The Future Soldier System

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Background. Rapid urbanization is changing the physical and political face of nations. The resultant population concentration has ensured that many future military operations will be taking place in urban environments. In today's war on terror, American soldiers are in desperate need of technology that will help them survive in the fight against terrorists in these urban environments characterized by the most dangerous and unpredictable type of combat which is CBQ (close quarters combat). Soldiers need information about what is around the next corner. Commanders need organized situational information to make better tactical decisions.

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To address these needs, Elliot Levy-Bencheton, Vincent Leone, and Asim Chaudry, undertook to develop the Future Soldier System, or FSS, in the context of a course at Polytechnic University. The purpose of this document is to provide an overview of the technology, cost, and benefits of the Future Soldier System.

The Future Soldier System. The FSS is a combination of two separate and distinct systems, one that operates on the individual soldier level and the other that operates at the base commander level. These two systems communicate with each other over radio frequency and provide both the individual soldier on the battlefield and his commander a revolutionary new degree of situational awareness. The FSS provides soldiers and commanders with organized information that can save soldiers' lives and help them win battles. Additionally, the technology that we developed on the FSS can be extended to different scenarios and operators, including policemen, firemen and search and rescue teams.

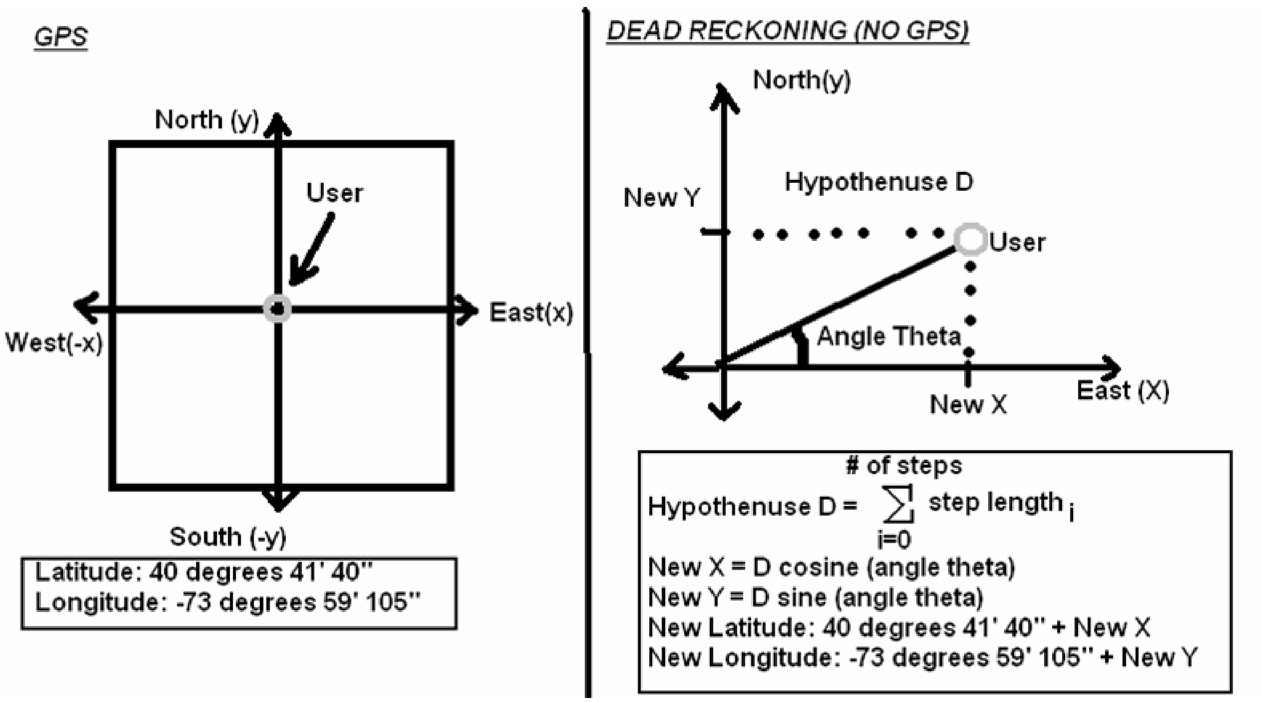
The FSS integrates a variety of state-of-the-art technologies, such as those used in GPS (global positioning satellites), HUD (heads up displays), digital compass, dead reckoning modules (including sonar and pedometers), RF (radio frequency) communication, and LCD (liquid crystal display) with pushbutton interface and a human body measurement system including analogue to digital conversion of body temperature data. Since the FSS was developed using COTS (consumer off the shelf technology), it is not only cost effective, but also light weight, modular and battle ready. In consideration of the United States military's new vision for future combat, the Future Soldier System that we have developed is currently the only system that meets the Department of Defense's MilSpec criteria with respect to cost (under $70,000 per unit) and weight (under 80 lbs per unit).

In complex urban environments like those found in Iraq, or in underground cave environments like in Afghanistan, our military forces have faced significant challenges in locating and coordinating men on the battlefield. As an example of this, we are reminded of Private First Class Jessica Lynch, who was a prisoner of war during the 2003 invasion of Iraq and who was the first successful rescue of an American POW since World War II. Lynch, then a 19-year-old supply clerk in the U.S. Army, was injured and captured by Iraqi forces after her group made a wrong turn and was subsequently ambushed on March 23, 2003, near Nasiriyah, Iraq, a major crossing point over the Euphrates River northwest of Basra. If Private Lynch, or any of her supply group, had been equipped with the Future Soldier System, it is certain that she would not have gotten lost and subsequently captured. Furthermore, if she had been captured, and had been equipped with the FSS, her commanders would have been instantly able to locate her and send help rather than listing her as missing in action.

