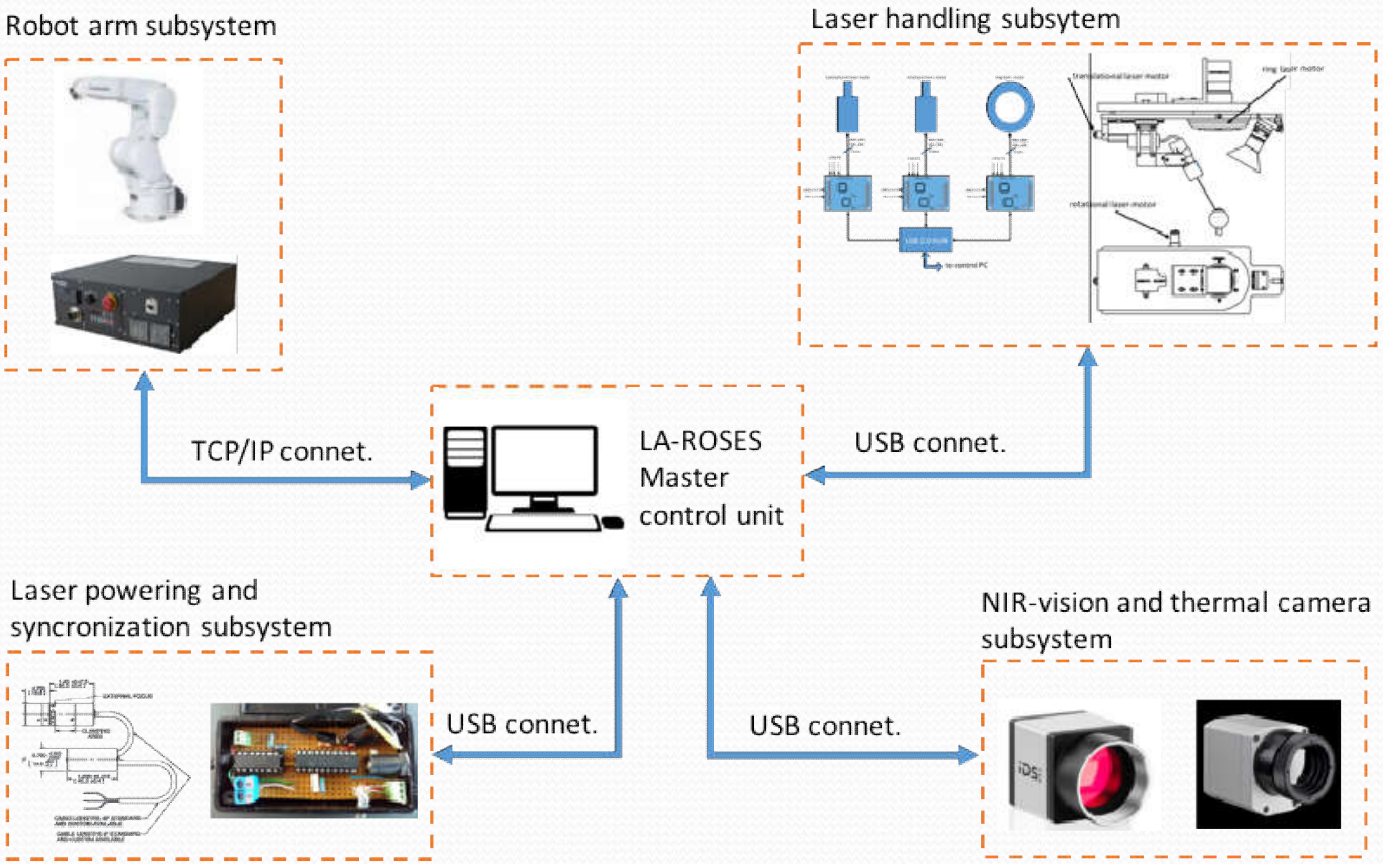
**Surgeon direct control**

However, the corneal welding task will not be fully autonomously executed by the robotic platform control system: the surgeon will have a direct control of the surgical procedure.

