

Building Your Magnetic Field Mapper with LEGO®

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UKMagSoc: Magnetic Measurement and Sensors

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Hall field mappers in 2007: Custom-built only

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

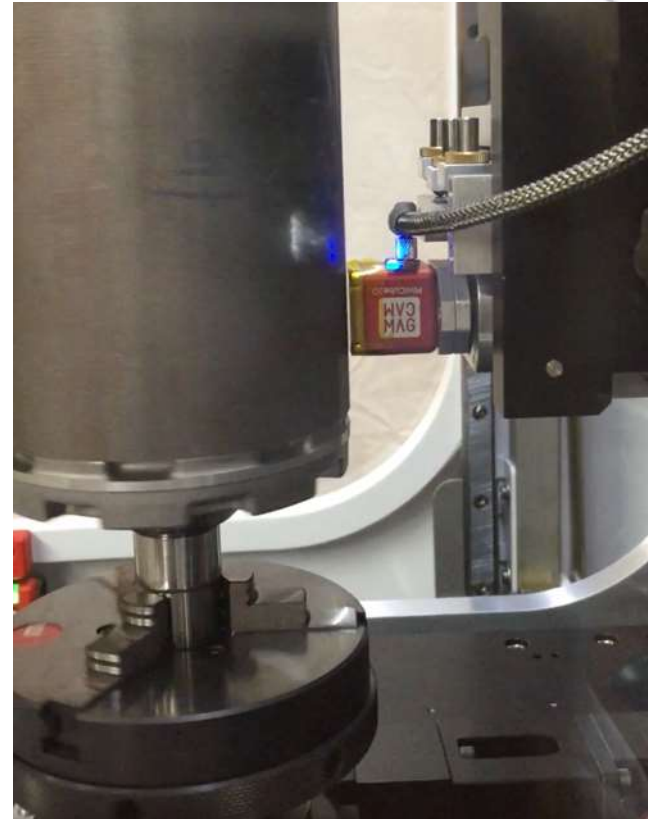


*From “Technologies for Precision Magnetic Field Mapping,”
presented at 2007 Magnetics Conference, Chicago, IL, USA*

Hall field mappers today: Choice of turn-key solutions



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



Magcam Combi Scanner
(www.magcam.com)

World's first turn-key field mapper: Metrolab NMR Magnetic Field Camera



1992



Today

Metrolab's Hall Magnetometers: Single-point, but compact & 3-axis



1995



Today

3-Axis Hall Magnetometers (a brief digression...)

- Advantages:
 - All vector components
 - Any probe orientation
- Challenges:
 - Orthogonality
 - Active volume size
 - Planar Hall Effect
 - Cost



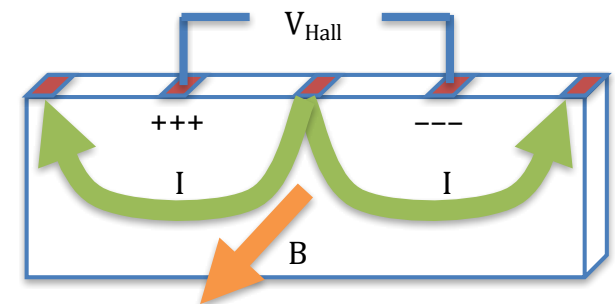
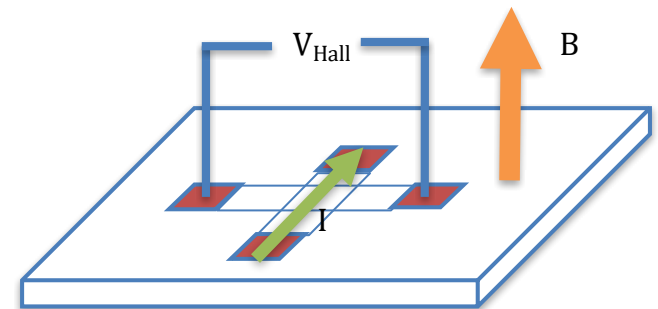
Credits:

- LakeShore Cryotronics (Model 460)
- Magnetic Sciences Inc. (F.W. Bell 8030)

3-Axis Hall Magnetometers

First revolution: integration

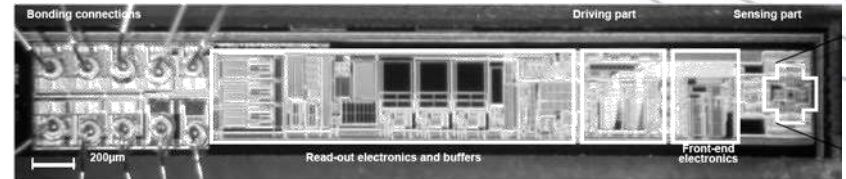
- Vertical Hall sensor
 - Integrated 3-axis sensors
- Advantages:
 - Simplified construction
 - ~100 μm active volume
- Limitations:
 - Si: lower sensitivity, higher noise



