Development of Low cost mobile platforms for indoor tracking, navigation and geo-location

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Abstract
This paper describes a novel method to locate and track entities in the absence of conventional navigation systems like Global Positioning Systems (GPS). The goal of this project is to develop low cost mobile platforms for Army Tactical Engagement Simulation training exercises that can demonstrate alternate and innovative tracking methods in urban combat areas. These platforms will play a crucial role in the Future Combat Force (FCS), as a soldier, linked to these platforms and sensors will have access to data that can provide a much more accurate picture of his surroundings. We are researching and testing schemes that will enable us to locate and track entities inside buildings, caves and dense foliage where GPS signals cannot be received. A host of sensors including Inertial Measurement Unit, GPS receiver, wireless video, Sonar, and rotary Optical encoders is used to extrapolate the GPS data as the entity loses the GPS signal when moving into an indoor location. A tablet PC acts as the central control and command terminal to receive sensor data and also to control and monitor the platform. A live wireless video from an on-board infra-red camera mounted on the platform is also displayed on the PC. To ensure constant communication with the mobile platform, we are using a Mobile Ad-hoc routing protocol (MAR) to “hop” the sensor and control data between the platforms and the central control station through other platforms on the field. We used a 1/6 scale model of an off-road vehicle to mount on-board a small form factor computer, microprocessors and sensors. Software routines in Java are used to control and collect data from the sensors through the microprocessor. The on-board computer is used to compress the MPEG2 video signal feed from the miniature infra-red camera and transmit it to the central station through a wireless 802.11b wireless router in ad-hoc mode. The computer also performs sensor data integration and Kalman filter technique for sensor data error corrections and calculating the indoor geo-location data which is then transmitted through the wireless router to the PC. We are currently working on developing and testing multiple platforms that can collaborate and reconnaissance a combat zone. These teams of platforms could be used as expendable assets for locating and tracking enemies inside urban combat zones and could potentially save lives of soldiers. One of the features of this project is that all the hardware components are assembled from commercial off-the-shelf products that are easily available. Also the software was developed under Linux Operating system and the source code will be released under the GNU public license.

Introduction
In recent years there has been considerable interest in developing indoor navigation and tracking systems. Many universities and research institutes have developed new techniques for these systems [1, 2, 3]. We have been developing our own unique system that will use sensor integration and Kalman filter techniques for navigation and error correction. The goal of this project is to develop low cost mobile platforms that can be used during the Army Tactical Engagement Simulation training exercises. In these exercises sensor and navigation data will be routed between entities and also relayed back to a control station for control and after action review (AAR). The research work is being carried out by the Institute for Simulation & Training for the US Army Research Development and Engineering Command – Simulation Training Technology Center (RDECOM-STTC) as part of an Advanced Position/Navigation & Tracking for the Future Force – Army Technology Objective (ATO).

Approach
In selecting a Commercial off the Shelf (COTS) mobile platform for this project, it was necessary to meet certain criteria. These include: ruggedness, terrain scaling ability, a small platform for energy efficiency, a

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14. ABSTRACT

This paper describes a novel method to locate and track entities in the absence of conventional navigation systems like Global Positioning Systems (GPS). The goal of this project is to develop low cost mobile platforms for Army Tactical Engagement Simulation training exercises that can demonstrate alternate and innovative tracking methods in urban combat areas. These platforms will play a crucial role in the Future Combat Force (FCS), as a soldier, linked to these platforms and sensors will have access to data that can provide a much more accurate picture of his surroundings. We are researching and testing schemes that will enable us to locate and track entities inside buildings, caves and dense foliage where GPS signals cannot be received. A host of sensors including Inertial Measurement Unit, GPS receiver, wireless video, Sonar, and rotary Optical encoders is used to extrapolate the GPS data as the entity loses the GPS signal when moving into an indoor location. A tablet PC acts as the central control and command terminal to receive sensor data and also to control and monitor the platform. A live wireless video from an on-board infra-red camera mounted on the platform is also displayed on the PC. To ensure constant communication with the mobile platform, we are using a Mobile Ad-hoc routing protocol (MAR) to ?hop? the sensor and control data between the platforms and the central control station through other platforms on the field. We used a 1/6 scale model of an off-road vehicle to mount on-board a small form factor computer, microprocessors and sensors. Software routines in Java are used to control and collect data from the sensors through the microprocessor. The on-board computer is used to compress the MPEG2 video signal feed from the miniature infra-red camera and transmit it to the central station through a wireless 802.11b wireless router in ad-hoc mode. The computer also performs sensor data integration and Kalman filter technique for sensor data error corrections and calculating the indoor geo-location data which is then transmitted through the wireless router to the PC. We are currently working on developing and testing multiple platforms that can collaborate and reconnaissance a combat zone. These teams of platforms could be used as expendable assets for locating and tracking enemies inside urban combat zones and could potentially save lives of soldiers. One of the features of this project is that all the hardware components are assembled from commercial off-the-shelf products that are easily available. Also the software was developed under Linux Operating system and the source code will be released under the GNU public license.

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large enough platform to fit the computer and sensors, and structural design capable of being expanded. The platform we selected was the Tamiya TXT-1 off road vehicle. The TXT-1 is the largest electric off-road truck available on the commercial market. The vehicle's frame is constructed of an Aluminum alloy allowing for great strength without a great amount of weight. This also lends it self to chassis expansion. The four-wheel drive TXT-1 also has a four-link suspension as well as a front and rear open-differential gear box for increased maneuverability and turning.

