State Recognition of Pedicle Drilling With Force-Sensing in a Robotic Spinal Surgical System

Presented by Prasad Vagdargi
Authors: Ying Hu, Haiyang Jin, Liwei Zhang, Peng Zhang, Jianwei Zhang.

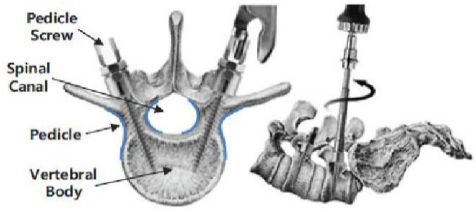
Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, China,

IEEE/ASME TRANSACTIONS ON MECHATRONICS, 2014

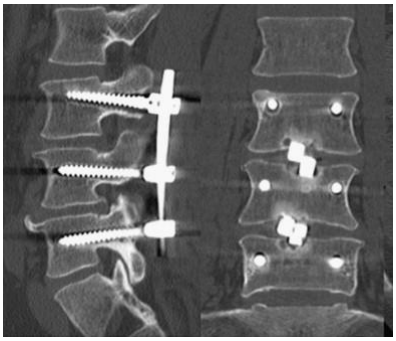
Recap: Project

- Force Sensing Drill for Skull Base surgery
- Using Galen hand-over-hand collaborative robot: currently head and neck microsurgery.
- Goal: To sense and provide feedback about the cutting forces to surgeon, implement safety limits
- Further applications:
  - Surgical Skill evaluation
  - Comparison of surgical techniques
  - Visualization of forces

Background

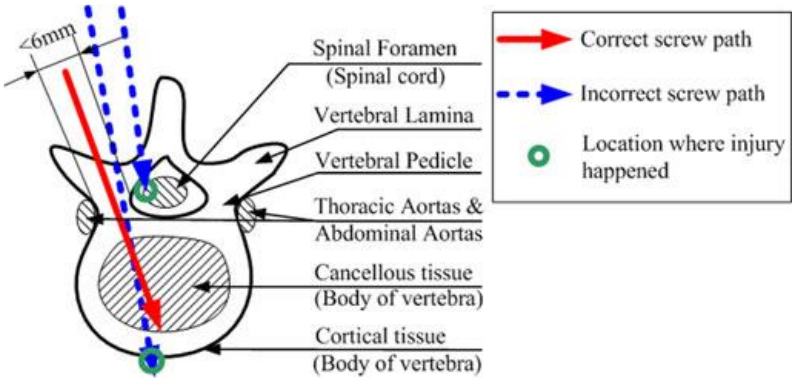


- Spinal Orthopedic Surgery is challenging due to precision in depth required, along with stability of movement.
- Restricted space available during surgery, lengthy : Use robots.
- E.g. Spinal Fusion surgery, where the vertebrae are drilled, bone screws are inserted into them and a rod is connected to increase strength.



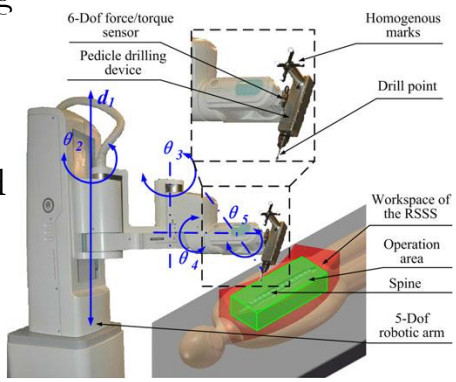
Challenges

- Width of the pedicle:
  - L: 5-6 mm
  - C: 3.5-4 mm
- Screw diameter:
  - L: 4–4.5 mm
  - C: 2.5-3 mm
- Operation error: ±1 mm

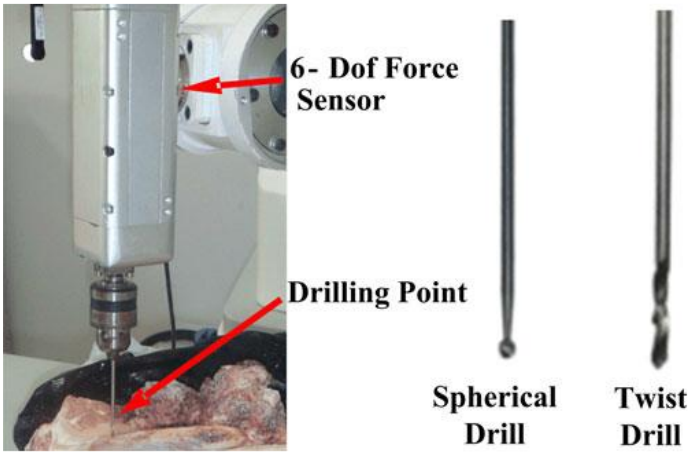


Robotic Spinal Surgical System:

- 5-DOF robotic arm ; 2-DOF pedicle drilling device
- Prismatic/Revolute Hybrid with increased workspace for motion
- 6-DOF force/torque sensor mounted at end
- Two modes of control:
  - Cooperative control: Where you can move the robot by pulling it manually
  - Active control: Feedback control based, used for fine positioning.