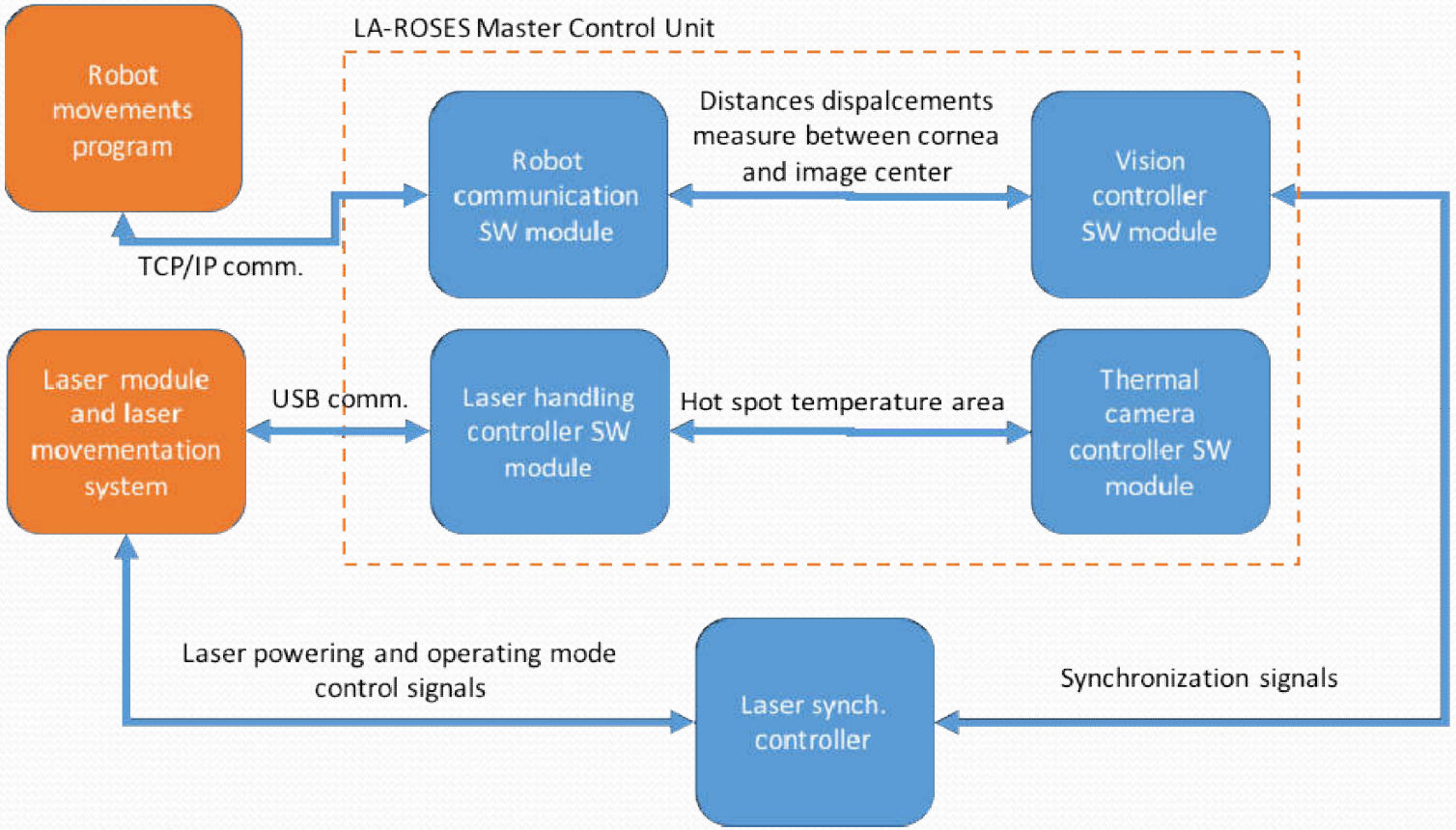
**"Collaborative" human-robot control paradigm**

- *Surgeon robotic welding-task supervision*: robot executes the welding task while the surgeon controls and adjusts (if needed) robot movements and laser parameters
- *Surgeon and robot can immediately stop the running welding-task*. Human expert like a surgeon is, is more capable to handle unexpected scenarios, as opposed to an autonomous robot; at the same time, the robot control system could autonomously decide to stop the task in case of coming out about dangerous situations to preserve patients' health.