Figure 1&2: Off-road platform with on-board computer, controllers and sensors

Computation & Sensors and Communication

Main processor: We chose a PC/104 stack as the central computer for this vehicle. The PC/104 has at its core, an Advance Micro Peripherals Limited Micro886 processor board and 1GB of Compact Flash for disk storage. Under idle conditions, this computer consumes less than 9 watts of power, due largely to the use of a 1GHz Transmetta Crusoe processor designed for this consideration. Additionally, the PC/104 stack is very small in comparison to other alternatives such as the Mini-ITX standards. The PC-104 is equipped with a 1GB Compact Flash Disk (CF-Disk). This is ideal for mobile platforms as there are no moving parts. While the CF-Disk slower to access than a traditional hard drive, it is fast enough for the purposes of this platform and therefore was the best option for our application.

Sensors: The next task was to select sensors that would be hosted on the platform. These sensors have to be miniature and also robust to support our application. Also these sensors need to be supported under Linux and there should be drivers available that will make these sensors compatible to work under Linux. The GPS unit that we used was an UBlox RCB-LJ GPS Receiver unit which is capable of outputting NMEA data, as well as a number of other protocols. This unit communicates via RS-232 serial to the PC/104 computer. We also used a MicroStrain 3DM-GM 3-axis Inertial Measurement Unit (IMU) that will be able to measure the 3-D movement of the platform and commercial webcam that can relay a live video feed from the platform to the control station. We tried to ensure that all the hardware components used were COTS equipment and would be easily available for future scalability. All the sensor and control packets and communicated between the platform and the control station through an 802.11b wireless link. A high power PCMCIA card is used on the platform for this purpose. Unlike conventional cards which are low power (50mW), the card we have used for our application is a high power NL-2511CD+ card having a 200mW output.

Power requirement Tests

We calculated the power consumed by the different components on the platform to determine the actual run-time for the platform based on the batteries that we could accommodate. The table 1 below shows the power requirements of the different components on the platform

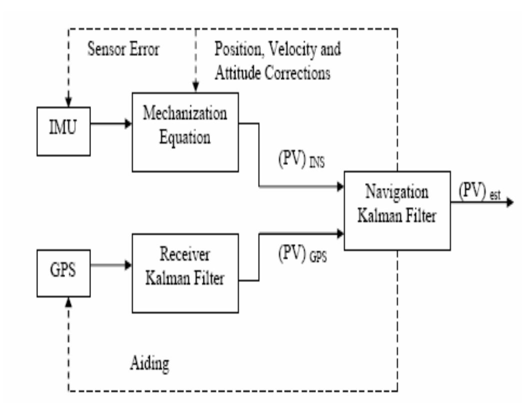
Component	**Voltage**	**Current**	**Power**
PC-104 Board	12 Vdc	5A	60W
MicroStrain IMU	5 Vdc	90 mA	0.45W
Camera	9 Vdc	250 mA	2.25W
IsoPod Controller	5 Vdc	300 mA	1.5W
GPS	12 Vdc	100 mA	1.2W
Wireless card	5 Vdc	30 mA	0.15W

Optical Encoder	5 Vdc	30 mA	0.15W
Total Current		5.8 A	65.7W

The six batteries on the platform are Lithium Ion rechargeable batteries that have a supply current of 15 Ampere-hours. Diving this value by the total current drawn by the different electronic components on the platform give us a run-time of 2.5 hours. Thus the platform can be operational for this period after which it has to be brought in to recharge the batteries.

Sensor Integration Testing

When the platform moves from outdoors to indoors the GPS data no longer registers in the system. We software will continuously monitor the GPS data and when it no longer updates we switch over to using the data from the onboard inertial sensors. The onboard sensor data will be used to extrapolate from the last known GPS position that was recorded by the platform. The onboard Inertial Measurement Unit (IMU) measures the roll, pitch and yaw of the platform. Inertial navigation systems (INS) in principle permit autonomous operation. However, due to their error propagation properties, most applications require high-terminal accuracy, and external aiding is usually utilized to reduce the INS errors. In a loosely coupled system that we used, the GPS receiver has its own Kalman filter to process which are used to calculate positions and velocities. GPS-derived positions and velocities are combined with INS positions and velocities to form the error residuals which are sent to the navigation Kalman filter. This filter corrects the INS in a feedback manner, and the effects of biases and drifts, as well as misalignment errors, will be significantly decreased [4].



