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Lightweight Handheld Detachable Compliant Robotic Laryngoscope with Lightweight Intelligent Visual Guidance

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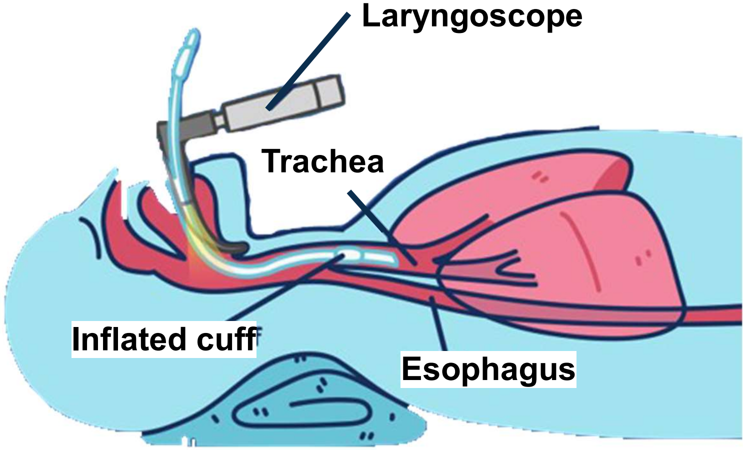
1 Background

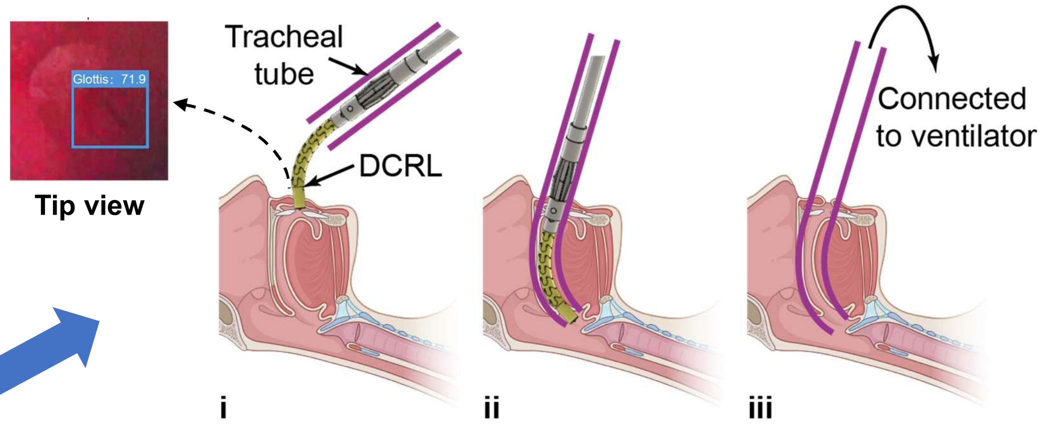
What is tracheal intubation(TI)?

Tracheal intubation is the act of passing a tube into the trachea via the mouth or nose (although access to the trachea can also be created via a direct surgical approach, namely a cricothyrotomy or tracheostomy).



Current approach

How to insert the tracheal tube using our robot?

