Saving lives sooner: leveraging ROS 2 for end-stage kidney disease

ROSCon 2024

Deanna Hood, Senior Robotics Engineer

M. Sc. Robotics & Computer Vision (2014)

B. Maths (Hons), B. Electrical Engineering (Hons)

Engineers Australia Young Professional Engineer of the Year 2022

My OTHER goals

- A category of robots I’m excited about
- Where ROS comes in
- Where you come in

Vexev's founding Mechatronics Engineer

Ronnie Shaddick

A portion of the Vexev team

My first ROSCon (2016)

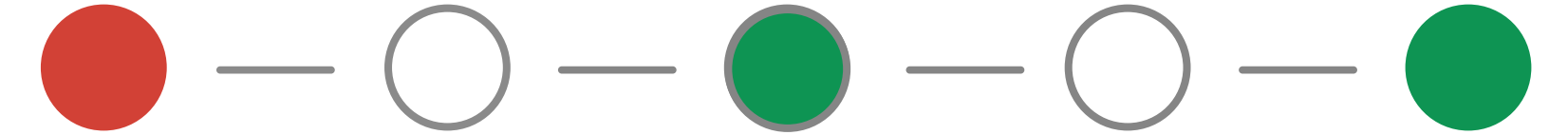
Photo credit: Evan Ackerman

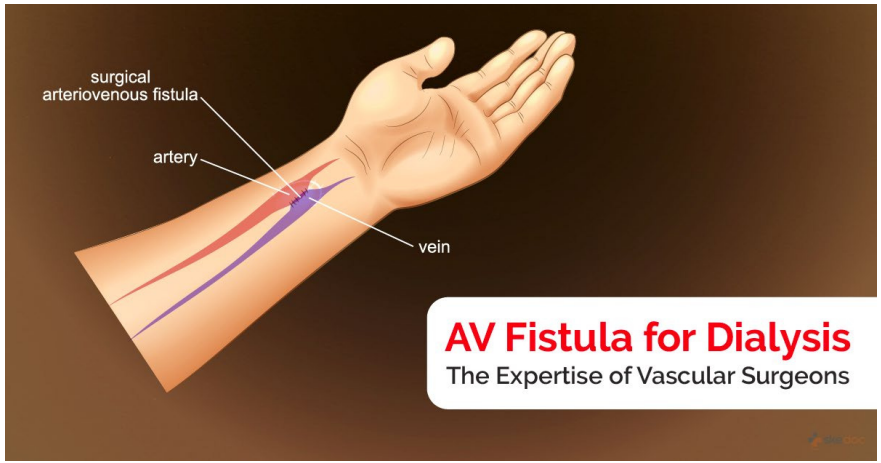
Can robots help with dialysis?

Kidney disease happens to lots of people AND for lots of reasons

Charlie, 12 at the time, on haemodialysis

Source: Kidney Research UK





Source: skedoc

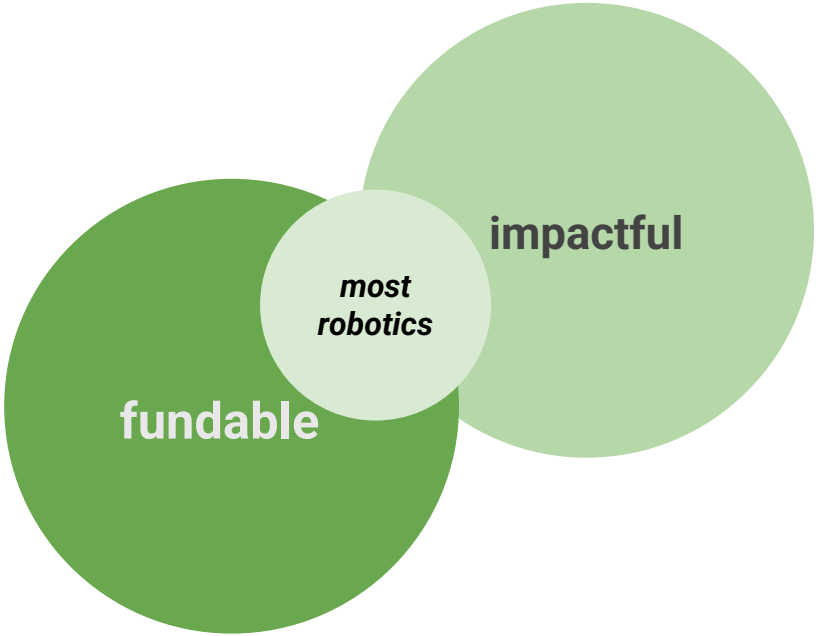
Imaging delays are meaning lives are lost

“I can make a diseased vessel look healthy and a healthy vessel look diseased”

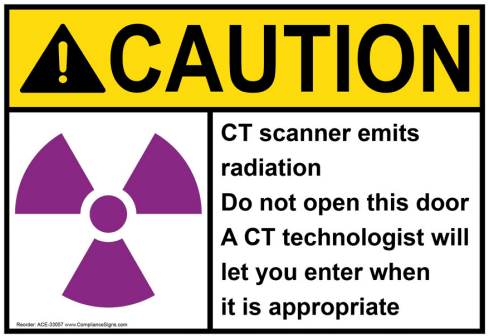
Chief Sonographer at leading Australian vascular clinic

Source: Primary Vein Care

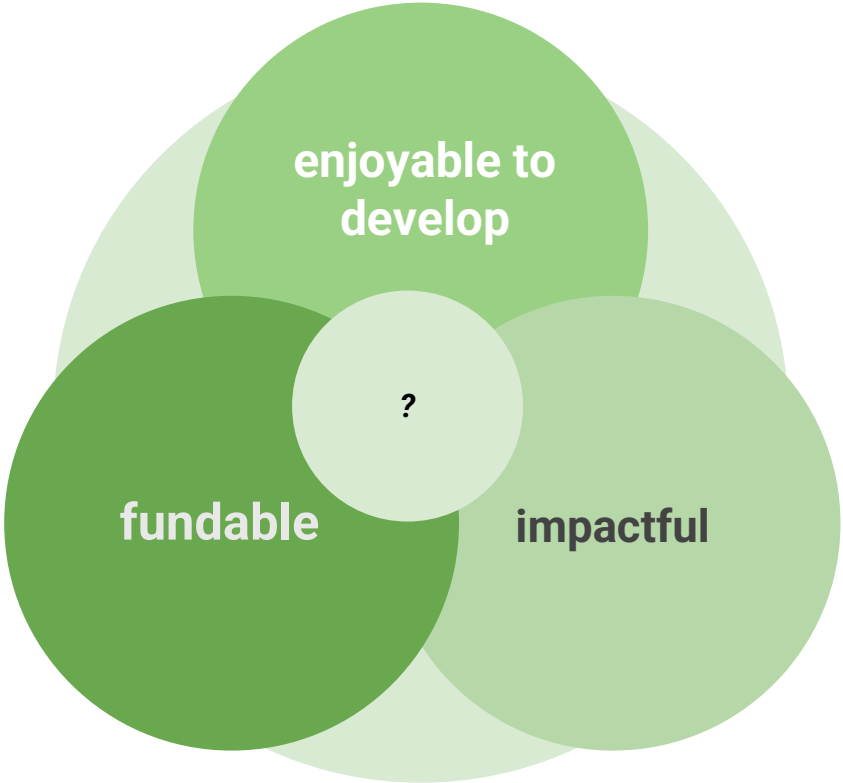
Robotics products: ideally



Take your pick…



Robotics products: if you're lucky!



