A Framework for Developing Modular Mobility Aids for People with Visual Impairment: An Indoor Navigation Use Case

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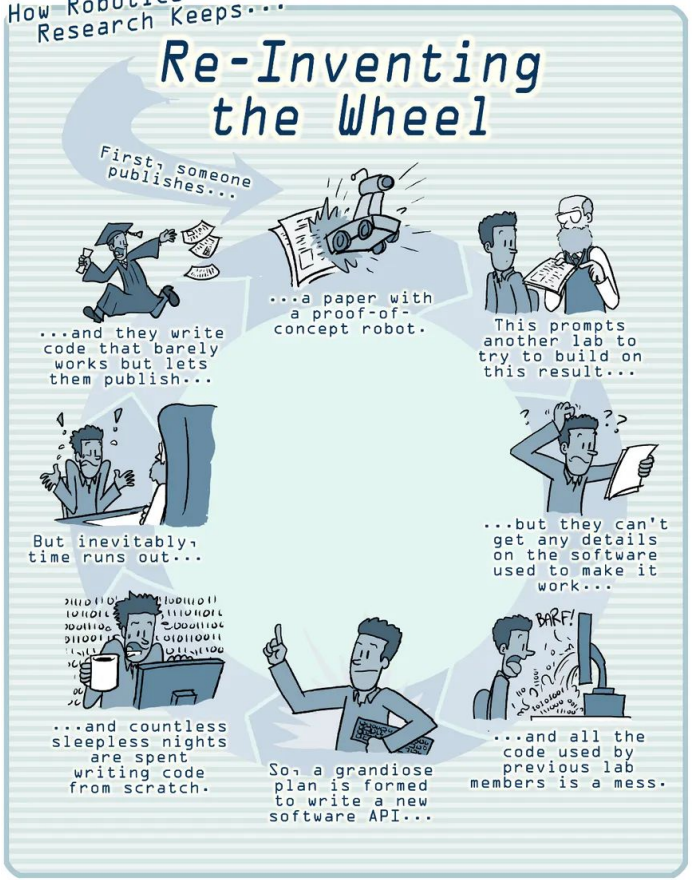
Problem Statement

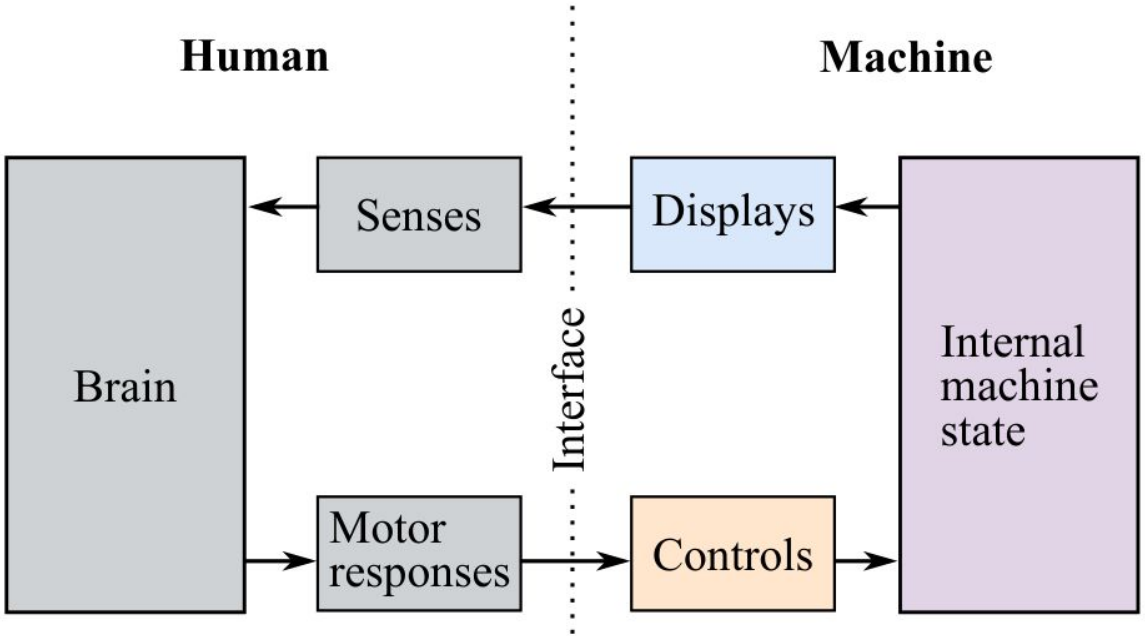
- 2007: Problematic pattern in robotics research discovered
- Wheel gets reinvented again and again
- Robotics solution: Robot Operating System (ROS) as common set of tools and software
- Similar problem pattern in active ETA research
  - Seen in multiple overview and literature review papers
  - Projects are similar with little innovation
  - Same technologies, subsystems and devices used
  - Much time spent on reimplementing work of others
  - No time for iterative improvement, testing, etc.
  - Only few projects result in usable products
- Potential for increasing efficiency
- ETA solution needed!



