Building Your Magnetic Field Mapper with LEGO®

Philip Keller
Magnetics 2018

Magnetic precision has a name

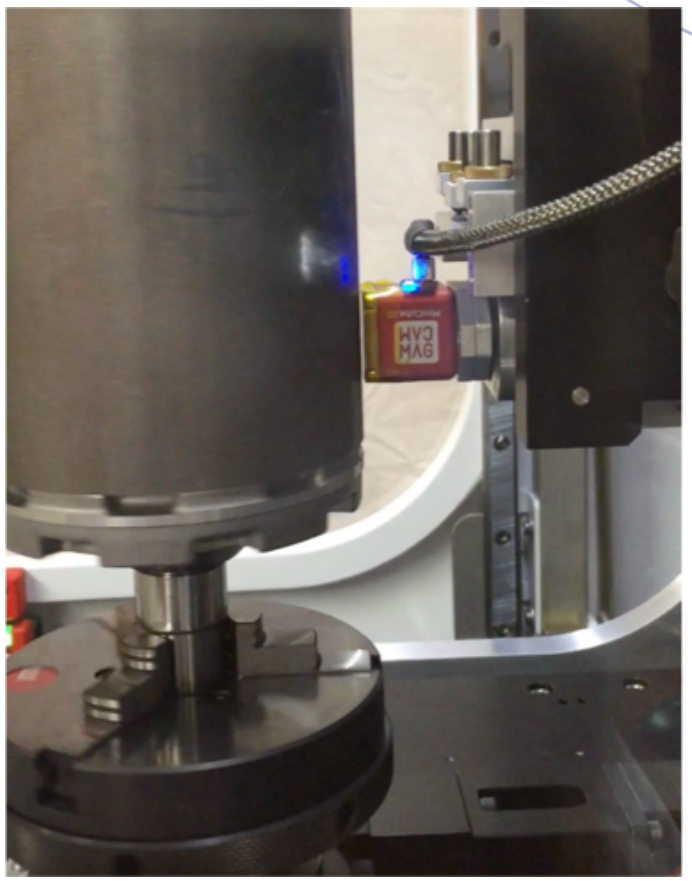
Hall field mappers:
(from Magnetics 2007 presentation)

- Need:
  - 3-Axis Hall sensor or array
  - Positioning jig
  - Temperature control
  - Calibration
- Get:
  - 3 components of **B**
  - Point-sampled
  - Low to medium precision

Metrolab
Magnetic precision has a name

Hall field mappers today: Turn-key solutions

Senis MMS-1A-RS
(www.senis.ch)



Magcam Combi Scanner
(www.magcam.com)

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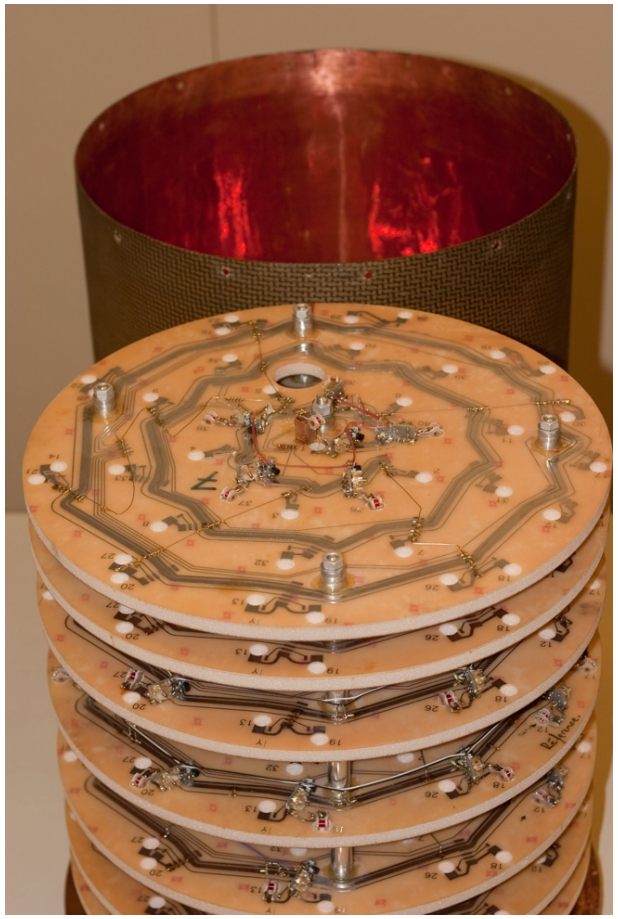
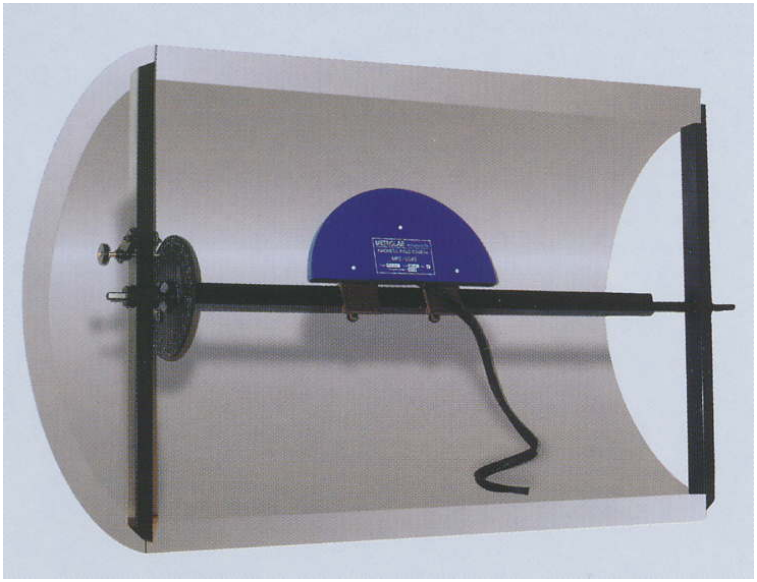
Oldest turn-key field mapping system: Metrolab NMR Magnetic Field Camera

