

EdgeP4: In-Network Edge Intelligence for a Tactile Cyber-Physical System Testbed Across Cities

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[deepakc7y.github.io](https://github.com/deepakc7y)

20.05.2026

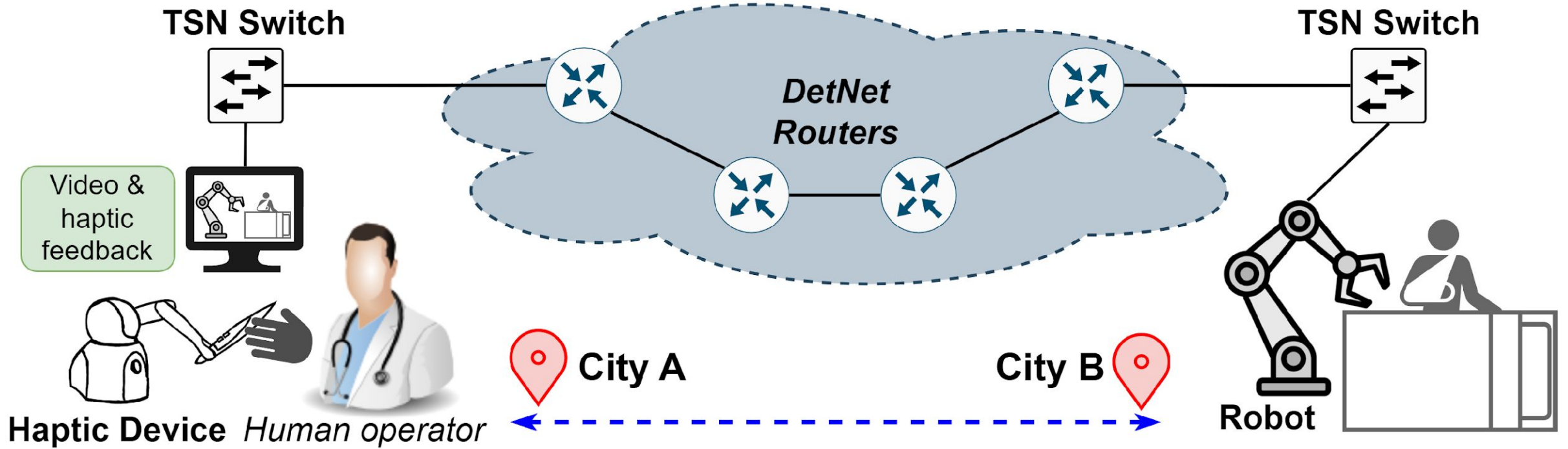


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- 1. Motivation**
2. Intercity testbed overview
3. Handling data in EdgeP4
4. Application #1: *Pose correction*
5. Application #2: *Tremor suppression*