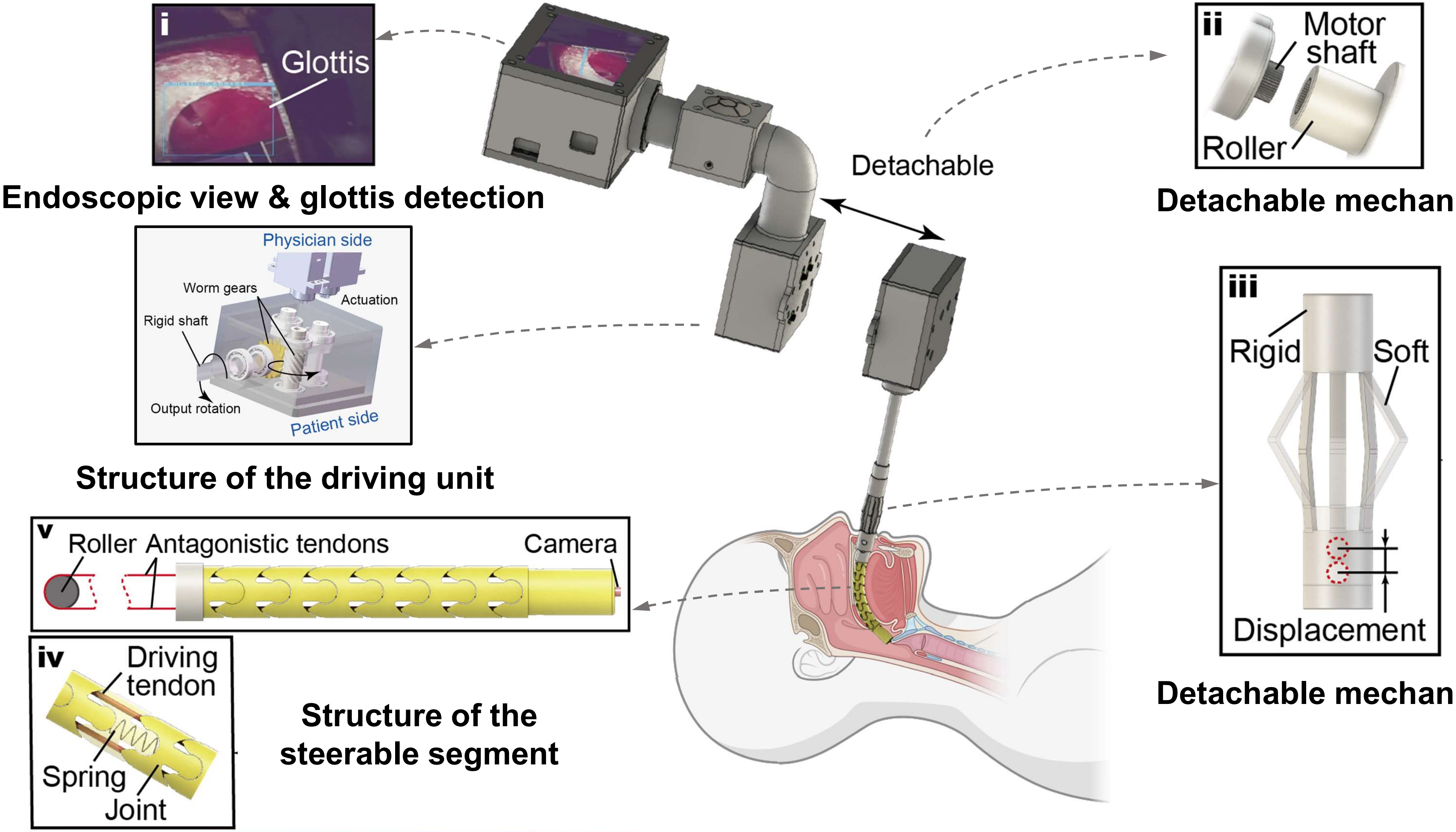


Higher dexterity !

Lower difficulty !

AI-based guidance !

