MAGIC

Automatic Calibration of Magnetic Tracking

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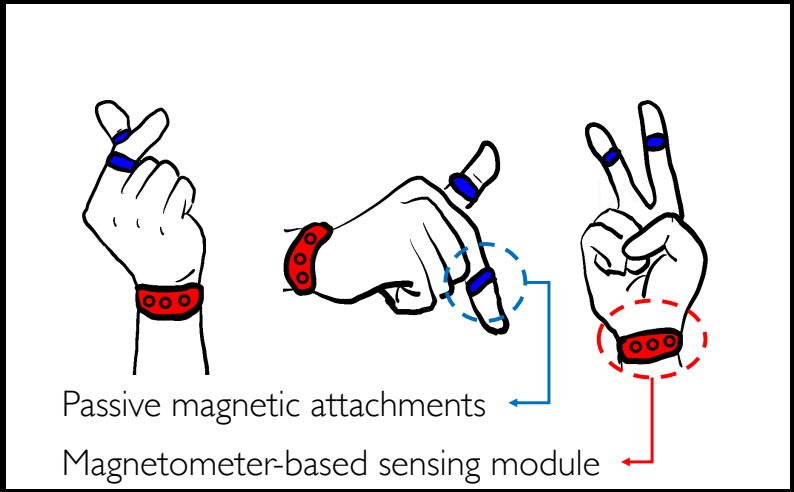
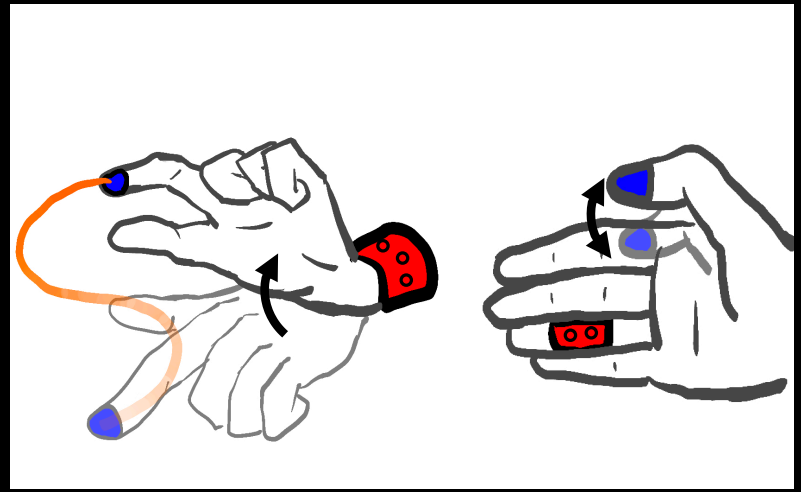
Recent Progresses in Magnetic Tracking

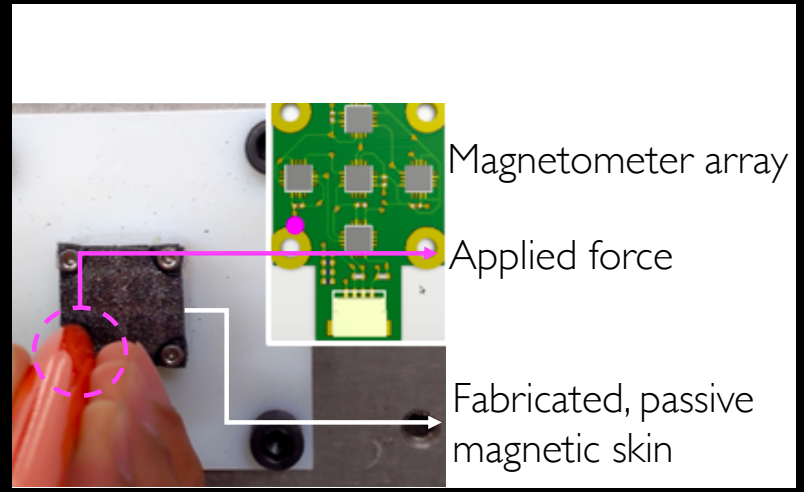
Fine-grained pose detection



Free-form, 3D input



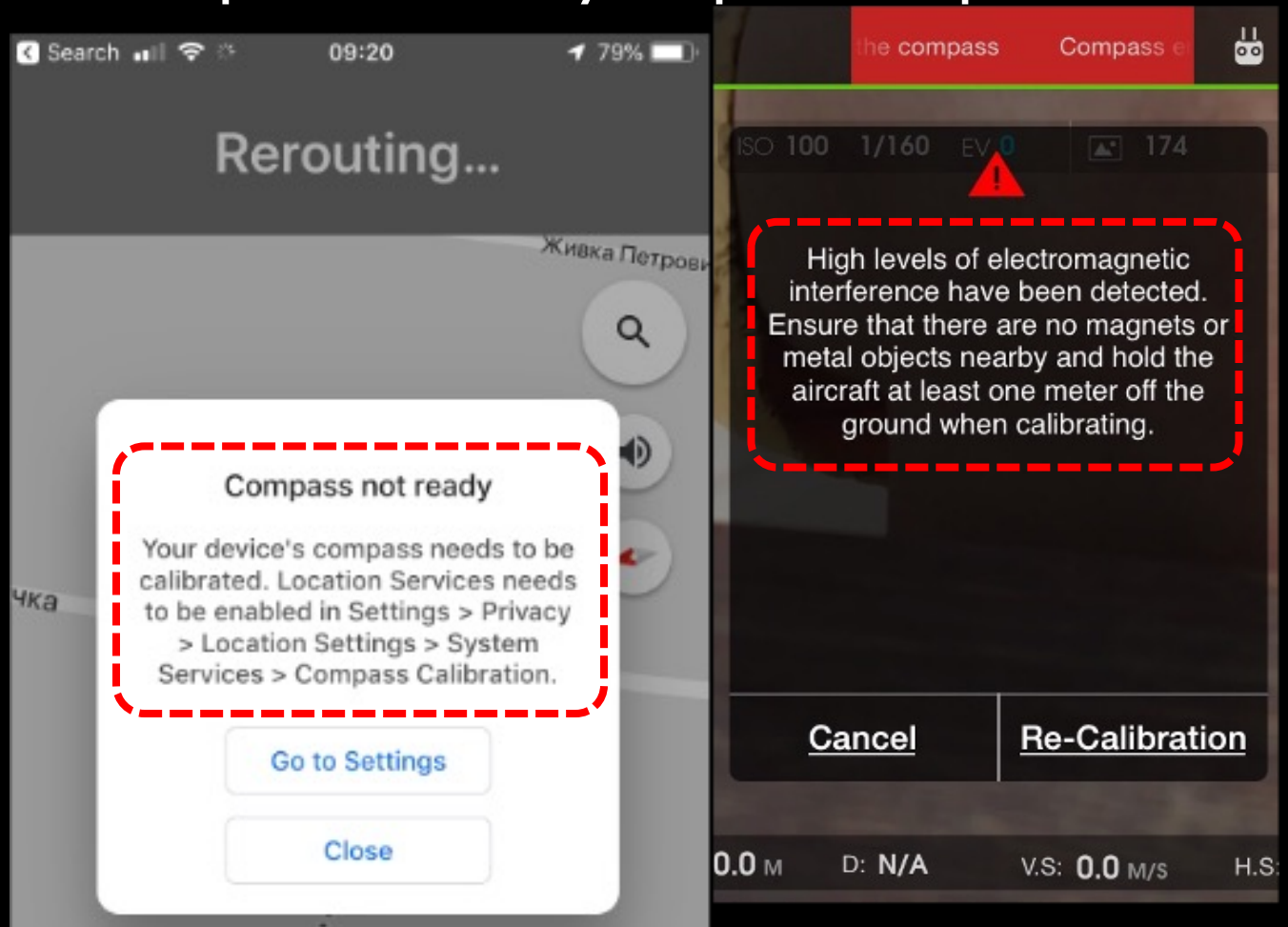
Tactile sensing



https://reskin.dev/

Wait...