Motivation | Remote Robotic Surgery



Contribution

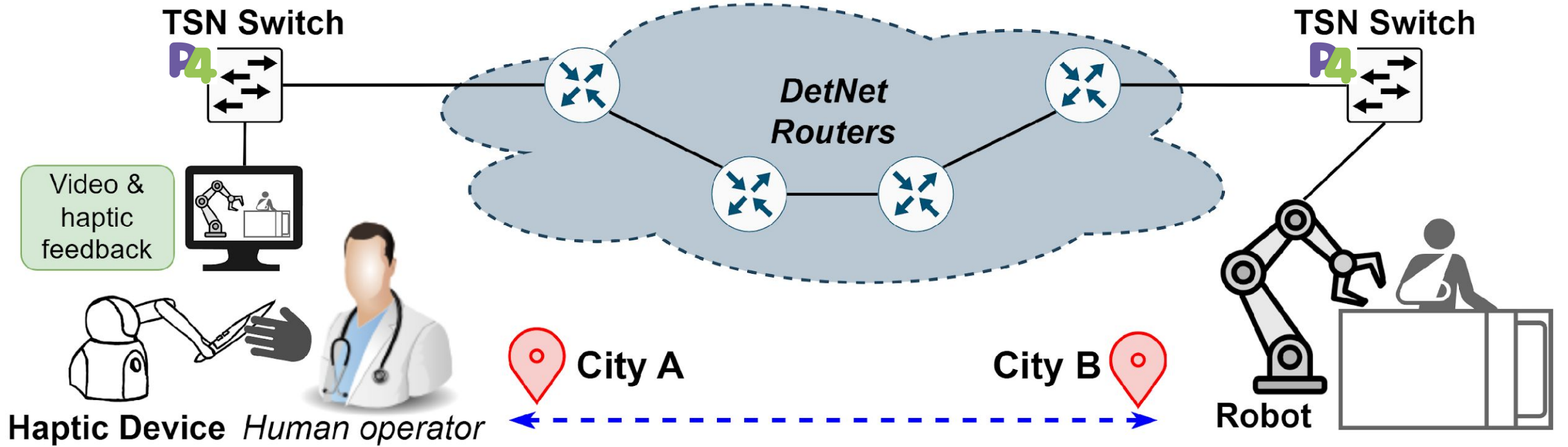
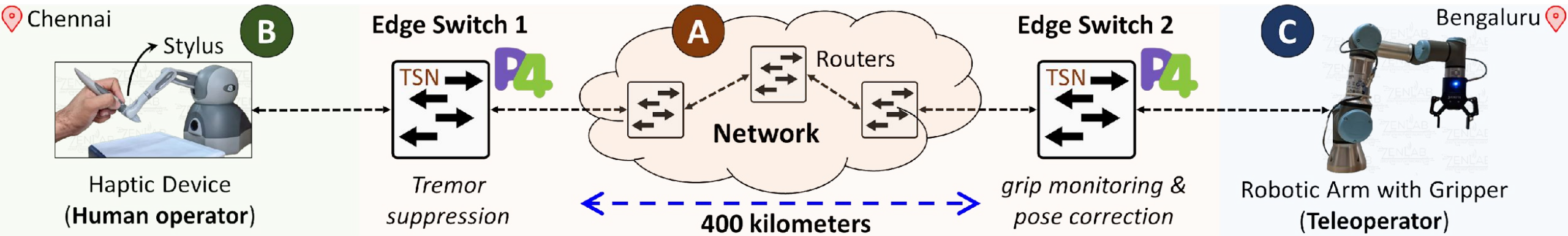