# LA-ROSES final realized system HW overall diagram



# LA-ROSES final realized system SW overall diagram

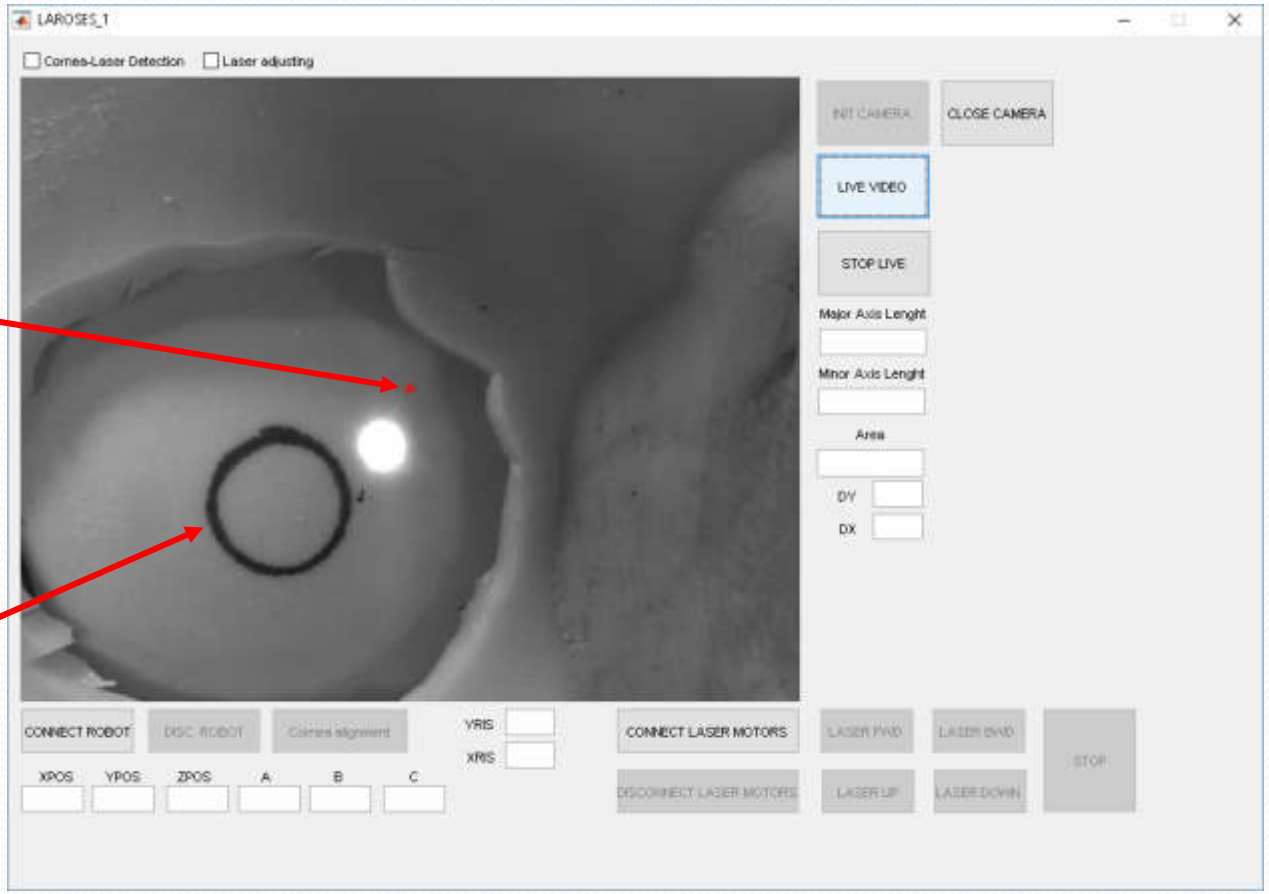