- Compasses usually require frequent recalibration

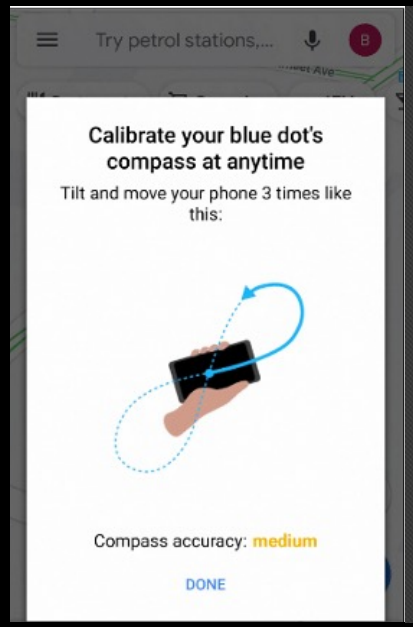


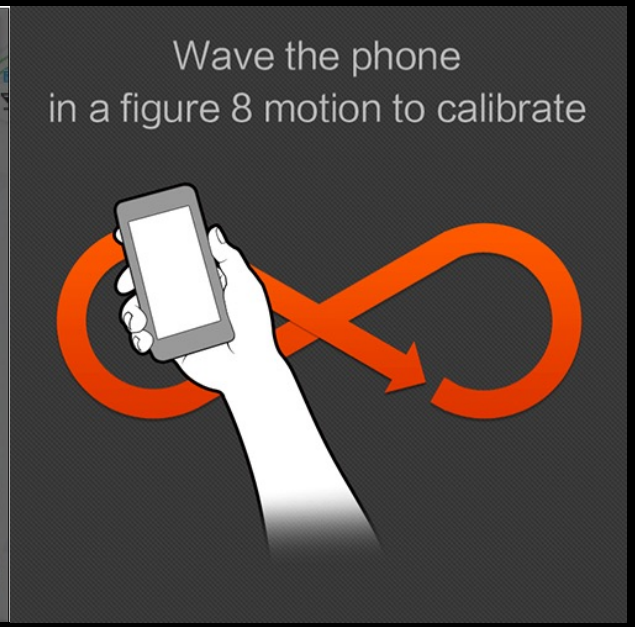
Calibration is not a Trivial Task

- These calibration methods are tedious

Tilt calibration

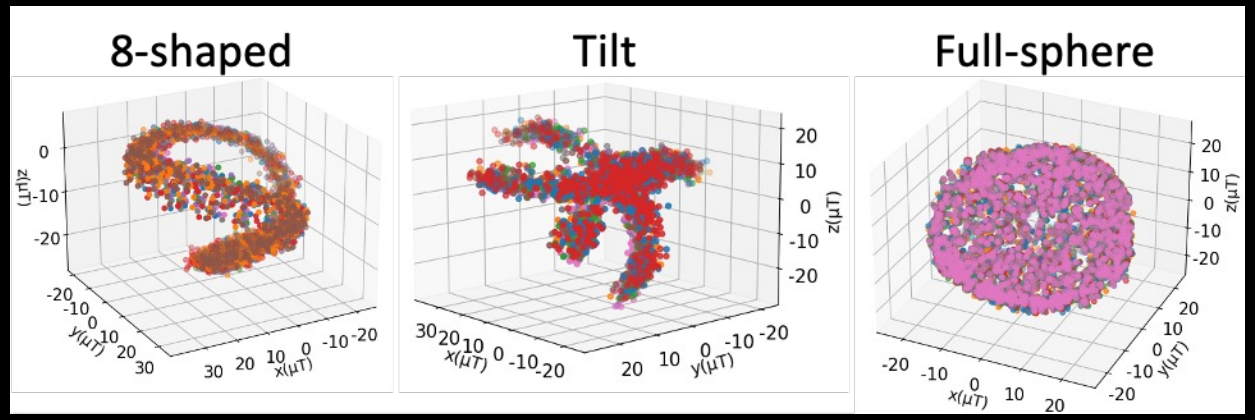
8-shaped calibration

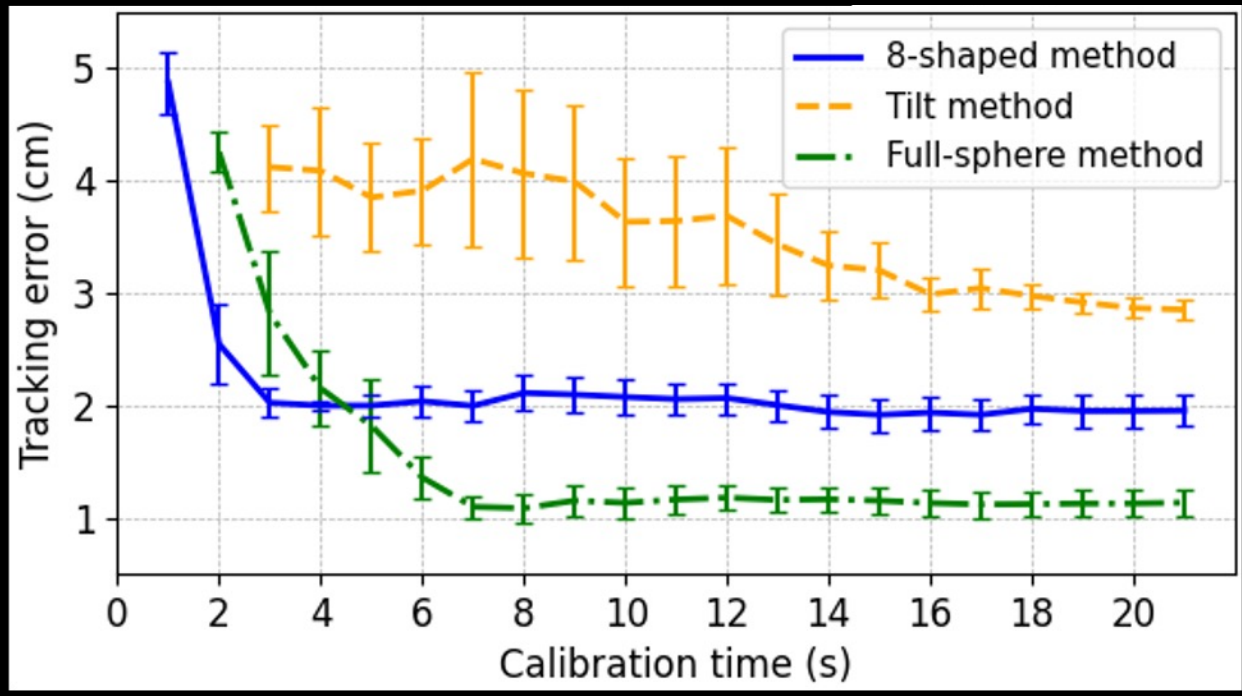




Six-sided calibration for UAVs

Calibration can also be Time-consuming



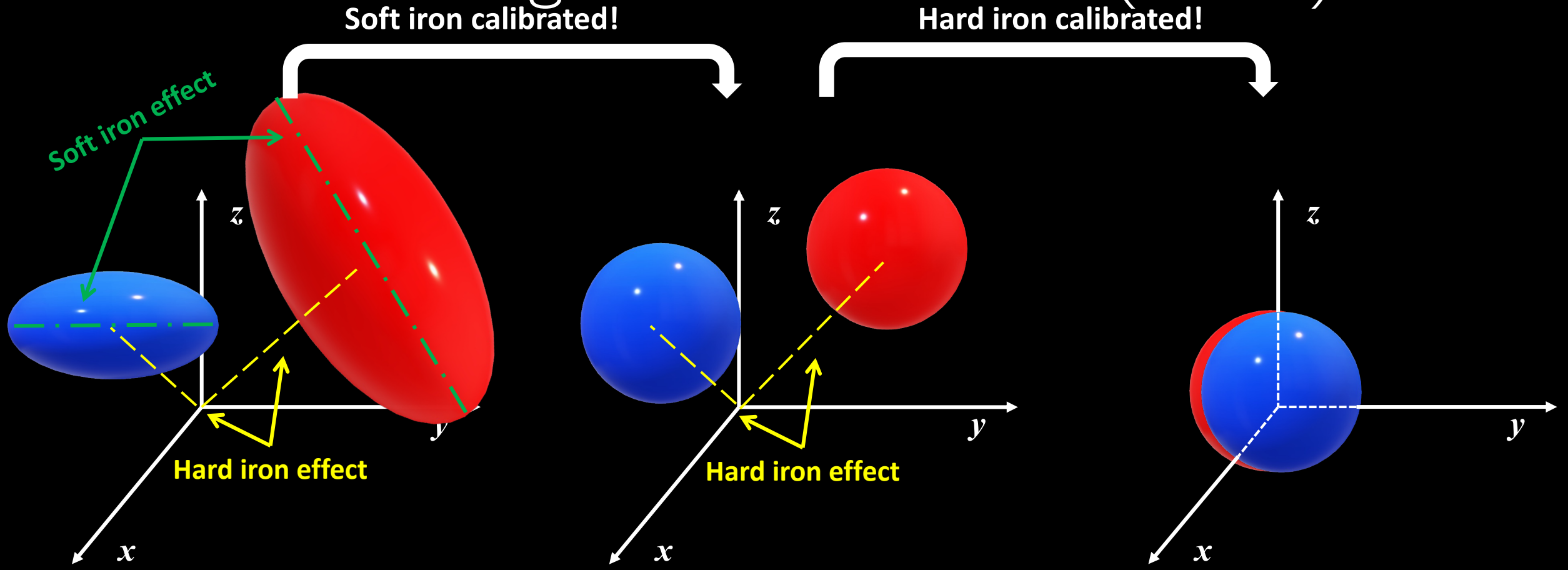


An extensive calibration is necessary for calibration performance

Understanding the Disturbance

- Magnetic disturbances
  - Hard-iron effect
  - Soft-iron effect

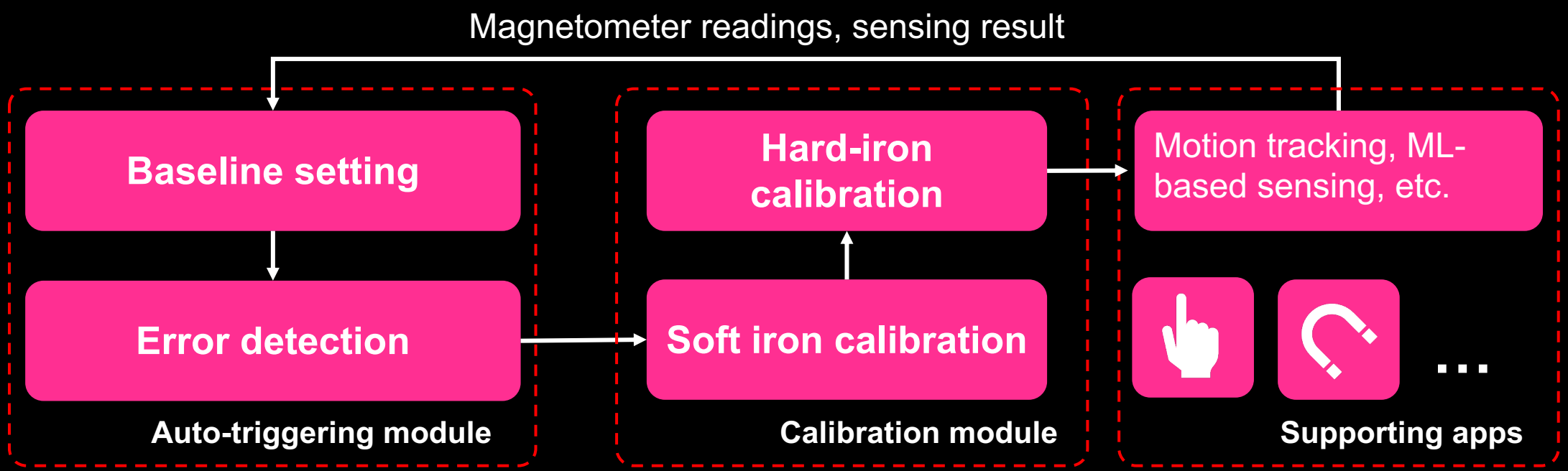
Understanding the Disturbance (Cont.)