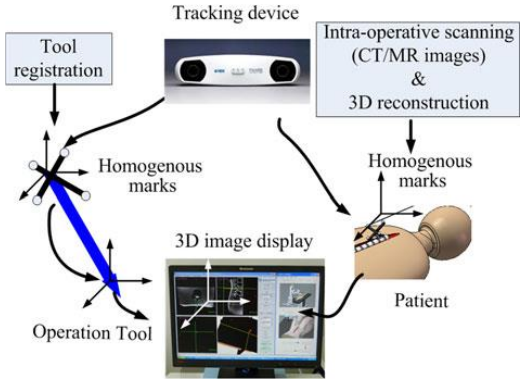


Setup



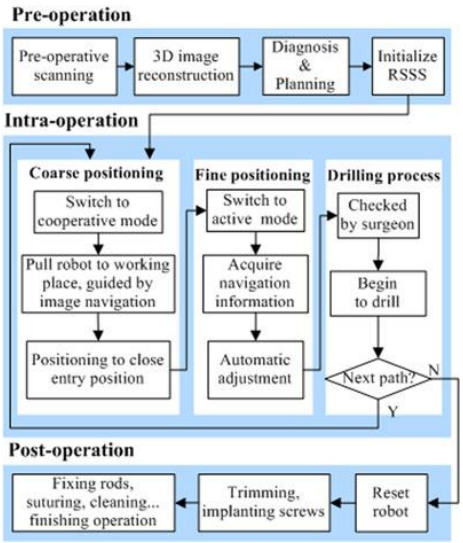
Current Workflow

- Implant tracking devices into patient
- Register the markers in CT
- Use optical tracking for tool register with CT frame
- Intermittently check the drill location during surgery, using prior 3D imaging data.
- Insert screws



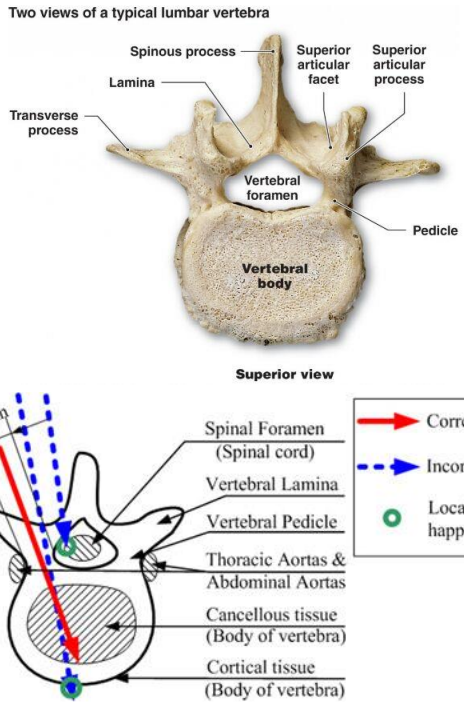
Improved Workflow

- Preoperative CT and 3D data in the same way as before
- Use robot as a guide to align with the screw insertion points(manual)
- Use the robot drill to enter the vertebrae
- Insert screws manually and close.