2 Mechanical design



Endoscopic view & glottis detection

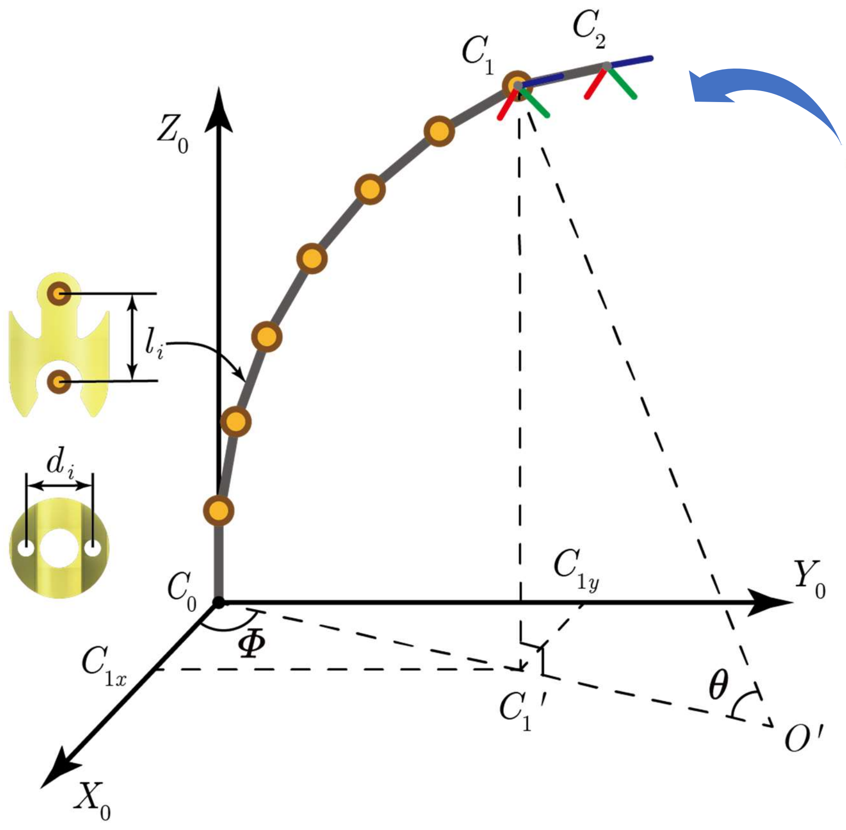
Detachable mechanism

Structure of the driving unit

Detachable mechanism

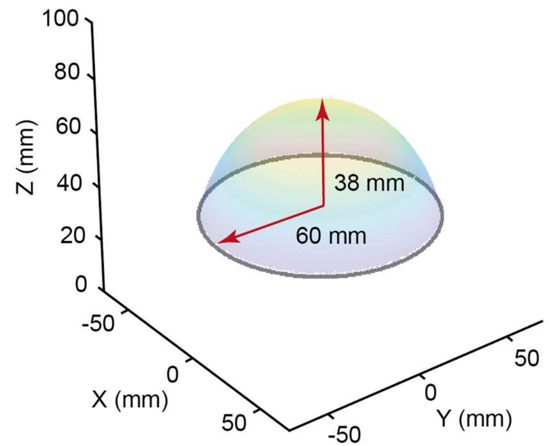
Structure of the steerable segment

2 Kinematic modeling



Coordinate system

Steerable segment



Workspace

Bending & rotation

2 Kinematic modeling

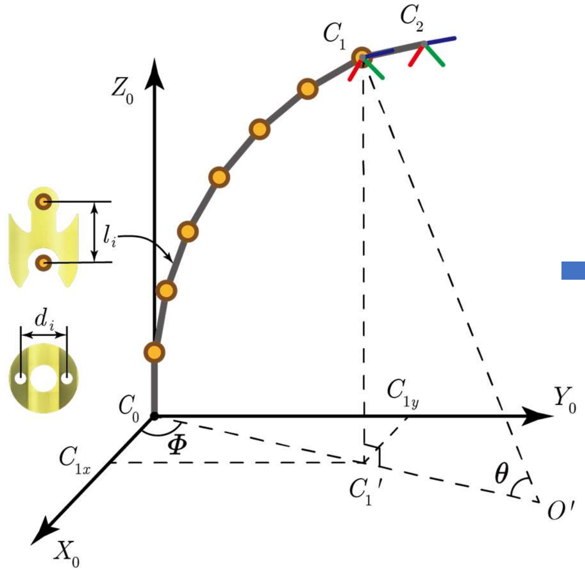
Forward kinematics

$$l_i = nl_i + (-1)^i \cdot \frac{\theta d_i}{2}, \quad \text{given} \quad i \in \{1, 2\}$$