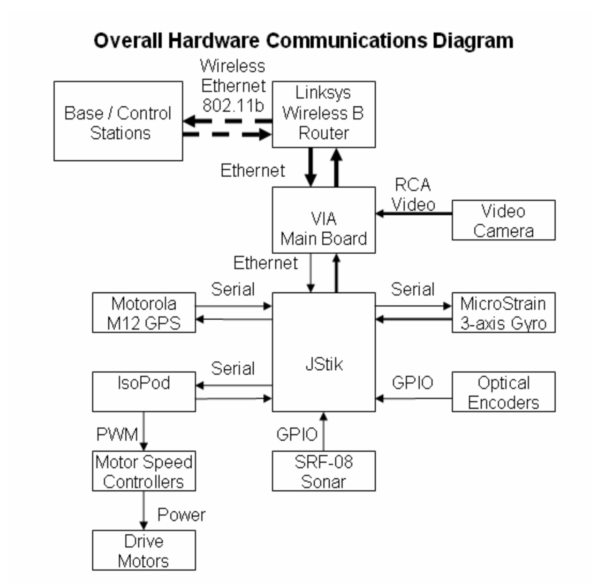


Figure 3: Loosely coupled INS/GPS navigation system Figure 4: Overall hardware communication diagram

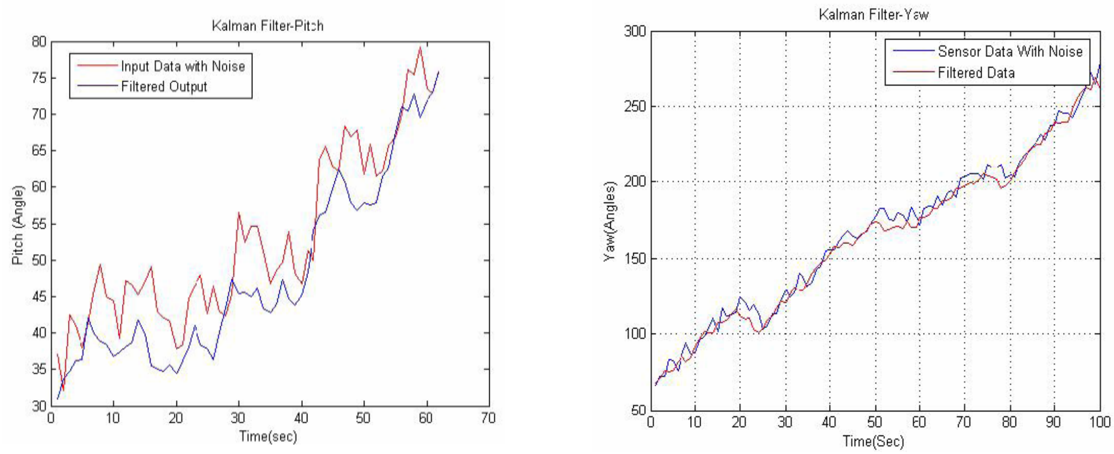


Figure 4: Kalman filter error correction for Pitch and Yaw movement from the IMU

When the yaw data from the IMU that gives the direction of motion is combined with the distance measurement from the optical encoder mounted on the wheels we could accurately measure the direction and distance traveled by the platform using dead-reckoning. We conducted tests and measurements support our research and compared the geo-location of the platform on a 2-D grid versus the GPS coordinates over a distance traveled. It was observed that over a period of time the geo-location data stabilized and showed similar values as the raw GPS data indicating that the software requires a finite amount of feedback data to reduce the overall errors.