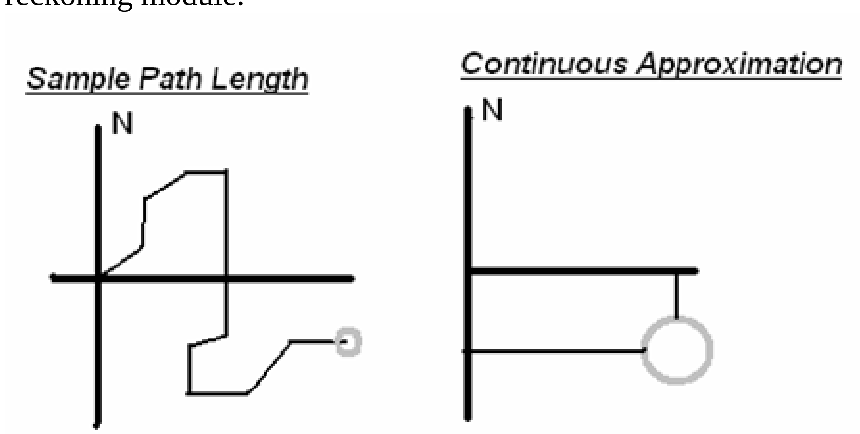
In these complex urban environments, coordination and localization of assets is critical to the success of any military operation. The FSS works on the principle that it should be possible to locate any human being in three dimensional space, given sufficient sensor data. The core of the FSS is the GPS system which provides the current latitude, longitude, altitude, speed, bearing, and way-finding for the individual soldier. Combined with RF communication, it is possible to get an exact fix on the current location of all the soldiers in a platoon sized element, for example. The commander, with the GPS coordinates of all his individual soldier elements, has a new horizon of situational awareness. The commander can now see, from a 3D or topographical view, where best to move his assets for offensive or defensive situations. While such a system would solve many of the needs of the commander on the battlefield, it would not be sufficient for the challenges today's military face in urban environments.

GPS Disadvantages. The limitations of GPS are significant due to the fact that they require a clear view of the sky and at least four continuous satellite connections. Inside a building or a cave, the GPS system becomes irrelevant and the commander no longer has a picture of where his assets are. This GPS limitation created the need for a human dead reckoning position system as a fallback system. The FSS operates on the principle that it is initially connected to GPS satellites. As the soldier moves into terrain that no longer allows a GPS connection, such as an indoor environment, the FSS microprocessor switches to a human dead reckoning system and continues to provide the soldier and the commander the same way finding and positioning data as the GPS system.

The mathematics involved in this conversion between GPS and non GPS coordinate systems is simple to understand but challenging to perfect. Below is a diagram illustrating the differences in positional systems between GPS and non GPS environments and how the microprocessor calculates an individual's non GPS position.



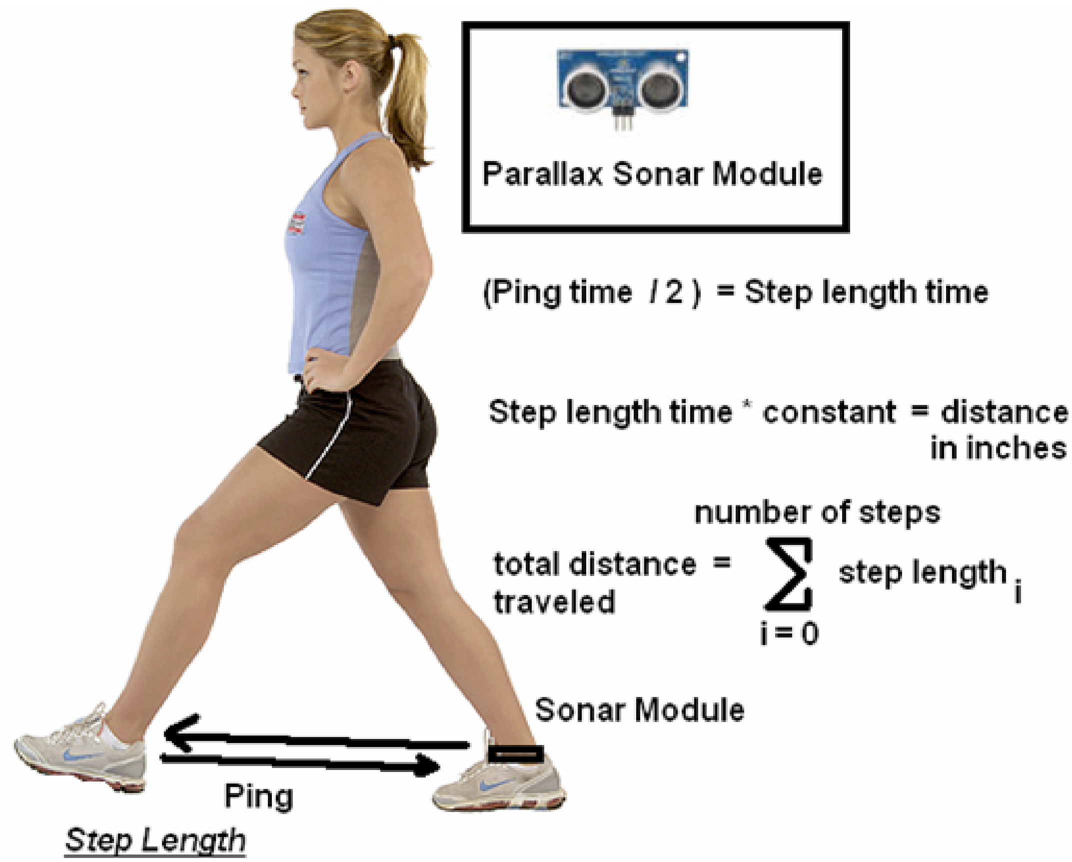
In the GPS environment, the user's current positioning data is updated and broadcast over RF every second. In a non GPS environment, the microprocessor reverts to the dead reckoning module. As illustrated in the above diagram, as the user moves in the first Cartesian quadrant, the user's new latitude and longitude can be calculated as the sum of the last known and good GPS coordinate with the X and Y offset from the dead reckoning module.



