Considerations and Approaches for High-Accuracy Robotics Applications

SOUTHWEST RESEARCH INSTITUTE®

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Agenda

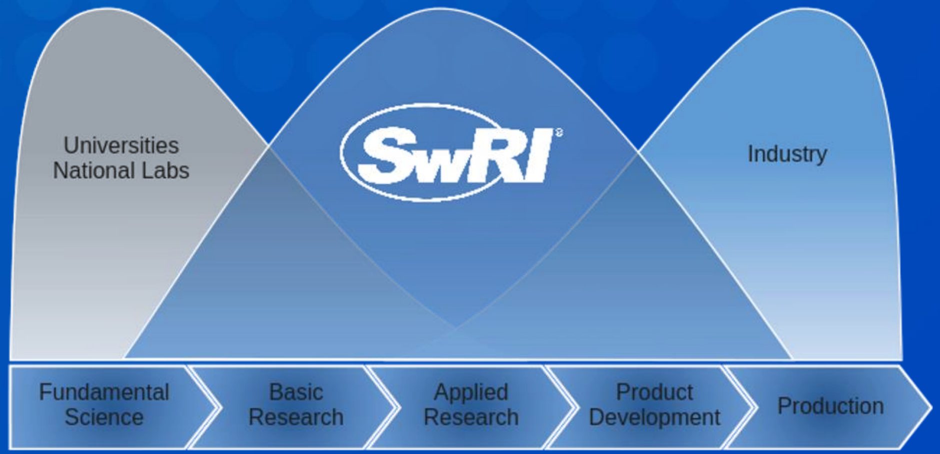
- SwRI Background
- Robot Accuracy Challenges at SwRI
- Case Studies
- Lessons Learned
- Future Needs

Southwest Research Institute

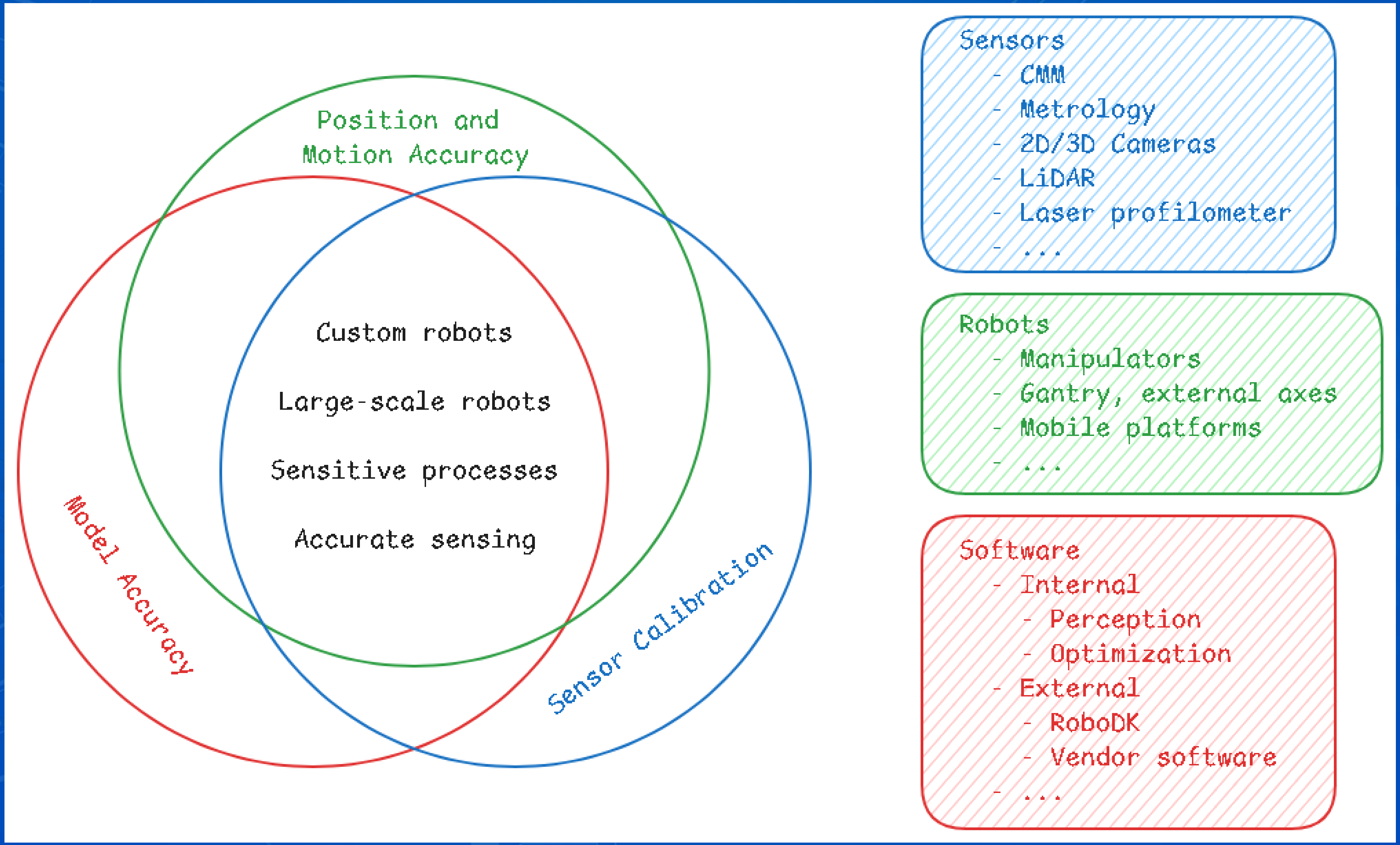
Committed to advancing science and applying technology to benefit government, industry, and all of humanity.