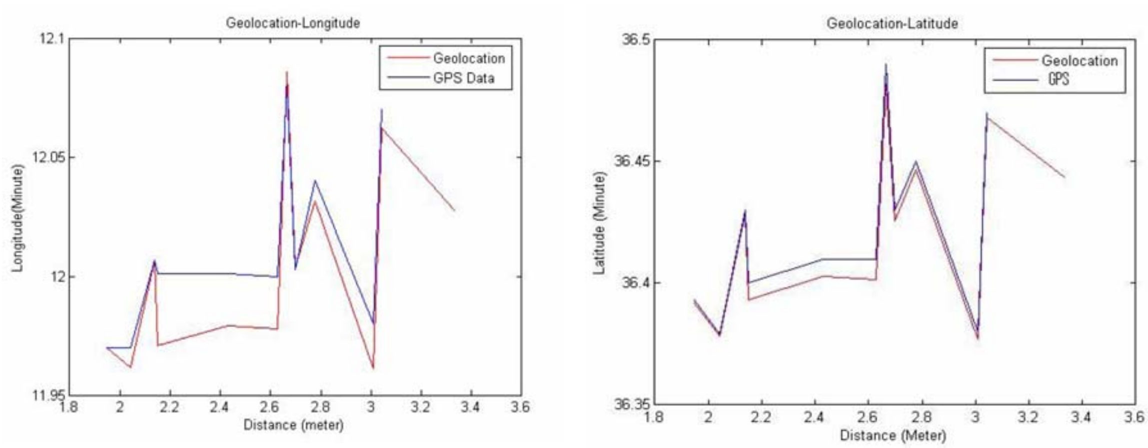


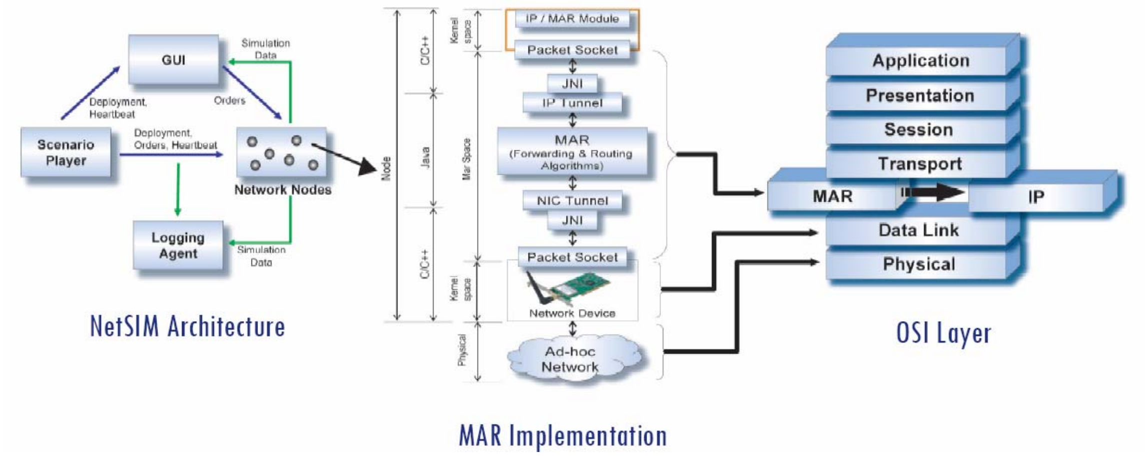
Figure 5&6: Longitude and Latitude data comparison of Geo-location data

Mobile Agent-based Routing

In such a situation that the platform cannot directly communicate with the control station we use the ad-hoc MAR protocol to "hop" the sensor data back to the control station through a series of intermediate platforms. The MAR protocol is a ad-hoc network based implementation providing automatic rerouting of connections in a mobile ad-hoc network and also Quality of Service (QoS). Some of the main features of MAR are:

- Ad-hoc routing with Quality of Service (QoS) guarantee
- Hybrid approach
- Priority based link preemption
- Negotiation-based topology exchange for overhead reduction
- Supports reconnection, preventive, opportunistic and priority rerouting
- Automatic multi-channel routes
- Hidden terminal interference considered during routing
- Seamless integration with IP networks (no bridges required)

MAR protocol is accompanied with the NetSim, a distributed agent simulation tool. NetSim provides an easy to use visualization of the network nodes and the associated traffic flow. Performance metrics can be easily evaluated using NetSim.



In designing the robot control system, we have begun developing a Common Robotics Architecture (CRA) to readily support our robotics needs. The CRA is critical to this project and its future expandability and maintenance. The high-level software architecture is a client-server design. This protocol is being designed to send specialized Protocol Data Units (PDU) over the network. This is a valuable addition for several reasons. First, the development of a PDU types allows for easy data dissemination across the network and eliminates the need for “direct-driving” from the network to the hardware control system. Secondly, eliminating the direct-driving system forces the control packets to follow a specific format, thereby virtually eliminating the possibility of accidental turns or commands that could cripple the platform on the field. Finally, we increase the safety of the system by implementing a timestamp in the PDU header to ensure data ordering. CRA library and protocol has much further-reaching implications and possibilities for future capabilities. We will be able to reuse the code for developing multiple platforms which are homogeneous and therefore easy to integrate into the overall network.

Conclusion and Future Work

One of the major impacts of this application would be to assist the Army in locating and tracking soldiers in hostile urban environment in the absence of GPS data. Units equipped with the sensors would be able to relay sensor data to other units in the team and also to a control station for effective monitoring. One of the civilian applications would be to track firefighters in buildings and doctors in hospitals. This work has helped us gain an understanding of many concepts related to networking, sensor fusion and robotic control. We plan to leverage off this work to actively develop autonomous robots that can navigate any terrain for reconnaissance and surveillance.

Reference:

[1] Frank Dellaert, Ashley W. Stroupe (2002). Linear 2D localization and Mapping for Single and Multiple Robot Scenarios. Proceedings of the IEEE International Conference on Robotics and Automation

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[3]. Reid Simmons and Sven Koenig (1995). Probabilistic Robot Navigation in Partially Observable Environments. Proceedings of the International Joint Conference on Artificial Intelligence, (pp 1080—1087)

[4] Thao Pham, et al (2005), Indoor location & tracking system using Cognitive Packet Network Protocol, IMAGE Conference, Phoenix, AZ

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RDECOM

Project Goals

- Develop a low cost unmanned mobile platform for Army Tactical Engagement simulation exercise to support the OneTESS program demonstration.
- Assist in locating and tracking entities in hostile urban environment in the absence of GPS data
- Relay sensor data to control station for effective monitoring of entities and After Action Review
- RDECOM funded project for the Advanced Position/Navigation & Tracking for the Future Force – Army Technology Objective (ATO)

Indoor Geo-Location

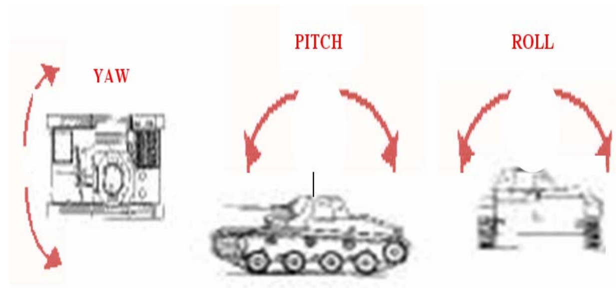
- Novel method for locating and tracking an entity in the absence of GPS signal
  - Inside buildings, tunnels, dense foliage
- Sensor Integration & fusion using Inertial Measurement Unit, Optical encoder, laser range finder and Sonar
- Mobile Ad-hoc routing protocol to relay sensor data from the platform to the control station

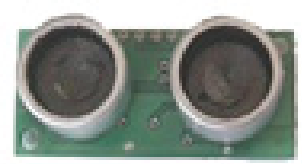
Comm./Nav. platform

- RC truck platform with off-road capabilities
- Modified to host sensors including GPS, Inertial Measurement Unit (IMU)
- On-board PC-104 computer and microcontroller used to process the collected sensor data.
- 802.11b wireless in Ad-hoc mode to transmit data to the central control station.