Can we enable a seamless calibration process that can

1. Fully calibrate electromagnetic disturbances;
2. Incur minimum user disturbances.

System Overview of MAGIC

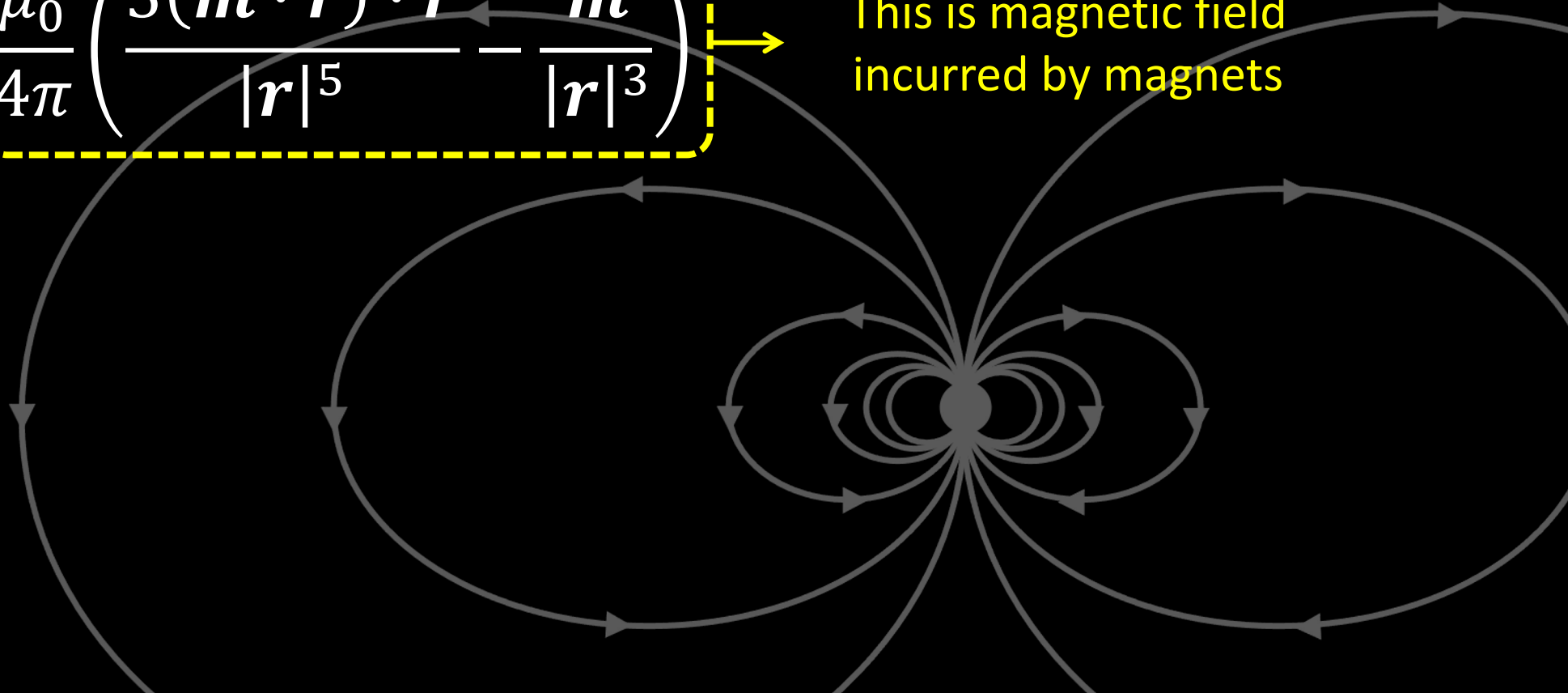


Soft-iron Calibration

- Know the soft-iron parameters

$$\boldsymbol{B} = \boldsymbol{G} + \frac{\mu_0}{4\pi}\left(\frac{3(\boldsymbol{m}\cdot\boldsymbol{r})\cdot\boldsymbol{r}}{|\boldsymbol{r}|^5} - \frac{\boldsymbol{m}}{|\boldsymbol{r}|^3}\right)$$

This is magnetic field incurred by magnets



Soft-iron Calibration(Cont.)

- Know the soft-iron parameters

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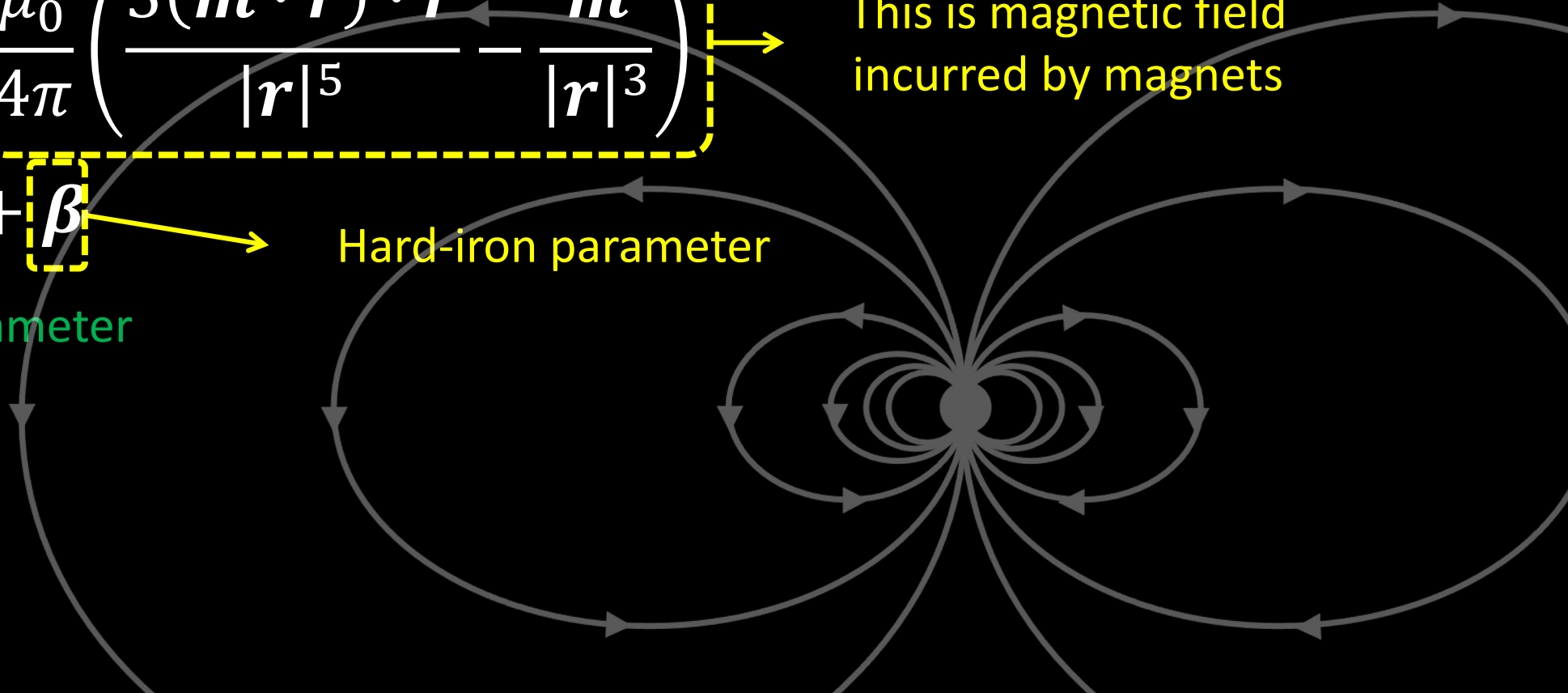
This is magnetic field incurred by magnets

$$\widehat{\boldsymbol{B}} = \boldsymbol{\alpha}\boldsymbol{B} + \boldsymbol{\beta}$$

Hard-iron parameter

Soft-iron parameter



Soft-iron Calibration (Cont.)

- Know the soft-iron parameters

$$\boldsymbol{B} = \boldsymbol{G} + \frac{\mu_0}{4\pi}\left(\frac{3(\boldsymbol{m}\cdot\boldsymbol{r})\cdot\boldsymbol{r}}{|\boldsymbol{r}|^5} - \frac{\boldsymbol{m}}{|\boldsymbol{r}|^3}\right)$$