As the user moves around in a non GPS environment, the dead reckoning module uses a series of continuous approximations to calculate the user's latest position. The microcontroller has access to two key mathematical numbers; the first is the step length of the user and the second is the angle theta that the step was taken in relative to magnetic north. With these two numbers, the microprocessor can continuously update the users new X and Y position by continuously measuring step length and compass angle and then taking the cosine and sine of this angle.

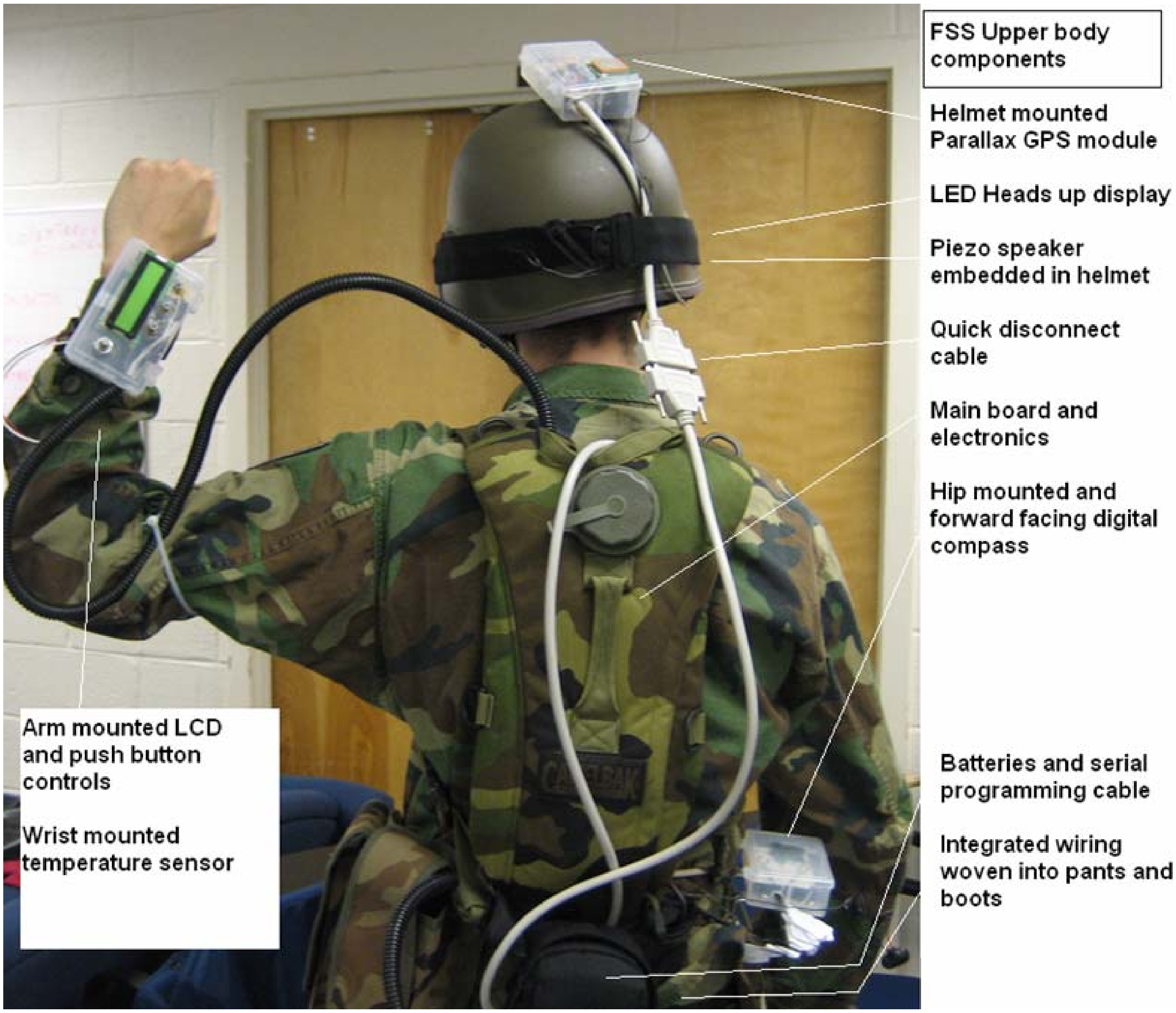
The dead reckoning system needs to measure the individual steps of the user. Initially, we tested an inertial navigation system for dead reckoning using a three axis accelerometer. We determined that the accelerometer as a pedometer was significantly flawed in that it operated on a single, fixed, step length constant. During testing, we discovered that the accelerometer signal was extremely noisy. This noise, compounded with the fact that when the user took different step lengths (running, jogging, walking etc.), the errors and inaccuracies increased exponentially, making the prototype dead reckoning system useless.