K. Wyrobek, “The Origin Story of ROS, the Linux of Robotics,” IEEE Spectrum, Oct. 31, 2017. https://spectrum.ieee.org/the-origin-story-of-ros-the-linux-of-robotics (accessed Apr. 15, 2023).

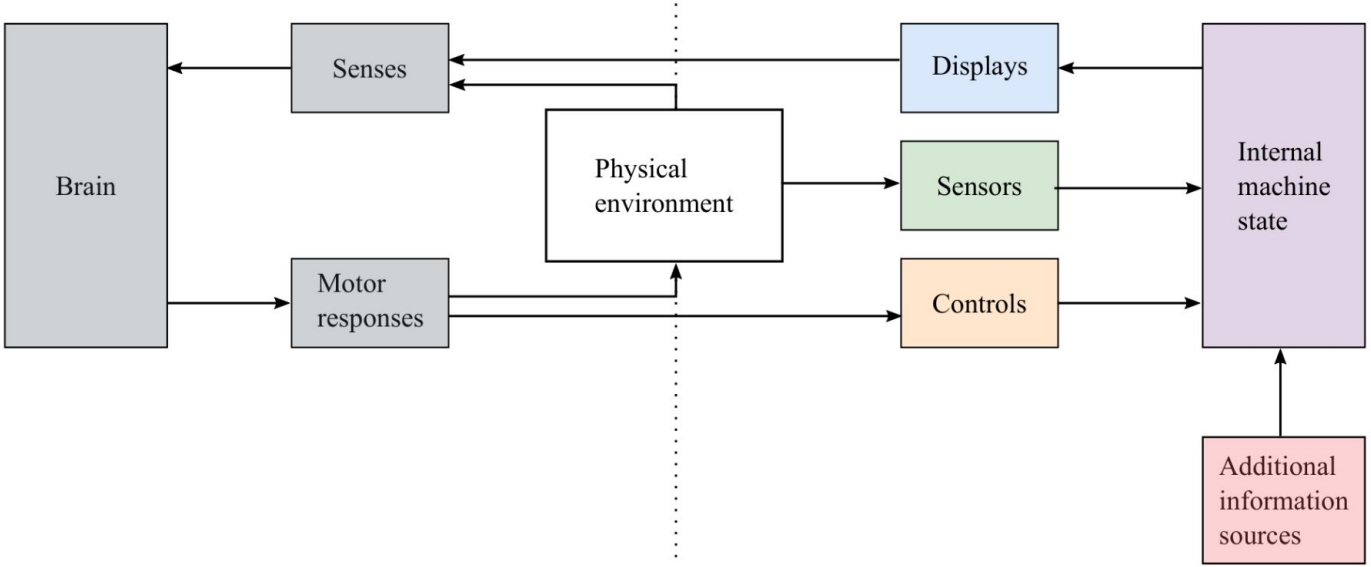
Contents

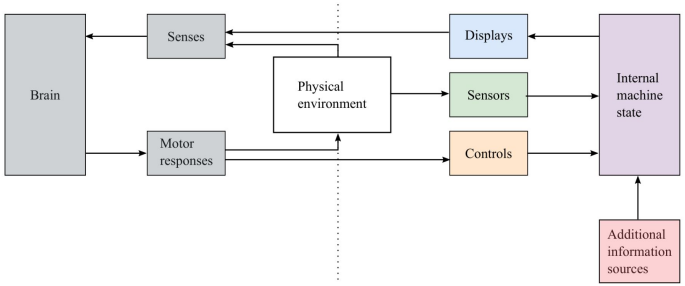
Human-Machine-Interface (HMI) Model (Kantowitz and Sorkin)



B. H. Kantowitz and R. D. Sorkin, Human Factors: Understanding People-System Relationships, 1st edition. New York Chichester Toronto: Wiley, 1991.