The ROS team in 2018

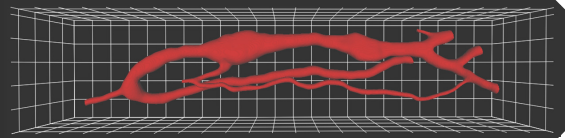
…releasing software without warranties or liability for damages of any kind 🌈

at a company without any VC investment or debt 😇

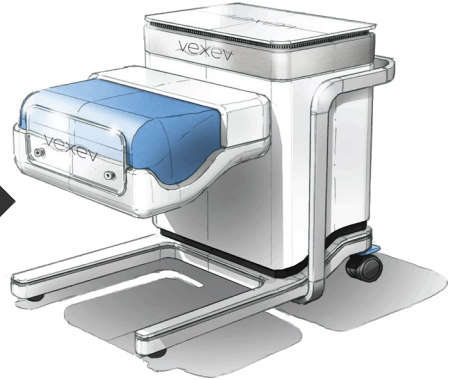
A fully autonomous ultrasound imaging robot for vascular monitoring

Vexev Wave makes vascular scanning simple, while generating advanced outputs (3D + 4D)

VEXEV IMAGING SYSTEM



From a simple



VEXEV CLOUD PLATFORM

We’re unblocking safer dialysis!

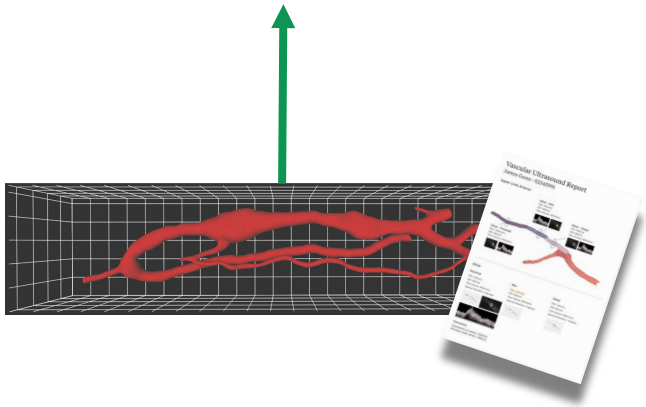
Direct access dialysis

Scan of vasculature!

Vascular surgery to create a fistula

Mature fistula

Vascular access dialysis



Where are we now?


On our way to dialysis clinics
😊

Inside the device

Vexev Wave: fully automated vascular imaging using safe and non-invasive ultrasound

Eamonn Colley
Co-CEO

Yige Cao
Robotics Engineer

Ultrasound is not the end goal, 3D models are!

We use this

To make this

(Note: not THIS ultrasound)

Image source: Samsung Medison

How does a robot scan,

without any intervention,

getting high quality data,

and know that it's done it?

1/ Get a robot to scan,

2/ without any intervention,

3/ getting high quality data,

4/ and know that it's done it

December 2020:

Everything else was de-risked

Off-the-shelf manipulator was ruled out

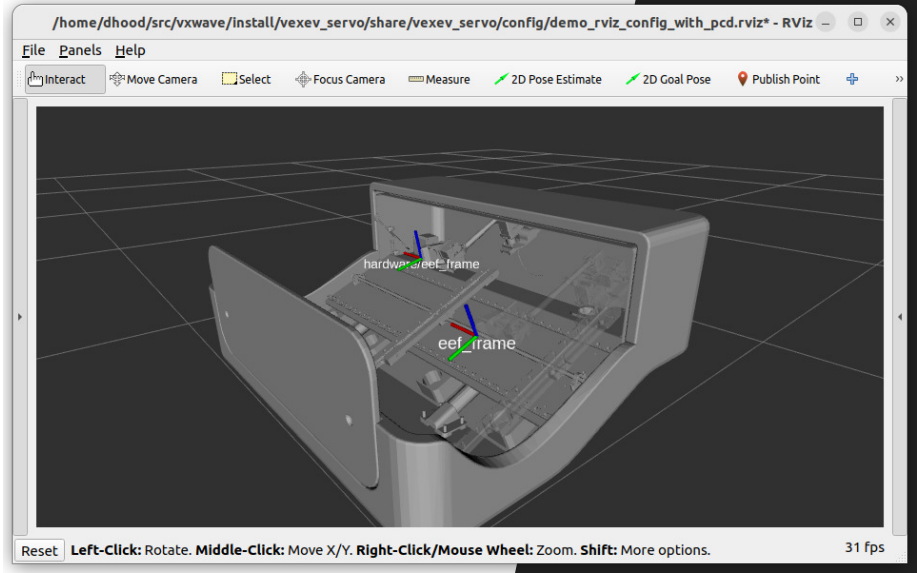
Robotics was the missing piece

Before using ROS

any controls we wanted, we had to make ourselves

After switching to ROS

Before ROS	Now, via ROS
Physical twin	**Visualisation!**
Joint jogging	**Inverse kinematics!**
Hard-coded sequences	**Path planning!**
Hard-coded sequences	**XBox controller**



Ronnie could scan himself!

“Did it take a lot of time to set up?”

Company meme from back in the day

Using ROS in our robot is like following an IKEA manual for how to build complex robotics