The above photo shows the revolutionary new dead reckoning system components, including the limit switches and the parallax sonar module. The solution that we developed was to abandon entirely any accelerometer or mechanical pedometer and measure steps and step length using the most accurate system we could come up with, i.e., one using sonar and limit switches. This system operates in the following way: the microcontroller in dead reckoning mode monitors the number of steps taken by the user, measuring a step as the transition of one of the limit switches from one state (up) to another state (down). In the case where the right foot has just been pressed down, the microcontroller activates the Parallax Sonar module and measures the time response of the ping. This time response is then converted to a distance in inches and is recorded as the step length of the user. An average step length is predetermined and is programmed into the dead reckoning system, since there is only one sonar reading when the right foot steps. At the moment that the left foot steps down, the system doubles the reading from the previous moment. If the reading is too large, the system reverts to the average step length.



The above diagram explains that as the user takes a step, the sonar module is triggered and measures the distance between the back of the heel of the user and the sonar module. This distance is equivalent to the step length and can be used to determine how far the user traveled in a particular compass direction.

The Digital Compass. The digital compass is another key component in the system and provides the user with a bearing with respect to magnetic north. Initially, the compass was mounted on the user's helmet; however, it was later determined that the head was too shaky and prone to rotational moments to get an accurate compass reading. The diagram on the next page depicts the Parallax digital compass which is mounted horizontally on the user's hip. This hip position is mechanically advantageous because the compass requires a steady platform to take measurements. The human legs act as shock absorbers, enabling the compass to always be mounted relatively parallel with respect to the ground terrain. One of the inaccuracies in the current FSS is the slight tilt that the compass is subjected to as the user moves. This inaccuracy could be corrected in a future model by introducing a tilt sensor which would compensate and recalculate the compass bearing as the user's hips move.



Design Decisions. The above photo depicts the upper body of the Future Soldier System and the mounting of all electronics. Many complex mechanical and electronic design decisions were made to arrive at the final solution shown above. For example, the LCD and push buttons are mounted on the user's left arm so the user can operate his or her weapon with his or her right hand and still have access to the display. Another design decision was to use a quick disconnect parallel printer cable to run the wiring from the helmet to the backpack mounted controller board. This quick disconnect allows the user to take off the helmet and become de-tethered from the heads up display. This configuration also allows different display modules and helmets to be added to the system depending on the user's needs. It is important to note that the main power switch to the system is in an easy to access spot on the user's wrist, in case the need arises to turn the system off. Additionally, the batteries are mounted in a pouch on the user's waist and can be easily swapped out.

Communication. After the system computes the users new X and Y position in dead reckoning mode, it transmits this data over RF back to base. As long as the user is within range of RF, the system will be able to communicate its positioning data back to base. With multiple soldiers wearing the FSS, we envision sharing positional data among all the soldiers, effectively creating a wireless local area network. In this configuration, one user with an uplink to base effectively enables all users to be connected.