# Preliminary LA-ROSES visual servoing control scheme implementation

**Cornea detection and alignment**

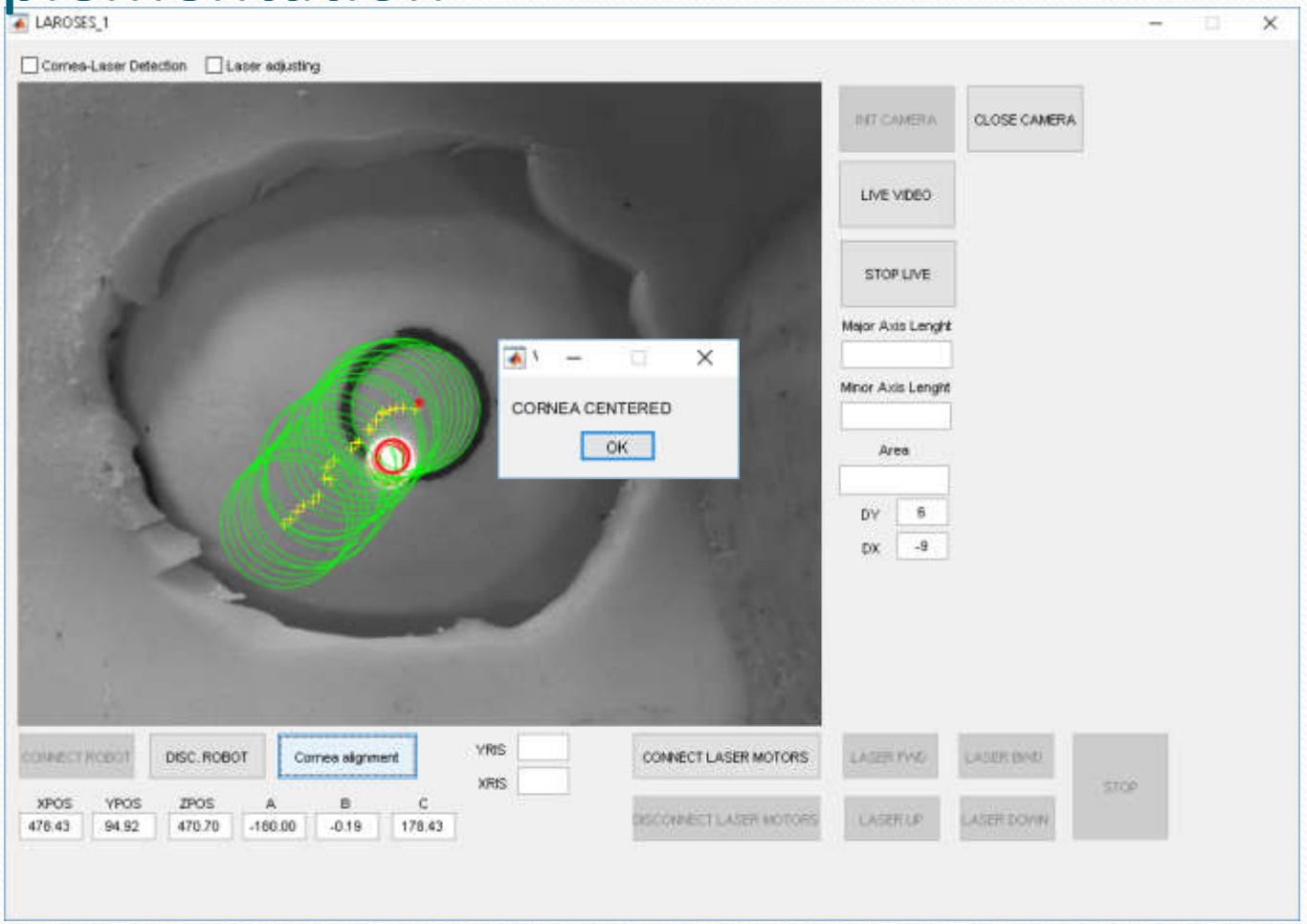