IKEA assembly guides

The *impact* of ROS at Vexev

We could spend our resources answering NEW questions

-> our company could *stay alive* and help people


July
2023

✅ Get a robot to scan,

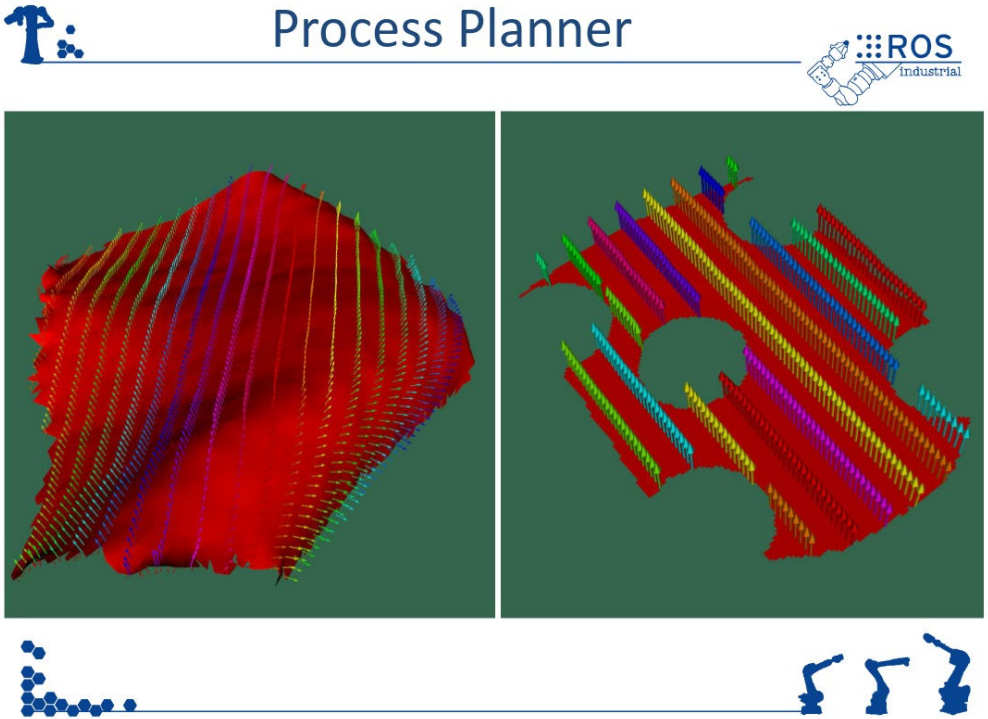
2/ without any intervention,

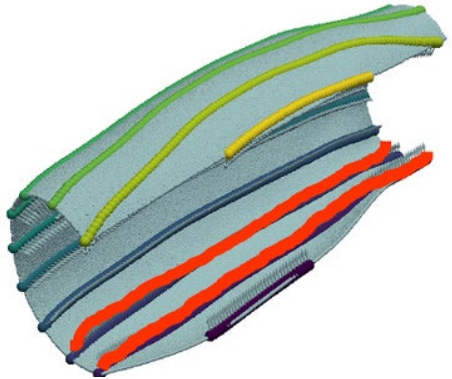
3/ getting high quality data,

4/ and know that it's done it

Autonomy, precision, and self-awareness

Goal: covevrage, but we all have unique arms

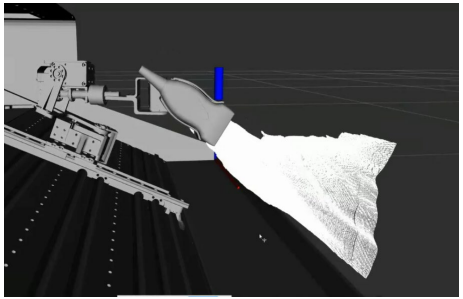




Our work

“Robotic Path Planning for Geometry-Constrained Process” at ROSCon 2017

Baseline autonomy



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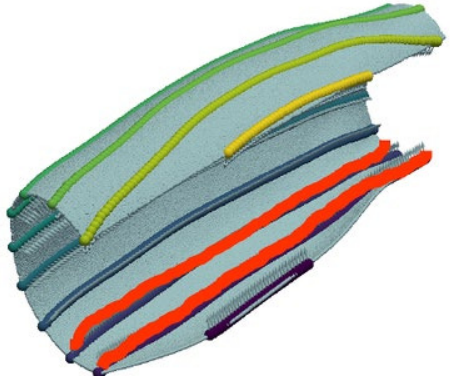
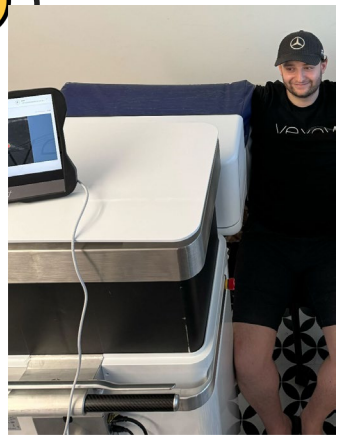


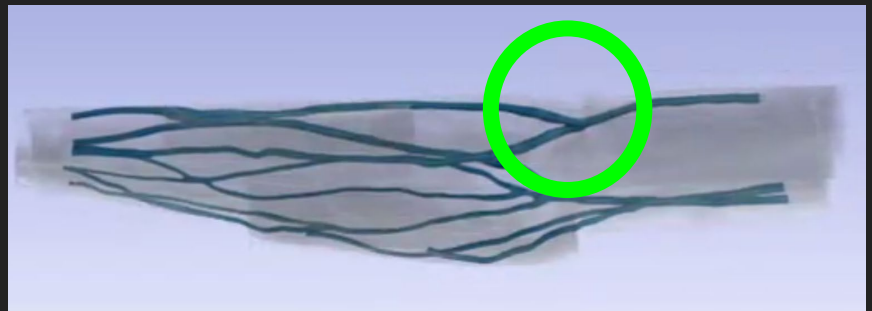
=>

Vein/arteries

Demo

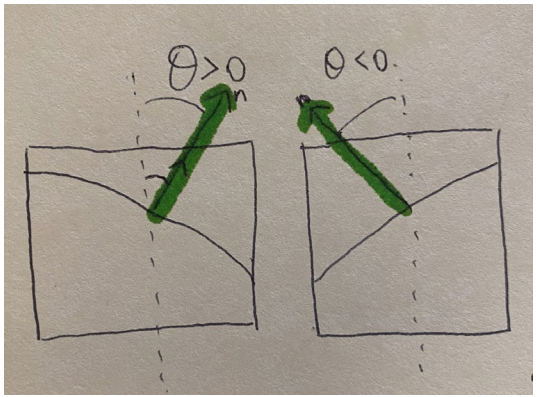
Autonomous scanning of vasculature with ultrasound (world first! 😊)