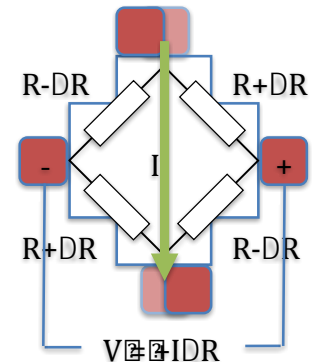
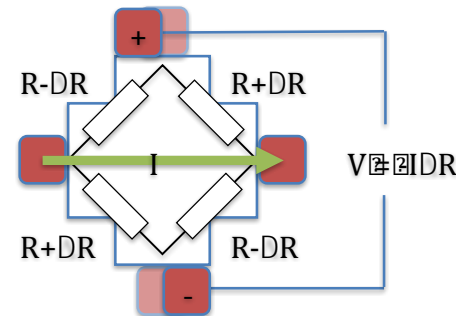
3-Axis Hall Magnetometers

First revolution: more advantages

- Integrated current source and amplifier
- Integrated temperature sensor
- “Spinning current” to minimize offset, Planar Hall Effect, and noise



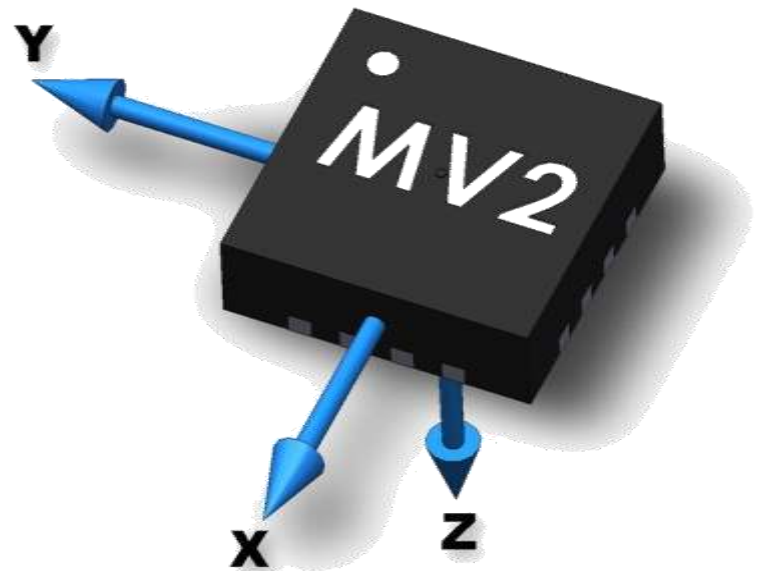
Credit: presentation by D. Popovic (Senis) at IMM-14