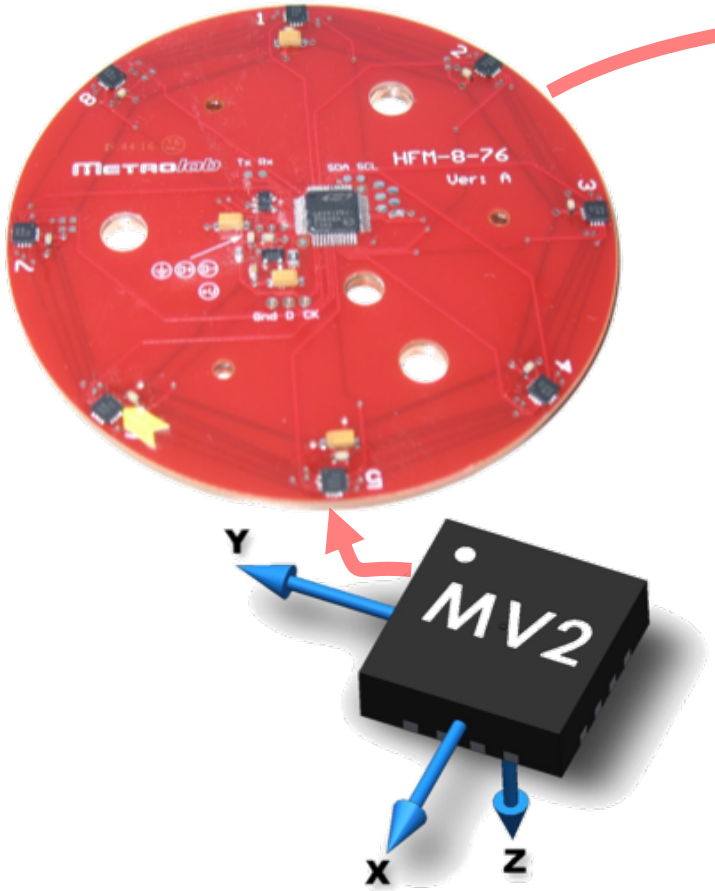


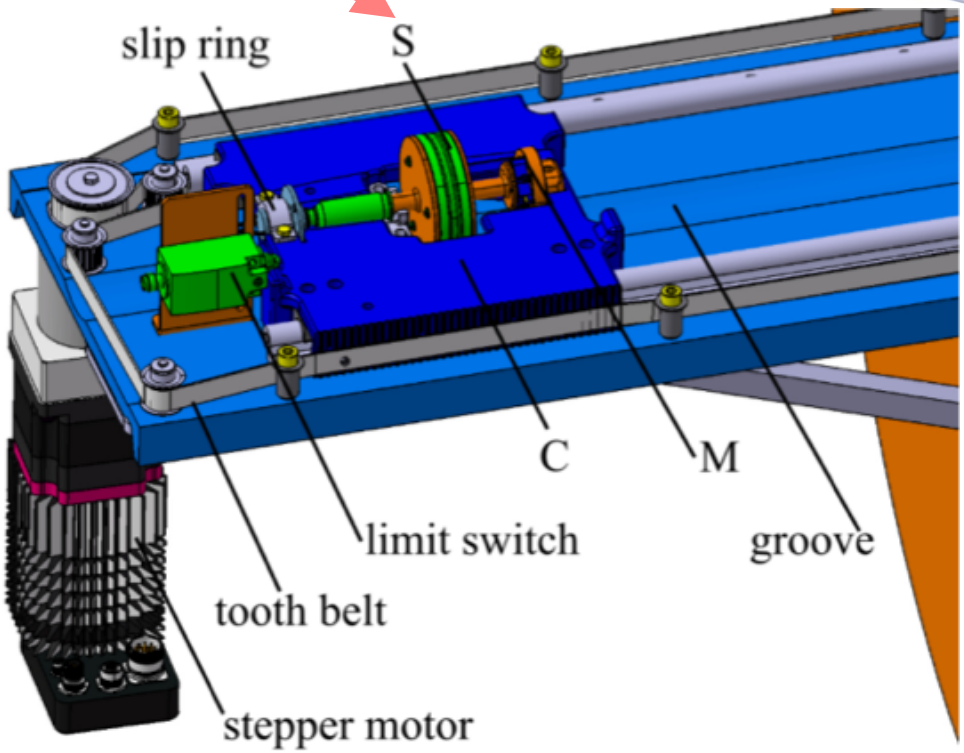


1992

Today

Another example:
Metrolab Hall Magnetic Camera
(Magnetics 2017 presentation)