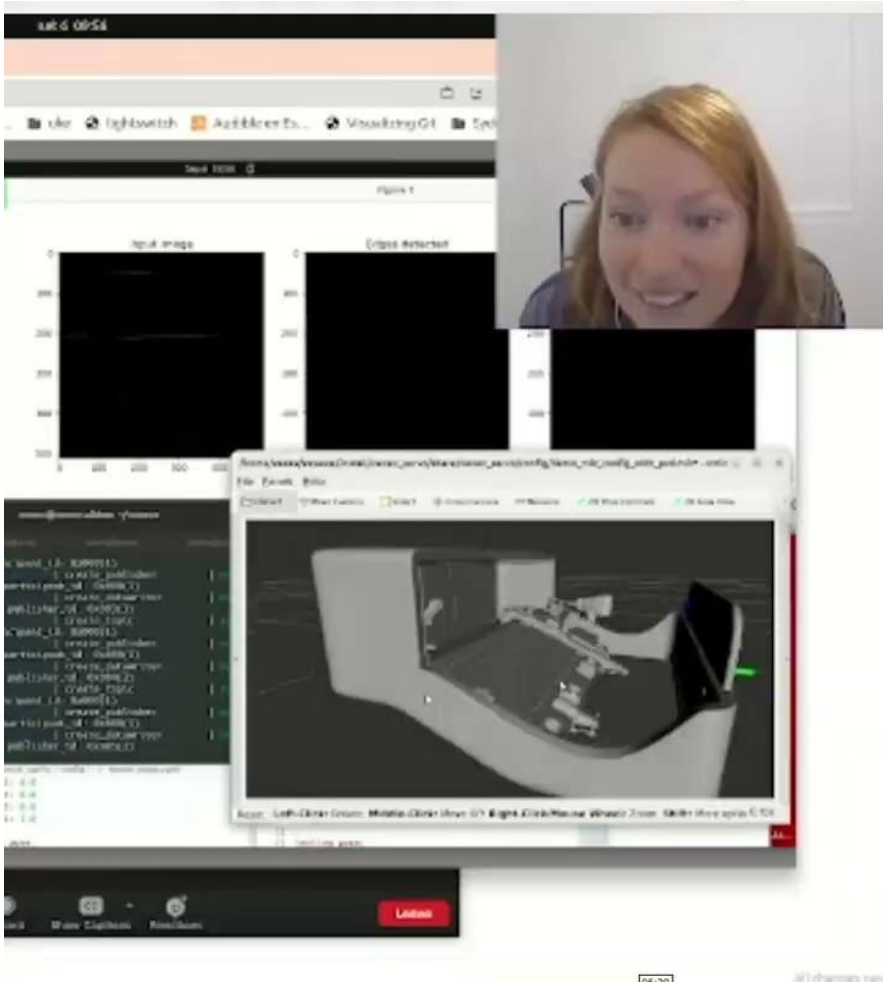



HOSE REEL
HYDRANT
FIRE EXTINGUISHER
vexev

Docking algorithm

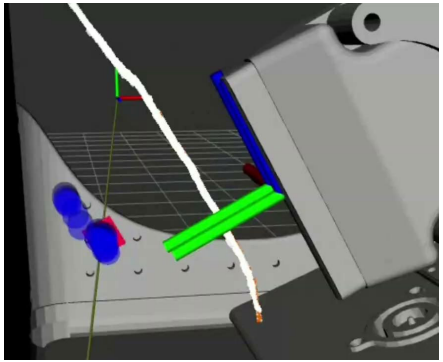


Designing the controller

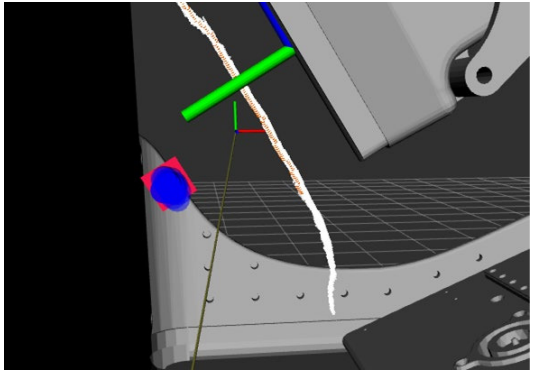


NOT precision: When stationary vessels move

BEFORE

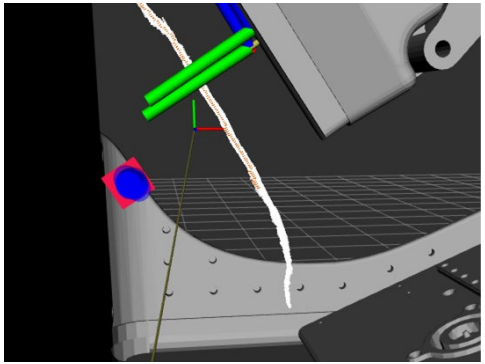


Starting point
(jitter is just a playback artefact)



Vessel drift from "last available" timestamp

AFTER



Using acquisition timestamp
This is even with the robot moving back and forth

✅ Get a robot to scan,

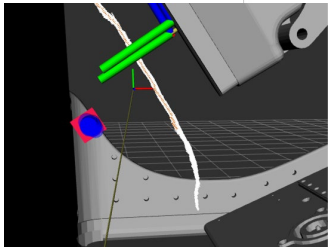
✅ without any intervention,

✅ getting high quality data,

4/ and know that it's done it

The value of “x-ray vision”

1. Are we seeing the vessels we care about?
2. Focusing ultrasound where they are
3. Doppler probe positioning along vessels (for flow)



John and Eamonn:

“One day, Deanna, we’ll scan based on what we see INSIDE the arm”

Founders and co-CEOs of Vexev > (plus me) in Portugal

The problems we're all solving: mapping

1. You can never *know* the state of the world, you have to *infer.*
2. Observations can't be trusted (entirely).
3. There IS "truth" in the form of consistency/constraints.

-> probabilistic map estimate

$$v_{ij} = z_i - h_j(\hat{x}^B_{k|k-1})$$
$$S_{ij} = H_j P^B_{k|k-1} H^T_j + R$$

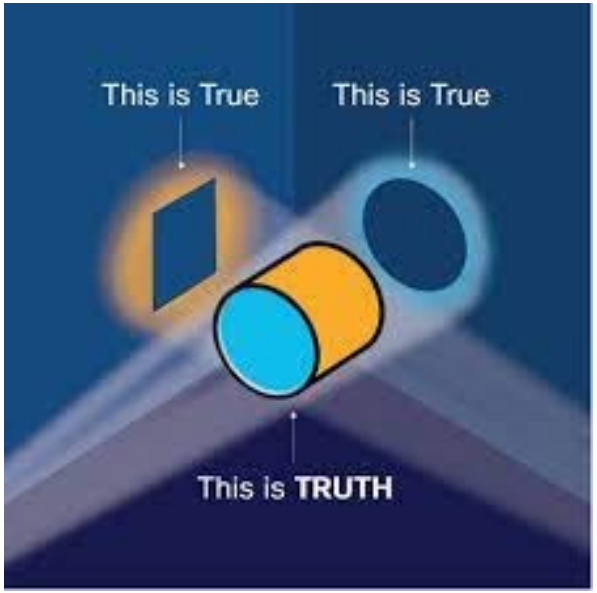
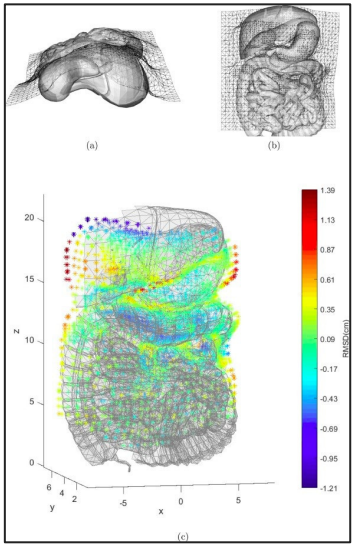
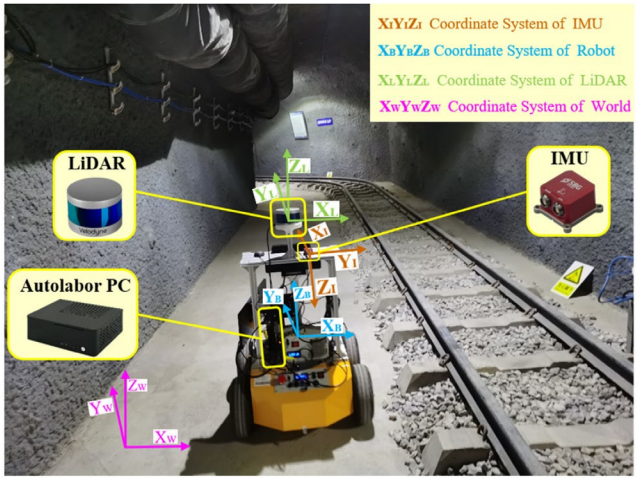