About SwRI:

- Est. 1947
- San Antonio, TX
- Independent, not-for-profit
- ~3000 staff
- Applied RDT&E services
- Physical sciences and engineering



Robot Accuracy Challenges at SwRI



Research Caveat

- Not using robots in traditional way
  - ~~COTS robots~~
  - ~~Teach pendant programming~~
  - ~~Physical touch-off~~
  - ~~Hard fixturing~~
- Teaching old robots new tricks
  - Motion planning with virtual models
  - Perception with sensors
  - Leveraging low-cost equipment + software
  - ...

Challenges

Custom Robots

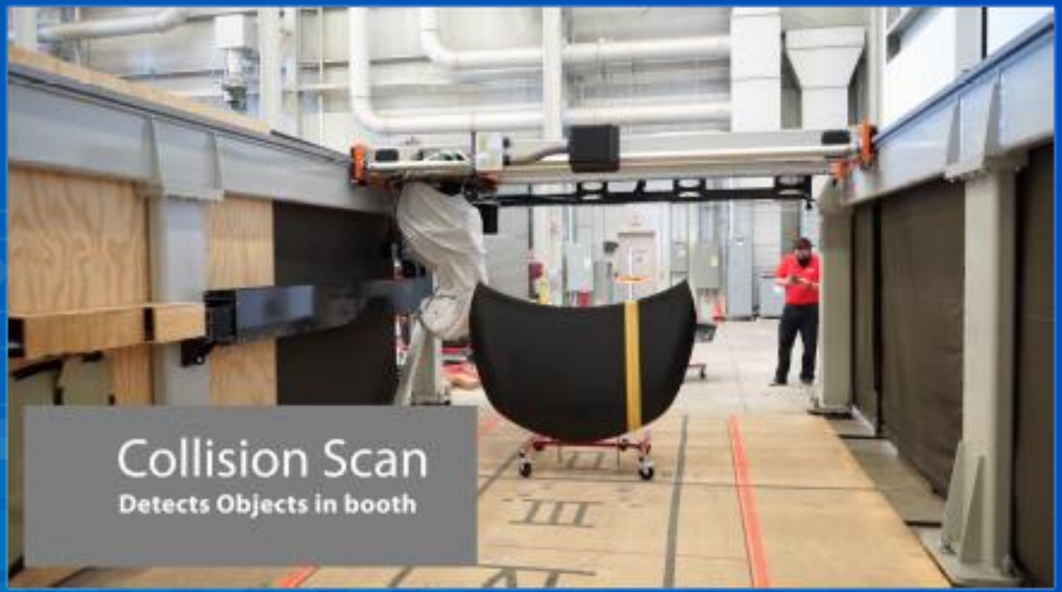
- Needs
  - Kinematic calibration
  - TCP calibration
- Constraints
  - Use kinematic structure with closed-form IK solution
  - Resource-constrained compute for control system
  - Vendor control system software access

Custom Robots

- Problems
  - How to handle backlash, hysteresis?
  - How to integrate optimized kinematic model into controller?
  - How to integrate live measurements of TCP into control system?
  - How to guarantee specific level of accuracy?
  - How to handle variations (temperature, loading, etc.)?