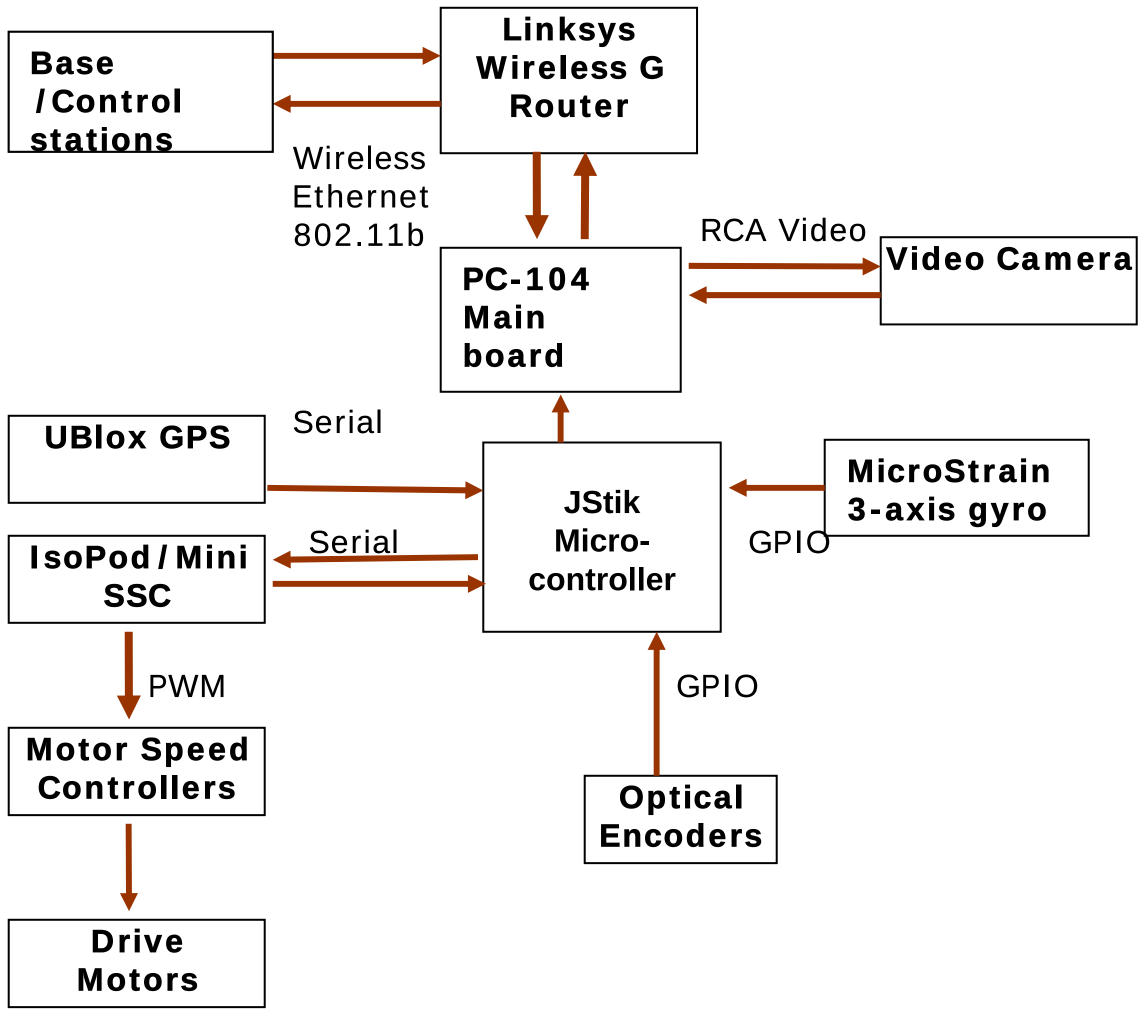
Sensors

- Inertial Navigation System
  - 3- Axis Gyroscope: Roll, Pitch, Yaw
- Optical Encoder
  - Estimate distance traveled.
- Sonar, video for obstacle avoidance
- Infrared video camera
  - Relay live video feed to the control station.
- GPS Unit
  - For outdoor navigation





Hardware/Communications



Hardware description

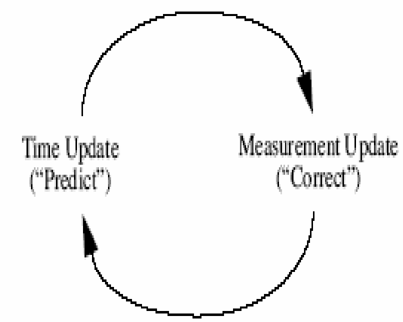
- PC-104 small form factor board, 1 GHz Transmeta Crusoe processor, 1 GB CF card.
- JStik microprocessor based on JAVA.
  - Used for controlling the sensors
- Onboard wireless 802.11b Router.
  - Wireless communication to tablet PC.
- UBlox GPS unit (L1 frequency), IR (70 degree) wide-angle camera
- Microstrain IMU - 0.1 degree accuracy/0.5 degree degrees error
- Sonar – Range: 6 meters