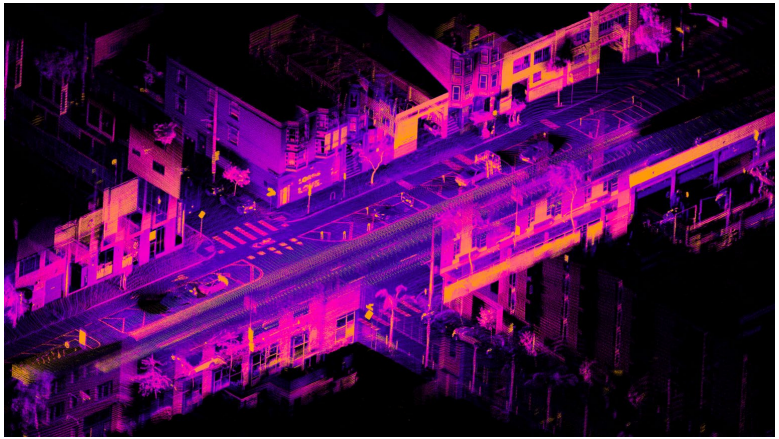
Image source: Extra-math - Perspective

SLAM-based dense surface reconstruction in monocular Minimally Invasive Surgery, L Chen et al

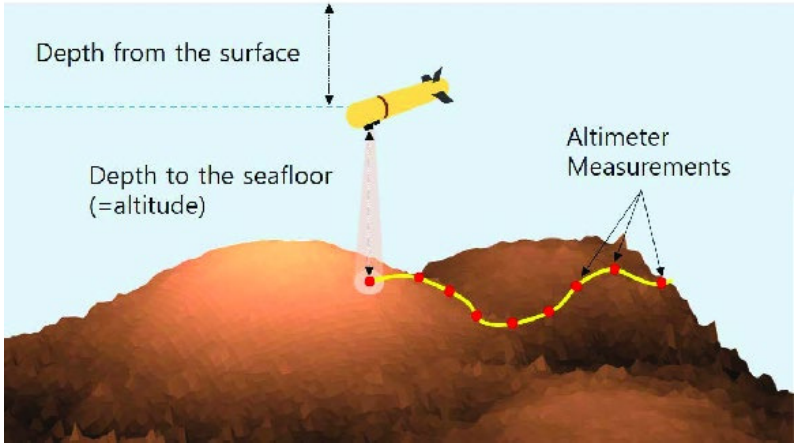




A Robust LiDAR SLAM Method for Underground Coal Mine Robot, X Yang et al

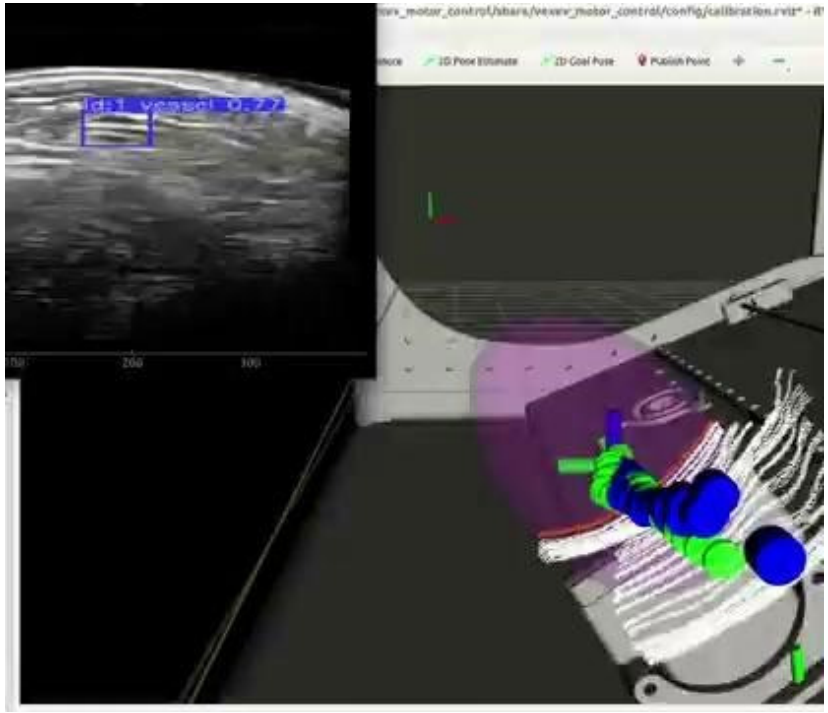


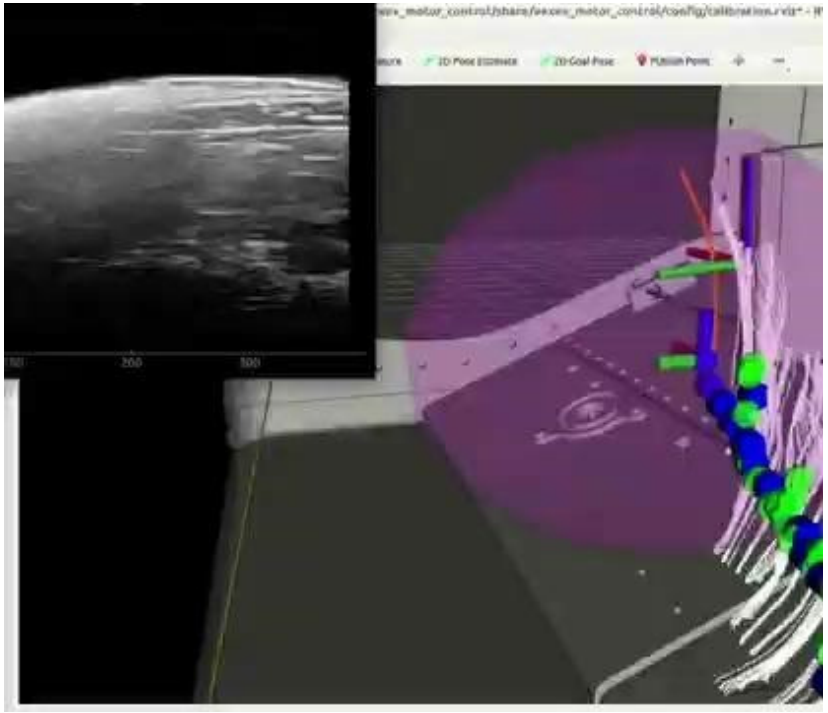
"Accumulated registered point cloud from lidar SLAM" Daniel Lu