Image center i.e. camera optical axis

Corneal wound



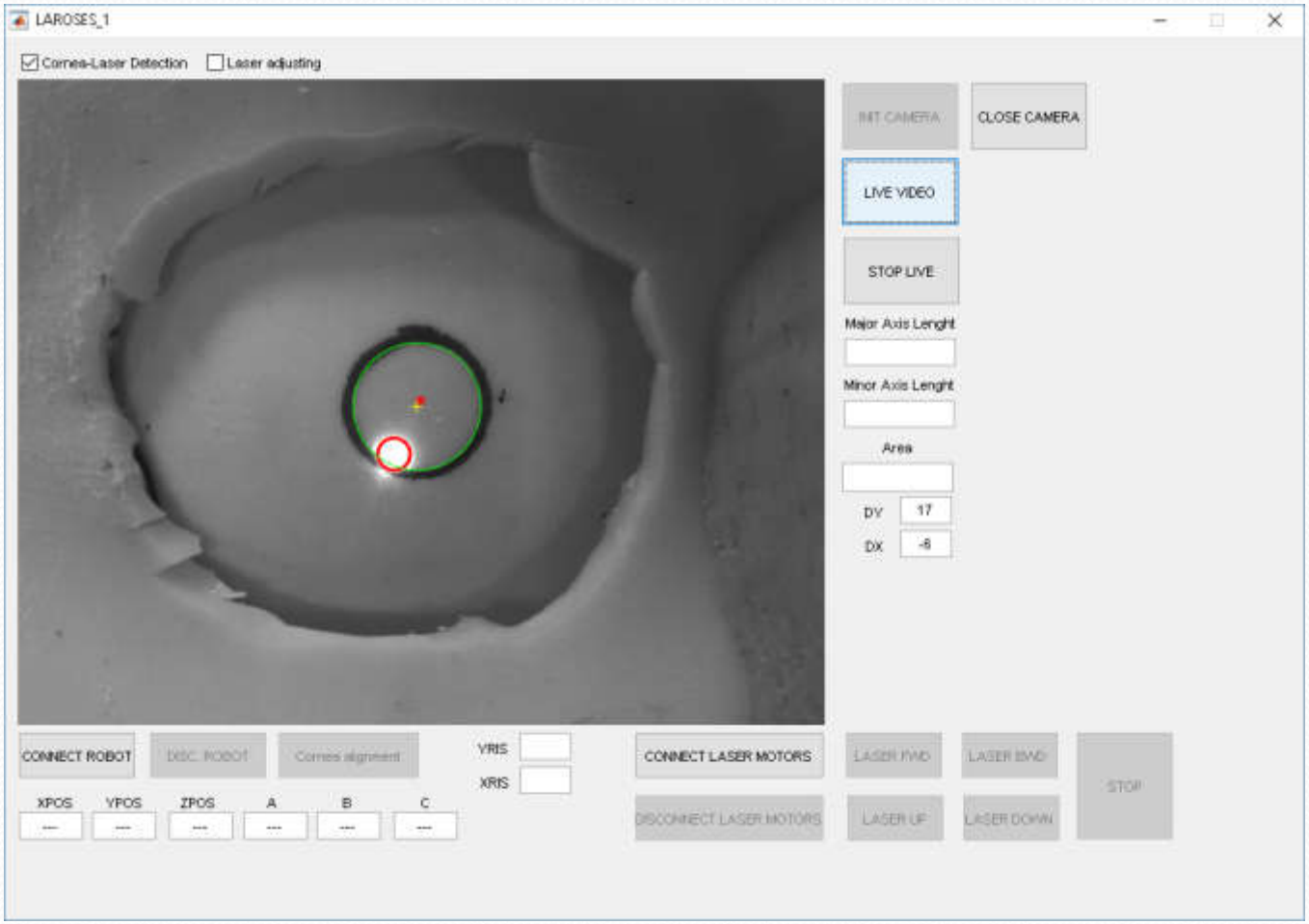
# Preliminary LA-ROSES visual servoing control scheme implementation