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Testbed overview



(A) Network domain

(B) Human operator domain

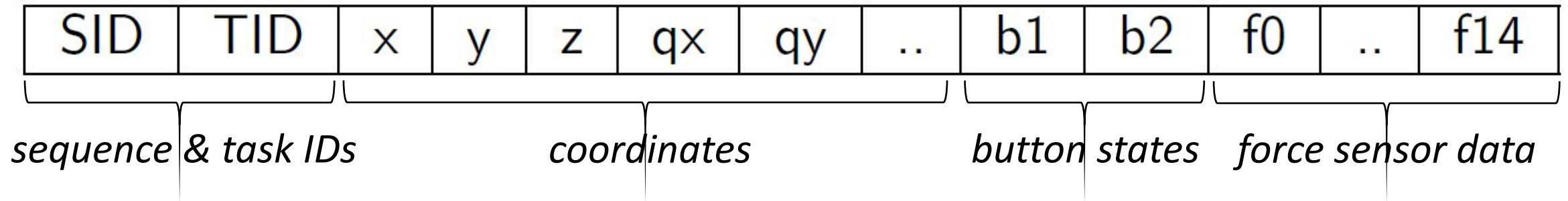
(C) Teleoperator domain

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Standardizing data exchange



coordinate_metadata

- sequence_id
- task_id
- x, y, z, qx, qy, qz, qw
- b1, b2
- f0 ... f14



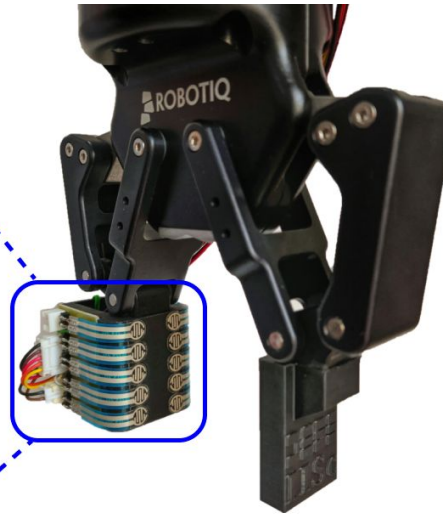
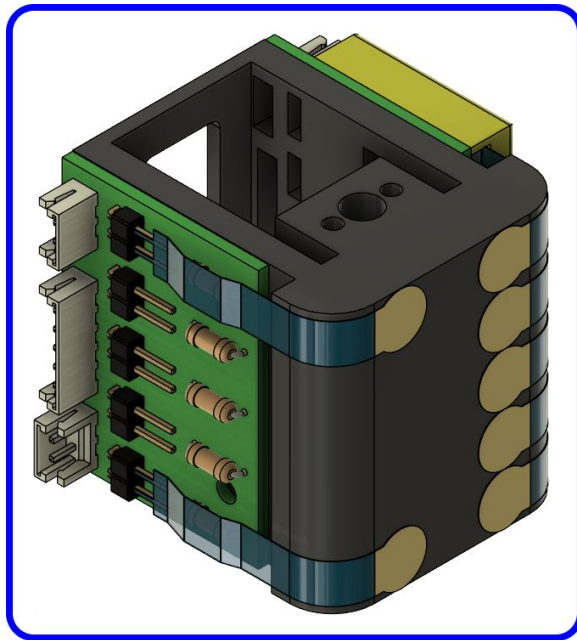
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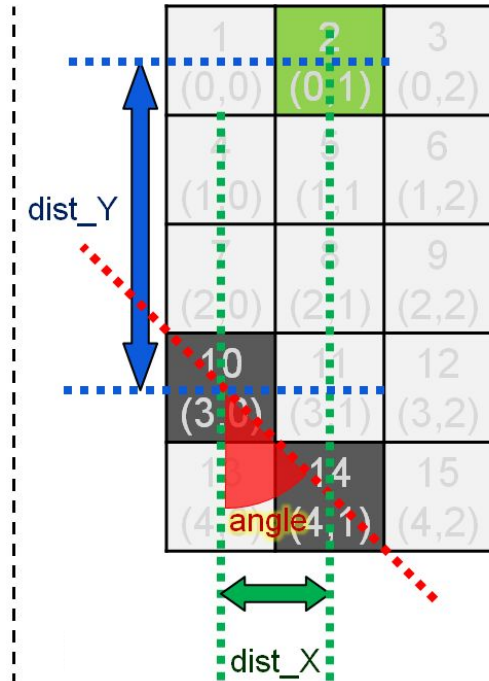
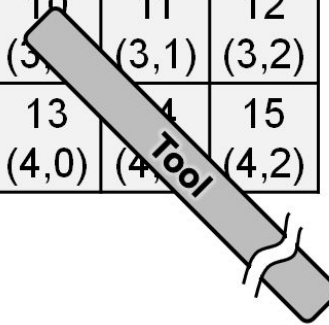


Pose correction: Custom-built force sensor array

- 5x3 array of FSRs
- Tool orientation detection



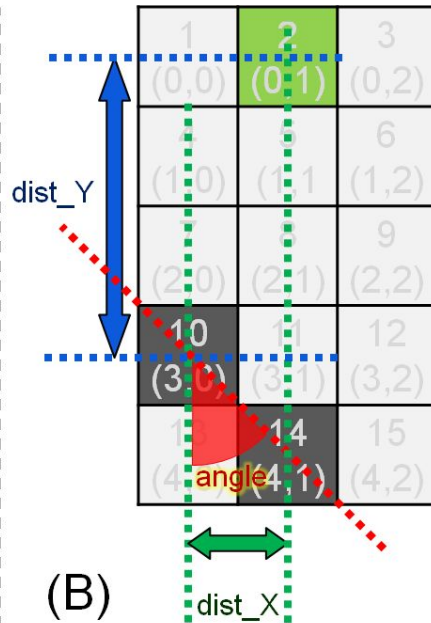
1 (0,0)	2 (0,1)	3 (0,2)
4 (1,0)	5 (1,1)	6 (1,2)
7 (2,0)	8 (2,1)	9 (2,2)
10 (3,0)	11 (3,1)	12 (3,2)
13 (4,0)	14 (4,1)	15 (4,2)