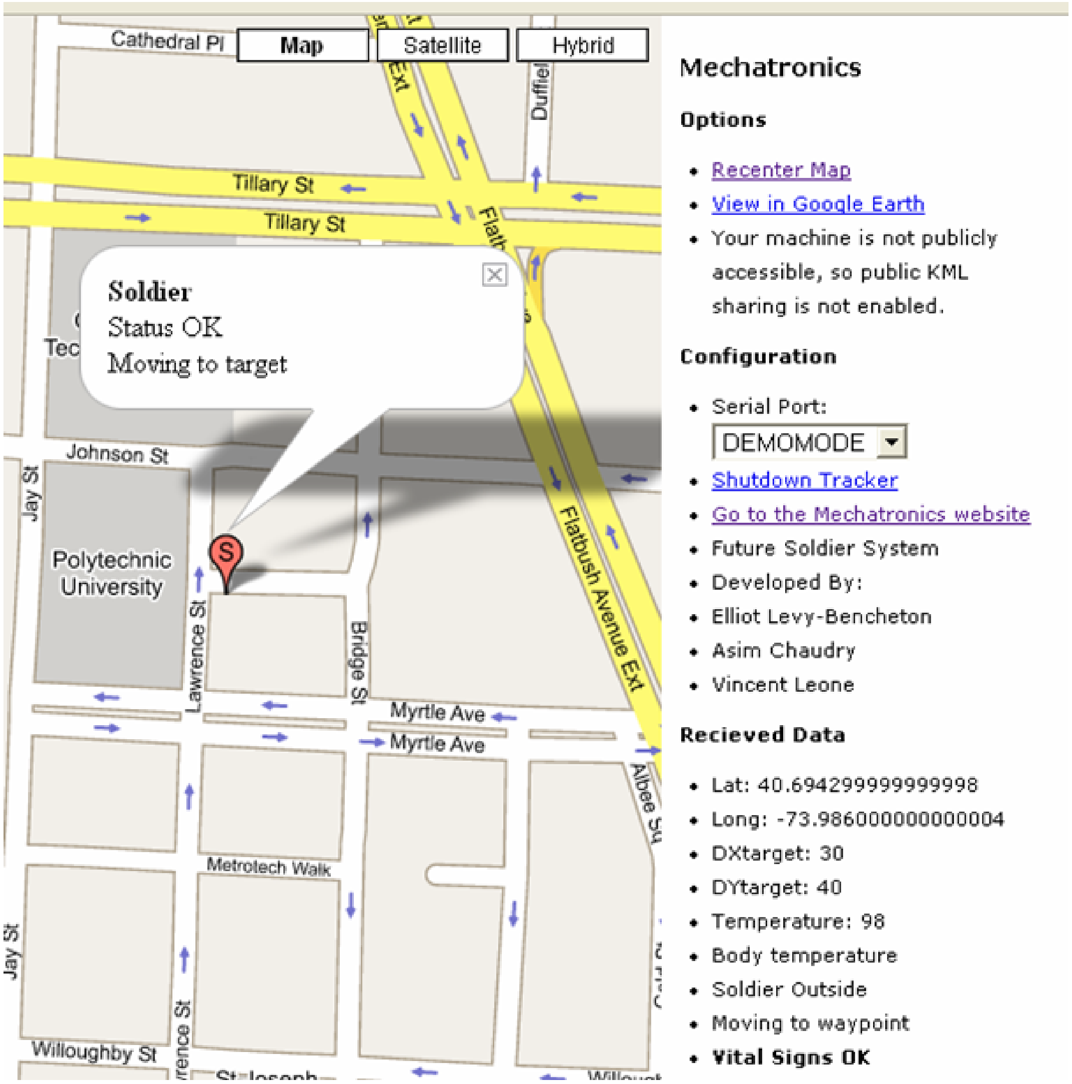
Feedback. While the user's positioning data may be useful for the commander, it does not necessarily help the individual user. The user is most interested in the question: "where do I need to go?" The FSS successfully answers this question by providing feedback using a number of kinesthetic, auditory and visual channels. When the FSS is first started up, it can be preloaded with waypoint data. This data is in the form of a series of X and Y coordinates that the base wishes the user to move to. It is important to note that these X and Y coordinates can be both indoors and outdoors, allowing the user an unparalleled informational and situational awareness.

The microprocessor on board the user, in addition to computing dead reckoning and GPS positions, also provides the user with a navigational system, thus allowing the user to navigate to predefined waypoints. With known X and Y positions, the microcontroller can also calculate the distance to target and angle to target using the same mathematical functions described in dead reckoning mode above. The FSS displays the distance to target and angle to target waypoint information to the user in several ways. First, this information is displayed on the arm mounted LCD, giving the user a textual message of bearing and distance. During a fire fight or a time of incredible duress, the user may not have time to look down at his or her wrist for this information. Fortunately, the FSS is also designed with a heads up display, allowing the user to look down range rather than at his or her wrist.

Heads Up Display. Above is a photo of the HUD or heads up display. The HUD consists of two LEDs mounted inside the user's goggles. When the left LED is on, it indicates that the target waypoint is to the user's left. When the right LED is on, the target waypoint is on the right and the user needs to turn his or her hips to the right to locate the target. When both LED's are on, it means that the user is locked on and facing straight at the target waypoint. This waypoint may be in the next room or several miles away; however, the user now has an understanding of his or her bearing with respect to the target. One important design decision to note is the use of small green LED's in the goggles. These were used to preserve the user's night vision and minimize the effects of glare against the goggles. From the user's perspective, these LED's automatically focus the user on a particular position and lead the user to target. Lastly, the system includes an embedded piezo speaker inside the user's helmet. As the user approaches closer to the target, the frequency and time duration of the sound pulses change to give the user an auditory sense of his or her position. When the user is within a 10 inch radius of the target waypoint, the piezo speaker emits several tones indicating waypoint arrival, and the system automatically loads the next waypoint from EEPROM memory. In this way, the user never has to take his eyes off the target down range while the system seamlessly guides the user from outdoor to indoor waypoints.