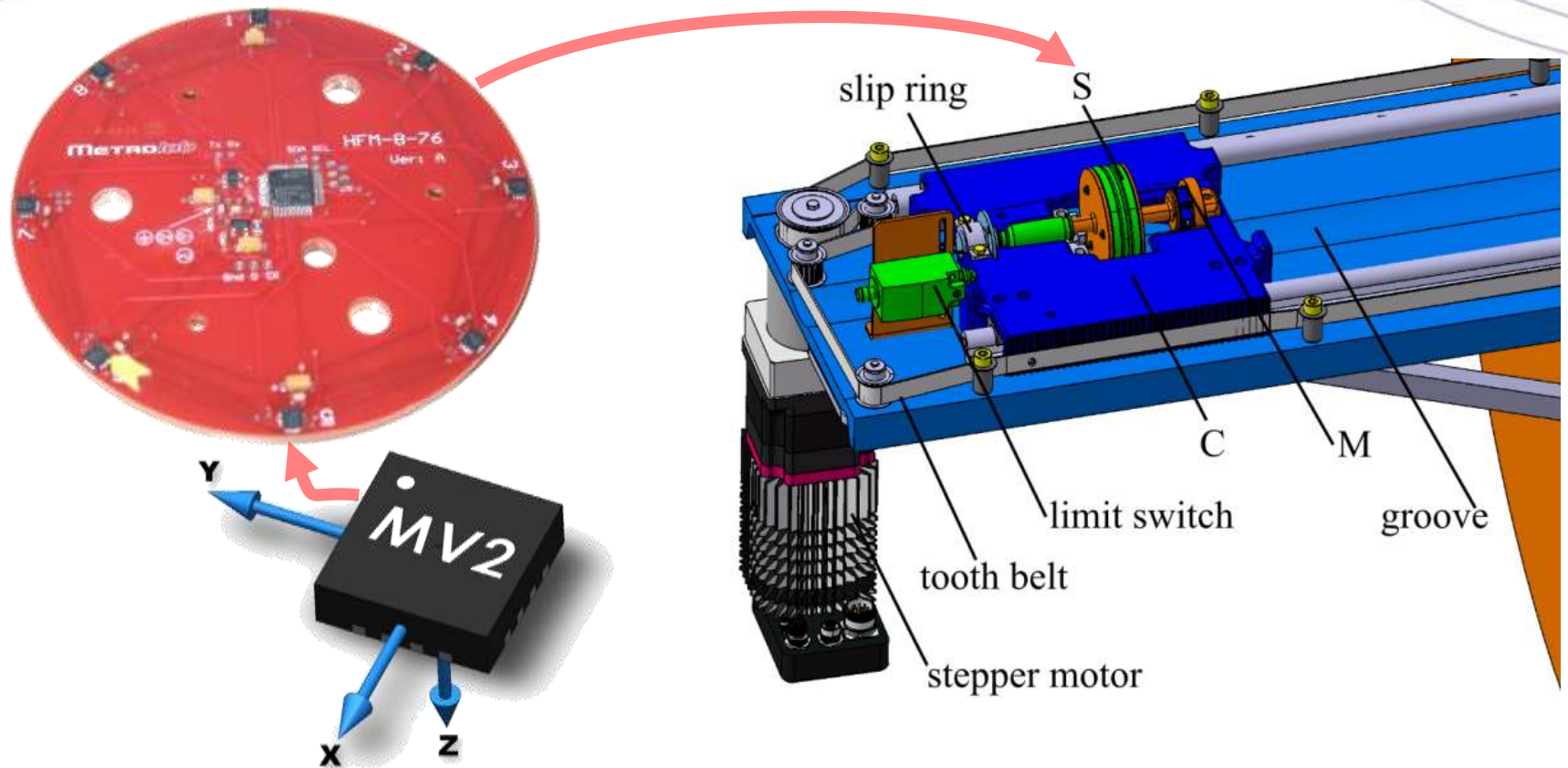
3-Axis Hall Magnetometers

Second revolution: digitalization

- Integrated ADC
 - Digital interface
- Advantages:
 - Minimize system complexity & cost
 - Minimize errors from inductive voltages
 - Additional controls
 - **Sensor arrays feasible**
- Limitations:
 - ADC performance



Metrolab's first Hall field mapper: Hall Magnetic Camera HMC9076



Sensor disc – Metrolab

Field mapper – FZ Jülich

Hall Magnetic Camera HMC9076

Advantages:

- 3-axis sensors
- Temp. stabilization (10^{-4} accuracy)
- Parallelism for speed
- Simplicity: USB only
- Optimized positions
- Standardized design

Limitations:

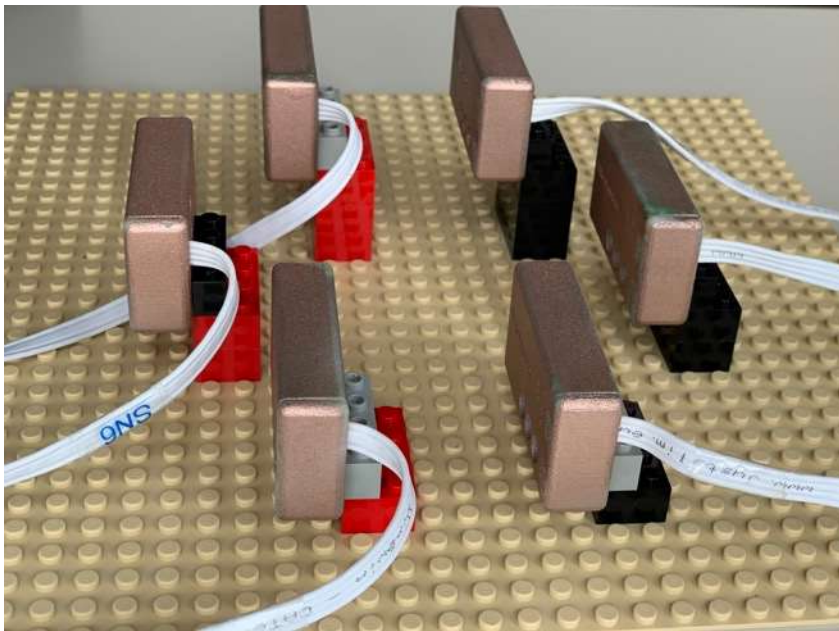
- Customized layout
- Too large to calibrate in normal magnet (calibrated by customer at CERN)

Concept: modular field mapper

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



First prototype: “MV2Lego”