Bathymetric SLAM with an acoustic altimeter, J Jang and J Kim

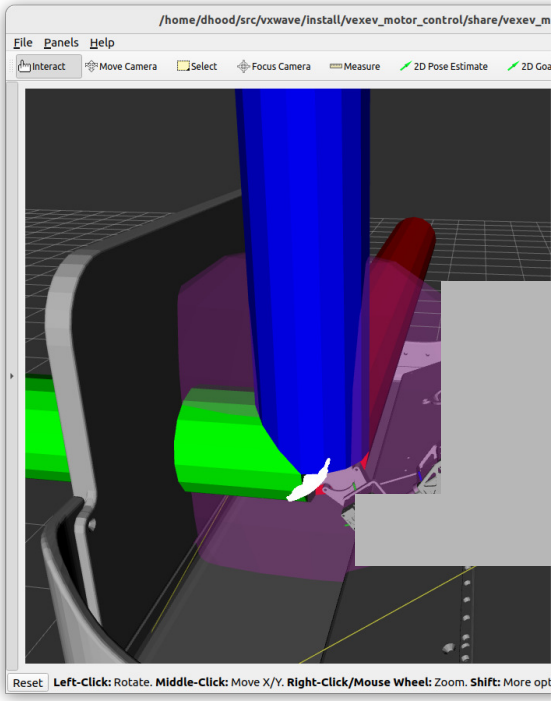
Kalman Filter in the context of vessels

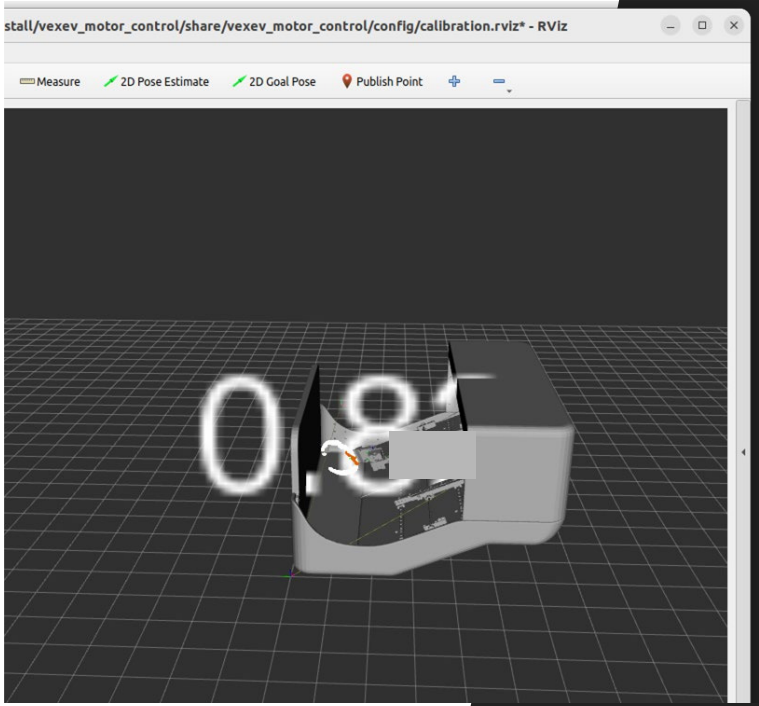




Vessel detections in green and tracking in blue, uncertainty in purple

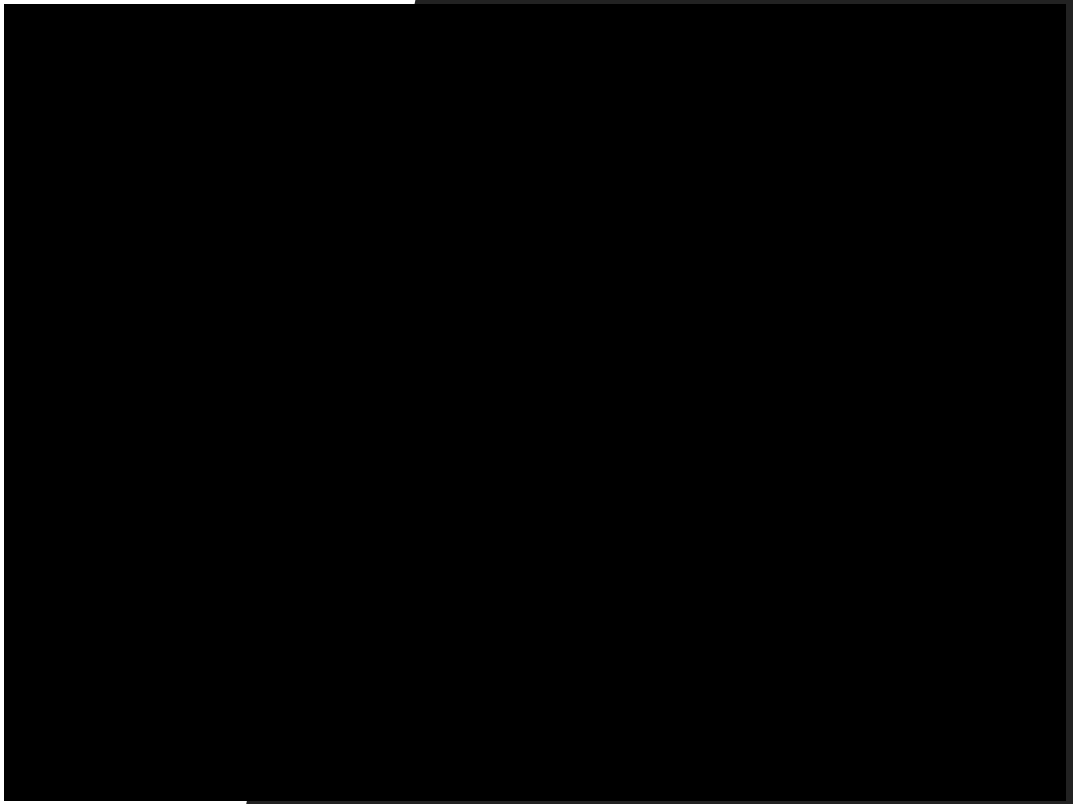
Reminders that we're mapping in miniature





Demo

Autonomous mapping in the context of 3D vasculature (another world first 😊)



You're part of the team 💚

GitHub

ros2_control

ROS

PlotJuggler

fetch robotics

MoveIt

How does a user TRUST

a robot to,

without any intervention,

get quality scan data,

and know that it's done it?

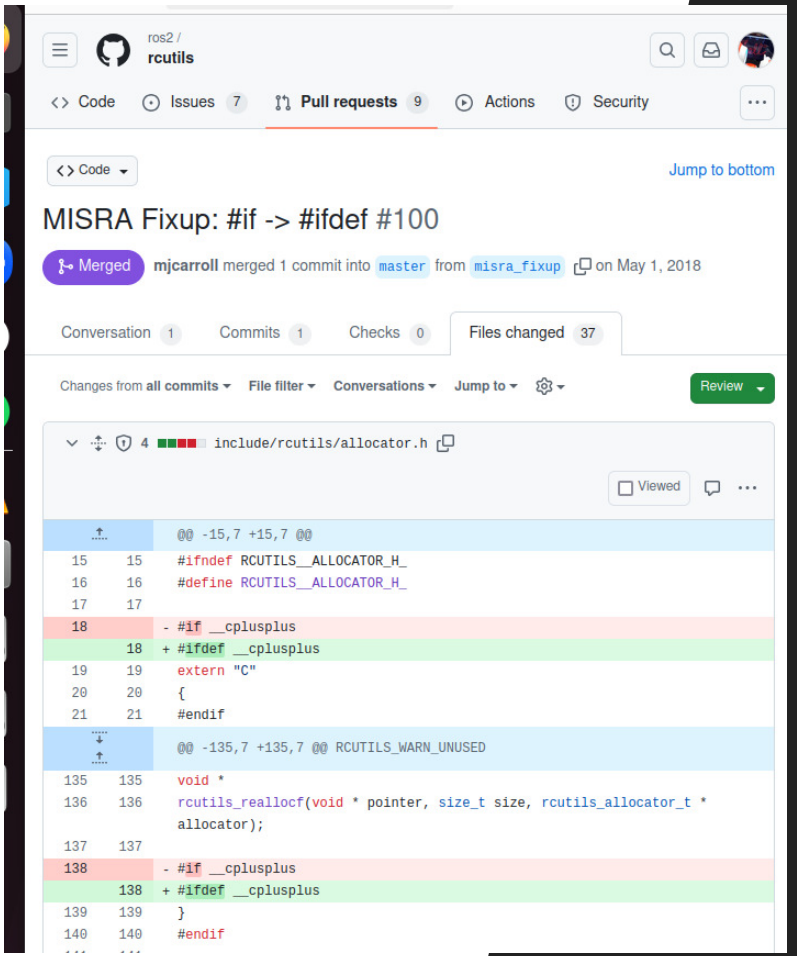
Medical device regulations: what surprised me