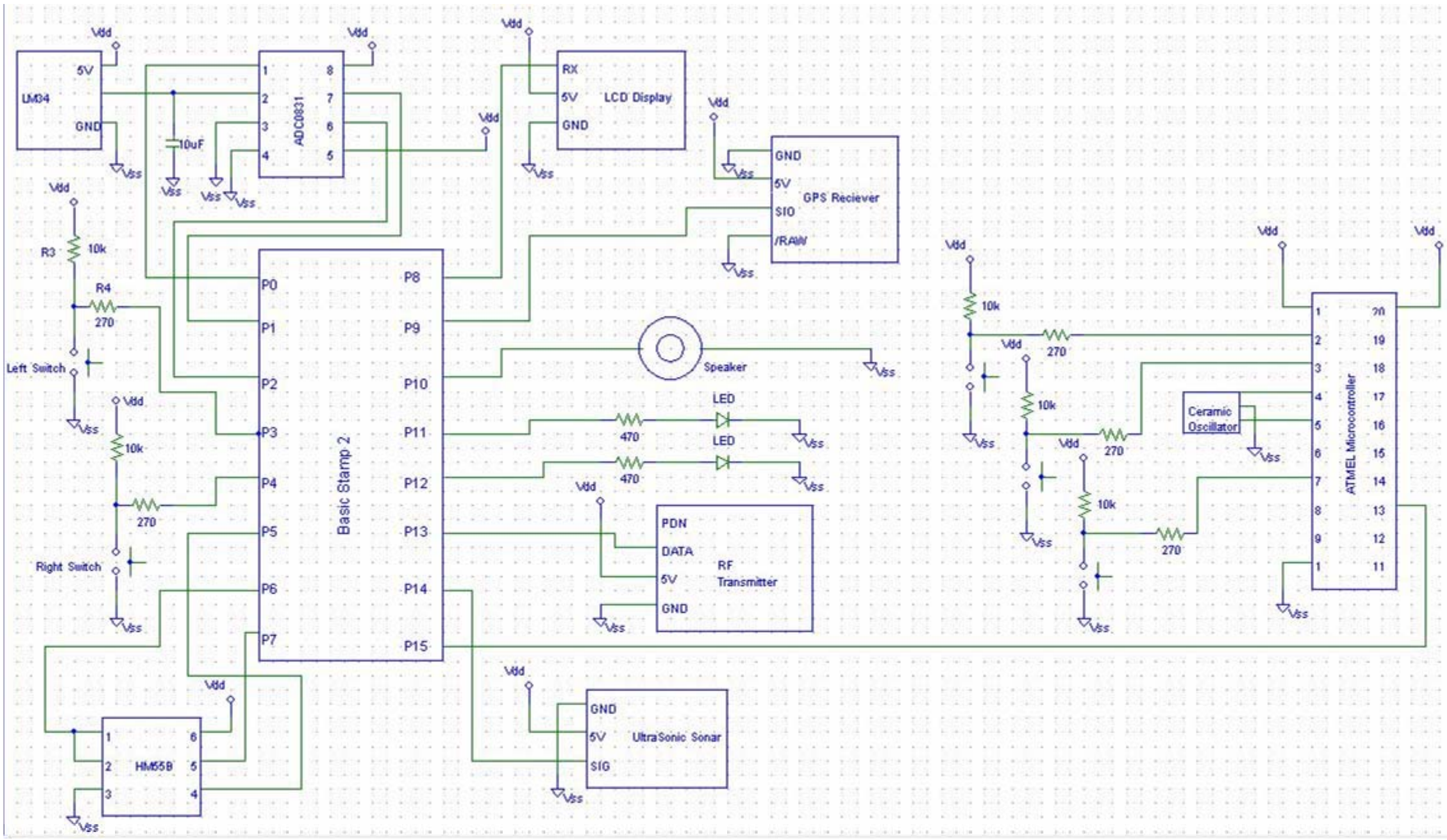
Commander View. Another key component of the Future Soldier System is the commander view. The commander needs an RF receiver and Parallax Basic Stamp 2 connected serially to his or her computer. Additionally, the commander needs an internet connection to download map data from Google maps. When the individual soldier wearing the FSS broadcasts his positioning data, he also sends a number of other important strings in the data stream. The RF data stream contains the following variables: latitude, longitude, body temperature, help signal, outdoors or indoors location, encryption code and distance in X and Y coordinates from target. This RF data stream is then forwarded via basic stamp to the computer serial port. From there, a python script parses this data stream into its different data blocks and overlays this information on Google maps in real time.

RF Disadvantages. The delay from GPS signal processing, to RF broadcast and receive, to Google maps plot, is approximately 1 – 2 seconds, depending on how far away the user is from the RF receiver. One disadvantage to our prototype is that the RF transmitter and receiver used have a 500 foot range. However, in a production model, the transmission of this data stream could be sent over a number of different protocols including WIFI, RF, UHF or even satellite uplink, allowing transmission of dead reckoning position data from anywhere in the world. For example, the President, located in the Oval Office in Washington, D.C., could monitor the progress of a Special Forces team on Google maps in real time while they operate deep in a cave in Afghanistan. Below is a screen capture of the commander view of Google maps. This screen capture depicts the exact position of a user wearing the FSS during a prototype test run in Brooklyn, New York. On the right of the screen is HTML code which is updated every second with the latest latitude, longitude, body temperature, and help data received over RF.



Next Steps. In the RF data stream, the FSS broadcasts the user's current temperature. In the prototype system, we monitored the user's temperature and alerted the commander if the temperature was below a certain level. The ability to monitor vital signs remotely offers new life saving technology to commanders who can coordinate Medevac and rescue assets if needed. In a production model, the FSS would monitor other vital signs, including heart rate, blood oxygen level, fatigue, and even blood loss. It is important to note that we initially had a heart rate monitor included in our prototype system. This heart rate monitor used infrared LEDs and analogue to digital conversion to monitor the user's heart rate and alert the base automatically if the heart rate did not meet certain normal human conditions. Ultimately, we were forced to remove the heart rate monitor due to a lack of free input/output pins on the basic stamp 2 module. The current FSS uses all 16 BS2 IO pins and four pins are used on another PIC chip used for button control. The production model would be designed to have sufficient IO pins for monitoring a variety of different human body vital signs. We envision the FSS production model capable of alerting medics of the soldier's condition before the medics even arrive on the scene, thereby reducing the stress and confusion that medics typically face when they first encounter someone in need.