Bricks

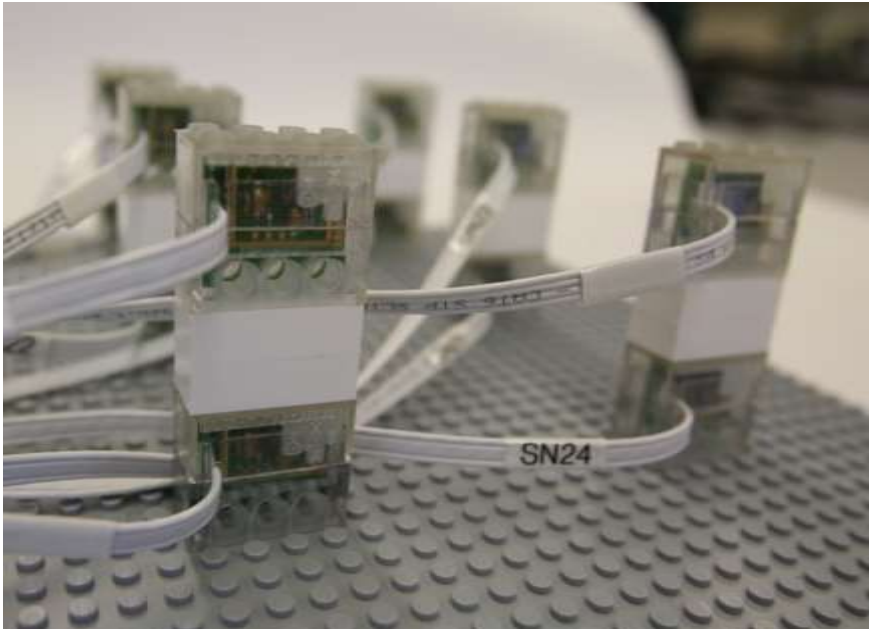
(USB power, control & communication,
5 holes for Technics axles)



USB “Super-Hub”

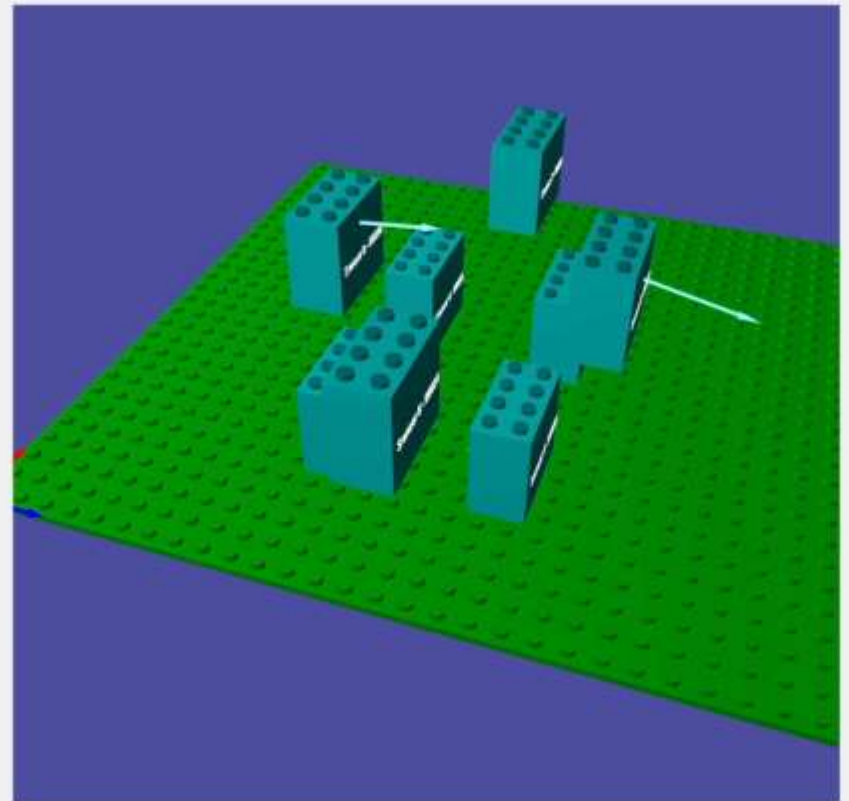
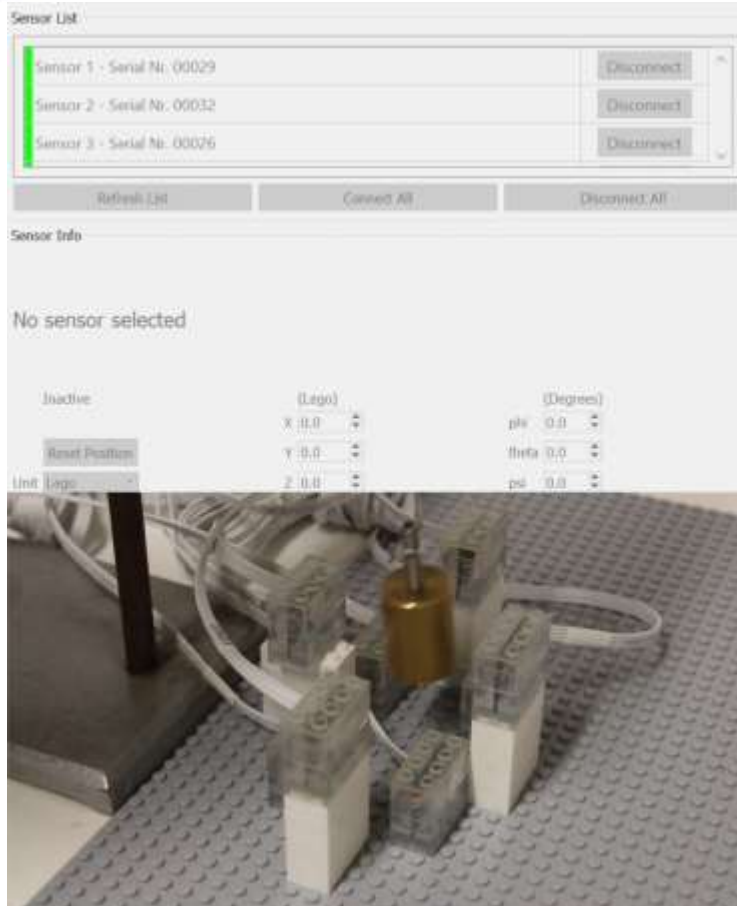
(synchronization,
non-magnetic connectors)