Coding standards != process standards

There are no mandated industry **code-level language-specific** standards like MISRA C

Relevant **process/lifecycle** standards:

ISO 13485, IEC 60601-1, IEC 62304, etc



Learn more

coursera

Yale

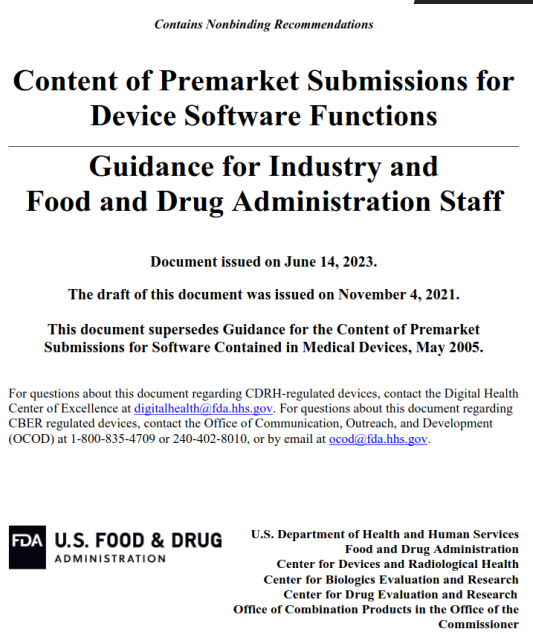
Introduction to Medical Software

Instructor: Xenophon Papademetris

FDA is on our team

It's all a **risk-based approach**

"The **least burdensome** approach was applied to identify the **minimum amount of information** that, based on our experience, would generally be needed **to support a premarket submission** for a device that uses software."



Contains Nonbinding Recommendations

Content of Premarket Submissions for Device Software Functions

Guidance for Industry and Food and Drug Administration Staff

Document issued on June 14, 2023.

The draft of this document was issued on November 4, 2021.

This document supersedes Guidance for the Content of Premarket Submissions for Software Contained in Medical Devices, May 2005.

For questions about this document regarding CDRH-regulated devices, contact the Digital Health Center of Excellence at digitalhealth@fda.hhs.gov. For questions about this document regarding CBER regulated devices, contact the Office of Communication, Outreach, and Development (OCOD) at 1-800-835-4709 or 240-402-8010, or by email at ocod@fda.hhs.gov.

FDA U.S. FOOD & DRUG ADMINISTRATION

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Center for Drug Evaluation and Research
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Learn more

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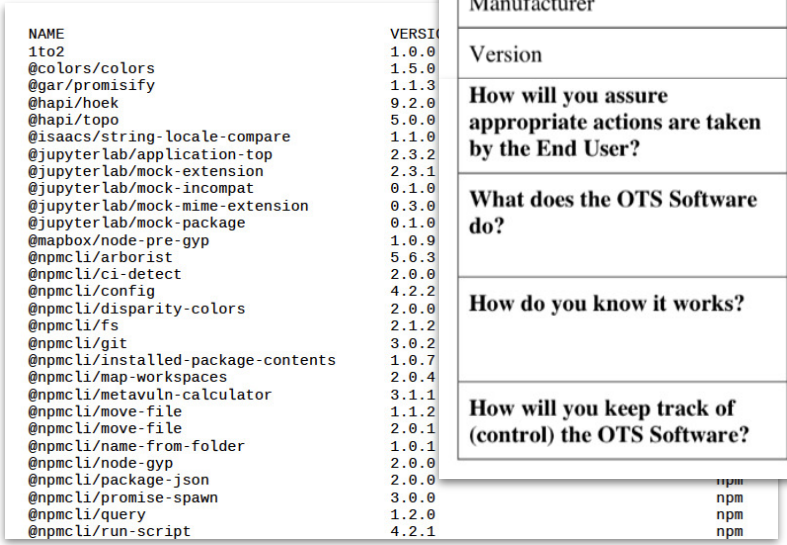
Introduction to Medical Software

Instructor: Xenophon Papademetris

Non-medical software is NOT a hard-no



NAME	VERSI
1to2	1.0.0
@colors/colors	1.5.0
@gar/promisify	1.1.3
@hapi/hoek	9.2.0
@hapi/topo	5.0.0
@isaacs/string-locale-compare	1.1.0
@jupyterlab/application-top	2.3.2
@jupyterlab/mock-extension	2.3.1
@jupyterlab/mock-incompat	0.1.0
@jupyterlab/mock-mime-extension	0.3.0
@jupyterlab/mock-package	0.1.0
@mapbox/node-pre-gyp	1.0.9
@npmcli/arborist	5.6.3
@npmcli/ci-detect	2.0.0
@npmcli/config	4.2.2
@npmcli/disparity-colors	2.0.0
@npmcli/fs	2.1.2
@npmcli/git	3.0.2
@npmcli/installed-package-contents	1.0.7
@npmcli/map-workspaces	2.0.4
@npmcli/metavuln-calculator	3.1.1
@npmcli/move-file	1.1.2
@npmcli/move-file	2.0.1
@npmcli/name-from-folder	1.0.1
@npmcli/node-gyp	2.0.0
@npmcli/package-json	2.0.0
@npmcli/promise-spawn	3.0.0
@npmcli/query	1.2.0
@npmcli/run-script	4.2.1

OTS Software	MONAI
Manufacturer	MONAI (open source)
Version	1.2.0 (2023-06-08)
How will you assure appropriate actions are taken by the End User?	N/A, the user does not have access.
What does the OTS Software do?	The OTS software allows for the reading and preprocessing of medical images into memory for use by the device.
How do you know it works?	The OTS software was tested indirectly by the system verification. See the unit- and system-level verification records in DOC-0045 Software Verification Report.
How will you keep track of (control) the OTS Software?	The OTS software is fully contained within the deployed system image.

*It's all a **risk-based approach,***

+ process standards

510(k) Example (via Innolitics)

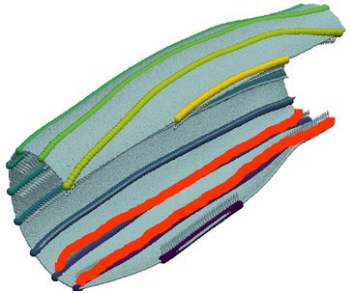
Creativity is Queen

Prevent something from happening

and/or

Human-in-the-loop for mitigating automation risks
"Collaborative autonomy"