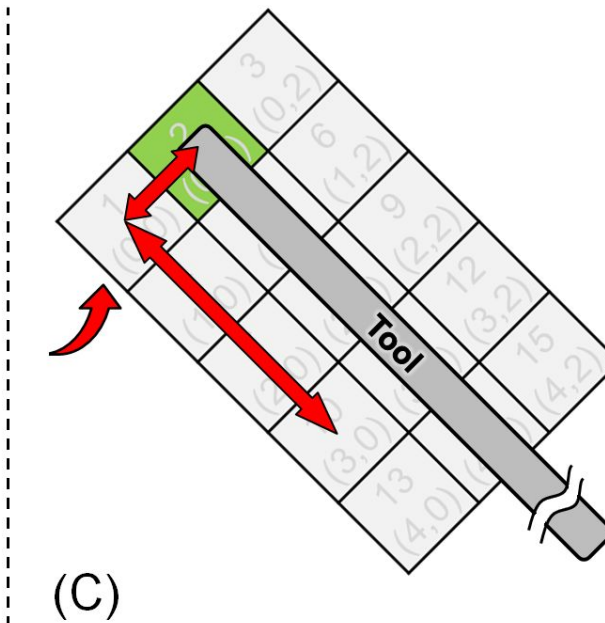
Pose correction: Logic

1	2	3
(0,0)	(0,1)	(0,2)
4	5	6
(1,0)	(1,1)	(1,2)
7	8	9
(2,0)	(2,1)	(2,2)
10	11	12
(3,0)	(3,1)	(3,2)
13	14	15
(4,0)	(4,1)	(4,2)

(A)



(B)



(C)

$$dist_x = (x_{10} - x_2) \times gap_x$$

$$dist_y = (y_{10} - y_2) \times gap_y$$

$$angle = \frac{(x_{10} - x_2) \times gap_x}{(y_{10} - y_{14}) \times gap_y}$$

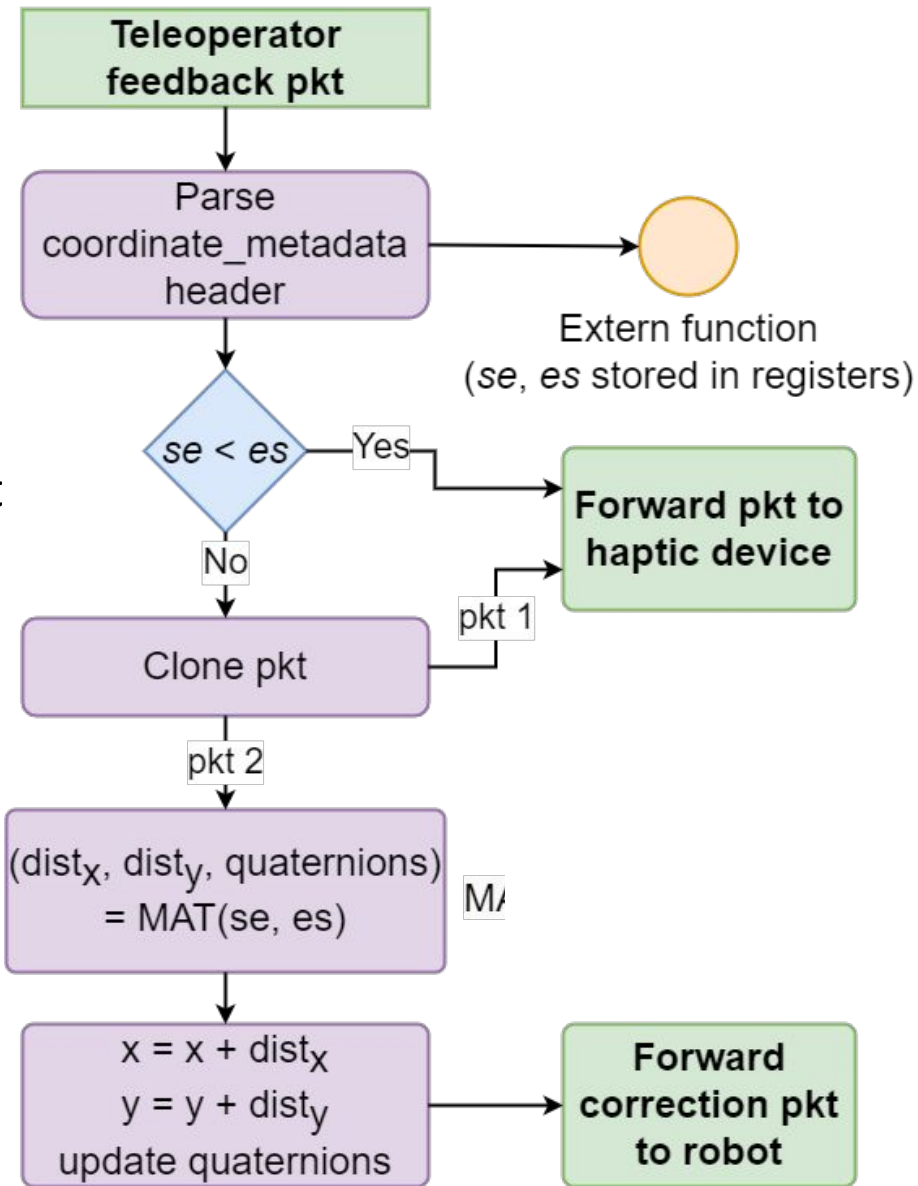
SID	TID	x	y	z	qx	qy	..	b1	b2	f0	..	f14
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FSR array	3	5	..	8	20	720	12	0	1	760	3
Index	0	1	..	7	8	9	10	11	12	13	14