“MV2Lego” version 2

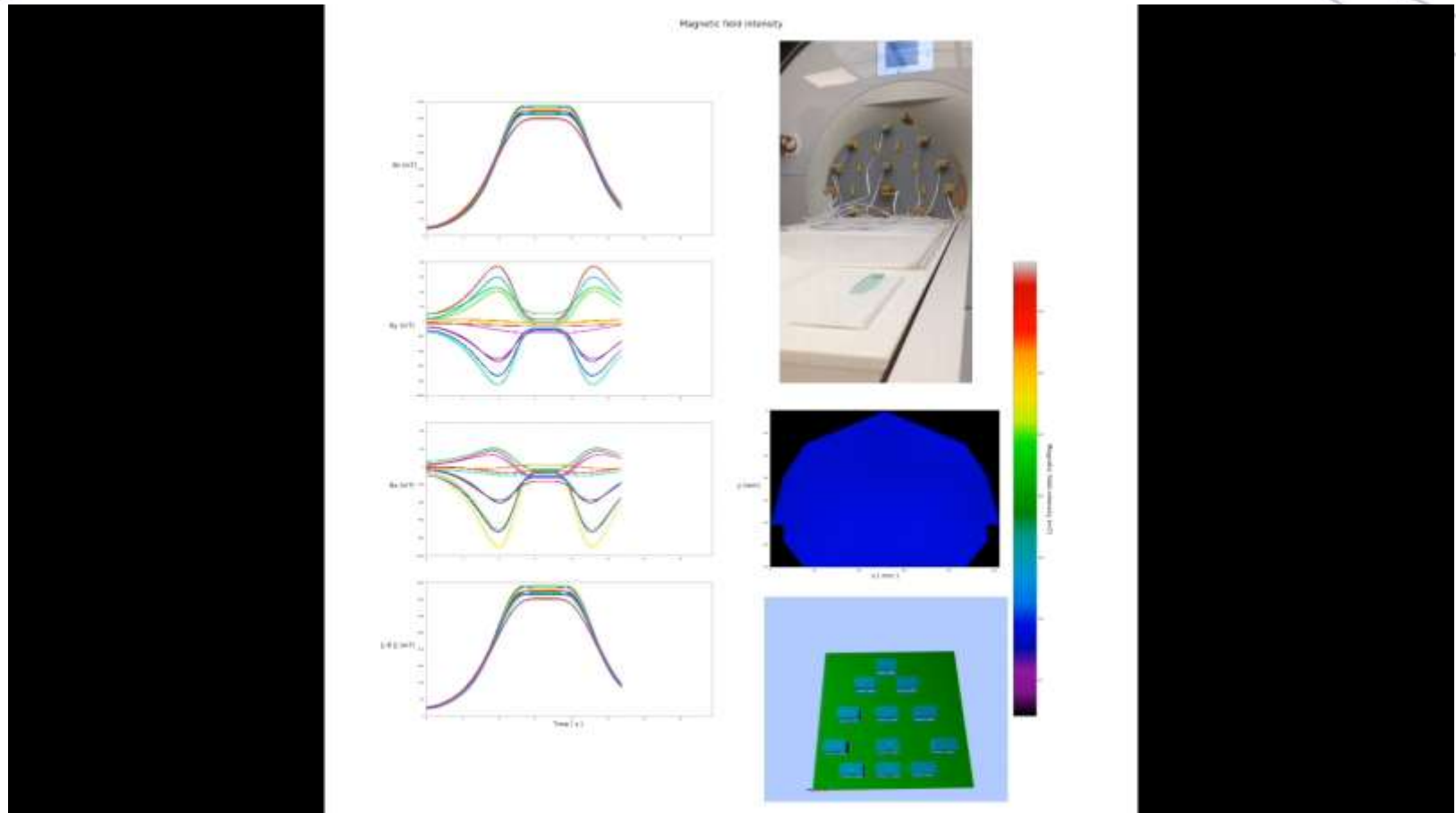


- Smaller: equivalent to stack of 3 2x4 bricks
- Standard 2x4 studs top/bottom
- 3 lateral holes for Technics axles
- Can remove LEGO housing
- Improved software