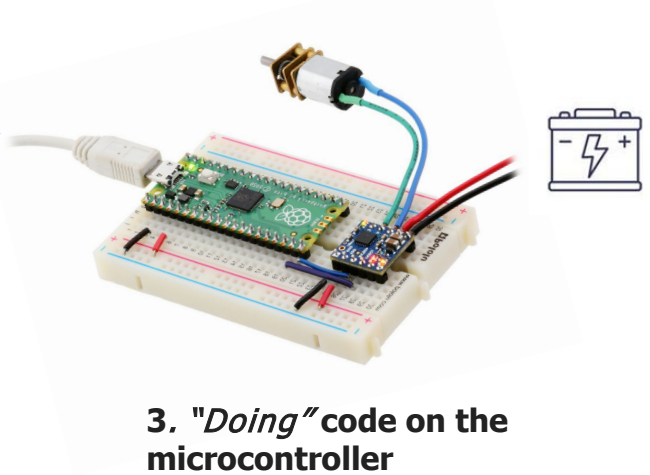
Derisk your software *with hardware*



1. Decision **of where to go (from the computer, 100% virtual)**

2. comms

4. Actual motor



3. *"Doing"* code on the microcontroller

push / crush / jab

Ways to use ROS in a device

Switch it out e.g. pure DDS

Supplemental for V&V e.g. just gazebo or just RViz

Bulk it up (just the necessary parts)

Leave it as is

Our impact now


Let the clinical trials begin
😊

My first ROSCon (2016)

ROSCon 2016 SEOUL

Changes since ROSCon 2015

- Windows feature parity (alpha 2)
- Fast RTPS supported as middleware (alpha 3)
- Partial port of core tf2 libraries (alpha 3)
- Python client library (alpha 4)
- 32- and 64-bit ARM experimentally supported platforms (alpha 5)
- Node "wait for service" functionality (alpha 6)
- Turtlebot demo using ported code from ROS 1 (alpha 7)
- ROS Client Library implementation (rcl) (from alpha 3, services alpha 5)
- Support for C messages (as opposed to C++) (alphas 4, 5, 7)
- Refactored C++ client library to use rcl (alpha 6)
- ROS graph events (alpha 6)
- Improved support for large messages (images) with Connext and Fast RTPS (alpha 6, alpha 7)

Open Source Robotics Foundation 16

Video Recordings Supported By ubuntu

Remember the dream?

My OTHER goals

- Asked or answered a question on ROS Answers/stack exchange
- Published a ROS-based project on github/somewhere google-able
- Published research in one of the topics I mentioned
- Contributed to one of the packages I mentioned (even a documentation fix)
- Joined the ROS Medical Community Group

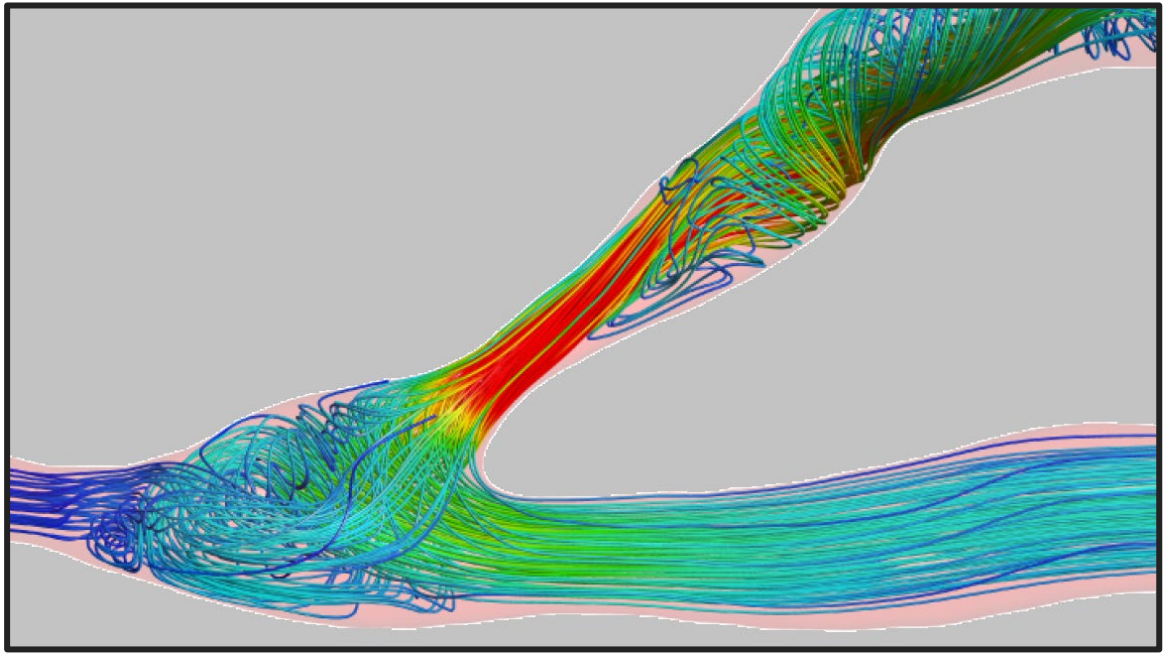
- Risk can be designed out
- Where ROS comes in
- Where you come in

vexev

Saving lives sooner: leveraging ROS 2 for end-stage kidney disease

Deanna Hood
ROSCon October 2024

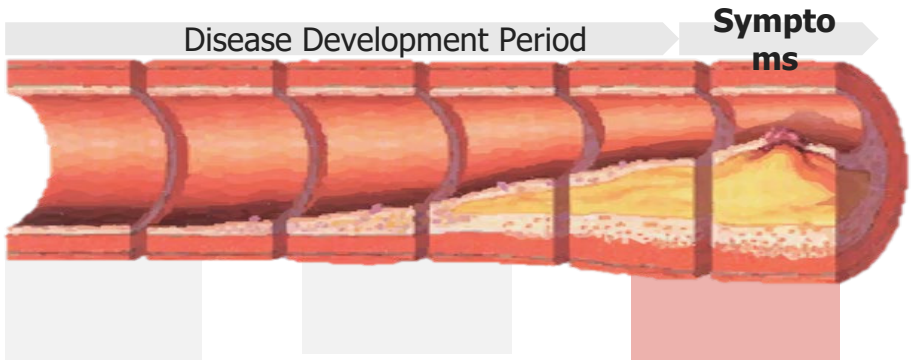
Nerd-sniped by 4D Haemodynamics



Computational fluid dynamics of blood flow

John Carroll and Eamonn Colley as PhDs

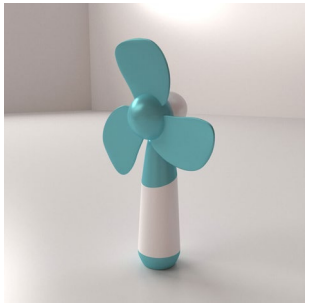
Cardiovascular disease (leading cause of death worldwide)



What potential harm do you need?

Someone else's worst case:

Our worst case:



Space ROS

- What is Space ROS?
  - Space ROS is a Software Framework for maturing Space-Qualifiable Robotic Software based on Open Community, Frameworks and Standards
    - Blue Origin, NASA Ames, NASA Goddard, NASA Johnson
- Why Space ROS?
  - Currently do not have a Space-Quality Software Framework for Intelligent, Autonomous and Collaborative Robotic Systems
    - Core Flight Software System (cFS) does not have built in capabilities like ROS Packages for robotics/autonomy
    - https://cfs.gsfc.nasa.gov/
- Why ROS?
  - Space robotics community desires an Open-Source framework that does for space robotics what cFS does for spacecraft flight software
  - Robotics research and technology development community already use ROS for rapid development and integration of prototypes. For this community, flight-qualifiable Space ROS should be easily adoptable.
  - Reduce cost/schedule by not having to port ROS code to something else

open robotics