High rate machine navigation and control using low-cost MEMS and GPS

and a lot of other information about technology and commercialization

www.trustedpositioning.com
Non-technical (business/commercial)

- Starting a Geomatics company in Alberta
  - In particular, spinning off from the UofC
- How to get through the first 2-3 years

Technical

- Low-cost MEMS/GPS for machine control
  - A real-world example of building an entire multi-sensor navigation system
- Future work
Non-Technical

Company creation and business advice
A spin-off company from the University of Calgary
- Geomatics Engineering Department
- Mobile Multi-Sensor Systems Research Group (Dr. El-Sheimy)

Incorporated in 2009
- 3 co-founders (Dr. El-Sheimy, Dr. Syed and myself)
- Operational in 2010 (first hire)

Trusted Positioning accomplishments to date
- 19 employees
- Several paying customers
- Patents

The first 2-3 years of a new company are really difficult and risky.
- How did Trusted Positioning get through the first 2-3 years?
Areas of Advice

1. Building a team
2. Meaning
3. Company structure
4. Company uniqueness and niche
5. Business model (getting $ from customers)
6. Financing the meaning (getting money any way you can to start)
7. Getting technology out of the University
8. Three P words
1. **Building a team**

- 3 co-founders: Naser El-Sheimy (professor)
  - Zainab Syed (Ph.D.)
  - Myself
- Our values aligned
- Our timing aligned
- We trust one another

- A common meaning united us: the desire to create positioning systems that work everywhere
A team is built from Trust

- Attention to Results
- Constructive Conflict
- Accountability
- Commitment

TRUST
Who was Darwin Smith?
- CEO of the leading paper-based consumer products company in the world!
- Kimberley Clark, i.e. Kleenex

Who was Colman Mockler?
- CEO of the company that created the most coveted business model – the razor blade model.
- Gillette
• Who was the CEO of the leading paper-based consumer products company in the world?

• Who was the CEO of the company that created the razor blade business model?
2. **Meaning** is most important in the long run. Teams are built around meaning. A ‘great idea’ comes and goes.

- HP: purpose beyond profit
- Marriott: excellent service (even hot dogs!)
- Motorola: superior products at a fair price
- Sony: to elevate the Japanese culture and national status

- Been to a Marriott hot dog stand lately?
3. Company Structure

- Owners
- Board
- CEO
- Employees
- Customers
4. **Company Uniqueness and Niche**

- What are you the best at in the world?

**Some interesting niches were:**

- Microsoft: BASIC for OS called CPM
- Hewlett-Packard: welding equipment for WWII
- Marriott: great service food vendor
- Motorola: battery eliminators for radios
- Sony: heating pads

**These niches allowed the companies to survive the first few years**
5. **Business model.** Niche your model too.

- **Simplify it as much as possible**
  - Define an economic scale that you pursue (e.g. yearly license fee)
  - E-bay: charges a listing fee plus a commission

- **Copy someone**
  - People have been in business for thousands of years…there aren’t too many new models
  - Google: far from free and not a new model.
6. Financing the meaning

For a University start-up you may want to look into the following:

- NSERC Idea to Innovation ($125k-$350k)
- NRC IRAP (up to $250k)
- Tecterra (up to $300k)
- CICP (up to $500k)
- ISTP Canada (up to $600k)

Or raise money (good luck in Calgary)
7. Technology transfer out of the University

- This could cancel about 9/10 good ideas
- Failure a combination of
  - Inventors and tech transfer office are on opposite ends of the spectrum
    - Inventor: “I invented and created this so I should own it.”
    - Tech transfer: “We deserve X% due to that nice lab and research environment you’ve been using for four years.”
  - Both sides are somewhat correct. A balance has to be met between sides.
    - The tech transfer office can take a LONG time to agree to something – be prepared
Before you file a patent through your tech transfer office do the following

- Go to their website, read their policies
- Ask some detailed questions:
  - Are you assigning ownership & rights of use?
  - If you want the patent back, will you have to repay?
  - Are they going to market your IP or is that up to you?
  - Do they have the knowledge & capability to take your patent to the commercial level?
  - What if you want to file your patent with another firm?
The tech transfer office *should be* available to you for good reasons. Typically,

- To commercialize research coming out of the University to provide returns to the University, inventors and the community as a whole so that future research and commercialization may flourish.