Electronics



The above diagram shows the electronic circuit diagram for the Future Soldier System. In a production model, the system would include more IO pins and use printed circuit board and surface mount technology to reduce size and cost.

Bill of Materials / Cost Analysis

Material	Quantity	Total Cost	Manufacturing Cost (per item)
Board of Education Kit with BS2	2	$199.98	$75.96
GPS Receiver Module	1	$79.95	$71.96
HM55B Digital Compass	1	$29.95	$23.96
RF Receiver	1	$39.95	$27.97
RF Transmitter	1	$29.95	$20.07
Ultra Sonic Sonar	1	$29.95	$25.00
Backlit LCD screen	1	$29.95	$26.96
LM34 Temperature Sensor	1	$3.94	$3.74
Piezo Speaker	1	$1.95	$1.95
ADC0831 A2D chip	1	$6.00	$6.00
ATMEL Microcontroller	1	$8.16	$8.16

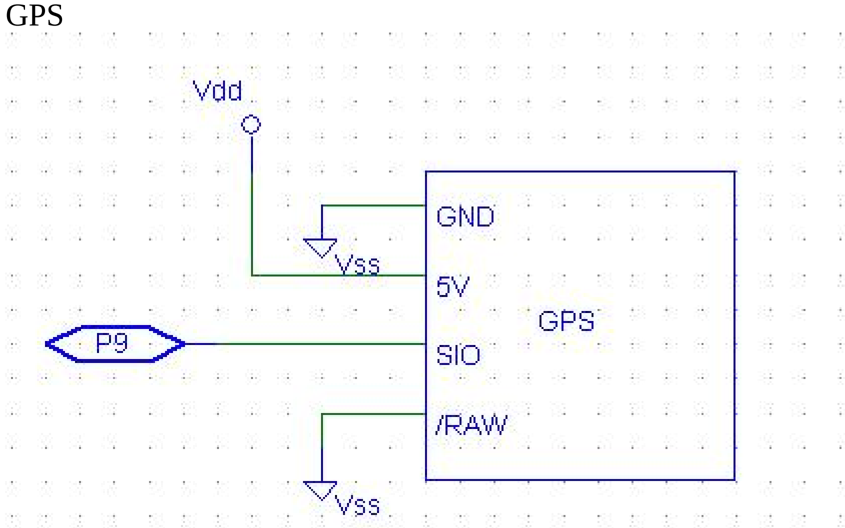
Buttons/Switches	6	$7.74	$1.29
Breadboards	2	$16.78	$8.39
Wires	125ft	$5.99	$5.99
Electronics cases	4	$10.99	$1.99
LED's	2	$1.99	$1.99

Total Cost of prototype: $503.22
Total Mass production Cost: $417.26

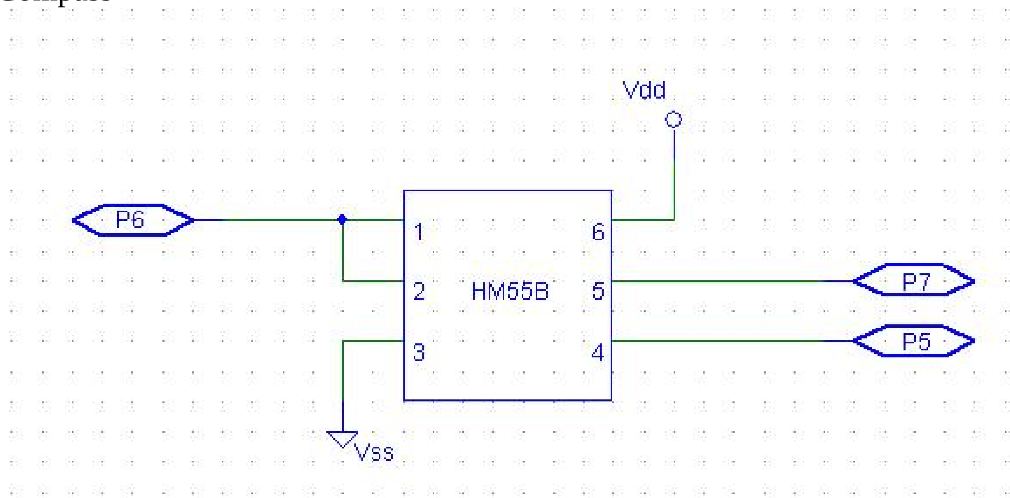
Conclusion. In the arena of complex urban environments, today's United States military forces face several new and significant challenges to coordinating individual soldier assets. In addition, soldiers on the battlefield are burdened with the difficult task of navigating, way-finding, and communicating their positions. The FSS or Future Soldier System that we have developed offers both individual soldiers and commanders an unprecedented situational awareness. This situational awareness extends to both indoor and outdoor environments and enables a team a new horizon of safety, security, and informational power. The Future Soldier System is currently the only system available for meeting the Department of Defense military specifications for budget and weight. With a weight just under 6 pounds and a cost just under four hundred dollars, the current FSS design meets all of the military specifications for the Land Warrior program at one hundredth of the cost of competing models. Using consumer off the shelf technology, the Future Soldier System is a low cost, reliable, and flexible solution to help meet the changing demands of the military. Most importantly, the Future Soldier system is ready for testing and deployment. The Future is now.