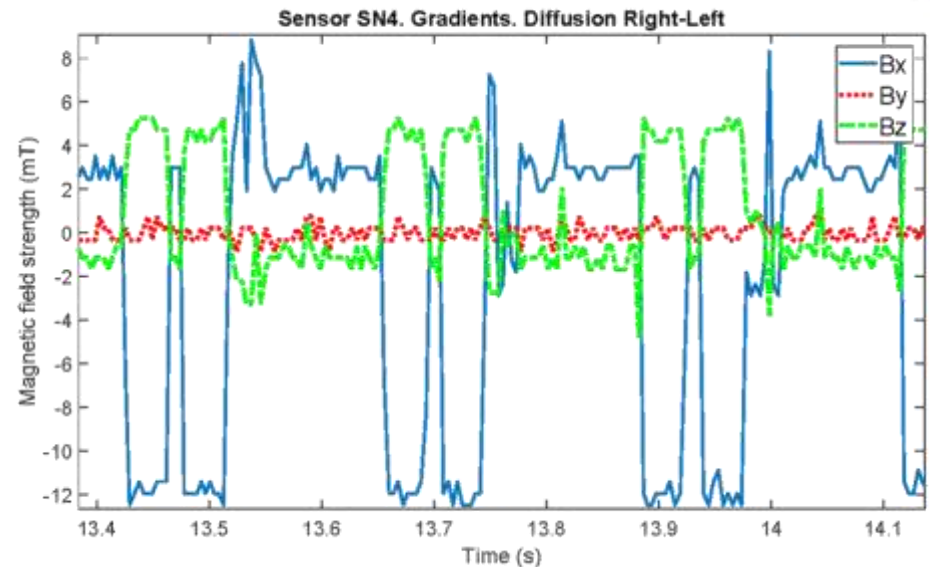
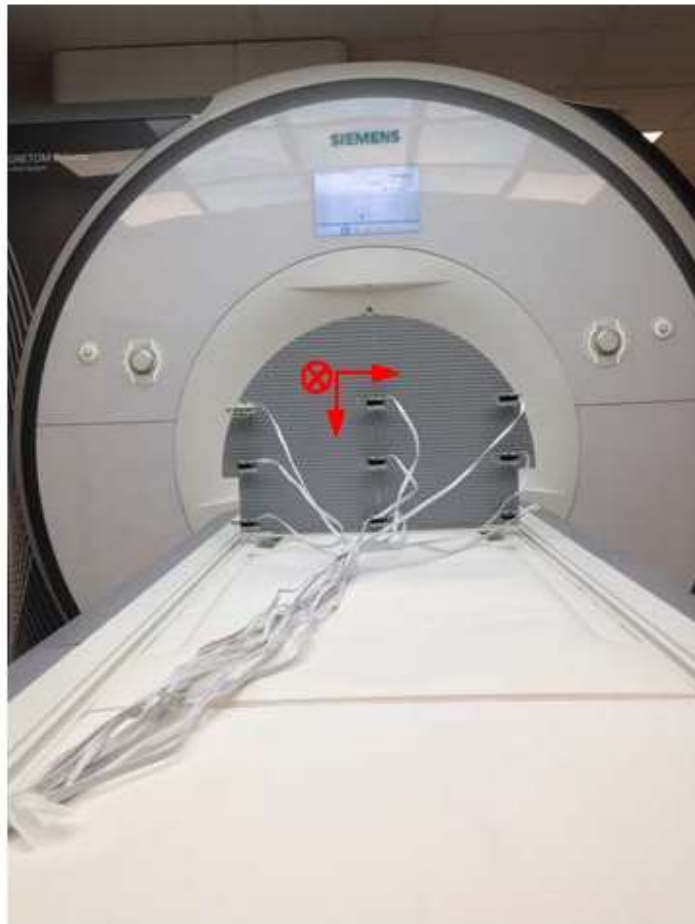
MV2Lego Software in Action