- Just make sure they actually follow their meaning and are not misaligned with it.
8. **Three P words**: Passion, Persistence, and Patience

- Like what you do
- Confront the brutal facts, get accurate information, and adjust accordingly
  - e.g. Intel left memory to pursue microcontrollers
- Be able to make decisions and follow them through with perfect alignment
- Keep faith that you will prevail in the end (if you’ve confronted the facts and adjusted accordingly)
Technical

A navigation product lifecycle example
Continuous, accurate and cost effective navigation systems are not available

GNSS-only
- Not always available
- Inaccurate due to multipath

Wireless (Wi-Fi, cell location…)
- Infrastructure is expensive and not always present
- Sparse networks or poorly surveyed networks are inaccurate

INS/GNSS, either
- Expensive ($20k+) & not portable
- Or low-cost & inaccurate
Different product lifecycles for each product.

The following technical slides cover the T-MN which touches on many technical aspects of creating a navigation product.
A few details
- Essentially a strapdown INS/GNSS with additional magnetometer and barometer
- INS uses low-cost MEMS ($10-$1,000)
- GNSS (single or multiple antennas)

Applications
- Machine control & guidance
  - Precision agriculture (heading & velocity)
  - Antenna array stabilization (attitude)
- Vehicle performance monitoring
- Earthworks
1. **System design.**
   - Choosing sensors, GNSS and processor(s).

2. **Hardware design.**
   - Including layout, fabrication and assembly.

3. **Operating system or kernel.**

4. **Firmware creation**
   - Timing of the various signals in real-time.

5. **Navigation software (offline & real-time).**

6. **End user software and display (GUI).**
Attitude determination product

- Technical requirement:
  - 0.1-0.3 degrees accuracy required at 1,000 Hz
  - Vehicle mounted
  - Can be used in a variety of environments, including off-road

- Commercial requirements:
  - Parts list must be under $5,000
  - Cannot use ITAR or Controlled Goods
Constraints

- Throughput @ 1,000 Hz
- Performance vs cost (MEMS + GPS)

Hardware

- Fast clock speed on processor (1 GHz)
- Microcontrollers for accurate timing synchronization and to offload the main processor for 1,000 Hz operation
Sensors and GNSS

- **Sensors**
  - IMU from Analog Devices Inc. ~ $800
    - Good MEMS gyros (avg. 15 deg/hr in run stability)
    - Accels are average for MEMS
  - HMC5883L magnetometer ~ $30
  - MEMS barometer ~ $25

- **GPS**
  - Trimble BD982 with dual antennas ~ $4,000
  - 0.1-0.2 deg accuracy for heading when RTK fixed
  - ~60 cm accuracy for position with SBAS
The OS resides on the ARM Cortex A-8

- The OS coordinates getting the sensor and GNSS data and processing the navigation solution.
- This is all happening at high rates (1,000 Hz)

OS options

- Android (not enough low-level control)
- RTOS (very expensive and hard to customize)
- Embedded Linux (inexpensive and customizable)
Firmware is the software in the microcontrollers that sets the timing of the sensors

- IMU: 1024 Hz
- Barometer: 10 Hz
- Magnetometer: 1 Hz

If the firmware is not done properly, the timing will not be correct, and the multi-sensor navigation solution will be badly affected.
The core of the system

- Navigation state estimation (3D PVA)
- Sensor and GNSS error modelling
- Magnetometer calibration
- Multi-sensor filter
- Various alignment techniques
- Multi-threaded software application

All hardware, OS and firmware has to be nearly perfect if the navigation software has any chance of performing to specification.
Trusted Machine Navigator (T-MN) results

Downtown environments (multipath)
No GNSS environments (INS only)
Downtown Portland

- Major challenge is filtering of GPS noise
Underground Parking Lot

- Drift of INS with good initialization
Does the INS drift more with poor initialization?
Looking forward

- Upcoming releases for consumer products in 2012
- We need smart & hard working people that are aligned with our meaning