Sensor disc – Metrolab

Field mapper – FZ Jülich

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Barriers to entry

- Cost (~ 50 - 100 k$)
- Up-front choices:
  (c.f. Magnetics 2007)
  - Use: R&D, production, field service?
  - Measurement: field components, total field, integral, gradient?
  - Field: strength, uniformity, AC/DC, stability?
  - Precision: 10% or 10 ppm?
  - Environment: vacuum, cryogenic?
  - Positioning: access, range, precision, reproducibility?
  - Speed: cost, external error sources, human error?
  - …

Goal: reduce barriers to entry

- Iterative design:
  - Start small
  - Explore
  - Test
  - Validate
  - Demonstrate
  - Grow
- Low cost of entry

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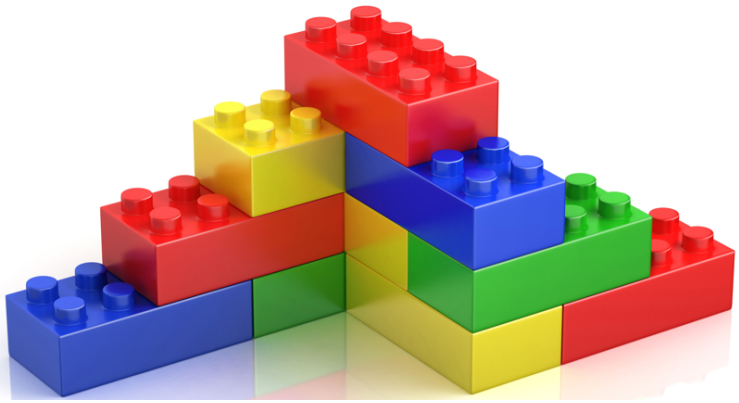
Concept: modular field mapper

- Magnetic field measurement: network of small, independent, flexible, low-cost sensor modules
- Mechanical positioning: easily reconfigurable, expandable, little mechanical expertise



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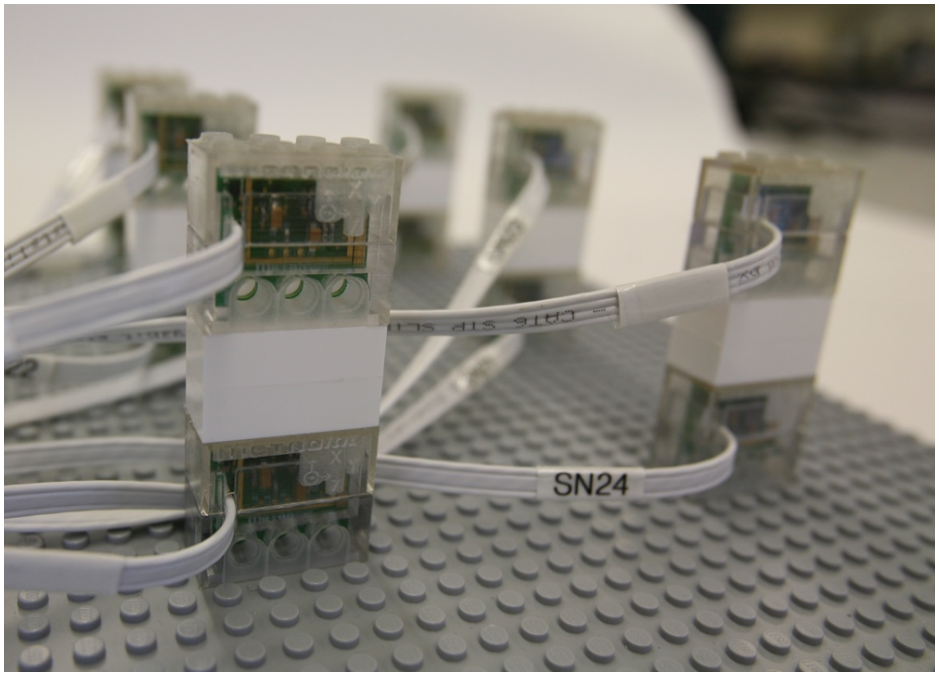
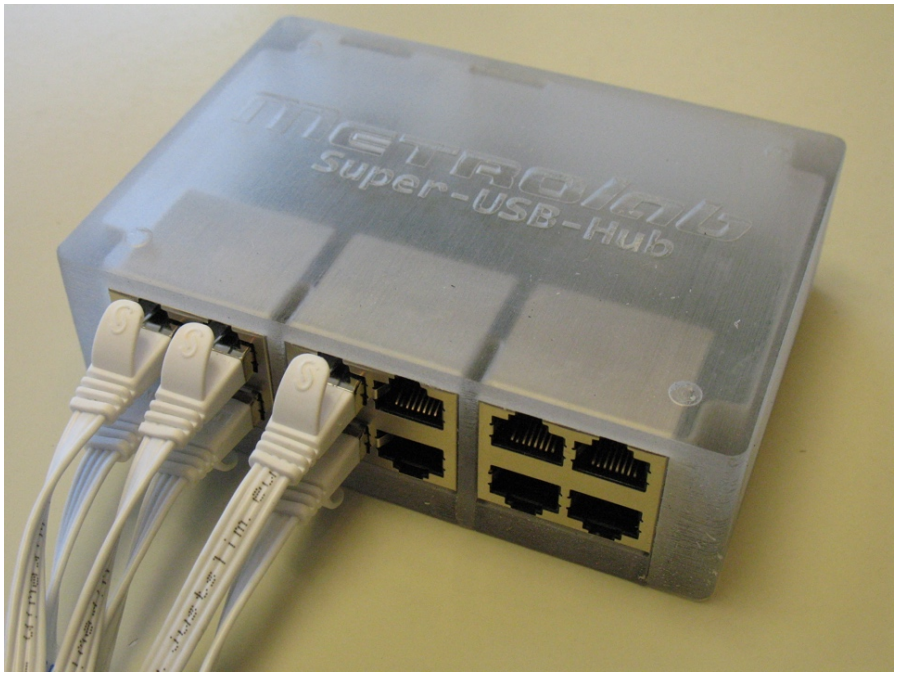
Realization: MV2Lego™