This is magnetic field incurred by magnets

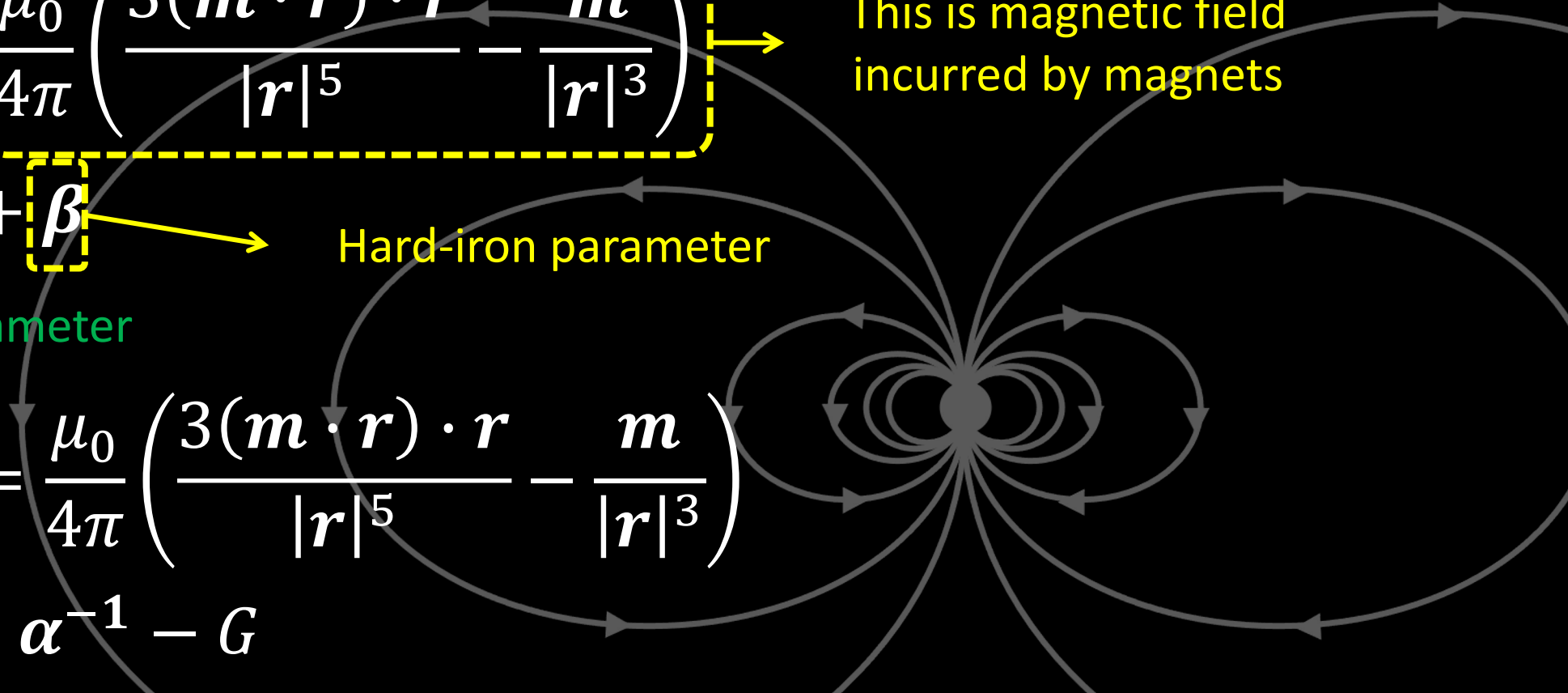
$$\widehat{\boldsymbol{B}} = \boldsymbol{\alpha}\boldsymbol{B} + \boldsymbol{\beta}$$

Hard-iron parameter

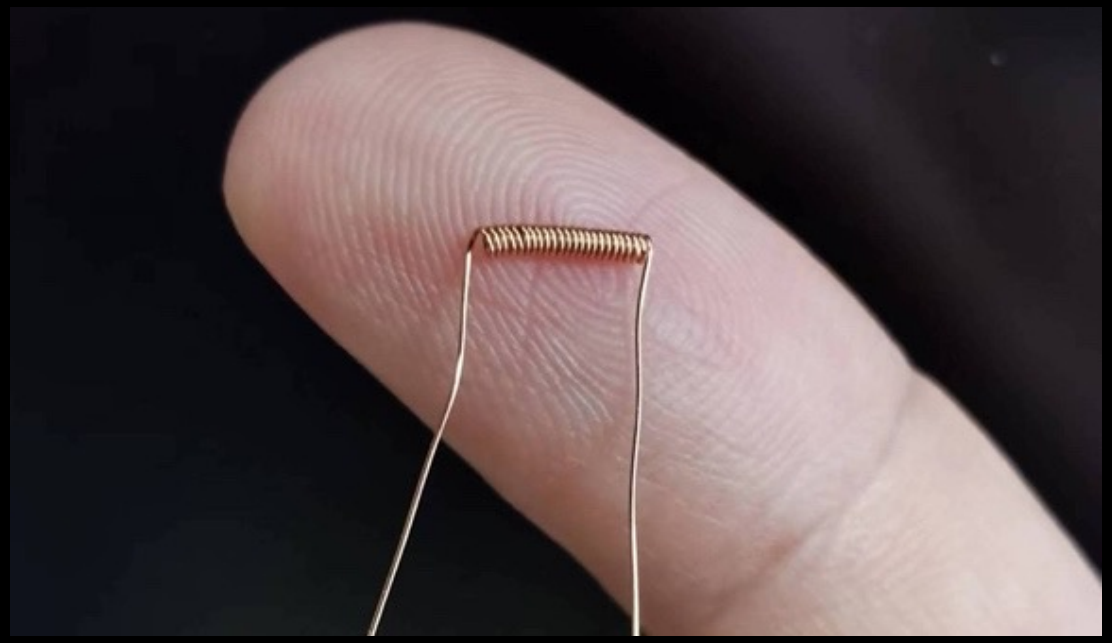
Soft-iron parameter

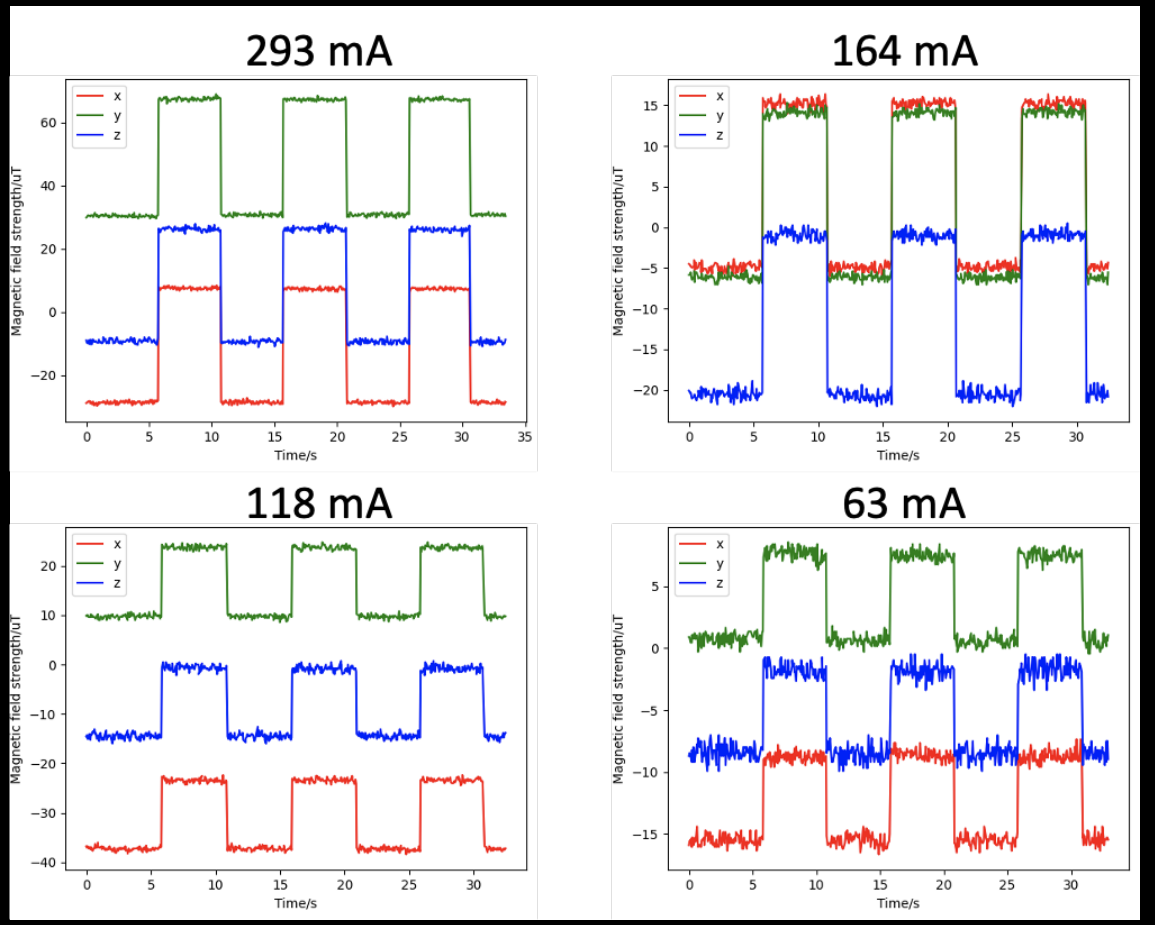
$$\boldsymbol{\gamma}\widehat{\boldsymbol{B}} + \boldsymbol{\omega} = \frac{\mu_0}{4\pi}\left(\frac{3(\boldsymbol{m}\cdot\boldsymbol{r})\cdot\boldsymbol{r}}{|\boldsymbol{r}|^5} - \frac{\boldsymbol{m}}{|\boldsymbol{r}|^3}\right)$$

$$\boldsymbol{\omega} = -\boldsymbol{\beta}\cdot\boldsymbol{\alpha}^{-1} - G$$



Solution: Using Electromagnets





Hard-iron Calibration

$$\widehat{\boldsymbol{B}} = \boldsymbol{B} + \boldsymbol{\beta}$$

Hard-iron parameter, it is an intrinsic feature with the sensor, it cannot be decoupled from ***G*** without extensive movement

$$\widehat{\boldsymbol{B}} = \boldsymbol{B}^{signal} + \boldsymbol{G} + \boldsymbol{\beta}$$

Constant feature with the environment

Now we introduce, $\boldsymbol{B}^{cali} = \boldsymbol{G_0} + \boldsymbol{\beta}$

$$\widehat{\boldsymbol{B}} - \boldsymbol{B}^{cali} = \boldsymbol{B}^{signal} + \boldsymbol{G} - \boldsymbol{G_0}$$