HMI Model for ETAs





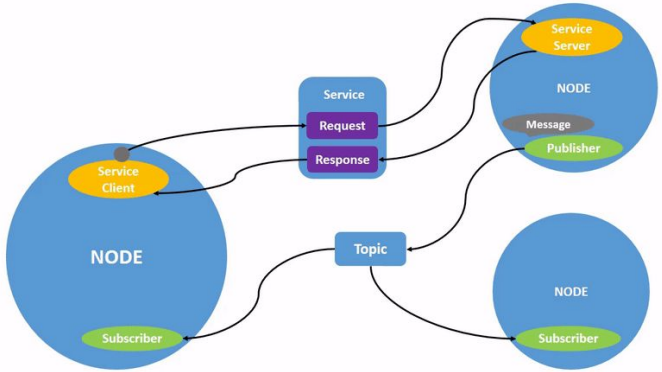
HMI Model for ETAs

- System components linked to the internal machine

  State: *Sensors, Controls, Additional information sources, Displays*
- ETA = composition of concrete components + business logic + interfaces between them
- Advantages of component-based model:
  - **Interchangeability**
  - **Reusability**
- Usage of **simulation environment**
  - Reproducibility and variability of scenarios
  - Mitigation of dangerous scenarios
  - Easy to embed in *HMI Model for ETAs*
  - Components can be tested individually in controlled manner
- Most known research projects on ETAs can be divided in these components
- Standardized, common ecosystem is needed

ROS2 - Robot Operating System

- Set of software libraries and tools for (mobile) robotics
- Open source
- Real-time capable communication protocol
- Platform, domain and vendor independent
- Debugging, visualization and simulation tools
- Architectural components:
  - Nodes
  - Topics
  - Services
  - Parameters
  - Launch files
  - Packages



Open Robotics, ROS2 Documentation: Humble, 2023. https://docs.ros.org/en/humble/Tutorials/Beginner-CLI-Tools/Understanding-ROS2-Nodes/Understanding-ROS2-Nodes.html (accessed Apr. 16, 2023)

- ROS2 system = set of intercommunicating nodes, grouped in packages
- Modular and extensible code, easy to share between projects
- Large and active community, supporting exchange between researchers
- Algorithms and drivers for environmental perception, navigation and orientation