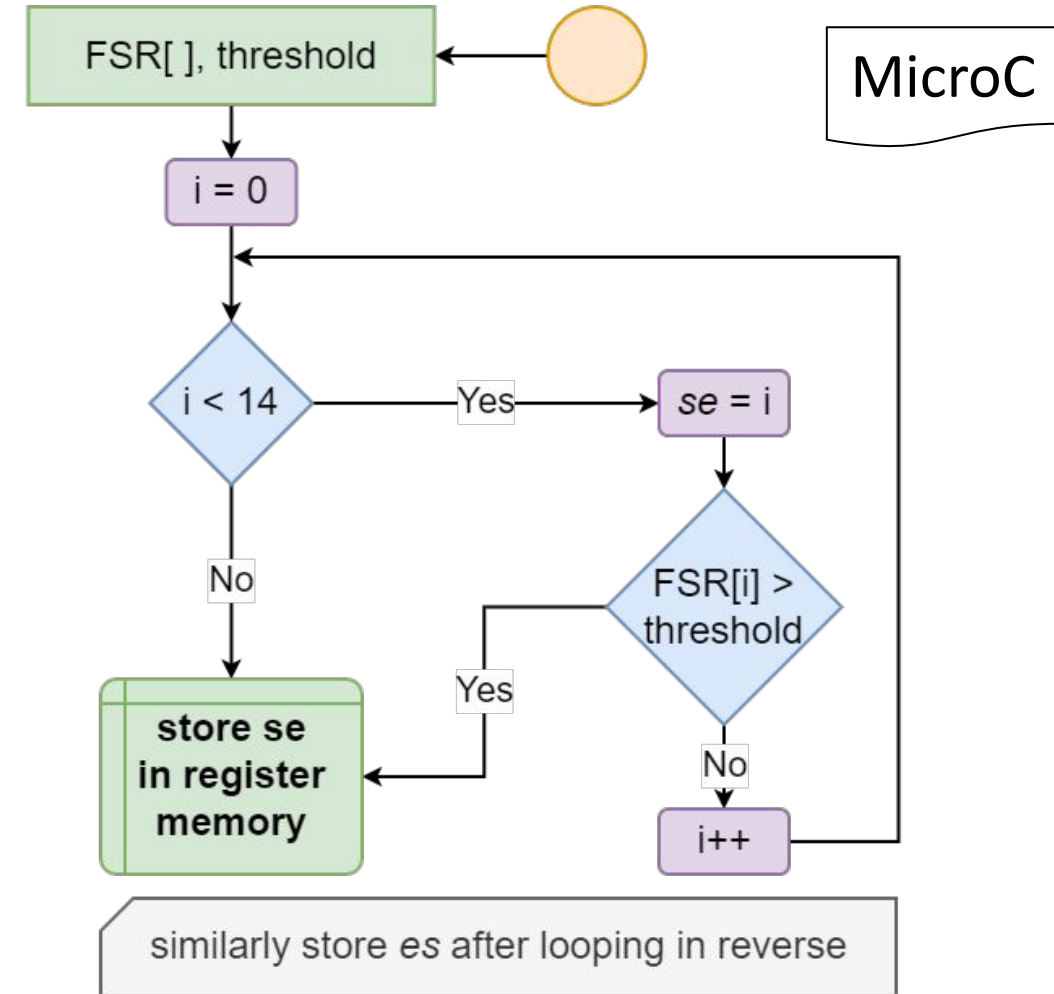


Pose correction: Algorithm

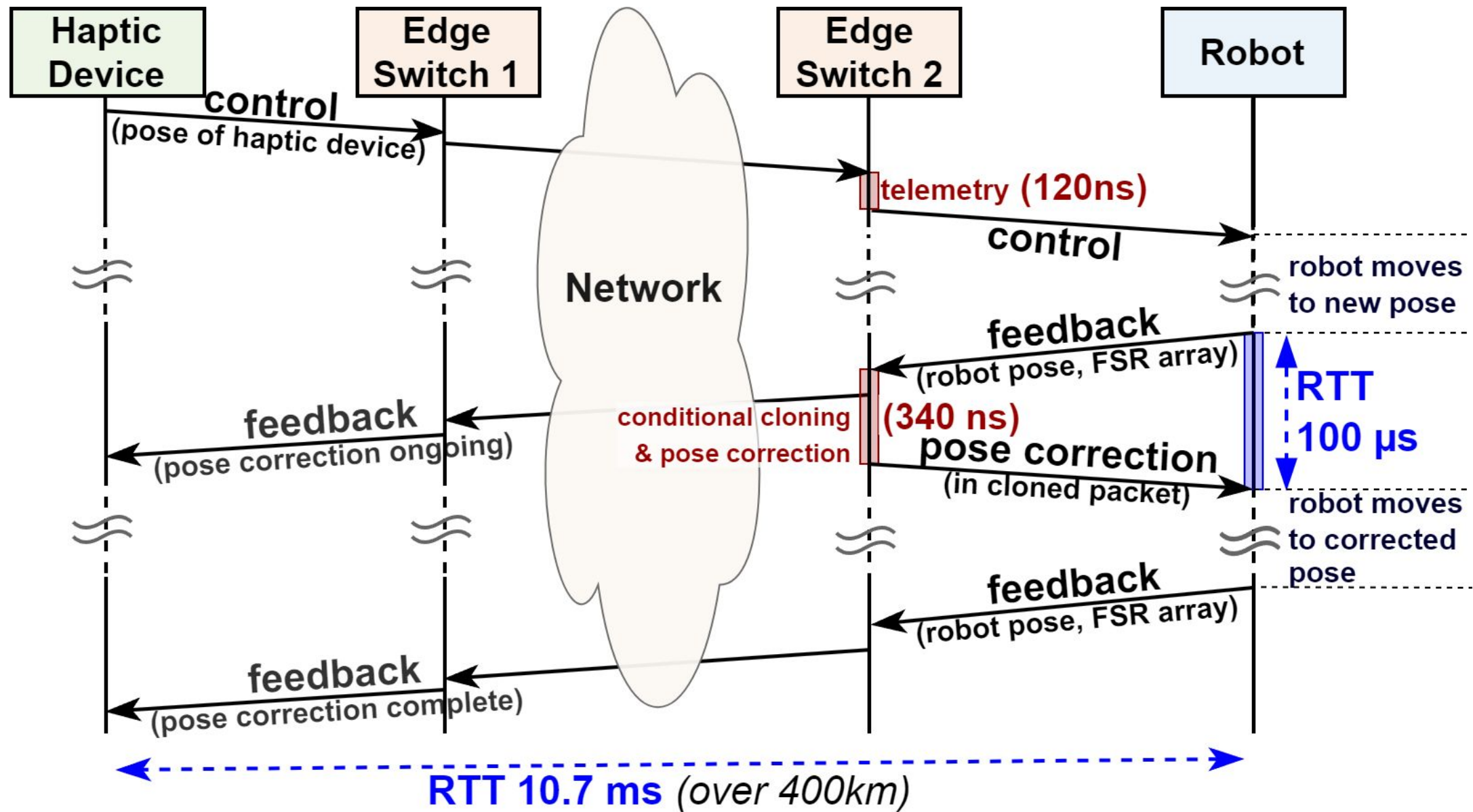
P4



EdgeSensors
Extern function



Pose correction: Experimental results



Pose correction: Key takeaways

- The teleoperator is agnostic to the source of the correction packet.
- Latency suitable for tactile CPS is achieved.
- Safeguard against stalling the feedback and correction process due to packet losses across the network.



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5. **Application #2: *Tremor suppression***