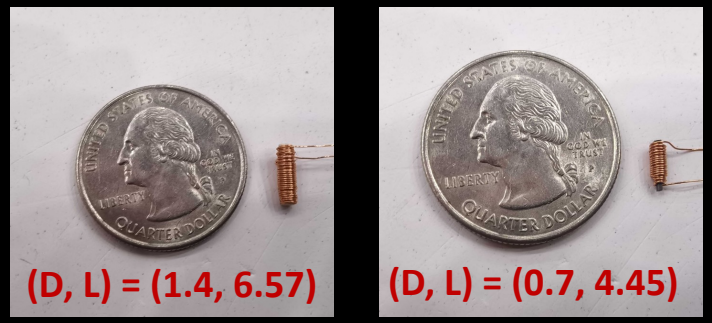
Auto-triggering Scheme

- Design goal: automatically determine whether calibration is needed

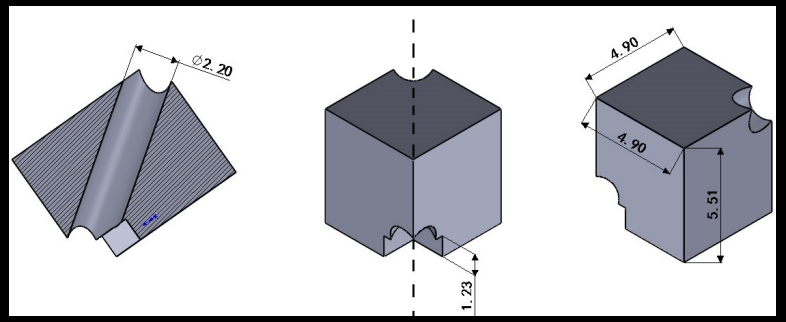
- The key idea: a two-step approach
  1. Determine a baseline of the current magnetic status
  2. Periodically monitor the magnetic status with a novel feature set