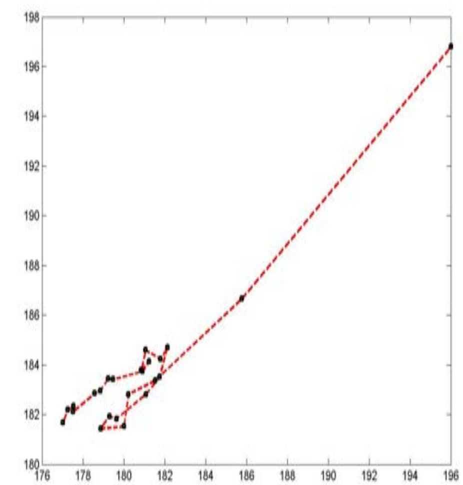
Indoor Location and Tracking

- GPS data unavailable when we move indoors
  - Automatic switch to data from inertial sensors
- Inertial sensors used to extrapolate from last known GPS position
- Yaw/Pitch data from IMU provides direction of motion
- IMU data combined with distance from optical encoder using dead reckoning
- Kalman filter for error correction

Sensor Integration & Testing

- Combine and filter sensor data
  - Tank orientation (RPY) from IMU
  - Distance based on encoder data.
- Kalman Filter
  - 2 stage process
  - Predict and Correct

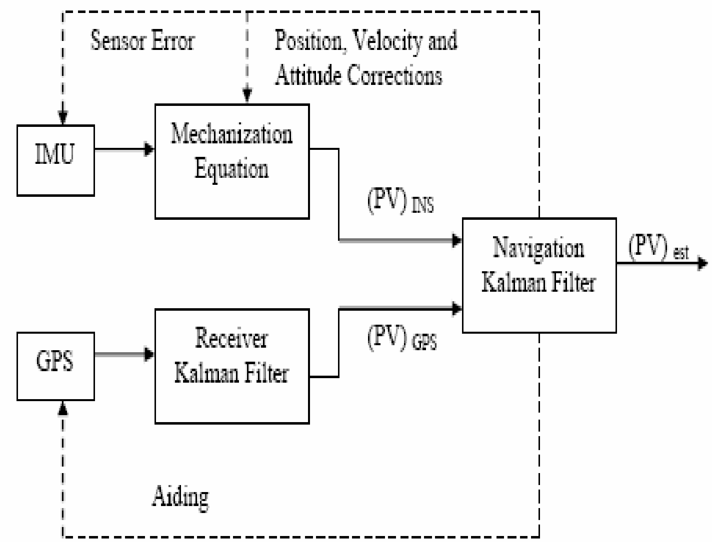




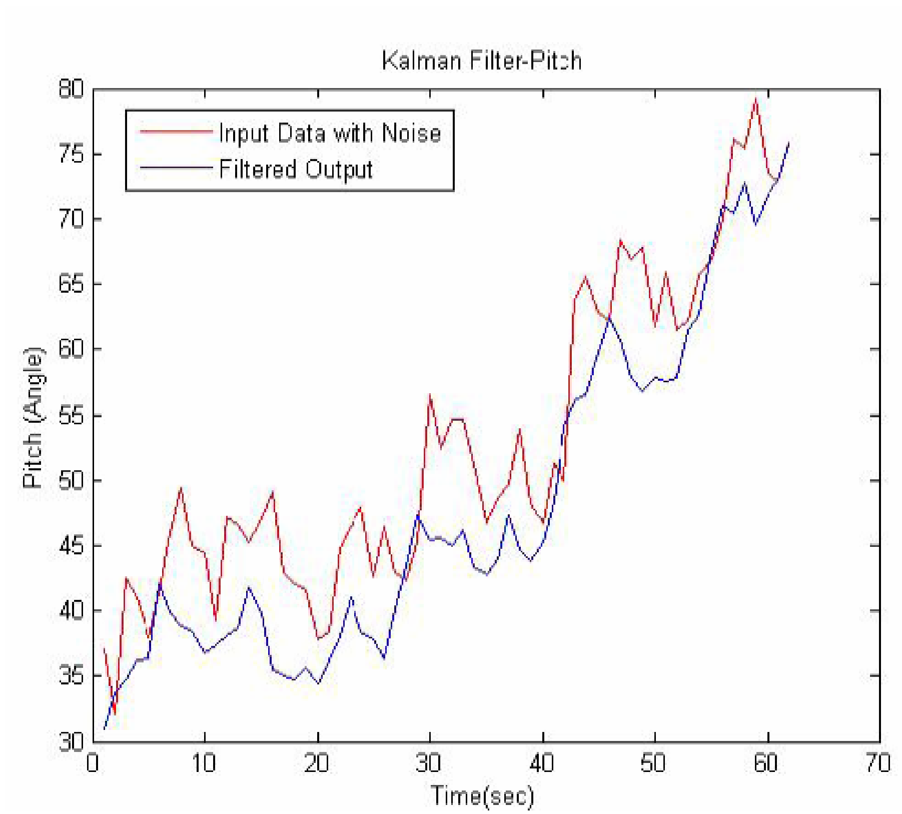
Two-dimensional grid display of the path of the platform