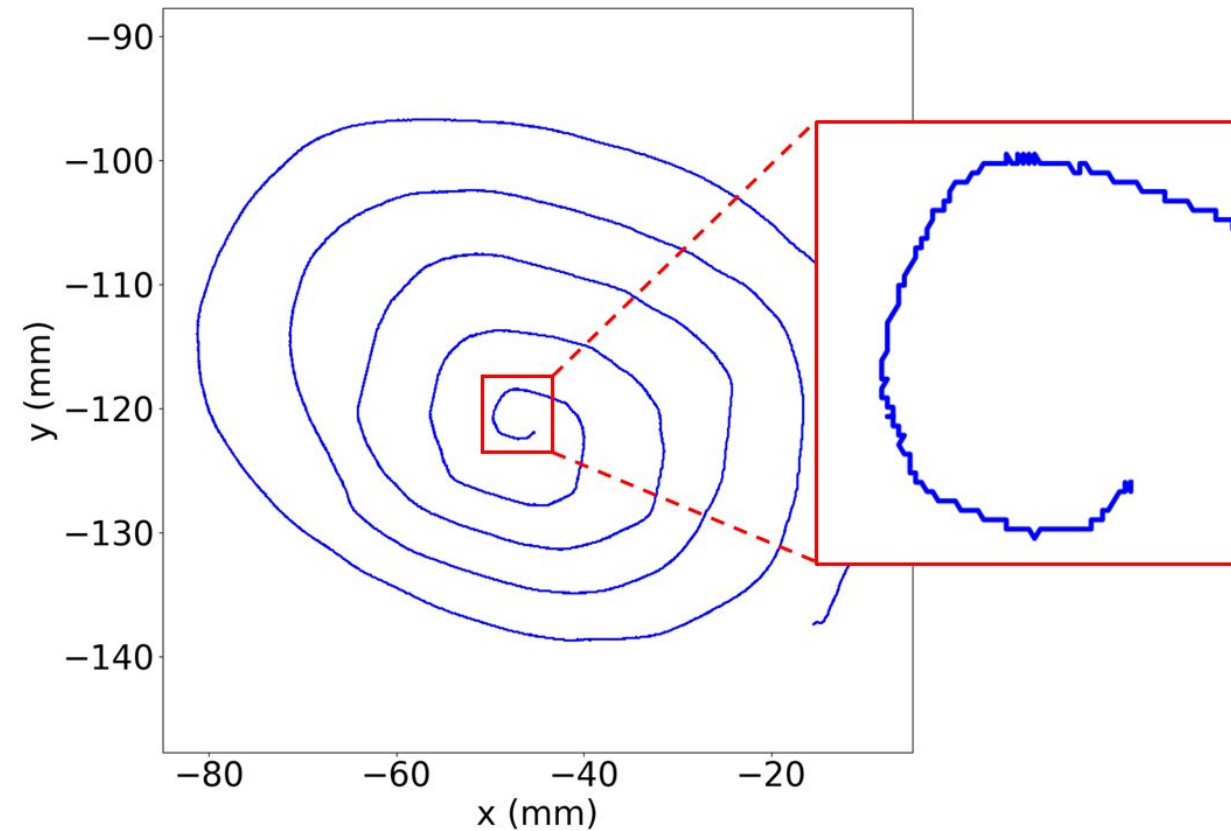


Tremor suppression: Physiologic tremors

- Everyone has physiologic tremor. It is rarely visible to the eye.
- Typically involves a fine shaking of hands and fingers.
- In real time teleoperation, this translates as vibrations in output movement of robot

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Tremor suppression: Logic

If, L1-distance between current and
previously stored coordinates >
threshold
the packet is **forwarded**