Early results: Longitudinal map of MRI magnet



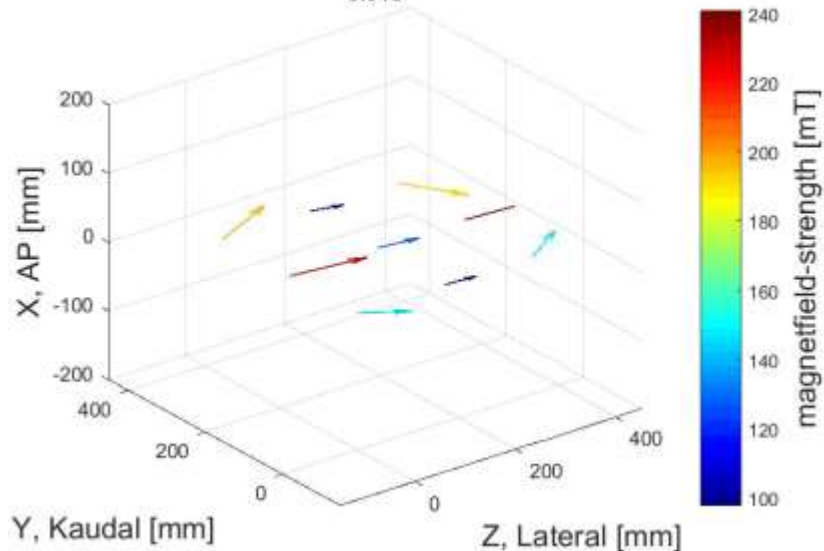
Early results: Measure MRI gradients



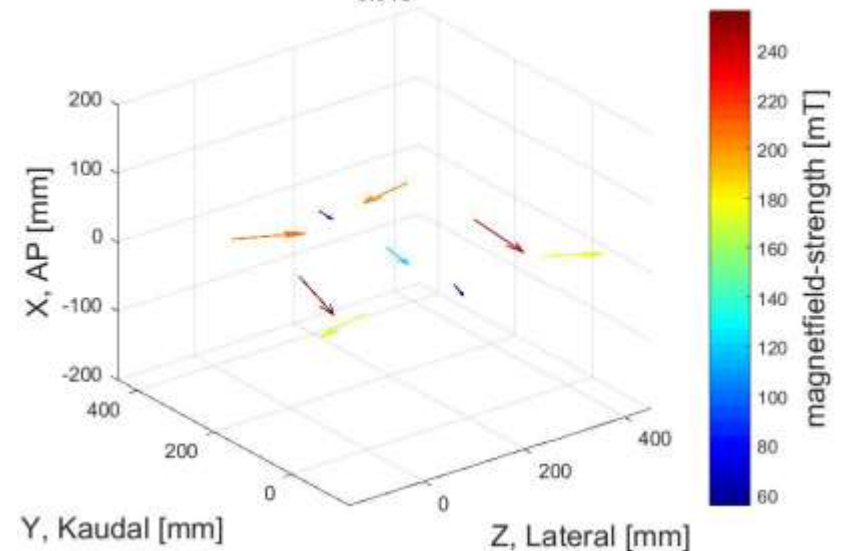
J. Pascal, N. Weber, J. Felblinger, J. Oster, "Magnetic gradient mapping of a 3T MRI scanner using a modular array of novel three-axis Hall sensors" (paper submitted to ISMRM 2018)

Early results: Map remote magnetic navigation system

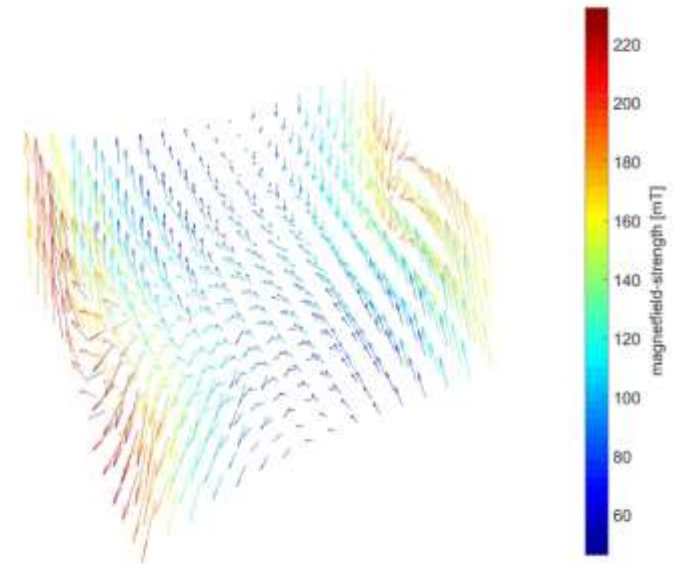
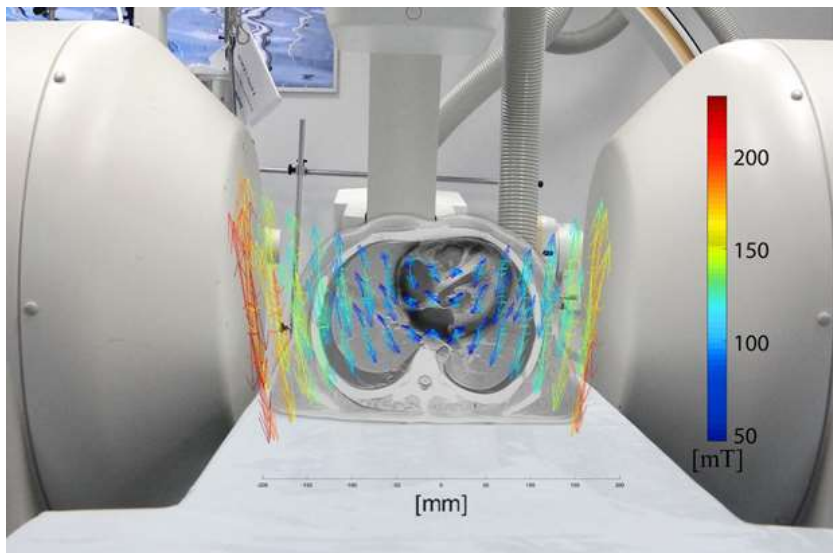
Change from left to right lateral direction. Measured in Centre
0.01s



