TA 1.3: The Global Positioning System: Challenges in Bringing GPS to Mainstream Consumers

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Location Awareness

As human society enters the age of increasing mobility, location awareness becomes an important attribute of the mobile communications infrastructure. Access to location information combined with appropriate infrastructure elements will (1) enable one to find the way around and reach destinations in the most efficient manner; (2) track loved ones and provide them with emergency assistance when needed; (3) develop and get location-based services; and (4) filter the incoming information based on the location. Global positioning system (GPS) is an infrastructure that provides instant location information anywhere in the world, at any time of the day under any weather conditions.

Global Positioning System (GPS): A Perspective

GPS is a space-based positioning, velocity and time system developed and operated by the US Department of Defense. The program was created in 1973 and the first GPS satellite, a Block I developmental model, was launched in February 1978. Between 1978 and 1985, eleven Block I satellites were launched to validate the concept. February 1989 marked the launch of the first operational satellite (Block II) and the full constellation of 24 satellites was achieved in 1993. The system was declared fully operational on July 17, 1995.

The GPS infrastructure has three main elements: space, control and user. The GPS space segment consists of 24 satellites, 21 navigational and 3 active spare, in six orbital planes. The satellites operate in circular 20,200km orbits at an inclination of 55° and with a 12-hour period. Each satellite transmits a spread spectrum signal on two L band frequencies, L1 (1575.42MHz) and L2 (1227.6MHz). L1 carries a precise (P) code and a coarse(clear)/acquisition (C/A) code, while L2 carries just the P-code. C/A code is available for commercial applications and is basis for standard positioning service (SPS), but the P-code is highly restricted and forms the basis for precise positioning services (PPS). The C/A code is a 1023b, repeating 1MHz pseudo random noise (PRN) code that modulates the L1 carrier signal. Each satellite has a different C/A code PRN. Each satellite broadcasts a 1500b navigation message at 50Hz that describes the satellite orbits, clock corrections and other system parameters.

The control segment consists of a system of tracking stations, one master and five monitor, located around the world. The master control has a two-way link to the satellites and provides updated navigation messages for each satellite and maintains the integrity of the system.

The user segment consists of the GPS receivers and user community. GPS receivers convert the satellite signals into position velocity and time estimates. The GPS receivers produce a replica of the C/A and/or P-Code to correlate with the satellite code and de-spread the signal. The basic technique is to use one-way ranging from GPS satellites that are also broadcasting their estimated position. Ranges are measured to four satellites simultaneously by matching the incoming signal with the user-generated replica signal and measuring the received phase against the user's crystal clock. Four satellites are typically needed to compute a solution XYZ (position) and time. With a clear view of the sky, a minimum of 6 satellites should be visible to users anywhere in the world. Figure 1 is a typical GPS receiver block diagram:

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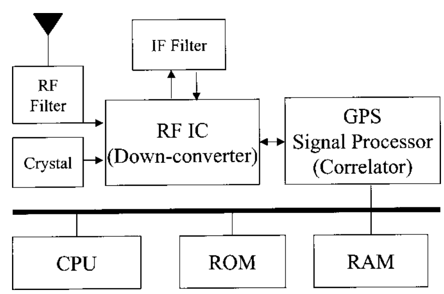


Figure 1: GPS receiver block diagram.

These receivers used to be the size of a box and cost thousands of dollars, but now a receiver module is the size of a credit card, or smaller, and costs less than $100, enabling a wide-range of potential consumer applications.

GPS Market Evolution and Mainstream Consumer Applications

The GPS market has evolved from defense-oriented applications to professional commercial applications such as surveying, timing, fleet management, marine and aircraft navigation. Now, GPS technology has started to penetrate the mainstream consumer domain. This brings up a set of new challenges. The long-term potential of consumer GPS is not as a stand-alone solution, but as a component of the overall mobile infrastructure environment. It can provide tracking, navigation and timing solutions for a range of applications in the mobile environment.