«Cornea» path



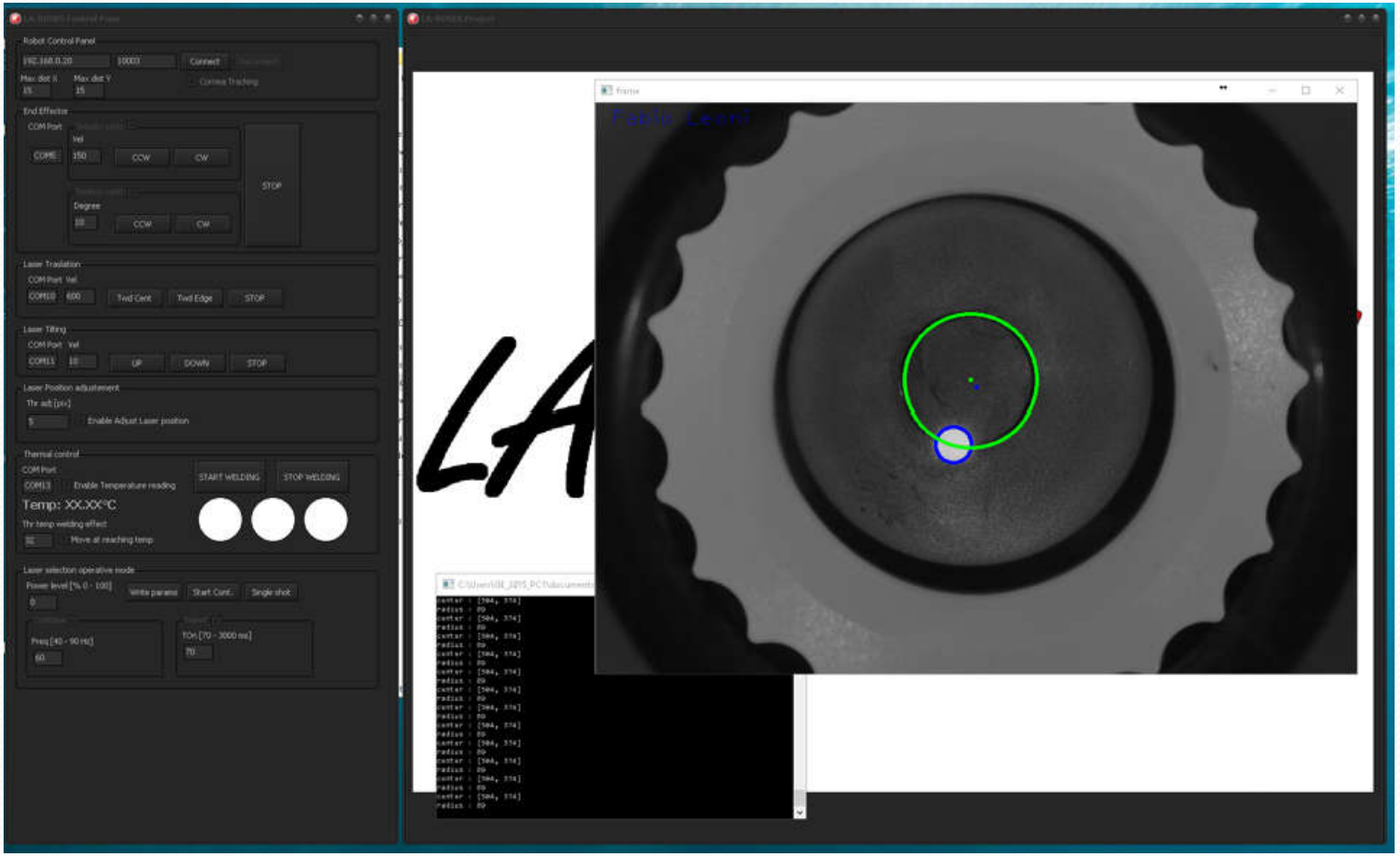
# Preliminary LA-ROSES visual servoing control scheme implementation

Cornea and laser spot detection



# LA-ROSES final GUI implementation

# LA-ROSES final GUI implementation cont.



# Tracing of LASER treated corneal wound