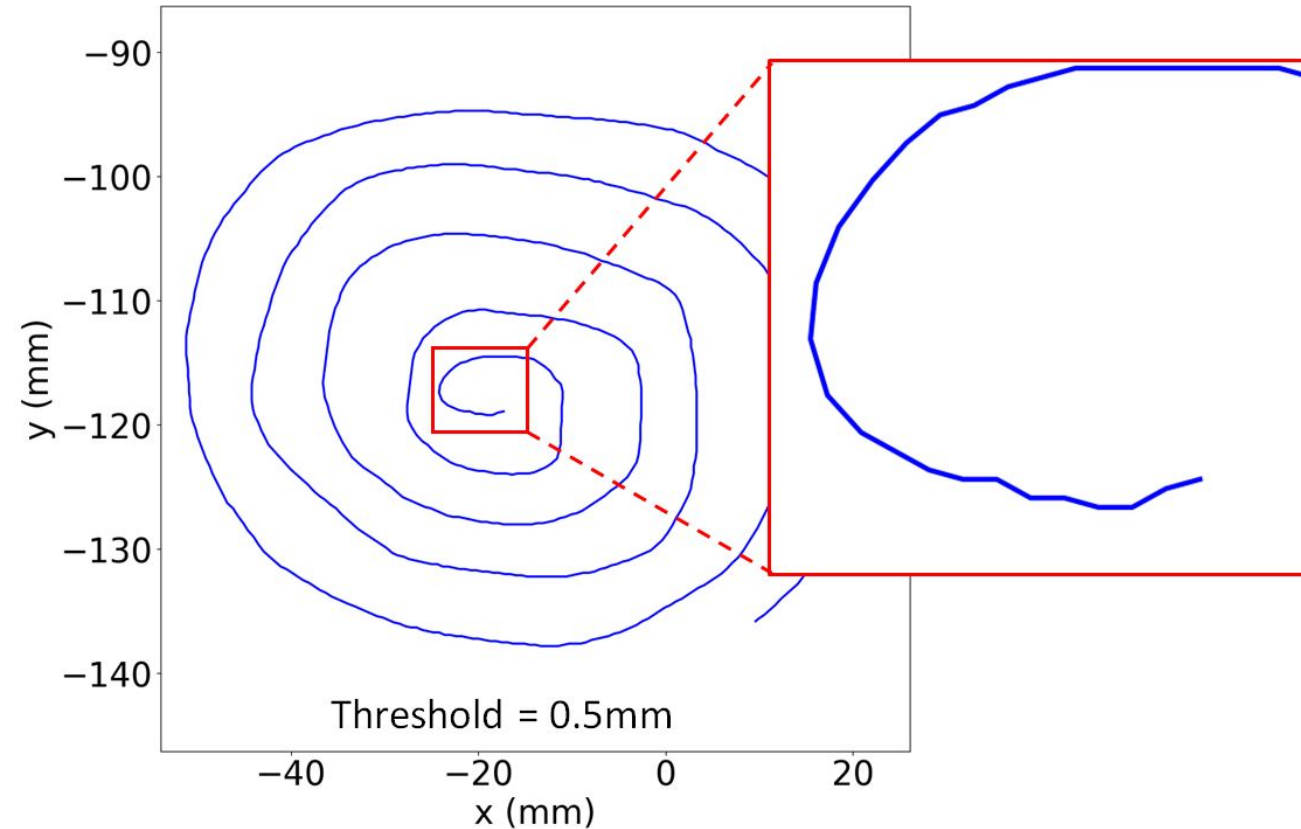
Else, the current haptic data packet is
discarded



Tremor suppression: Logic

If, L1-distance between current and previously stored coordinates $>$ *threshold*
the packet is **forwarded**

Else, the current haptic data packet is **discarded**



Tremor suppression: Experimental results

- Sampling @ 1kHz
- Packet size = 130 bytes
- Data transmission rate = 1Mbps

Traffic reduction for different tasks

Task	No. of packets transmitted	No. of packets discarded	Average data rate (kbps)	Traffic reduction (%)
Spiral	813	14182	55	94.58
Line	250	4718	51	94.97
Hold	5	9950	0.5	99.95

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Effect of different thresholds in drawing a spiral

Threshold (mm)	No. of packets transmitted	No. of packets discarded	Average data rate (kbps)	Traffic reduction (%)	Drawing length (mm)
None	14992	0	1015	0.0	600
0.1	2299	12621	148	84.6	507
0.5	813	14182	55	94.6	527
1	423	14494	29	97.2	506
2	226	14714	15	98.5	512



Tremor suppression: Key takeaways

- Reduced data rate while drawing a spiral from over 1Mbps to as low as 55Kbps with a bandwidth savings of over 94%.
- Suppressing the hand tremors while holding the stylus steady results in bandwidth savings of up to 99.95%.
- Reduced travel length of the teleoperator tool => reduced tissue bruising in robot-assisted medical tasks.

EdgeP4: Seamless switching between algorithms

task ID (16 bit field in *coordinate_metadata* header)

... to switch between edge intelligence algorithms associated with different tasks and robots.

SID	TID	x	y	z	qx	qy	..	b1	b2	f0	..	f14
-----	------------	---	---	---	----	----	----	----	----	----	----	-----

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The same edge switch can support

- different tasks
- different CPS devices (*robots, haptic devices, etc.*)

... all stored in the same MAT.



Conclusion

- We present **EdgeP4** framework for TCPS applications (e.g., telesurgery).
- Demonstrate **EdgeP4** over a 400 km intercity testbed.
- Two applications:
 - Pose correction—implemented on the *teleoperator* side
 - Tremor suppression—implemented on the *human operator* side



Publications

EdgeP4 (<https://ieeexplore.ieee.org/document/10620719>)

TSN-DetNet Intercity Testbed (<https://ieeexplore.ieee.org/document/10620882>)

Code

EdgeP4 (<https://github.com/nithishkgnani/EdgeP4>)

Configuring Netronome SmartNICs (<https://github.com/deepakc7y/netronome-config>)



Thank you! Questions?