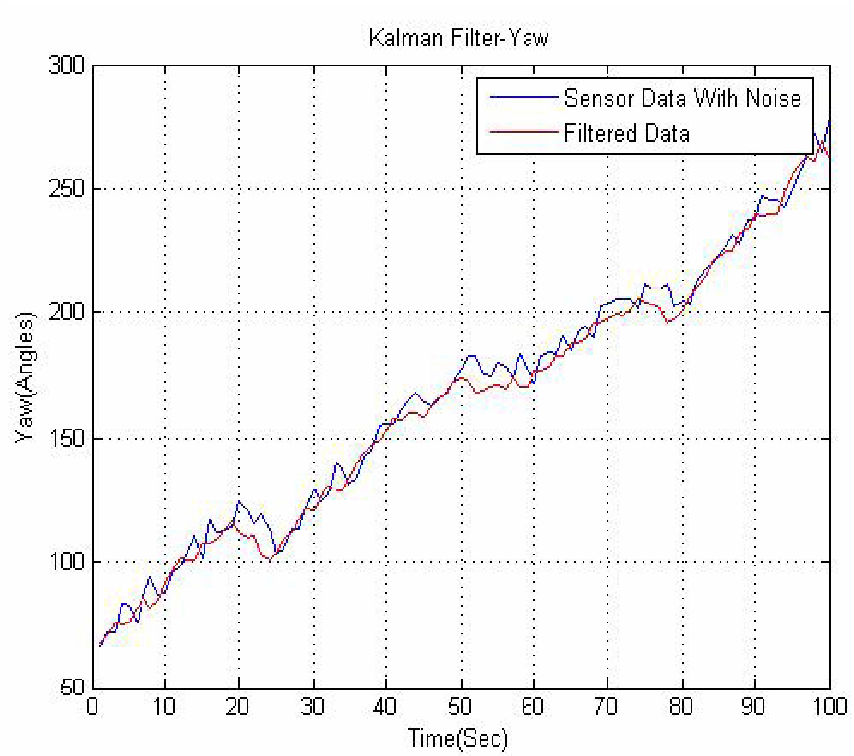
Kalman filter

- The Kalman Filter is an extremely effective and versatile procedure for filtering out noisy sensor inputs.
- It allows for the estimation of the state of a system with uncertain dynamics
- The actual sensor measurement are passed through the Kalman filter to compensate for errors and sensor drift



Kalman filter Testing



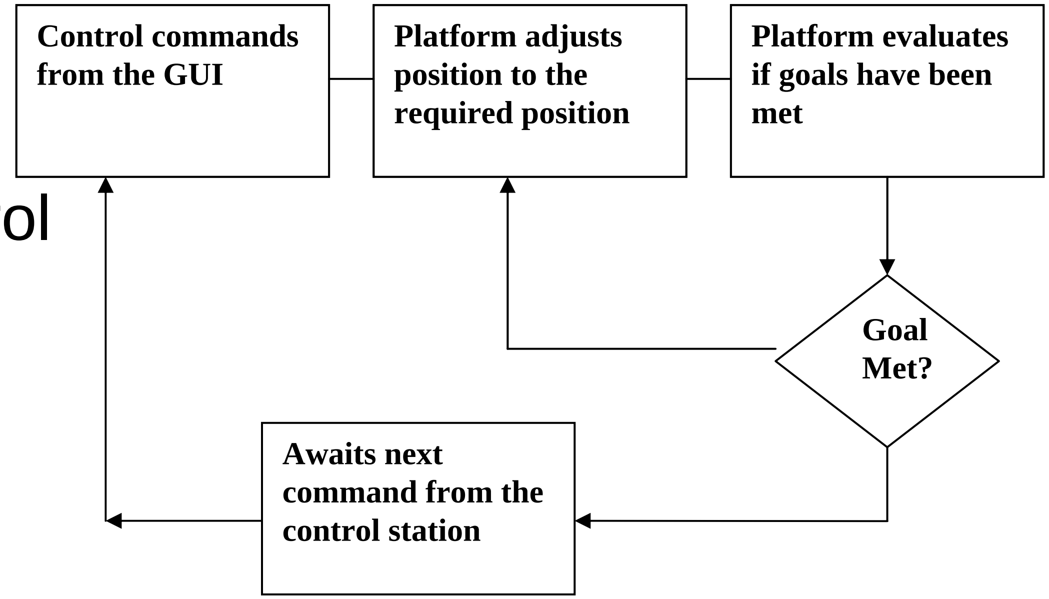


Power and Range testing

- Demo time specified – 6 hours
- Li-Ion batteries with 9 Amp-hours power for the electronics and drive motors
- Load tests on Electronics – Average current drawn 1.2 A
- Load tests on drive motors – operated for 4 hours continuously