Put Everything Together

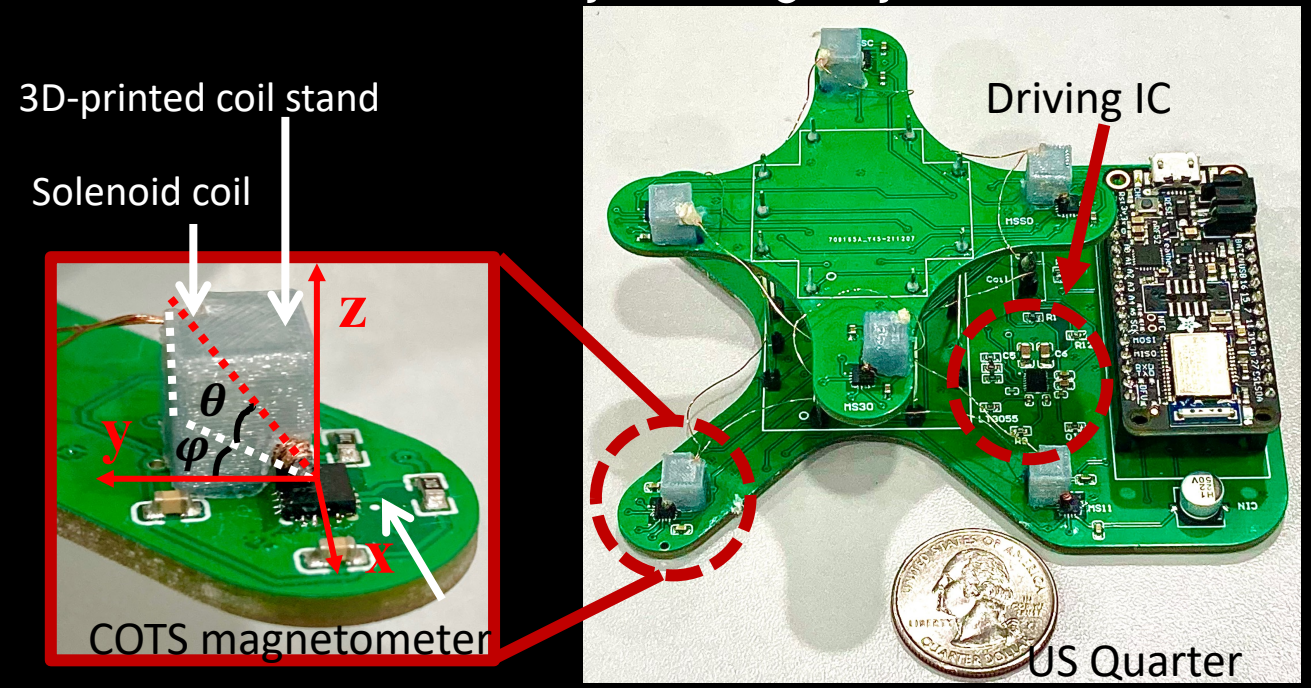
Design of the coil and stand



Medium coil Compact coil

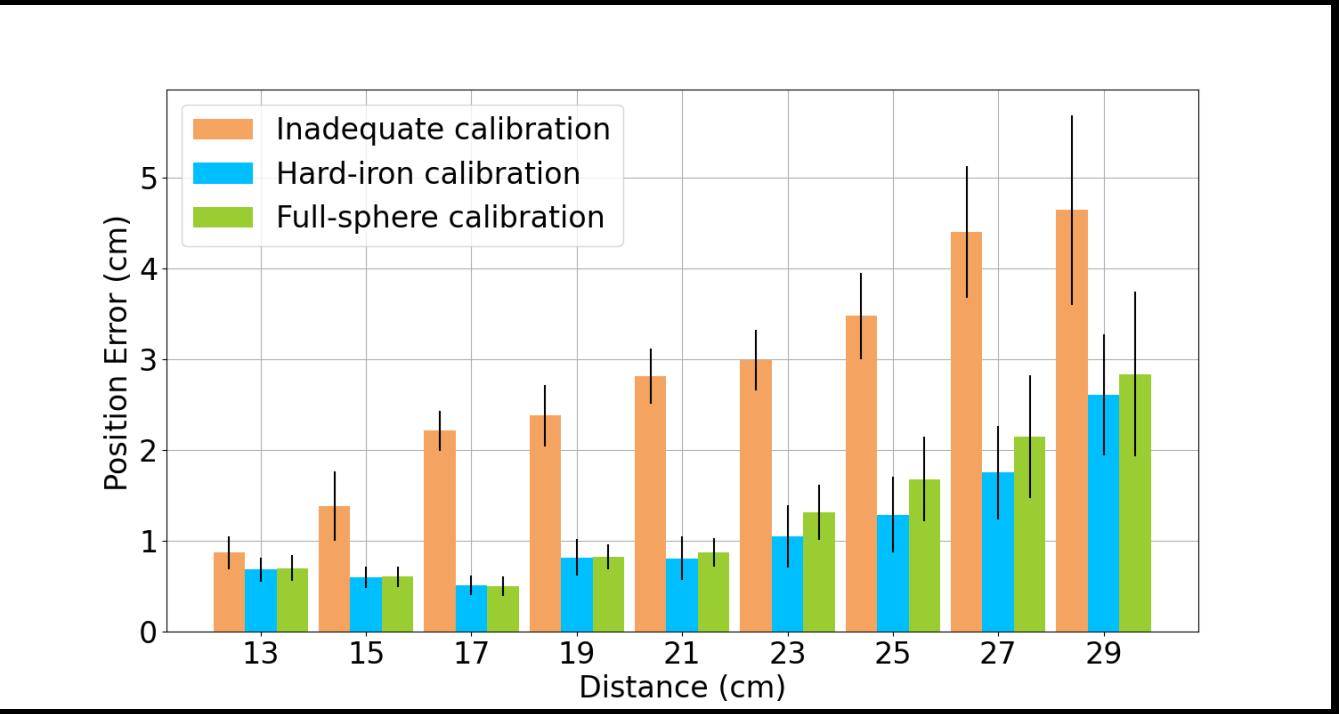


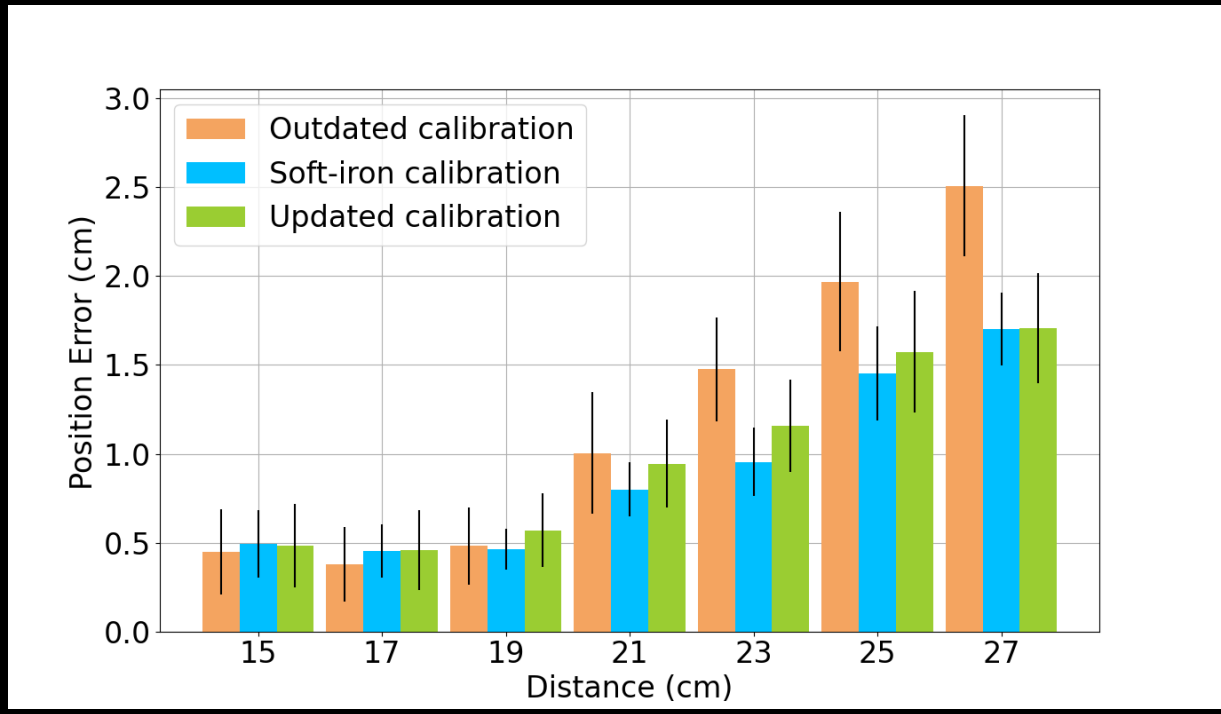
MAGIC's assembly on MagX system



Performance Evaluation

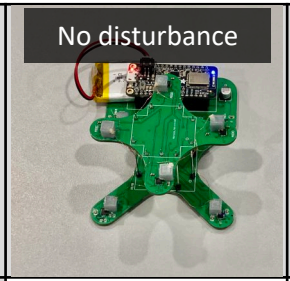
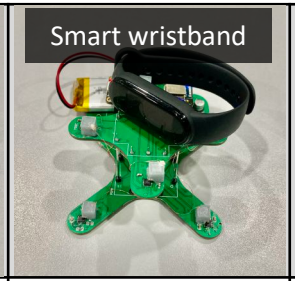
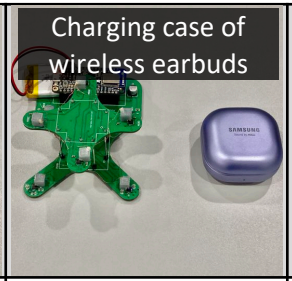
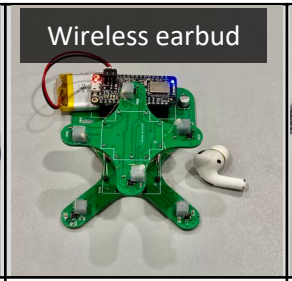
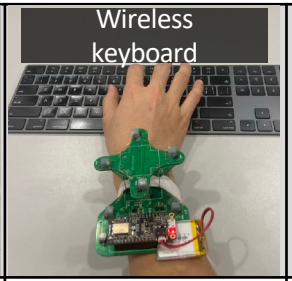
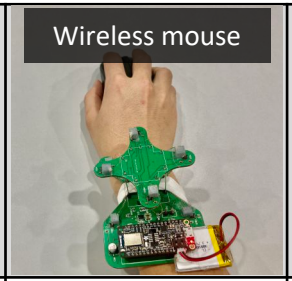
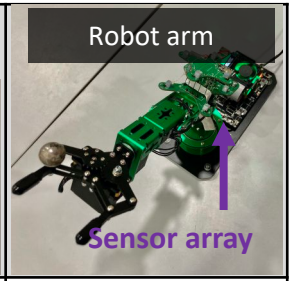
- Hard iron and soft iron calibration





Performance Evaluation

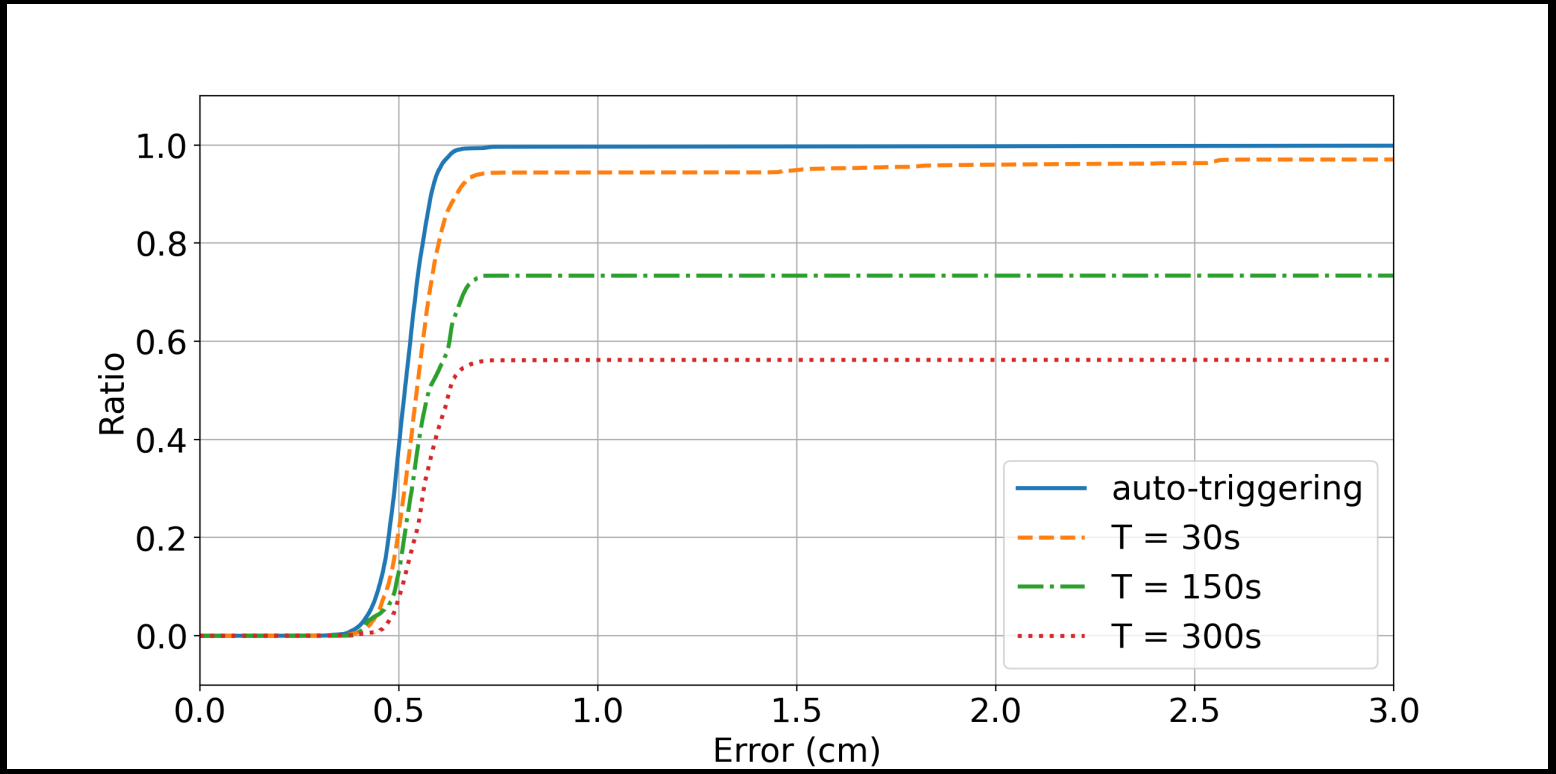
- Auto-triggering scheme

Electronic devices tested in experiments	No disturbance 	Smart wristband 	Charging case of wireless earbuds 	Wireless earbud 	Wireless keyboard 	Wireless mouse 	Bone conduction earphone 	Robot arm 
Need calib.?	**NO**	**YES**	**YES**	**NO**	**NO**	**NO**	**YES**	**NO**
Err. (mean, std)	(0.98, 0.04)	(6.52, 0.78)	(6.76, 0.46)	(2.73, 0.11)	(0.98, 0.03)	(1.01, 0.04)	(9.11, 6.88)	(1.11, 0.13)

With MAGIC's baseline setting and status monitoring
We can accurately connect the calibration status with system performance, and trigger calibration ONLY when NEEDED

Performance Evaluation

- Auto-triggering vs. periodic calibration methods



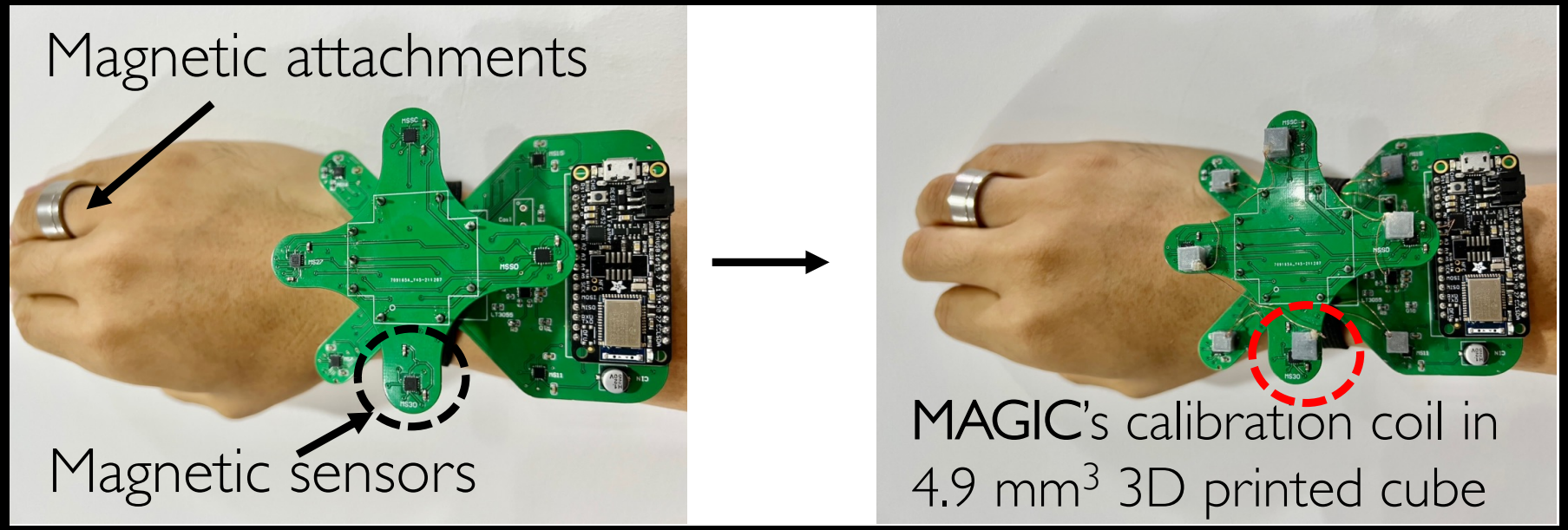
The Energy Cost of MAGIC

- We compared MAGIC's energy cost with different time intervals'