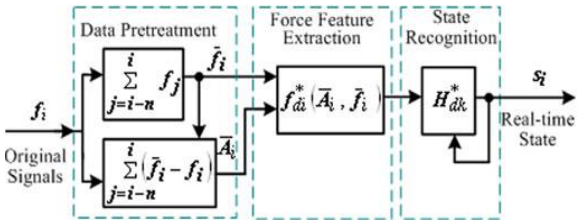
States of Drilling

- Initial State
- State 1
- State 2
- State 3
- State 4

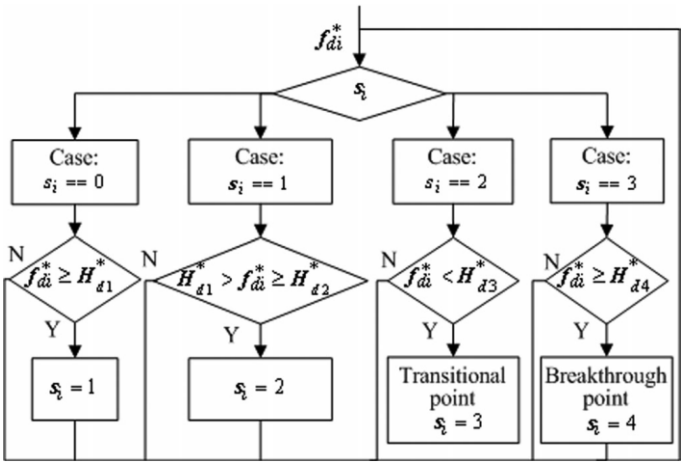


Filtering and Classification

- State feature function : combines short moving average force, magnitude difference of force from average.
- $f_i^*(\overline{f_i}, \overline{A_i}) = \overline{f_i}.\overline{A_i}$
- Thresholding : output state as required.
- Thresholds by experimentation

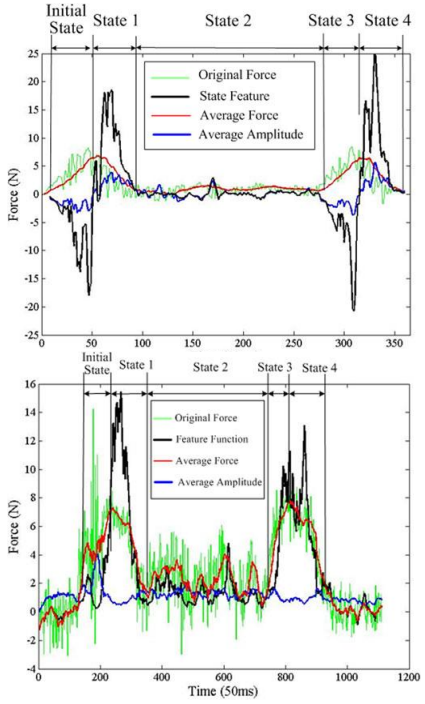


Thresholds



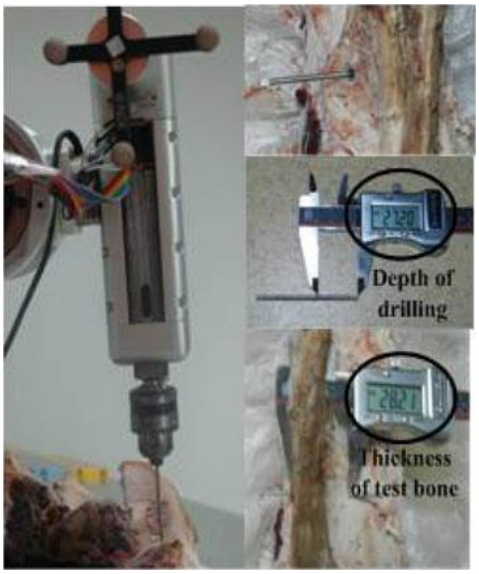
Results

- Classification into states performed in realtime
- Can provide warning before the drill contacts the end, stage 4
- Tested with spherical drill, another set with twist drill



Validation

- Allow robot to drill and stop at the edge of the state
- Measure depth
- Drill through and measure thickness of bone
- Check the wall thickness left out.



Pros and Cons

- End to end solution, including robot design and its application into drilling
- Control Modes
- Detailed description of states
- Not enough details on sensor/sensing.
- Simplistic state feature functions, could be better
- Validation with different drill tips and methods.

Conclusion/References

- Can use this to measure and provide feedback on current estimate of safety, but needs further improvement and testing.

[1] L. W. Sun, F. V. Meer, Y. Bailly, Y. Bailly, and C. K. Yeung, "Design and development of a da vinci surgical system simulator," in *Proc. Int. Conf. Mechatronics Autom.*, Harbin, China, 2007, pp. 1050–1055.
[2] Spinal Fusion, (2012, Jun. 7). [Online]. Available: http://baptisteast.adam.com/content.aspx?productId=115&pid=3&gid=100121
[3] W. Tian, *Practice of Orthopaedics*. Beijing, China: People's Medical Publishing House, 2008, pp. 511–518.
[4] H. An and P. Benoit, "Saline injection technique to confirm pedicle screw path: A cadaveric study," *Amer. J. Orthop.*, vol. 27, pp. 362–367, 1998.
[5] J. Lee, S. Kim, Y. S. Kim,W. K. Chung, andM. Kim, "Automated surgical planning and evaluation algorithm for spinal fusion surgery with threedimensional pedicle model," in *Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst.*, San Francisco, CA, 2011, pp. 2524–2531.