Bricks
(standard 2x4 studs top/bottom,
3 lateral holes for Technics axles)

“Super-Hub”
(synchronization,
non-magnetic connectors)

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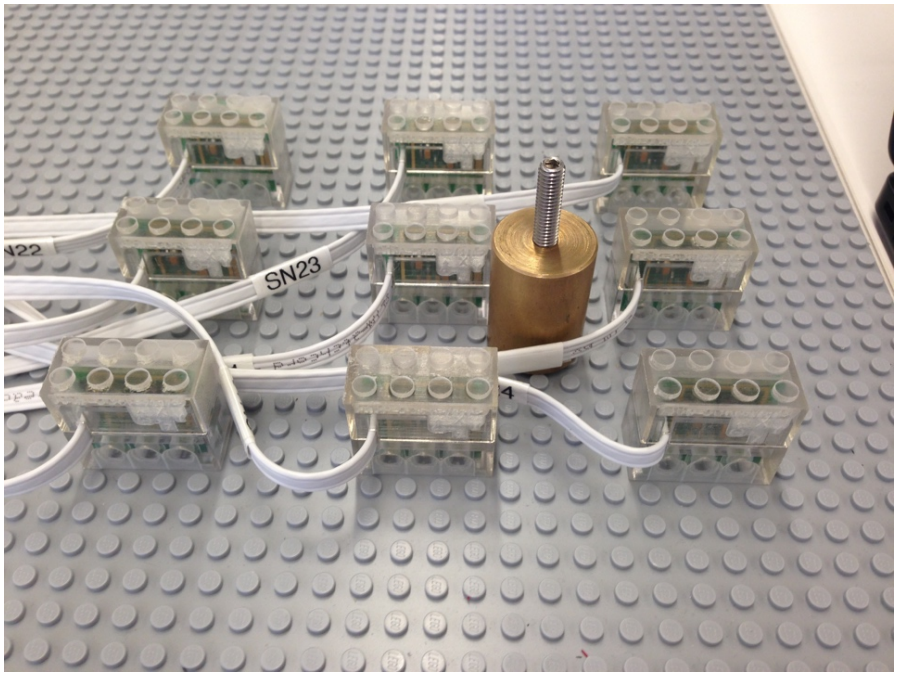
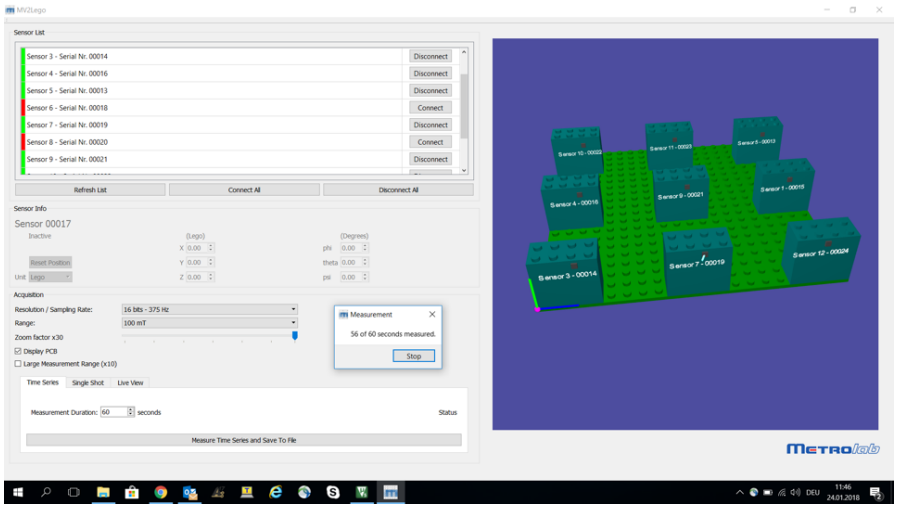
MV2Lego™: Demo