Consumer GPS applications include vehicle or personal navigation systems that combine GPS with digital mapping and destination databases; telematics systems that link GPS with wireless infrastructure to provide real-time traffic information and emergency response; cellular phones that integrate GPS to comply with FCC's enhanced 911 mandate; personal locator systems for children and elderly that can also act as a panic button by combining wireless connectivity with GPS; smart watches that are self-calibrated and location-aware to adjust time and many more. However, a number of infrastructure elements need to be put in place, including (1) digital wireless infrastructure that can support location awareness, (2) location based services & applications and (3) affordable consumer products incorporating GPS (Figure 2).

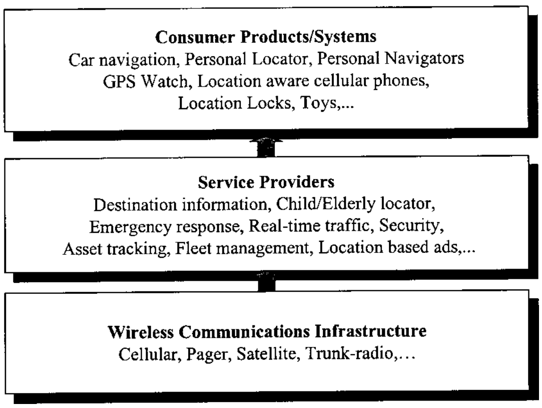


Figure 2: Consumer GPS applications infrastructure.

Challenges for consumer success of GPS

Bringing GPS to mainstream consumer applications brings a new set of technical challenges: (1) availability (2) accuracy (3) power consumption (4) size (5) cost.

Availability of GPS signal in urban canyons and foliage environment is a requirement for GPS to succeed in consumer applications. The original system, assuring visibility of at least 6 satellites anywhere in the world, was developed with the assumption of having a clear view of the sky. However, the GPS signal at -160dBw is weak and can be completely blocked by buildings in the urban canyons and significantly attenuated by the dense foliage of trees. These obstructions reduce the visibility of GPS satellites as shown in Figure 3 and thus reduce availability of GPS-based location solution.

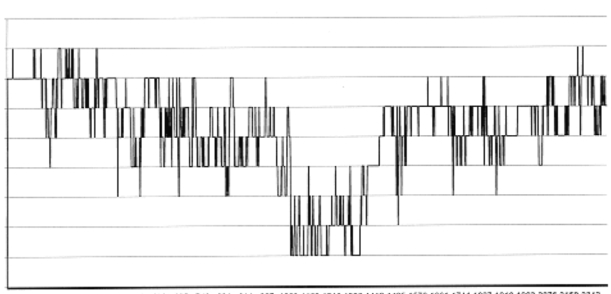


Figure 3: Satellite visibility in an urban canyon environment. V - satellites visible (9 full-scale). H. - distance (2200m full-scale).

(1) Faster acquisition and reacquisition of satellites to take advantage of short visibility intervals; (2) better ability to track weaker signals and (3) computation of location solution with less than 4 satellites visibility can significantly improve the performance of the GPS-based location solution. Faster acquisition and reacquisition require better search capability by using techniques such as multiple correlators to quickly scan for the visible satellites. Ability to track weak signals is a function of minimizing implementation losses and using signal-processing techniques to separate the noise from spread-spectrum signal. Computation of position with less than 4 satellites involves algorithms to model certain unknowns. Recent advances in GPS system architectures have shown significant progress in improving the performance of GPS in urban canyons and dense foliage situations. A GPS receiver with 100ms reacquisition time, ability to track signals to -170dBw and compute location with fewer than 3 satellites shows reasonably good results in urban canyon environments, without any dead-reckoning assistance as shown in Figure 4.