$$\theta = (-1)^i \cdot \frac{2\left(l_i - nl_i\right)}{d_i},$$

$$\begin{cases} {}^0_1T = \mathrm{Trans}\left(P_{10}\right) \mathrm{Rot}\left(z, \phi\right) \mathrm{Rot}\left(y, \theta\right) \\ {}^1_2T = \mathrm{Trans}\left(P_{21}\right) \\ {}^0_2T = {}^0_1T \cdot {}^1_2T \end{cases}$$

$$\mathcal{R}_z(\theta_z) = \begin{bmatrix} \cos\theta_z & -\sin\theta_z & 0 \\ \sin\theta_z & \cos\theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \mathcal{R}_y(\theta_y) = \begin{bmatrix} \cos\theta_y & 0 & \sin\theta_y \\ 0 & 1 & 0 \\ -\sin\theta_y & 0 & \cos\theta_y \end{bmatrix}$$



Inverse kinematics

$$\phi = \arctan\left(\frac{P_y}{P_x}\right)$$

$$P_z = \frac{nl_i}{\theta}\sin\theta + l_t\cos\theta$$

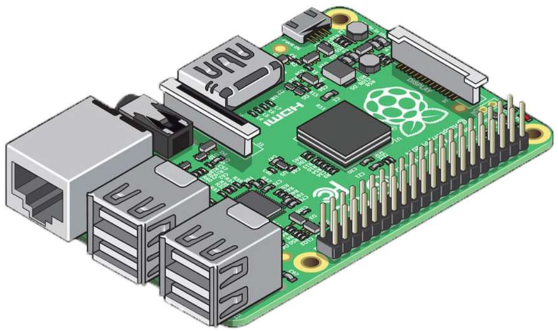
$$\lim_{\theta\to 0}\frac{\sin\theta}{\theta}$$

$$\begin{cases} \sin\theta = x - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} + o\left(\theta^7\right) \\ \cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} + o\left(\theta^6\right) \end{cases}$$

$$P_z = nl_i\left(1 - \frac{\theta^2}{3!} + \frac{(\theta^2)^2}{5!}\right) + l_t\left(1 - \frac{\theta^2}{2!} + \frac{(\theta^2)^2}{4!}\right)$$