Contents

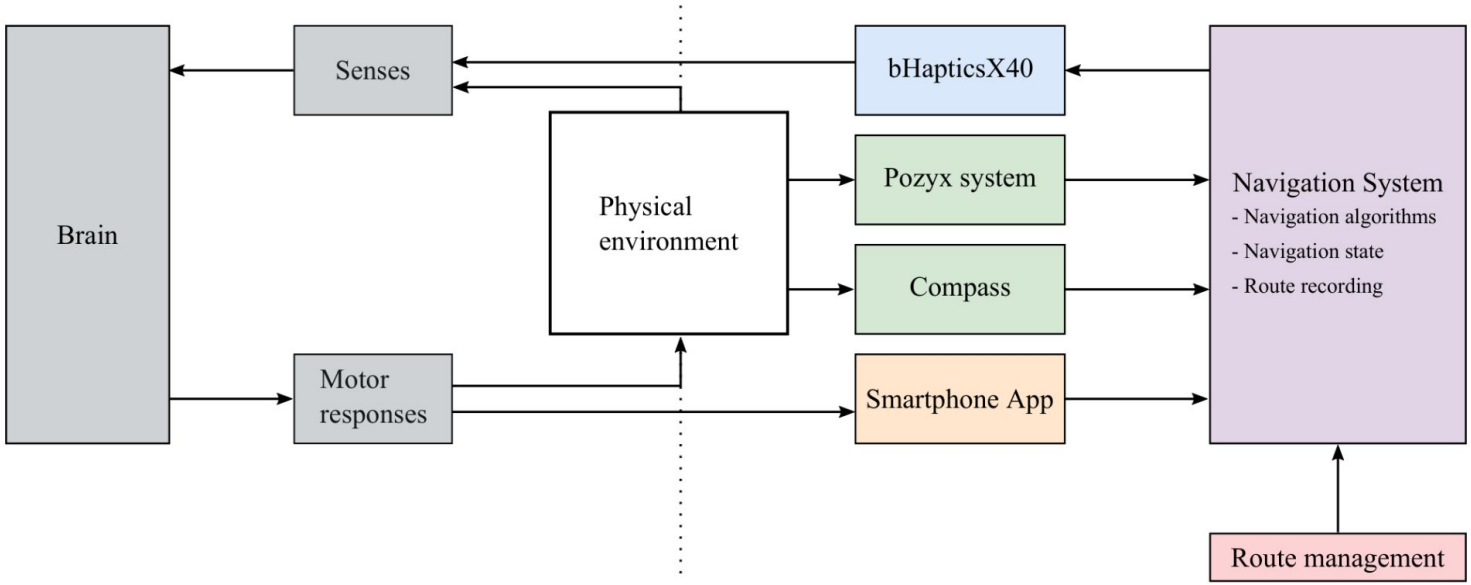
Proof of Concept: Indoor Navigation System

- Goal: show advantages of component-based development with ROS2
- Components:
  - bHapticsX40 vibration vest from bHaptics®
  - Headphones connected to smartphone
  - Ultra-wideband (UWB) real time location system from Pozyx®
  - Smartphone app (controlling system and providing compass)
  - Raspberry Pi 4
- Configure system
- Record new routes
- Navigate along recorded routes
- Alternative feedback options:
  - Haptic feedback: vibration patterns for heading correction
  - Audio feedback: voice instructions for heading correction

https://www.bhaptics.com/shop/tactsuit-x40 (accessed Apr. 16, 2023)

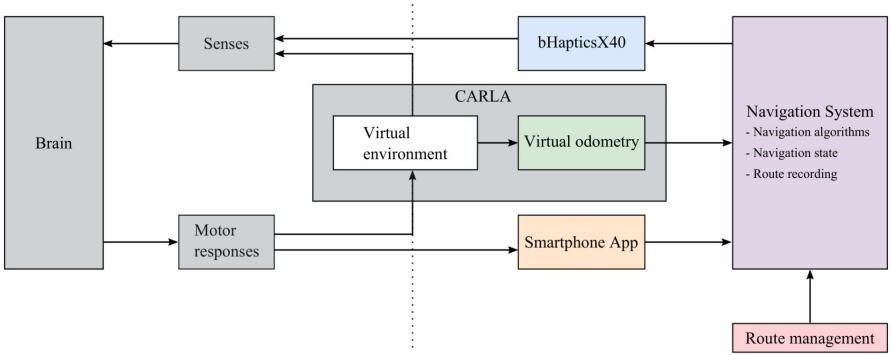
https://www.pozyx.io/creator-one-kit (accessed Apr. 16, 2023)