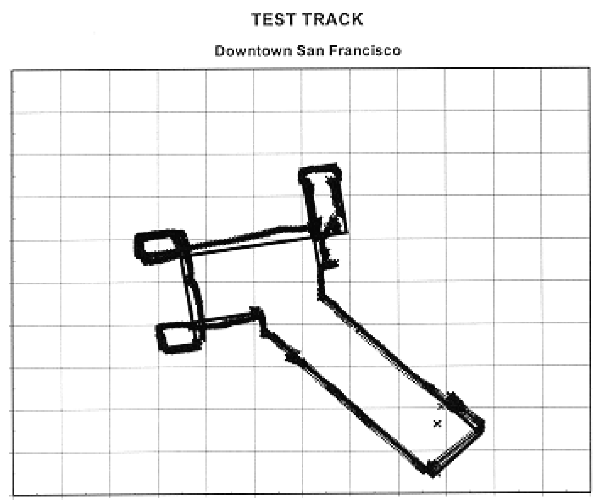


Figure 4: GPS position vs actual track. V - distance north. H - distance east. 200m units.

Accuracy of GPS-based location is a function of multiple error elements: (1) selective availability (SA) is intentional degradation of the GPS signal by the DOD, using a time varying bias. It reduces the potential accuracy of C/A code to around 100 meters. (2) Ionosphere and troposphere delays generate range errors in 10-15 meters range (3) Multipath errors are caused by reflected signals that are time delayed, thus causing ranging errors. These ranging errors are magnified by the range vector difference between the receiver and the satellites as measured by geometric dilution of precision (GDOP). GDOP is a function of receiver position relative to visible satellites.

Differential GPS (DGPS) techniques can be effective in bringing GPS location accuracy to within 3-5 meters range; good enough for most consumer applications. The DGPS implementations correct bias error by calculating the error on a known position and broadcasting individual pseudo-range corrections to GPS receivers. The US Coast Guard transmits DGPS corrections covering much of US coastline and many public and private companies provide corrections in US, Japan and Europe. Today different broadcast mechanisms are used for DGPS corrections, making it expensive. In the next 2-3 years, DGPS signals will be transmitted using geosynchronous satellites at GPS frequencies as part of the wide area augmentation system (WAAS) proposed by the FAA in US and adopted by other international agencies in Europe and Japan. This will enable DGPS support in standard silicon implementations, making it more cost effective. The WAAS satellite will also increase the availability of GPS signal in areas of low GPS satellite visibility by acting as an additional satellite in the solution. Multipath errors can be reduced by using narrow-correlator, multiple-correlator and advanced code-correlator techniques.

Power consumption is a major issue for GPS integration into battery-powered and hand-held platforms. Typical GPS receiver consumes 1-1.5W at 5V. The move to 3.3V 0.35µm CMOS and BiCMOS process technologies has enabled reduction in power consumption to <500mW. Further power reductions can be achieved using hardware and software power-management techniques. To enable GPS in a watch-type application, development of low-voltage process technologies that can perform at < 2V is required. Technologies in 1-1.5V range will also be more suitable for digital-RF integration to reduce power, size and cost.

Size of a typical GPS receiver is now small enough to fit in a wallet, but still too large to put in a child-locator or a cell phone or a watch. Advances in silicon technology will enable integration of most of the digital logic to decrease in size, but RF integration is still an issue. The RF section needs high-performance 12-15GHz f_T process technology to lock on to 1.575GHz signal, but a low-noise, low-f_T digital technology to reduce digital interference. A GPS receiver is sensitive due to the weak incoming signal and susceptible to self-jamming as the digital section gets closer to the RF section. Fast transitions in the digital logic can easily cause self-jamming especially in receiver designs with integrated antennas. As the process technologies move to lower voltage levels and develop better isolation structures, it will become more practical to move towards RF-digital integration for GPS. New processes, such as 0.18µm CMOS with optimizations for RF integration, have the performance, but CMOS devices may not meet the low-noise threshhold needed for GPS. SiGe and SOI processes with good signal-noise characteristics provide interesting options, but need to be more cost effective.

Another issue in size reduction is reducing size of antenna. A typical GPS patch antenna has a narrow-band structure, about 3MHz, due to its size. Maintaining it centered around a 1575 band in high volume production environments is a challenge. The narrow band allows makes it susceptible to proximity effects that become an issue in hand-held environments.