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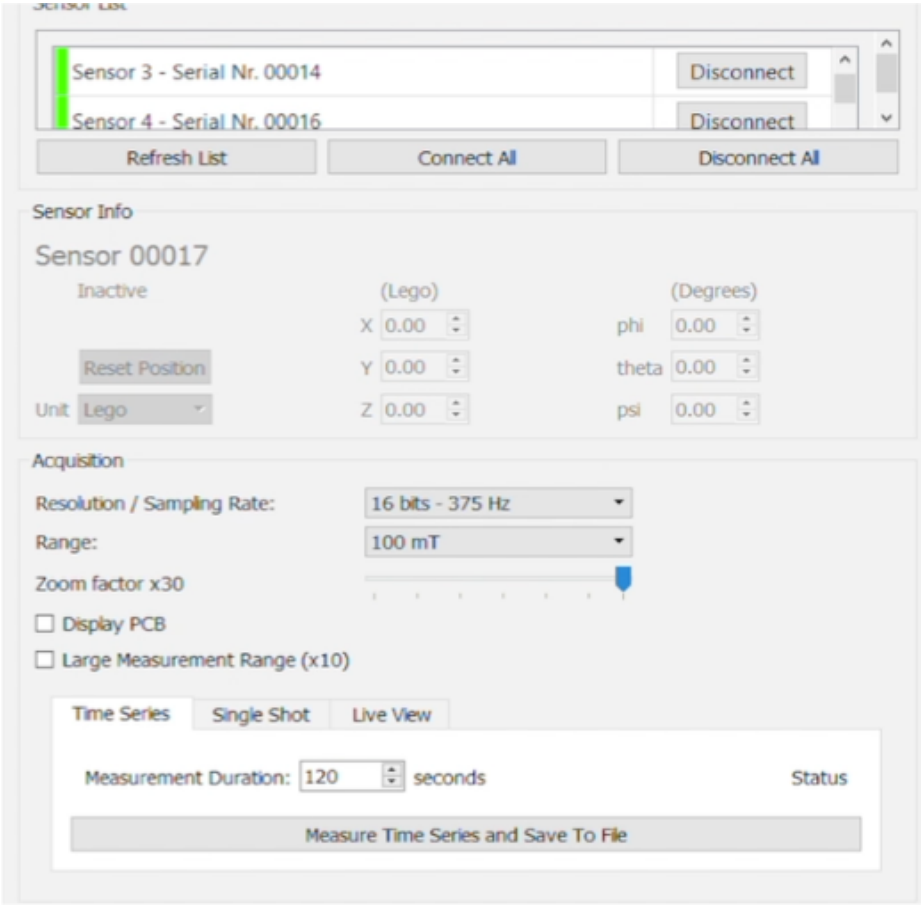
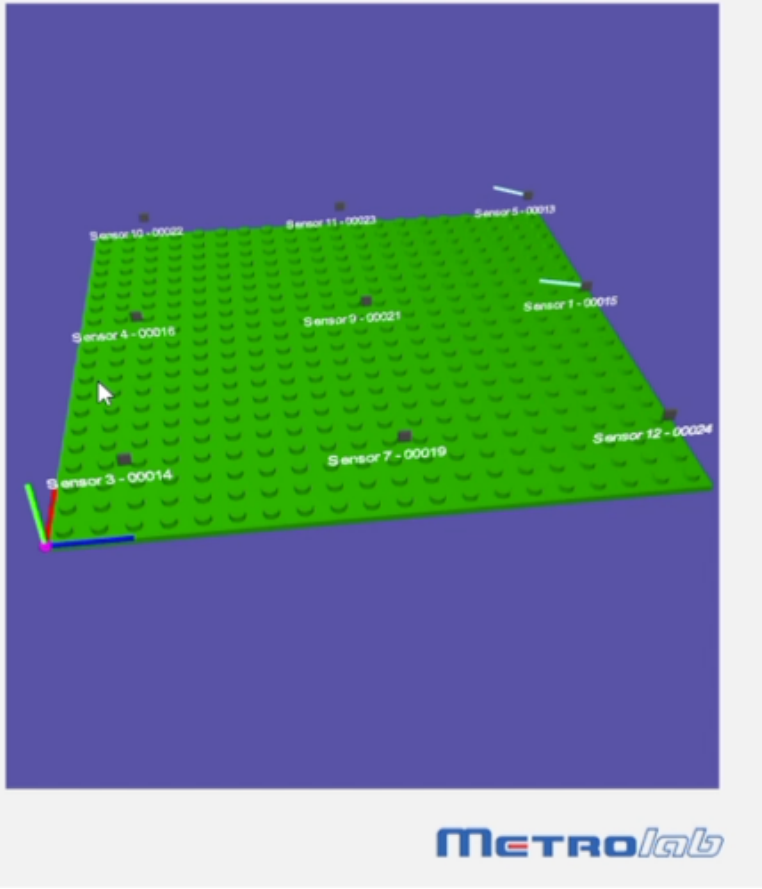
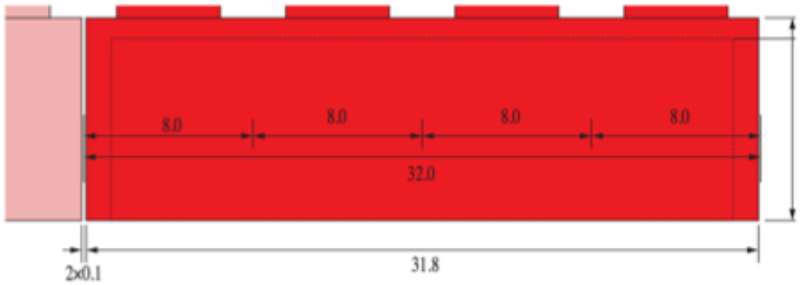
MV2Lego™ Software in Action