Proof of Concept: Indoor Navigation System



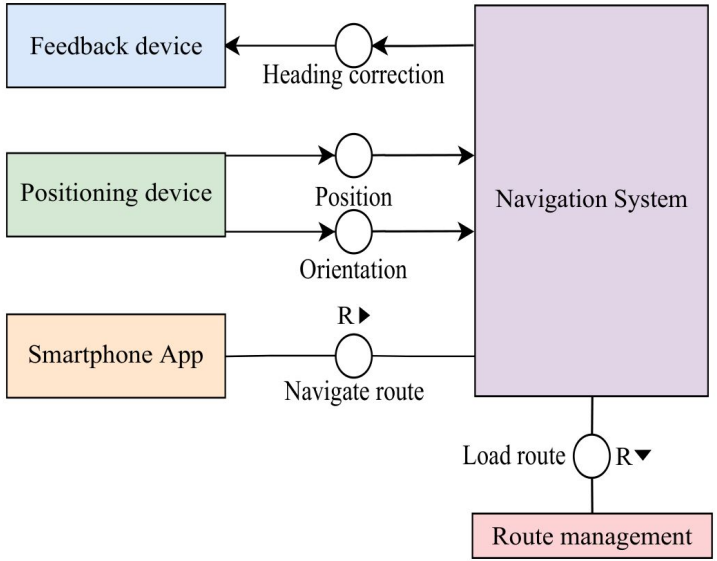
Proof of Concept: Simulation

- Goal: Show practical use of simulation environment for ETA development (specifically with ROS2)
- **CARLA**
  - Open source, known from autonomous driving research
  - Allows customization of environment
  - Virtual sensors (LIDAR, cameras, GPS, etc.)
  - Built-in integration with ROS2
- Used in our indoor navigation system for e.g. testing the display components



Proof of Concept: Architecture

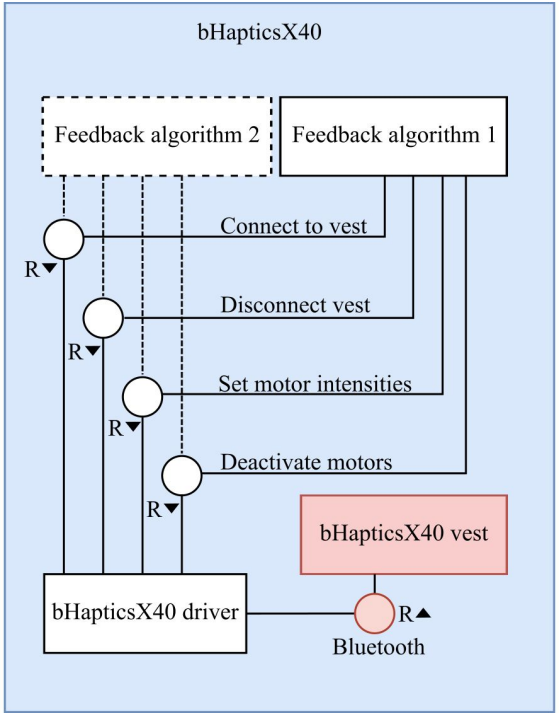
- Navigation logic as example
  - Needs/provides five interfaces to other components:
    - **Navigate route** (ROS2 action)
    - **Position** (ROS2 topic)
    - **Orientation** (ROS2 topic)
    - **Load route** (ROS2 service)
    - **Heading correction** (ROS2 topic)
  - Setup of sensing and user interface devices freely configurable
  - Each component is a set of ROS2 nodes
  - System startup configuration using modular system of ROS2 launch files



Contents

Results and Evaluation

- **Reusability** and **interchangeability** …
  - … on component level
  - … within individual components
  - Shown for bHapticsX40 vest as *displays* component
    - ROS2 package consisting of two ROS2 nodes
    - Whole component interchangeable (e.g. headphones)
    - Reusable driver node
    - Interchangeable feedback algorithm node
- Loose coupling in ROS2 by …
  - **Generic communication interfaces**
  - **Launch files**
- Open Source status of ROS2 has pros and cons
- ROS2's origin in robotics shares similar problems with ETA development (existing tools could be reused)



Contents

Conclusion

- In ETA research, hardware, software and algorithm components get **redeveloped** instead of **shared**
- Could be counteracted by developing within a common component-based framework
- Model for decomposing ETAs into loosely coupled building blocks
- Applicable to known ETA projects from literature
- ROS2 as open-source framework to support component-based ETA development
  - Real-time navigation and environmental perception as common subjects in robotics and ETAs
  - Sensor drivers, standardized message interfaces, algorithms, tools already exist
  - Designed for **reusability** and **interchangeability** of components
  - Open source status enables rapid results and innovation
- Implications for future development:
  - More ETA components needed
  - Open platform could be created to support exchange of ROS2 packages and nodes for ETA components
  - More concrete policy for component creation to ensure compatibility