Cost is clearly the driving force behind the mainstream consumer success of GPS. Today a GPS receiver bill of material is down to $50 range, but integration into cell-phones and other platforms requires a cost structure in a range of $20 or less. Higher-level integration can drive the costs down by reducing the number of components, but the sensitive nature of GPS signal requires careful screening of components such as crystals. Typical GPS receivers used to require TCXOs and sophisticated SAW filters, but now many of those requirements have been relaxed by using improved signal-processing techniques. Tracking a weak signal at 50Hz data rate still requires good quality crystals that maintain phase coherence over a 20ms period. Since the receiver is running narrow loops, phase jumps in 1-50Hz range cause cycle slips. Further advances in system architecture will enable elimination of more of the tight-tolerance components.

Conclusion:

The GPS technology has exciting potential for bringing location awareness to many mainstream consumer platforms and making lives more convenient and safe. These opportunities bring a new set of technical challenges that can be solved through better infrastructure, improved receiver architectures and use of high-performance, low-cost and low-voltage process technologies.

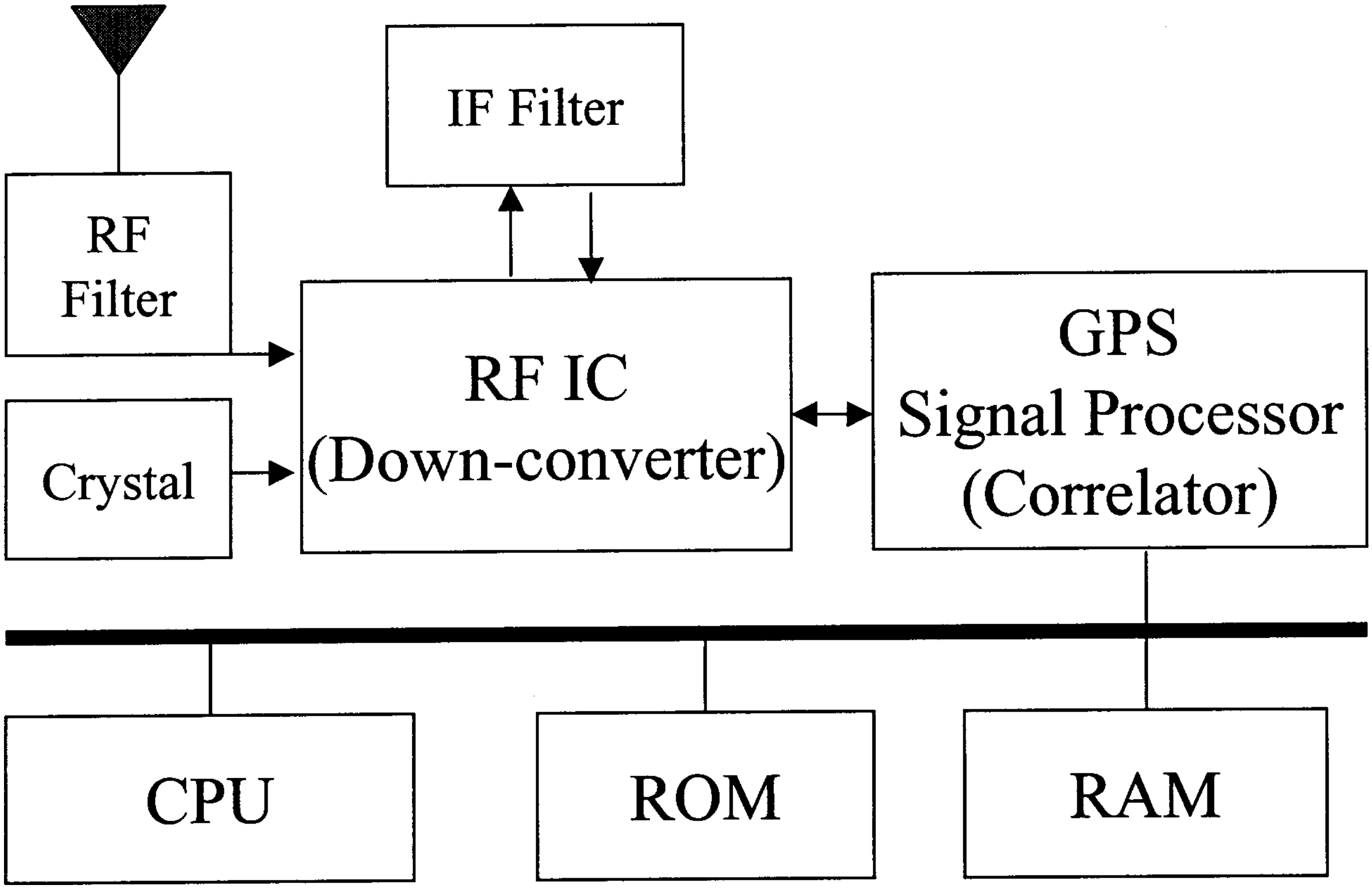
References:

[1] Dana, P., *The Geographer's Craft Project*, The University of Texas, Austin, TX.

[2] US Coast Guard Web Site.

[3] Global Positioning System: Papers Published in NAVIGATION, vol. I: The Institute of Navigation, Washington, D.C.

[4] Parkinson, et al., "Global Positioning System: Theory and Applications," American Institute of Aeronautics and Astronautics, Inc., vol. I.



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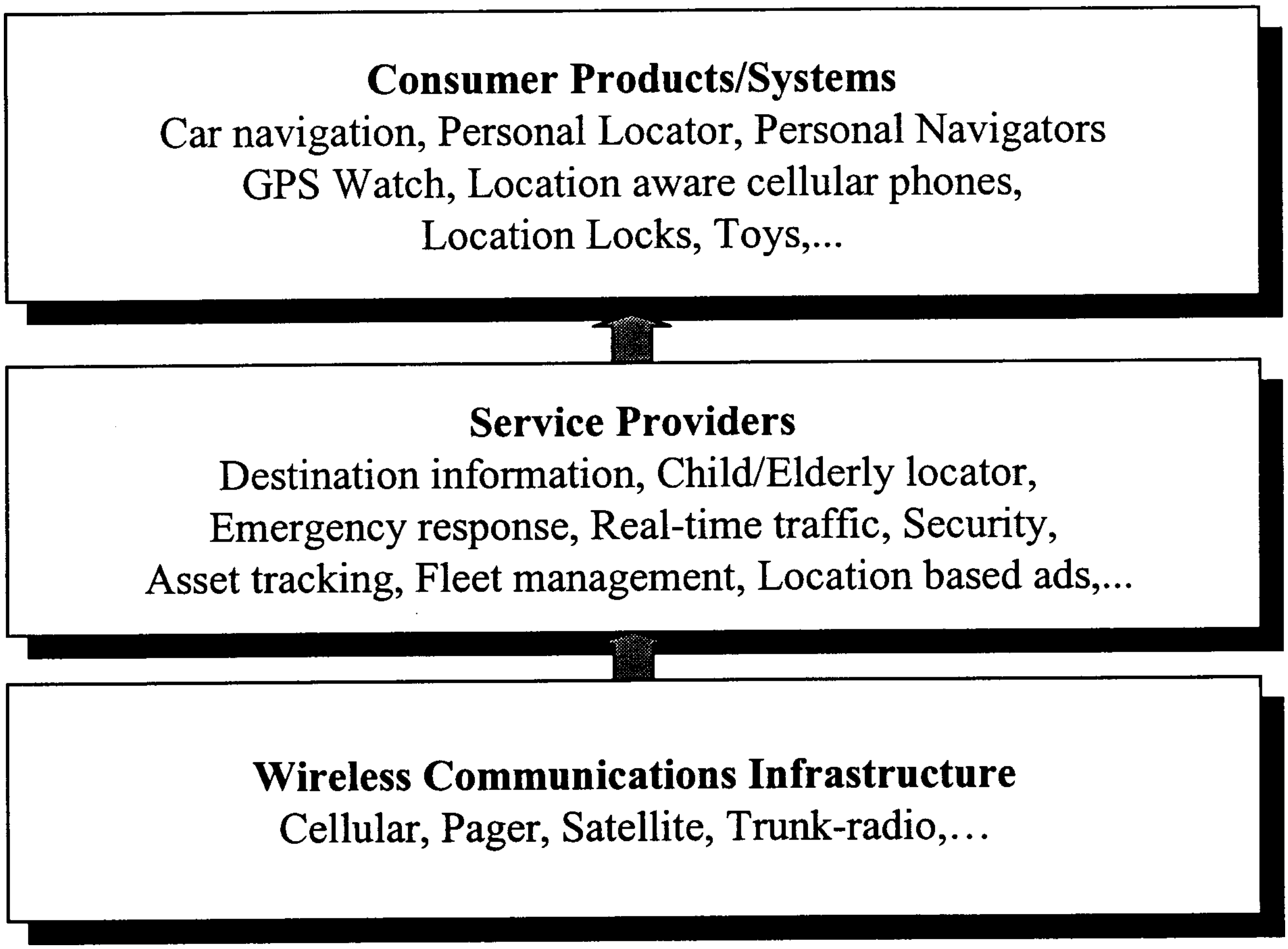
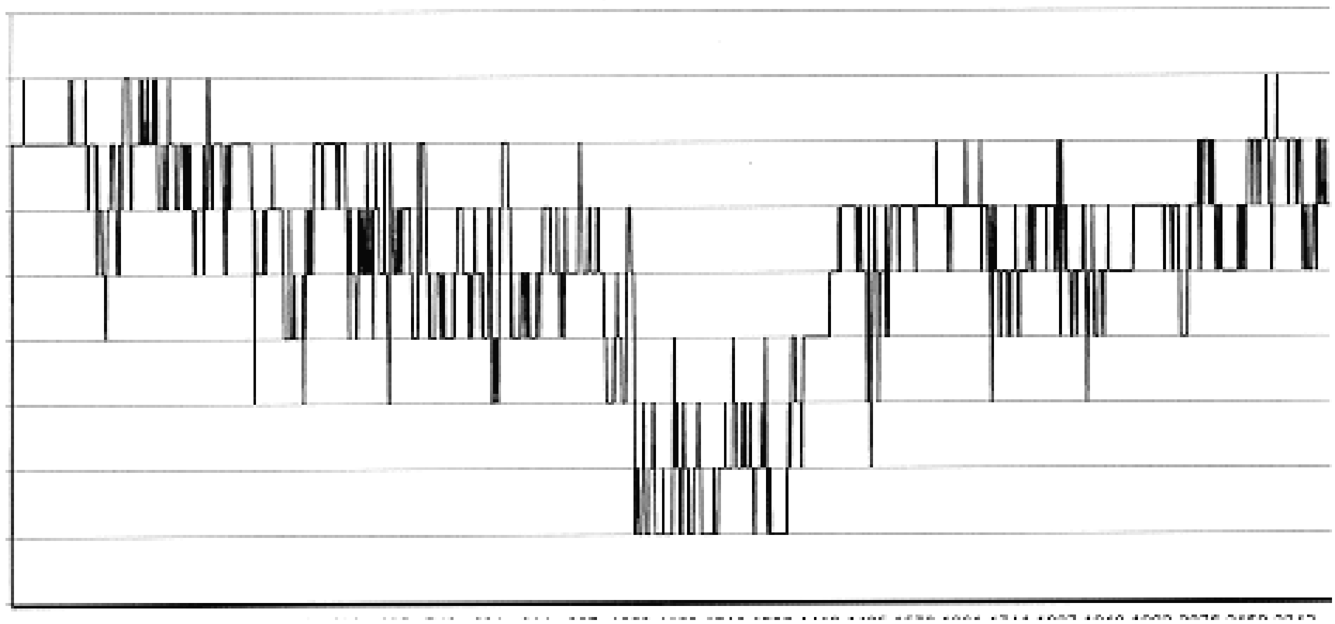


Figure 2: Consumer GPS applications infrastructure.