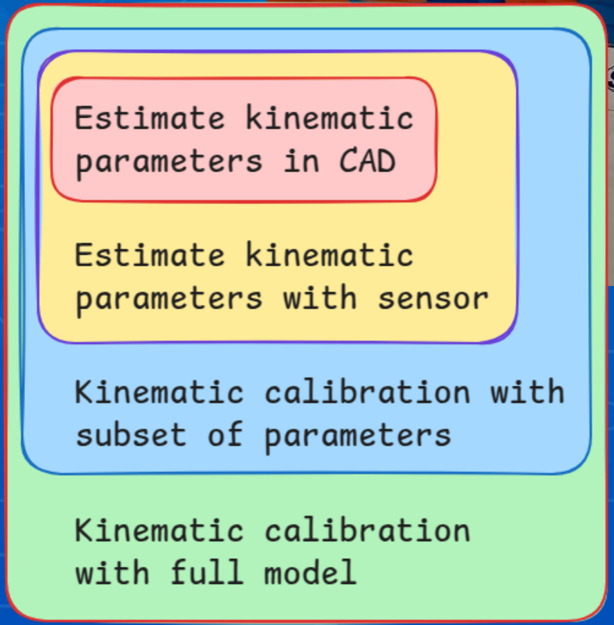
Large-scale Robots

- Workspace extension (rail, gantry, part positioners) required for many applications
- Problems
  - Dissimilar levels of hardware accuracy
  - Integrated with robot, but considered separate
  - Calibration of external axes performed with robot
  - Correspondence to virtual models
  - "Regular" accuracy tolerances become difficult at larger scales
  - Physical deflection under load
  - Closed-loop TCP control system may still be necessary