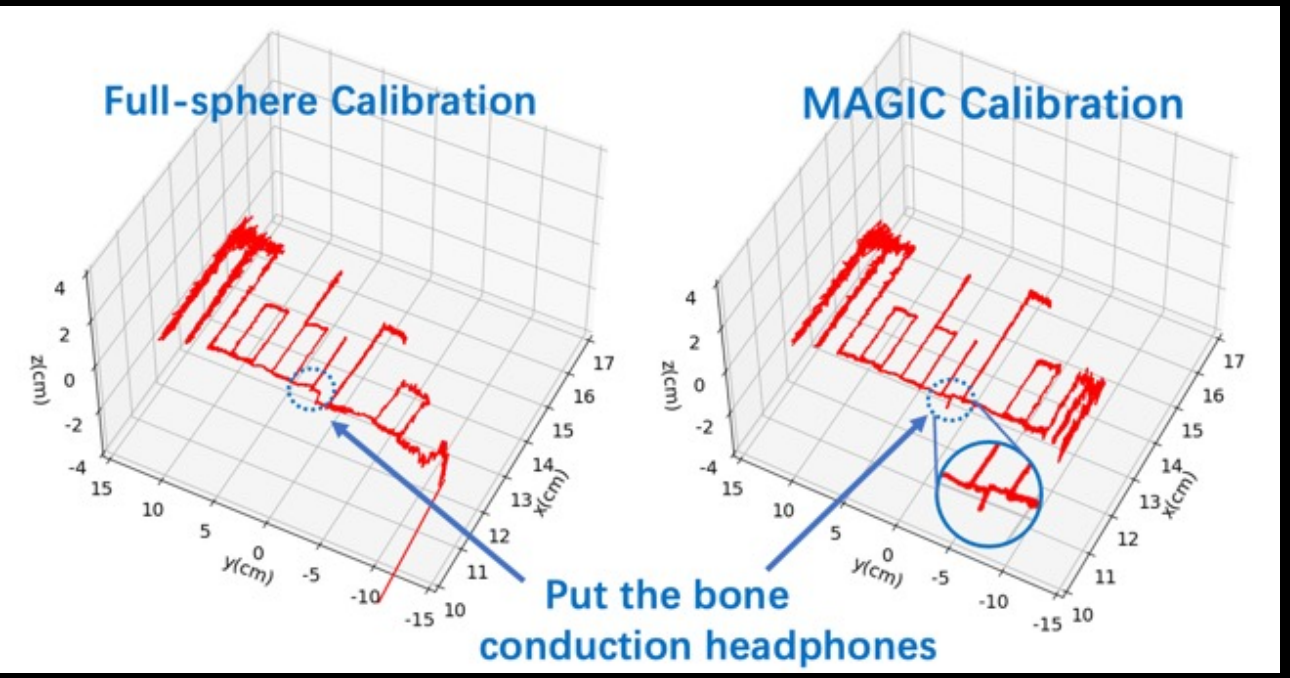
Interval	Auto-triggering	300 s	150 s	30 s
Energy cost (J)	270.82	270.82	275.24	310.59
Occurrences	3	3	6	30

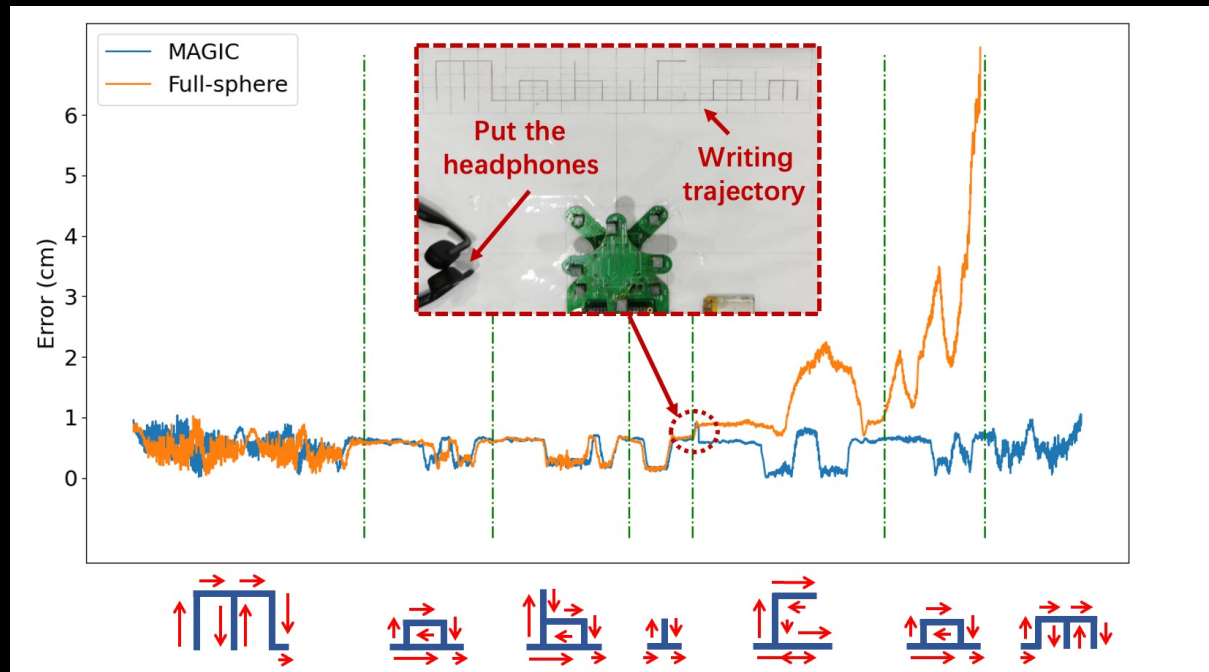
What can We Achieve with MAGIC?

A workable, wearable, and efficient **essential** for magnetic tracking technology

