Frameless Stereotactic Navigation

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Abstract

Stereotactic navigation is a method used in medical procedures to determine the location of an instrument relative to locations on and within the patient during surgery. The project goal was to design a more affordable and portable version of current computerized stereotactic navigation systems by using commercially available 3D object tracking hardware and software. An accomplished design would increase the availability of this technology for a wider range of procedures, including spinal injections, nasal reconstruction, and even areas of dentistry. The current prototype uses two HD Red/Green/Blue (RGB) cameras and colored markers to track the tip of a spinal needle.

Motivation

- Size and cost of current system limit availability to a few select operation rooms
- Typical system costs >$600,000 [4]
- Reserved for high-risk invasive surgeries, such as brain or spinal surgery
- Similar technology could prove useful in interventional radiology and pain procedures

Design Criteria

- Accuracy must be within 1mm from a distance of 1-2m
- Must be able to accurately track within a space of $0.028m^3$ ($1ft^3$)
- System coordinates must coordinate with patient x-rays as in Figure 1
- Budget of $1000

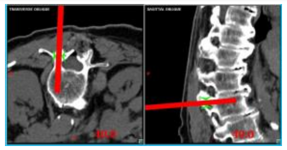

Figure 1: Current display of stereotactic navigation during a spinal procedure. The red line indicates the tool in respect to the x-ray [5].

Background

Triangulation

- After setting two cameras at a set angle and distance apart (baseline dimension), an object may appear in both cameras field of vision
- The *parallax*, or the distance between the identical points in the two visual fields as shown in Figure 2, of the overlapping fields of vision can be determined
- Knowing the parallax and camera dimensions, the *law of sines* can be used to calculate an object's spatial location
- *Law of sines:* $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$

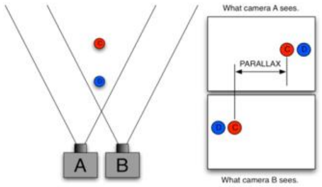

Figure 2: A diagram of triangulation using two cameras [1]

Current Practice

- Variety of products on market from companies such as Brainlab and Medtronic, as exampled in Figure 3 [2]
- These devices utilize triangulation using infrared (IR) and RGB spectra based cameras
- Utilize tracking markers placed on the patient which are used as reference points
- Using the references, the patient's X-ray or MRI images can be aligned with the subject

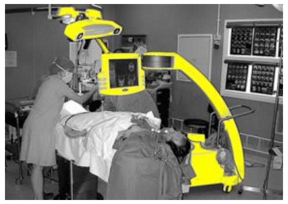

Figure 3: The highlighted portion is *Vector Vision 2* by Brainlab, a current stereotactic navigation system [2].

Final Design

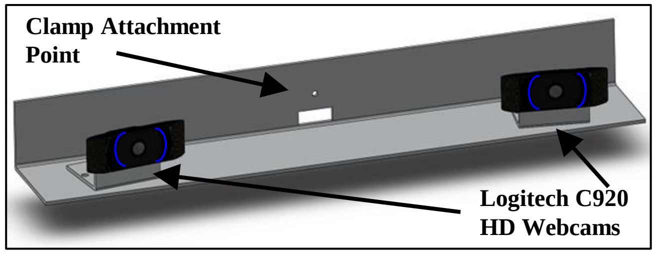

Figure 4: Camera mounting unit

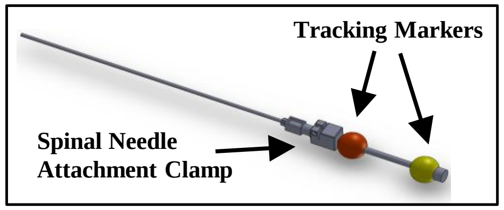

Figure 5: Spinal needle with tracking attachment

Figure 6: *Nootle* clamp by Grifiti, the attachment arm between mounting unit and and I.V. pole [3]

Figure 7: Complete system attached to I.V. stand

Future Work

- Integrating X-Ray images
- Redesign needle attachment clamp to accommodate a wider range of needles
- Restrict camera tilt
- Incorporate wireless data transmission
- Create enclosed stand attachment package
- Develop reference arc autocalibration
- Increase accuracy of tracking
- Reduce the size of trackers
- Active infrared (IR) tracking

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Testing

Stability Test: Tipping conditions caused by the mounting unit arm length were calculated using the least stable commercially available I.V. stand (Drive Medical's 4-legged Economy I.V. pole, leg length of 0.21 meters).

- *Length to cause tipping: 0.74 m*
- *Current length: 0.12 m*

Shadow Test: Using a light-obstructing board, a tracking marker was covered from directly overhead to determine the brightness threshold of the system at which the color could no longer be reliably located:

- *At minimum distance from camera of 0.31m: 15 lumins*
- *At maximum distance from camera of 2.44 m: 36 lumins*

Range Test: A tracking marker was moved incrementally by 0.15m (0.5ft) until the maximum distance the program could reliably locate the object was reached.

- *Minimum Distance: 0.31 m (1ft)*
- *Maximum Distance: 2.44 m (8ft)*

Accuracy Test: The needle tip location was calculated by the device at several locations and orientations in both the x-z and x-y planes. The system measurements were compared to the real world location.

- *Average distance off at 64.5cm: 1.50cm*
- *Average distance off at 82.5cm: 3.97cm*

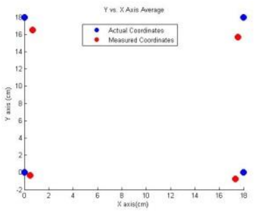

Figure 8: Actual 3D location (blue) with measured 3D location (red) in the YX plane

Discussion

Testing:

- Currently the center of gravity of the device is 0.12 m from the center of the IV stand giving it a safety factor of 5.94 due to tipping
- Ideal tracking distance is between 1.22m (4 ft) to 1.83m (6ft)
- Shadows can change hue/saturation and affect reliability, needs to be used in a well lit room
- Precision was determined to be consistently high at a standard deviation in X of 0.23cm, in Z of 0.34cm
- At 64.5cm the system was off by 1.72% and at 82.5cm it was off by 4.08%
- Without a reference arc, the system's error at varying depths increased exponentially with distance

Budget:

- Used $197.48 of $1000 budget

References

[1] Daniel, Lau. Triangulation Using Two Cameras. Digital image. *Vision-Systems.com*. Vision Systems Design, n.d. Web. 5 Dec. 2013. <http://www.vision-systems.com/articles/print/volume-17/issue-4/departments/leading-edge-views/3-d-imaging-advances-capabilities-of-machine-vision-part-i.html>.

[2] E W H To, E H Y Yuen, W M Tsang, E C H Lai, G K C Wong, D T F Sun, D T M Chan, J M K Lam, A Ahuja, and W S Poon The use of stereotactic navigation guidance in minimally invasive transnasal nasopharyngectomy: a comparison with the conventional open transfacial approach *Br J Radiol April 2002 75:345-350*

[3] Nootle 1/4 20" Clamp. Digital image. *Amazon.com*. Amazon, n.d. Web. 5 Dec. 2013. http://www.amazon.com/Grifiti-Threaded-Microphone-Diameter-Motorcycles/dp/B00E5M39AW

[4] Medtronic Stealth Navigation System, CP 101 Contract Authority & Review. 2010

[5] Trost, Gregory R. "Frameless Stereotaxis: What The Hell Is It ?" 16 June 2004