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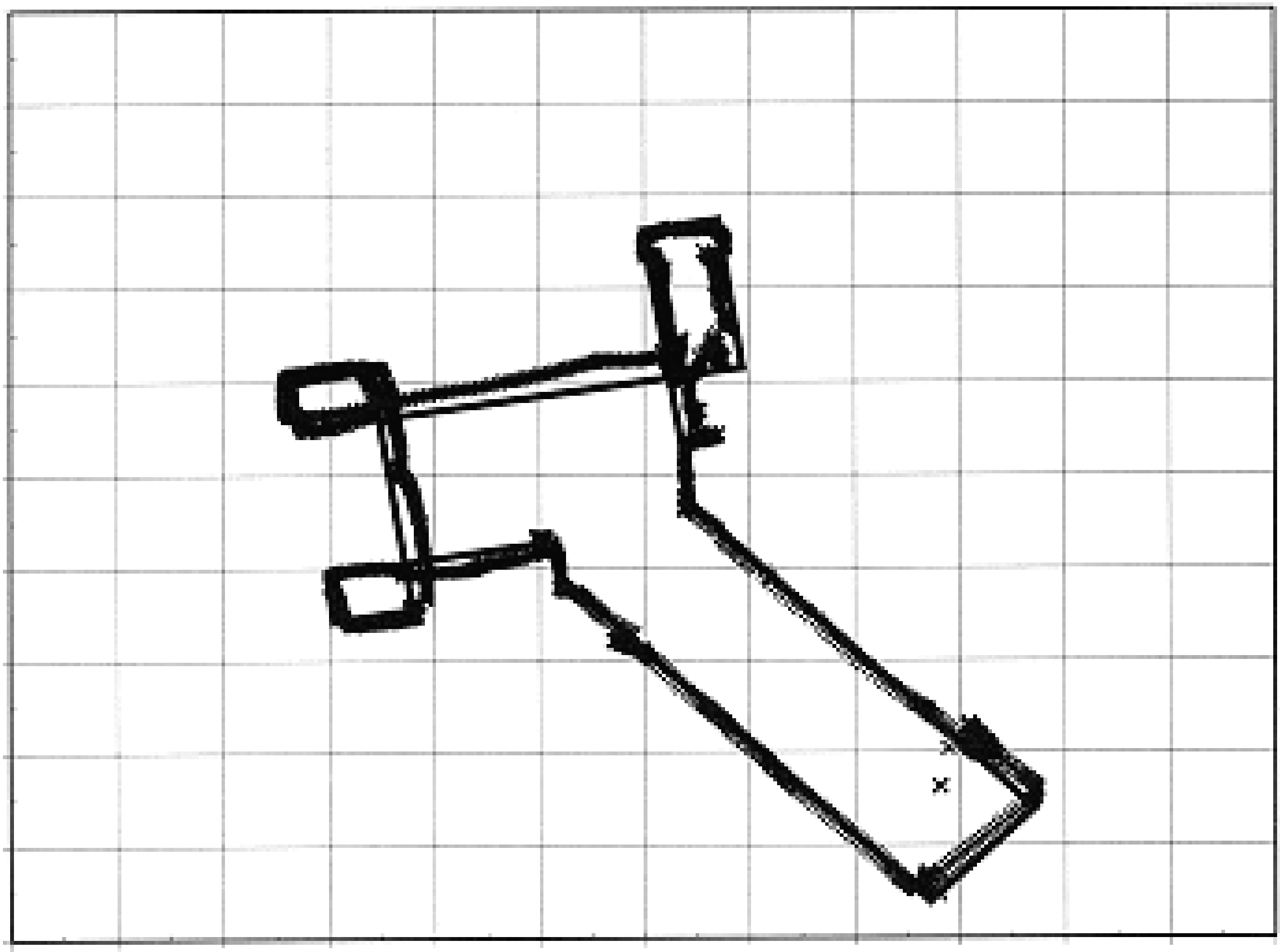
TEST TRACK

Downtown San Francisco



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