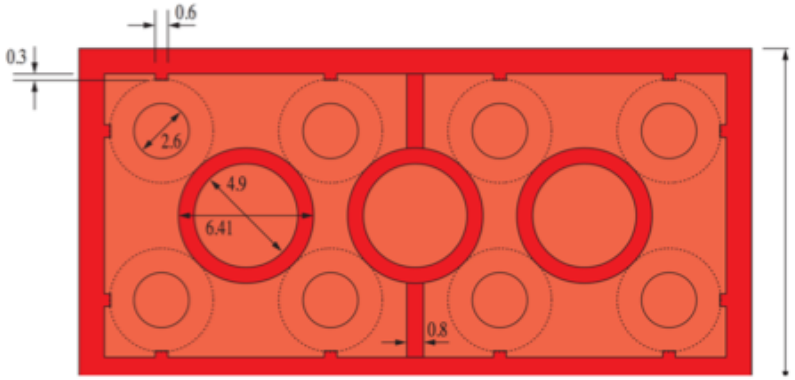




Why LEGO?

- Modularity
- Variety of elements (including Technic and Mindstorms)
- Availability
- Familiarity
- Cost
- Mechanical precision





https://www.cailliau.org/Alphabetical/L/Lego/Dimensions/General%20Considerations/

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LEGO gallery

Technic

Mindstorms

A devotee and his project

https://www.youtube.com/watch?v=gsPTgKrJX8A

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My personal favorite:
World-champion Rubik's Cube Solver

https://www.youtube.com/watch?v=staapsj3eRQ

Why not wireless?

- Complexity, size, cost: antenna, comm. chip, battery, charging system, firmware, more powerful µ-processor, …
- RF interference (e.g. MRI scanners)
- Ferromagnetic material in components

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MV2Lego™: key figures

- Magnetometry:
  - **Calibrated**
  - Measurement ranges:
    0.1, 0.3, 1, 3, 10, 30 T
  - Resolution:
    14, 15, 16, 16+ bits
  - Sample rate:
    ≤ 3 kHz
  - Active volume:
    200x200x10 µm
  - Triggered acquisition
- Modularity:
  - Magnetometry:
    - Up to 12 modules
    - Synchronized trigger
  - Mechanical:
    - Equivalent to 3 2x4 bricks
    - 3 Technic axle holes
- Size:
  32 x 16 x 29 mm
- Cost:
  - ??? ~ 5 k$ per unit
- Schedule:
  - ??? End of 2018

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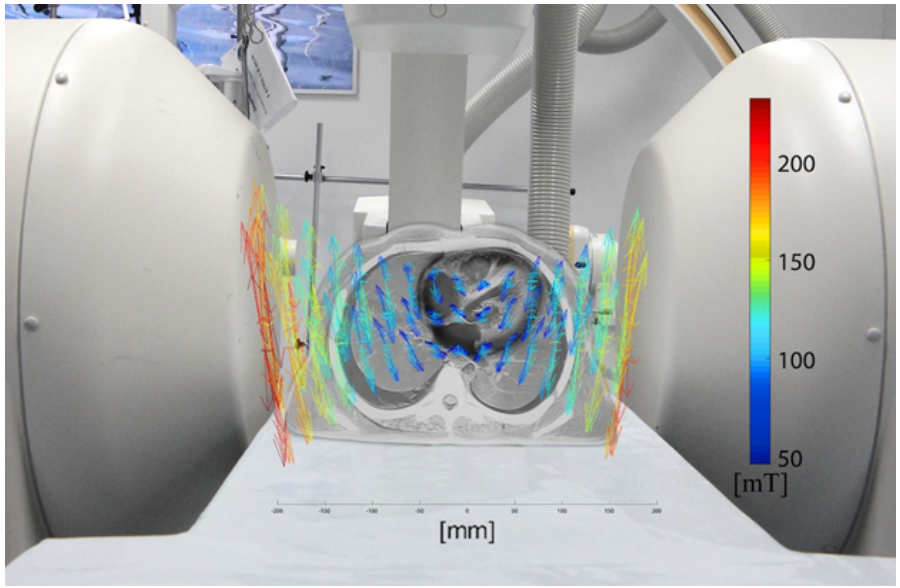
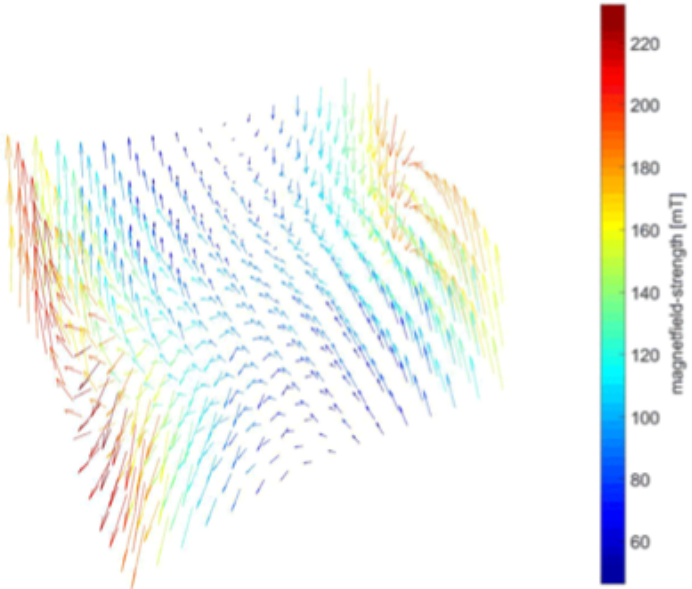
Early results: mapping of remote magnetic navigation system