3 Glottis Detection

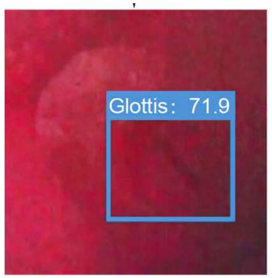
A lightweight solution

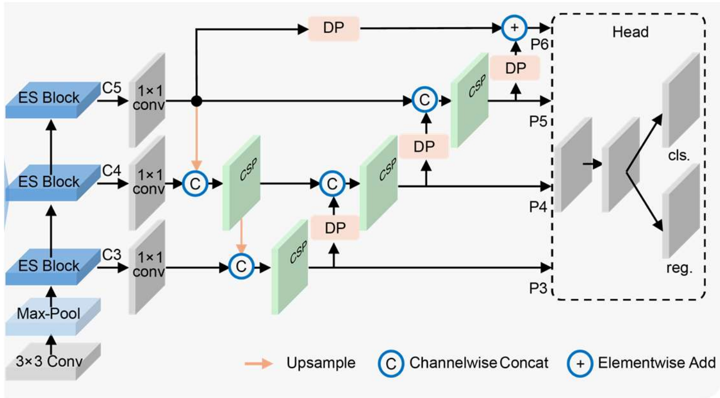


Raspberry Pi

85 mm × 56 mm
2.4 GHz CPU and an 800 MHz GPU

Endoscopic view
&
Glottis detection



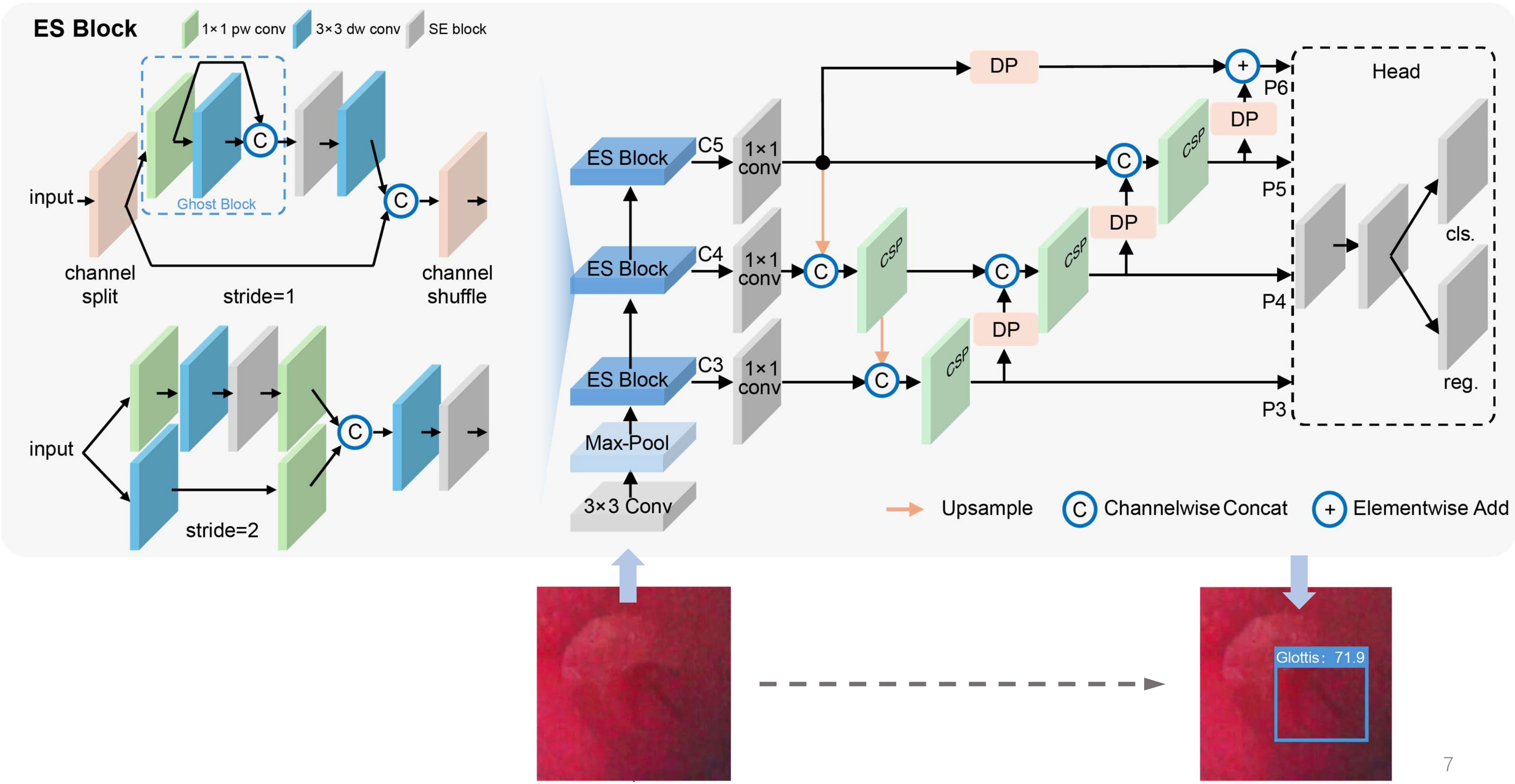


Lightweight network

Only 5M

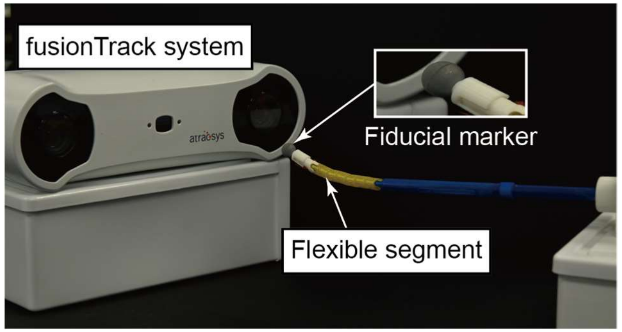
deploy

3 Glottis Detection