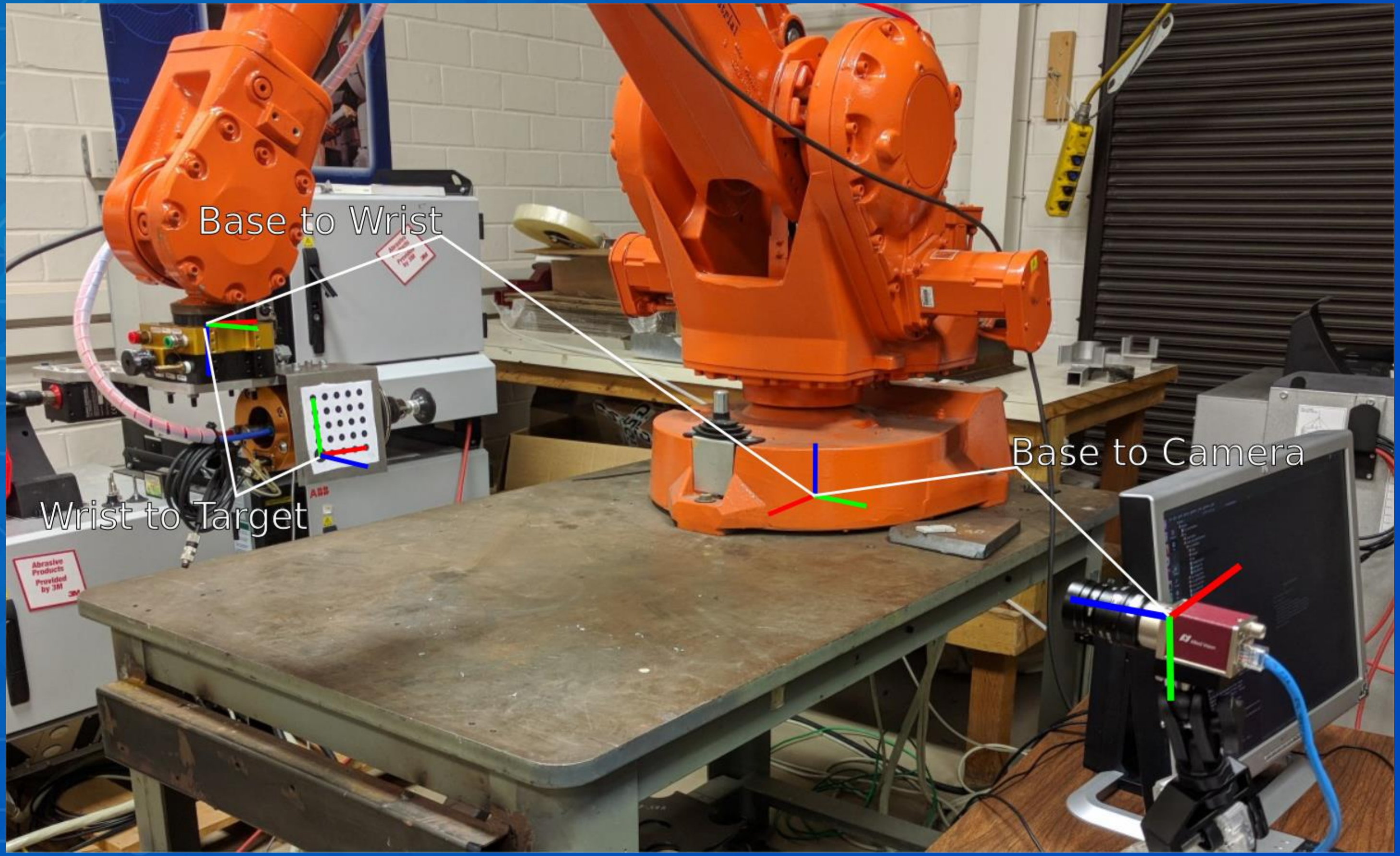
Custom and Large-scale Robots

- Approaches
  - Perform various levels of kinematic calibration
  - Fix it in hardware
  - Fix it in software



Robot Accuracy + Sensor Calibration

- Problems
  - Interdependence of extrinsic sensor calibration on robot position accuracy
  - Sensor mounting is critical
- Approaches
  - Calibrate where robot operates
  - Error/uncertainty modeling
  - Calibration metrics (residual error, reprojection error, uncertainty)



Case Studies

Case Study: Large-scale Plasma Cutting

- Plasma cutting on castings in a steel foundry
- Hardware
  - ABB IRB6700, absolute accuracy (<1.5 mm)
  - 2-axis positioner (1500 kg cap.)
  - Photoneo Phoxi XL 3D sensor

Case Study: Large-scale Plasma Cutting

- Constraints
  - Geometry differs per casting
  - 1-4 mm gap for arc
  - Environment (soot, dirt, temperature fluctuation)
  - Heat, light, vibration from plasma torch
  - Workpiece size
  - Cost

Case Study: Large-scale Plasma Cutting

- Problems
  - Plasma standoff controller
  - Hardware, sensor calibration
  - Positioner deflection
  - Temperature fluctuation
  - Sensor mounting
- Approaches
  - Camera calibration
  - Kinematic calibration
  - Manipulator-mounted camera

Case Study: Large-scale Plasma Cutting

- Result:
  - Improvements from kinematic calibration and wrist-mounted camera
  - Not enough for full success with plasma cutting
- Lessons learned
  - How to handle virtual model vs. hardware discrepancies
  - Camera mounting is critical
  - Local control system might be better than globally accurate sensor reconstruction

Case Study: High-accuracy Assembly

- Insert "lid" into "box" containing sensitive contents
- Previous approach required tedious physical touch-off
- Constraints
  - 0.001" position fit tolerance
  - Box/lid fixturing not accurate/repeatable
  - Touchless
- Hardware
  - UR5e manipulator
  - Fixture for box mounting
  - End effector fixture for holding lid

Case Study: High-accuracy Assembly

- Approach
  - Add features to fixtures for visual detection
  - Perform “local” calibration
  - Detect poses of box, lid
  - Estimate pose offset for assembly
  - Command relative pose

Case Study: High-accuracy Assembly

- Result
  - Successful calibration of 4 cameras
  - Successful assembly within tolerance
- Lessons learned
  - OTS robots can have high local accuracy
  - Kinematic calibration is not always required
  - Many environmental factors become important at tight tolerances (lighting, temperature, vibration, etc.)

Conclusions

General Lessons Learned

- Many factors influence accuracy: test and measure
- Solutions exist on a spectrum
- Operate locally when possible
  - Control systems vs. calibration
- Is it necessary to build fully calibrated, accurate "world" models?
- Sensor mounting: static vs. robot-mounted?
- Accessibility for operators

Future Needs

- Integration of complex kinematic models into software
  - Robot controller
  - User applications
- Standard approach to kinematic calibration for various types of common setups
- Taxonomy of kinematic calibration approaches
- Metrics for evaluation of calibrations
- Robot accuracy heat map in workspace

Thank You

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