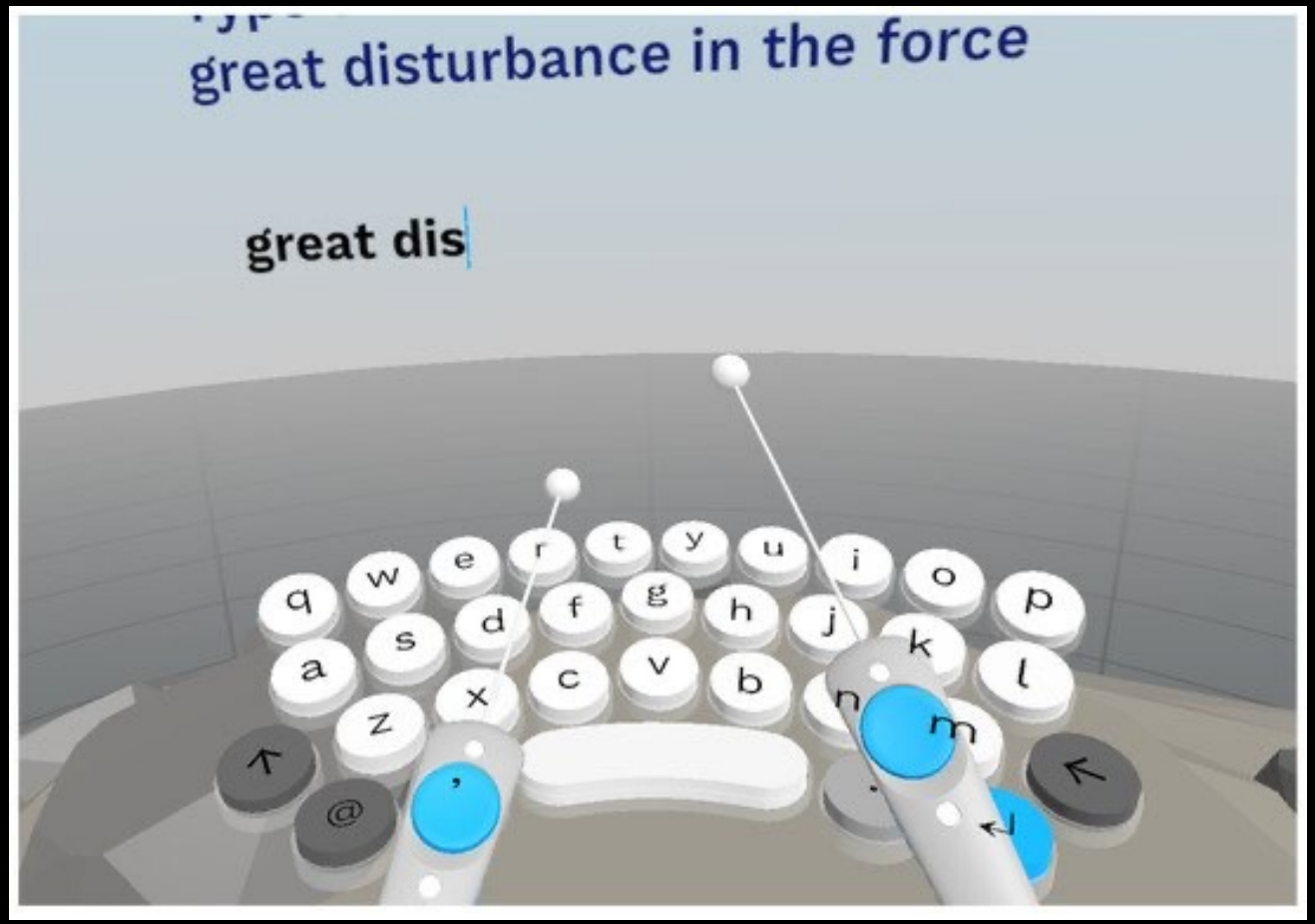


Hand-writing Experiment





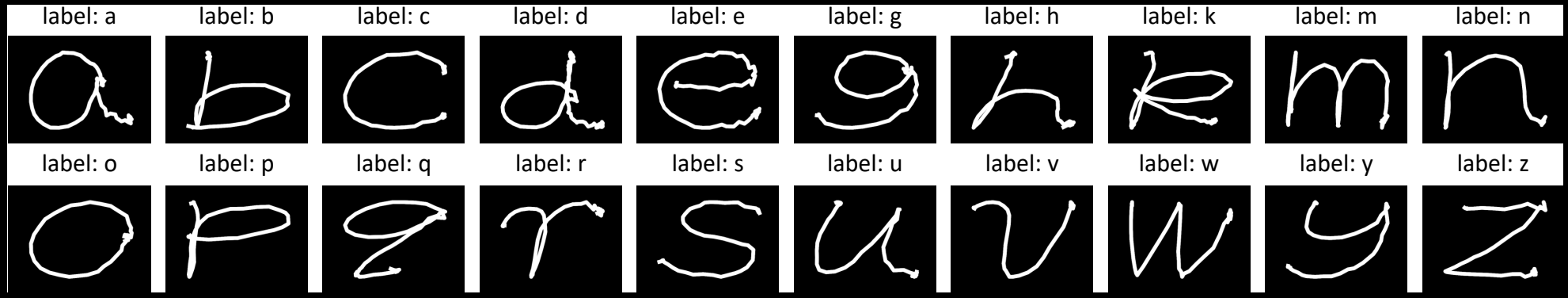
Text Entry in VR is a Nightmare …



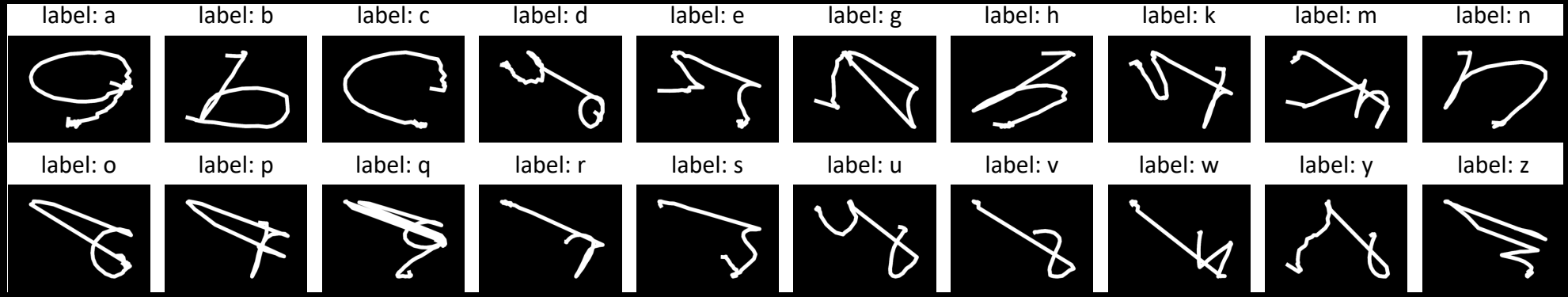
https://www.mdpi.com/2227-7080/7/2/31

3D Handwriting, Made into Reality

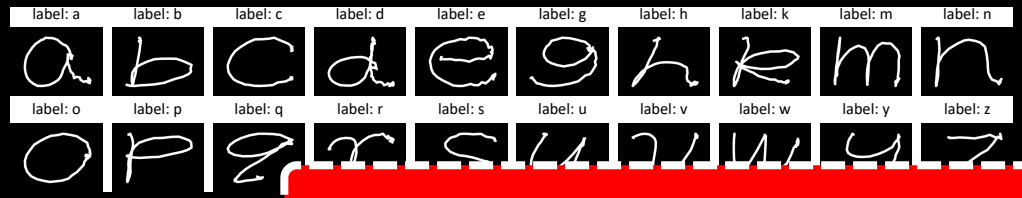
Calibrated with MAGIC

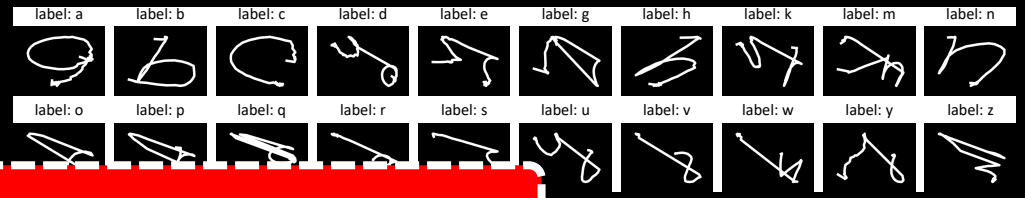


Calibrated with full-sphere method

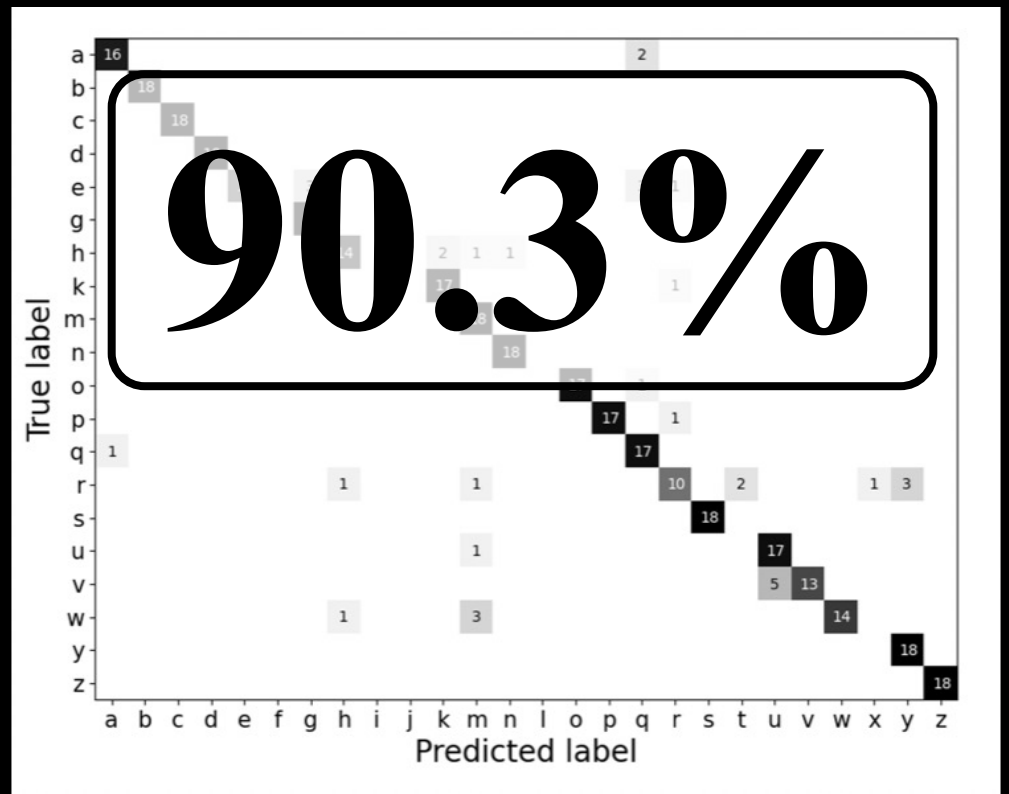


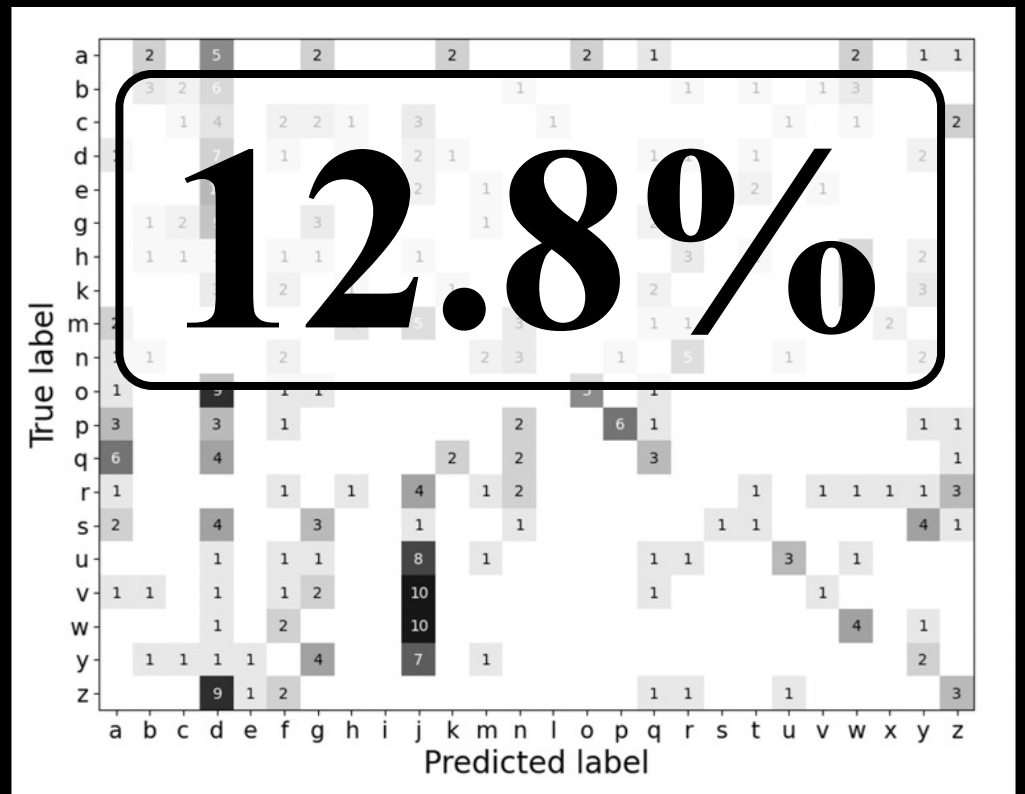
3D Handwriting, Made into Reality





The classifier was trained with MNIST Letters dataset





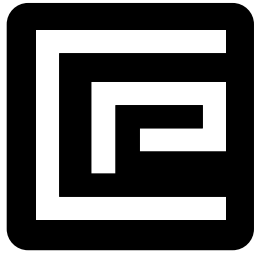
Conclusion

- MAGIC is a practical and easy-to-use calibration system for magnetic sensing apps
  - MAGIC handles notorious soft- and hard-iron disturbances
  - MAGIC enables end-to-end automatic calibration by using a lightweight auto-triggering scheme

Thanks!

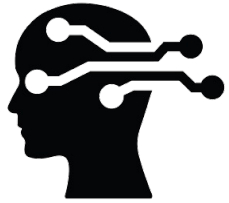
Q & A

Research Presented by:



IIOT

Intelligent IoT Research Center



Interactive Sensing & Computing Lab