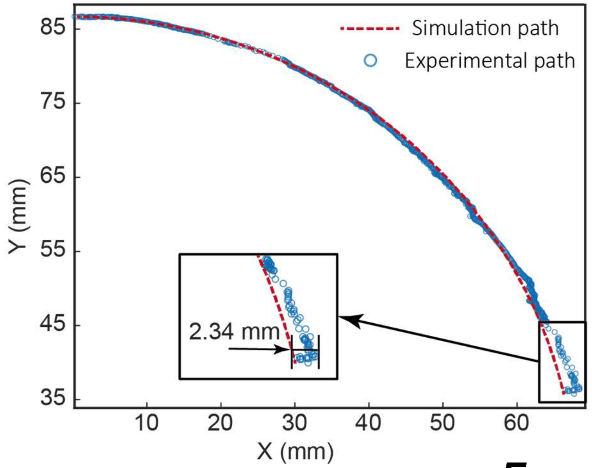


4 Experiment

Verification of the kinematic model:



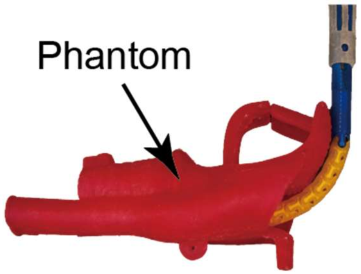
Experimental set up



Experiment results

The experiment result indicates that the position error is smaller than 2.34 mm, which is 2.7% over the total length of the flexible segment and the fiducial marker.

Evaluation of the glottis detection:

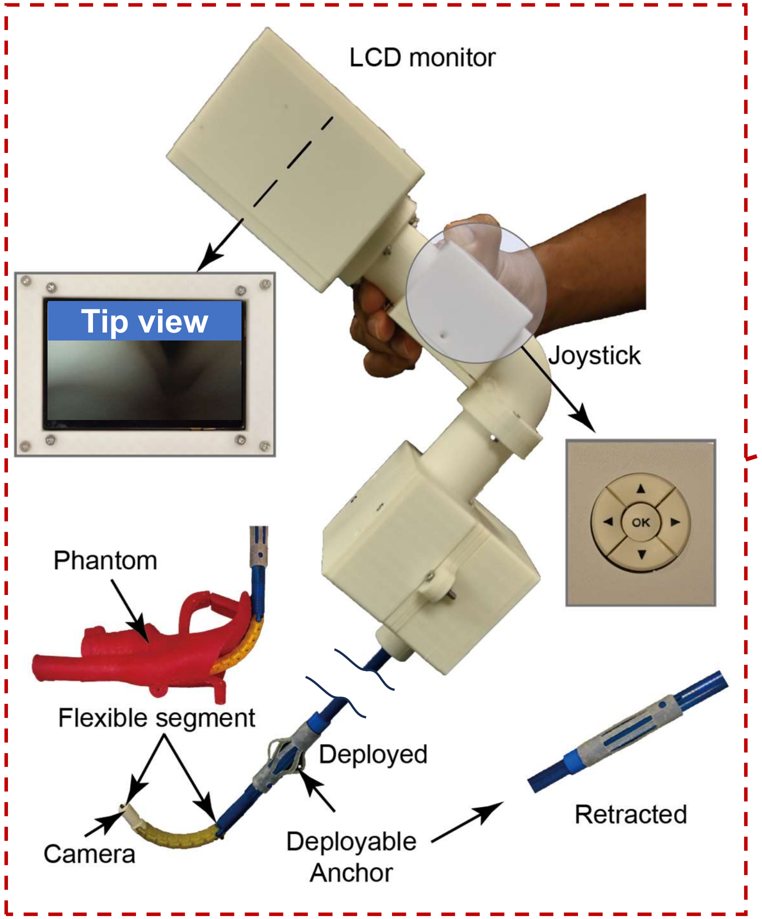


The phantom

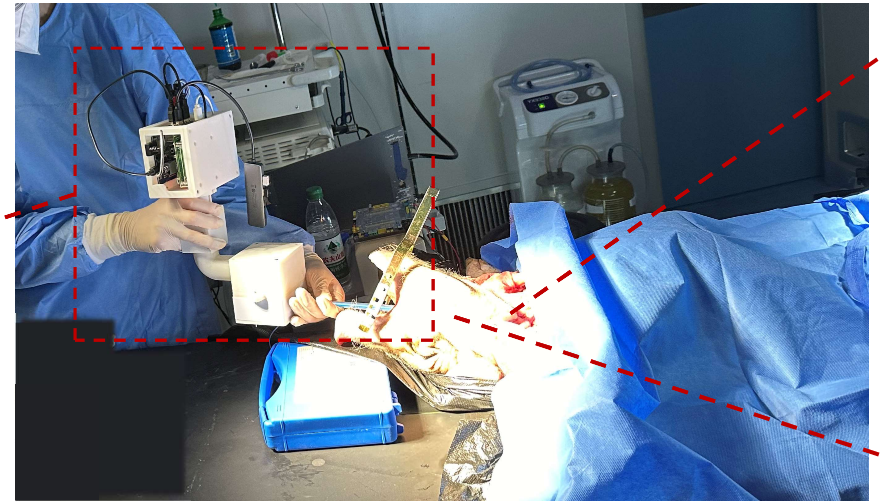
Under the blurry condition, our detector could identify the glottis with over 70% confidence coefficient and a dynamic bounding box, with a model size of less than 5 MB and a time cost of around 50 ms.

The detection results

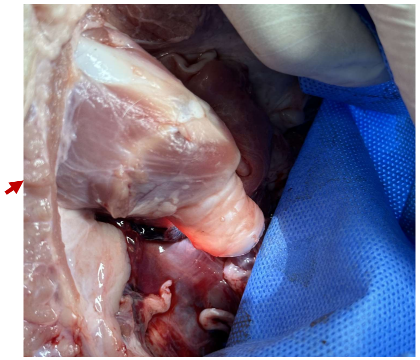
4 Experiment



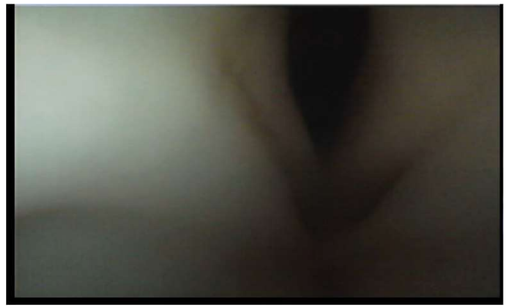
System structure



Pig carcass experiment set up



In vitro view



In vivo view

5 Main contribution & future work

The core contributions of this work include the following:

- **Lightweight Compliant Robotic Laryngoscope**: An all-in-one lightweight detachable compliant robotic laryngoscope (0.65 kg) is developed. The robotic laryngoscope comprises a steerable flexible segment with an endoscopic camera and a three-DoF (bending, axial rotation, and anchoring) flexible segment that can be steerable in one hand.
- **Detachability:** A detachable design is adopted to allow the disassembly and assembly of the steerable flexible segment swiftly to ensure sanitation.
- **Lightweight Intelligent Visual Guidance:** A self-contained, lightweight glottis detection network displays the target glottis at the laryngoscope monitor in real time is proposed.

Future work:

- **Structure optimization of the steerable segment and ergonomic optimization for the system.**
- **Development of more AI-based surgical process guidance functions**

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Thanks for listening!

Best Regards

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