J. Pascal, F. Yeung – FHNW-HLS-IMA

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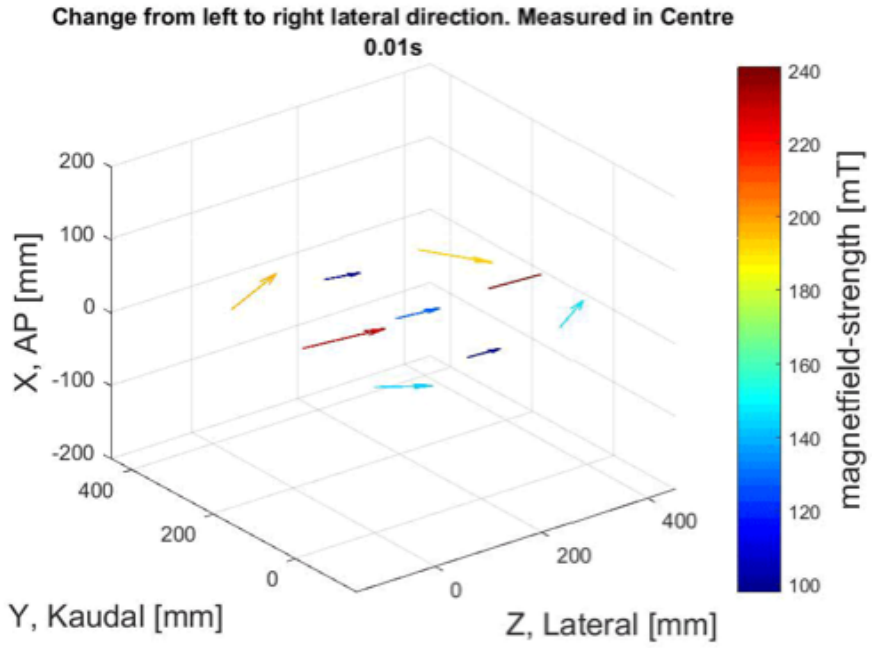
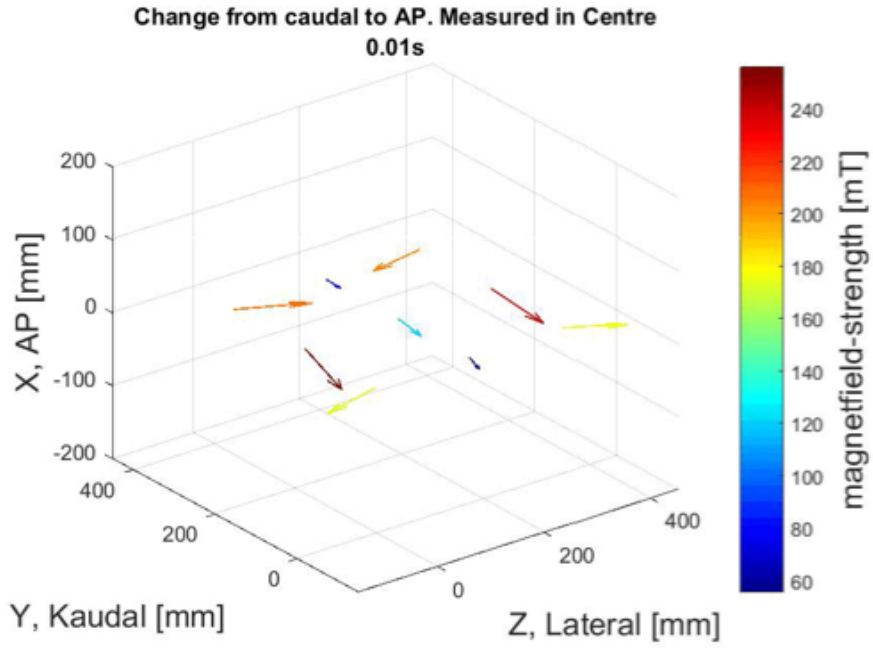
Early results: mapping of remote magnetic navigation system