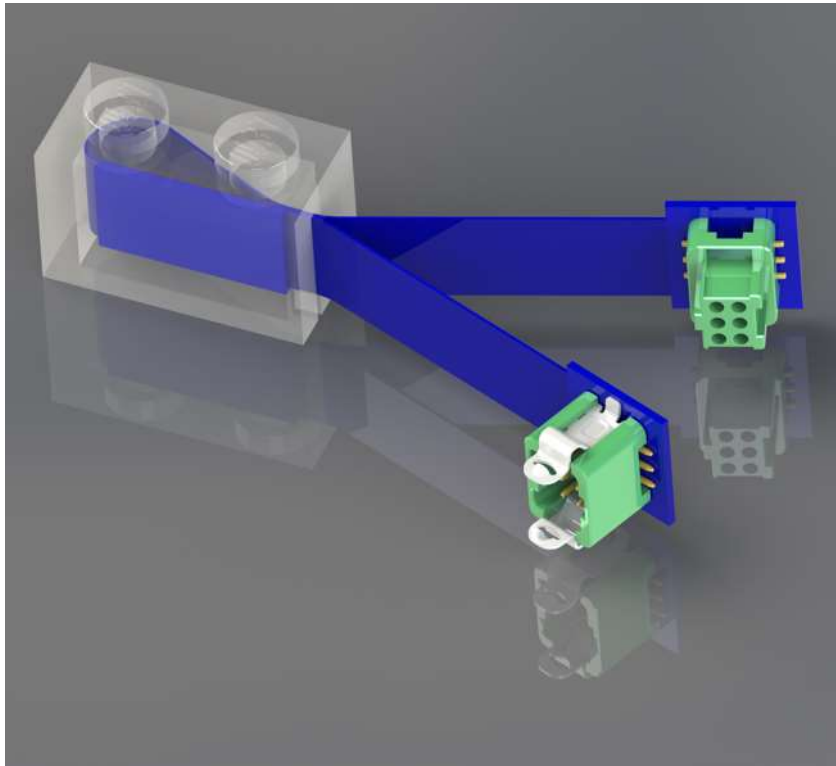
Change from caudal to AP. Measured in Centre
0.01s



Early results: Map remote magnetic navigation system



Industrialization



- Smaller yet:
higher point density
- Daisy-chained:
less cabling
- Real LEGO bricks:
quality, rights
- Part of THM line:
Compatibility

Key figures

■ Magnetometer:

- Measurement ranges:
0.1, 0.3, 1, 3, 10, 30 T
- Resolution:
14, 15, 16, 16+ bits
- Sample rate:
up to 3 kHz
- Active volume:
200x200x10 μm
- Triggered acquisition
- **Calibrated**

■ Modularity:

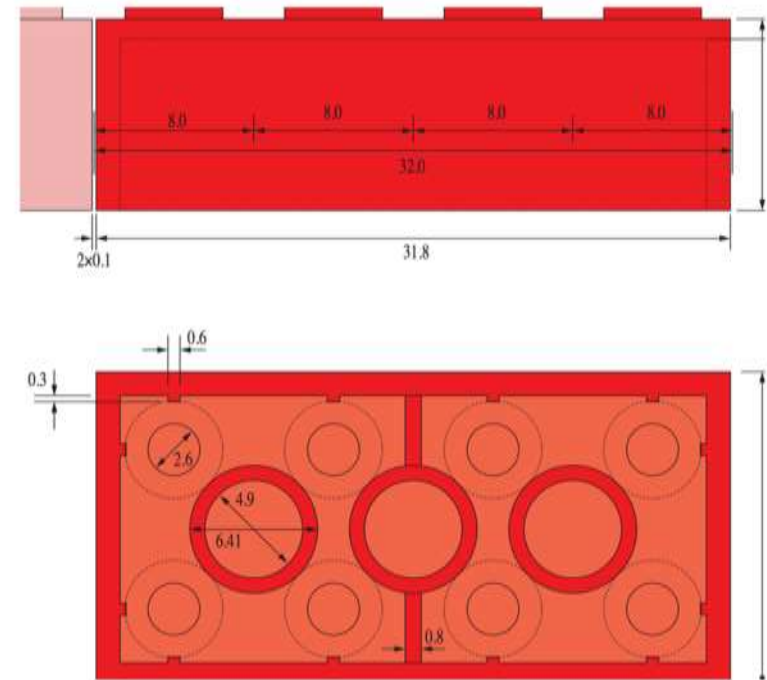
- 1x2 LEGO brick
- Daisy-chains to ~5 m
- Synchronized trigger

■ Contents:

- Control unit
- Bricks
- Extension cables
- Software
- C++ interface library

Why LEGO?

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



LEGO gallery



Technic



Mindstorms



A devotee
and his
project

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

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



Why not wireless?

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



Magnetic field mapping systems: reducing barriers to entry

- Low cost of entry
- Expandability
- Reconfigurability
- Large magnet systems
- Standard calibration
- Optimal sensor placement
- True 3-axis
- DC as well as AC fields