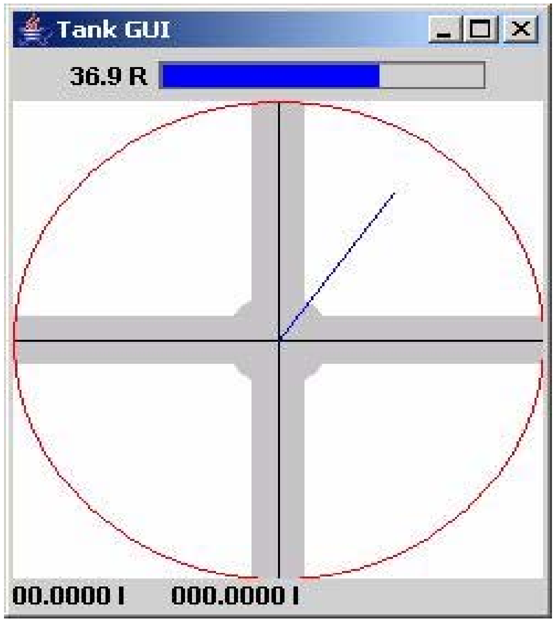
Control Station

- iPAQ
  - HP-5550 Hand Held device (400 MHz, XScale processor)
  - “Familiar” Linux-3.0 and Java.
  - Enables wireless communication.
  - 3-Nodes and 1 control station.

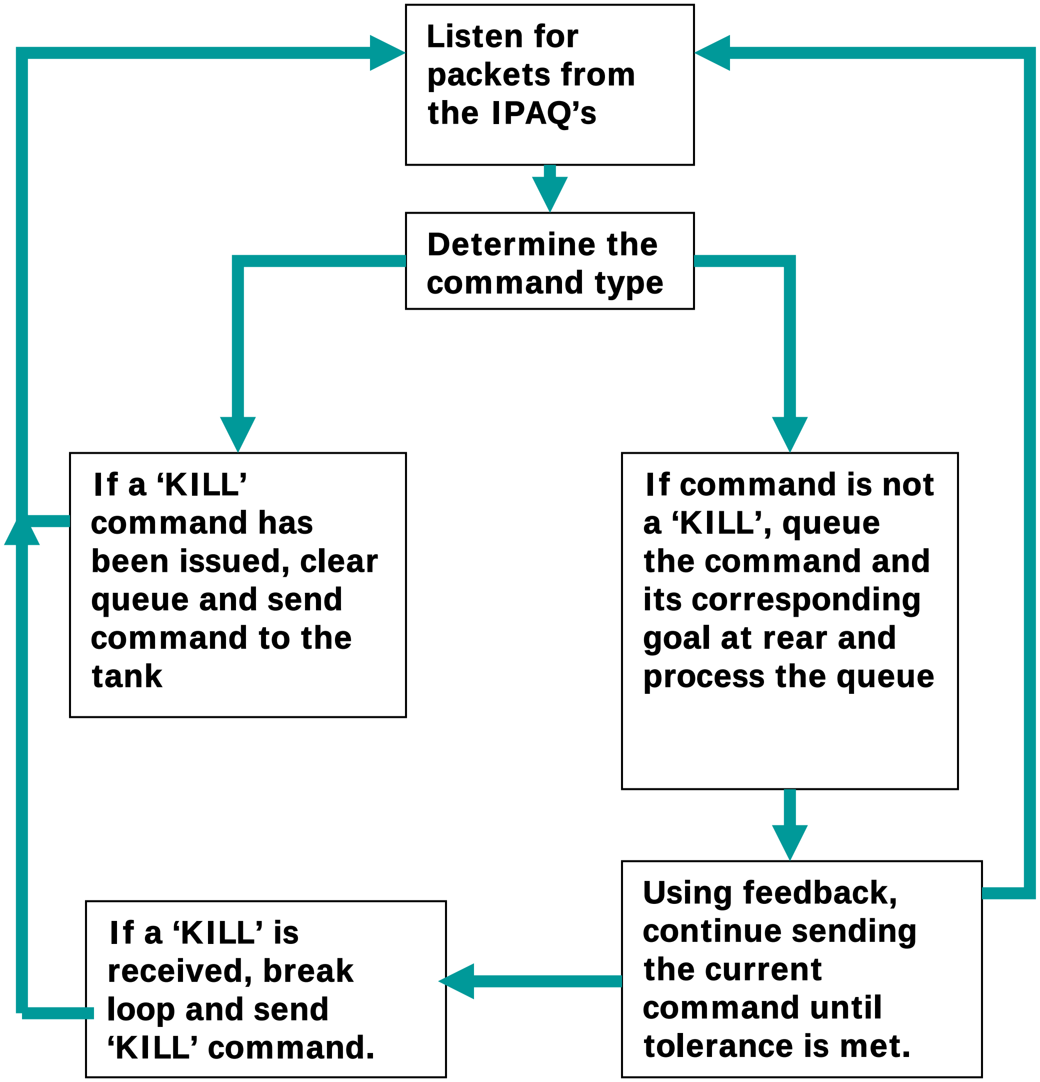


Graphical User Interface

- Java based GUI on iPAQ/tablet PC.
- Easy to use interface for command and control.
- Display Sensor data and Control the platform
- Option to switch to video or control mode



High Level Design of Control



MAR Network

- Used to extend network range by "hopping" data over the network.
- Data routed intelligently through intermediate nodes (other platforms)
- Individual performance metrics can be specified.
  - Packet loss, Error rates, Transmission time.

Features

- Scalability of the system to include multiple entities
- Reusability of software code
- Commercial Off-the-shelf hardware
- Free source software, Linux, Java, C++

Future Work

- Build and deploy multiple platforms in a network
- Multiple platforms act as master-slave
- Supplemental nodes help transmit data
- Controlled by a network of iPAQ’s