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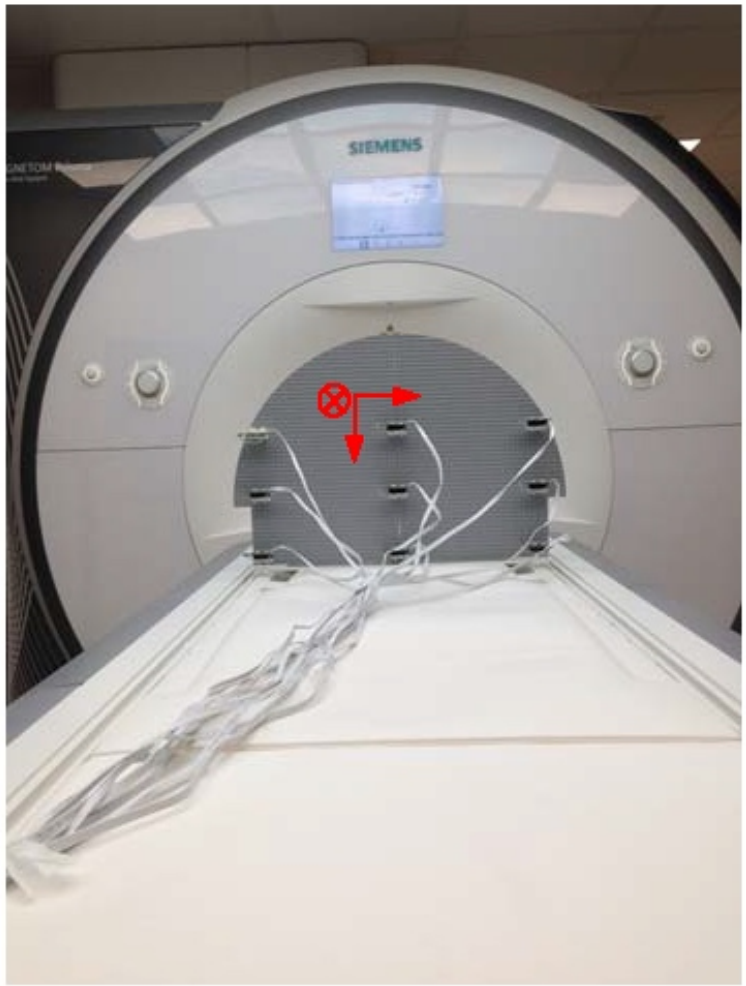
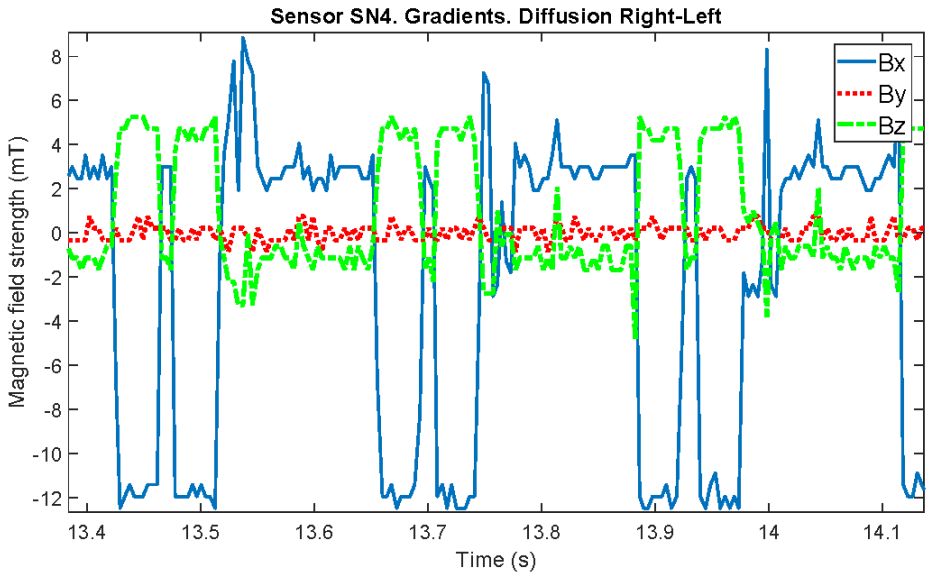
Early results: Same sensors reconfigured to measure MRI gradients





J. Pascal, N. Weber, J. Felblinger, J. Oster, “Magnetic gradient mapping of a 3T MRI scanner using a modular array of novel three-axis Hall sensors” (paper submitted to ISMRM 2018)

Conclusions

- Flexible, expandable magnetic field mapping system
- DC as well as AC fields
- Not a universal solution: constraints of mechanics, magnetometers
- Can be used with non-LEGO positioning systems
- Low cost of entry
- Cost of maximal system similar to existing mapping systems