Reference of all component sketches:

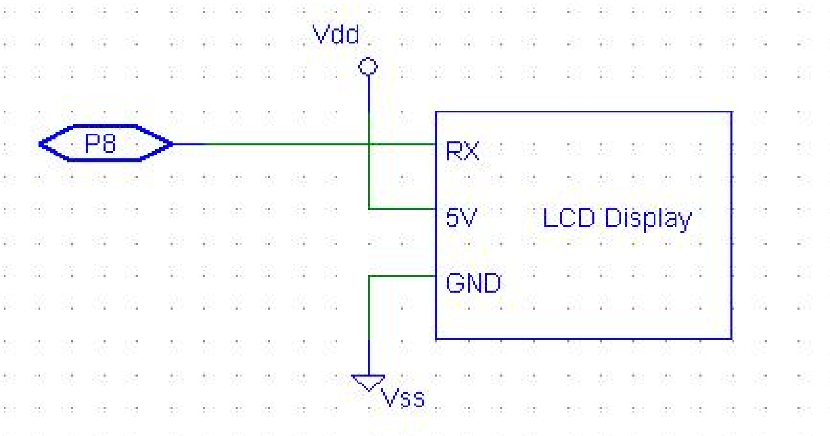
GPS



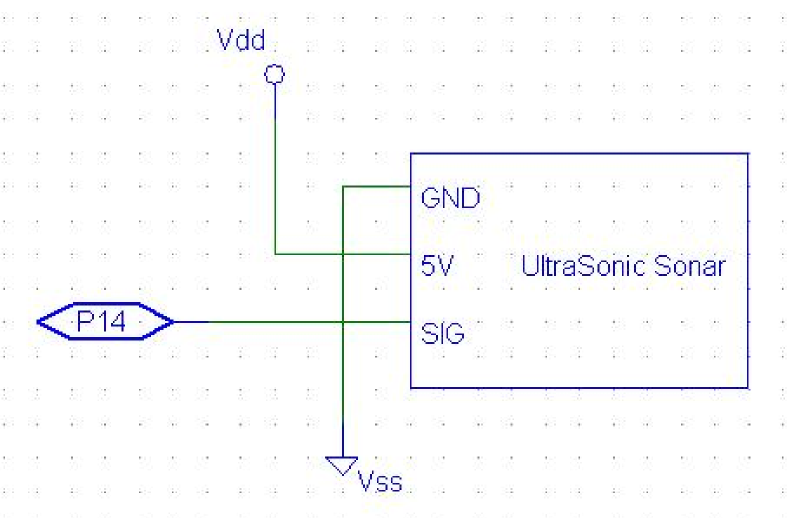
Compass



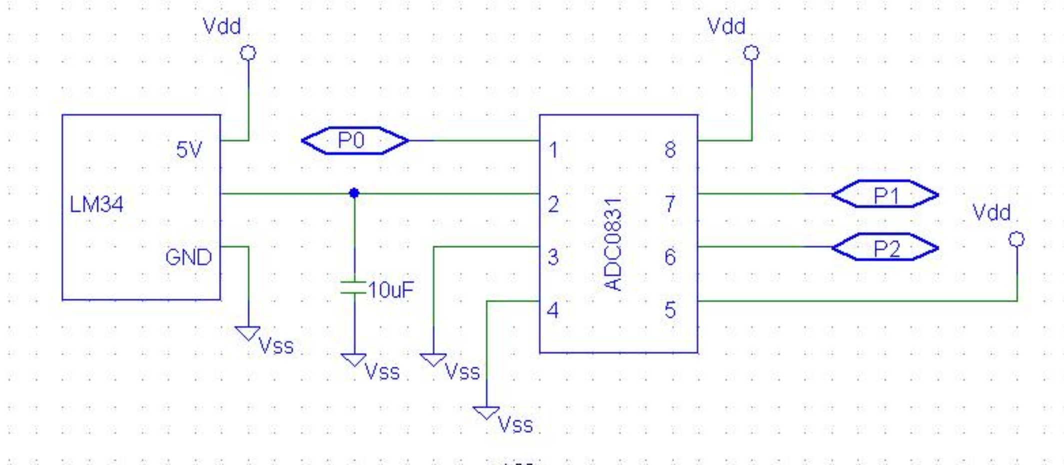
LCD Screen



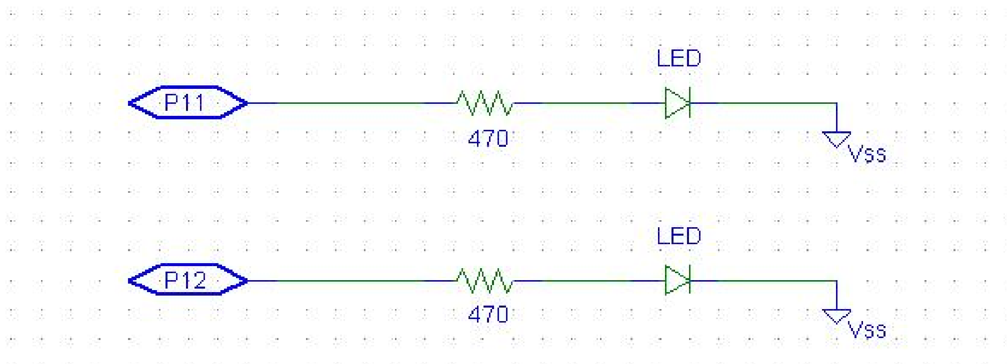
Sonar



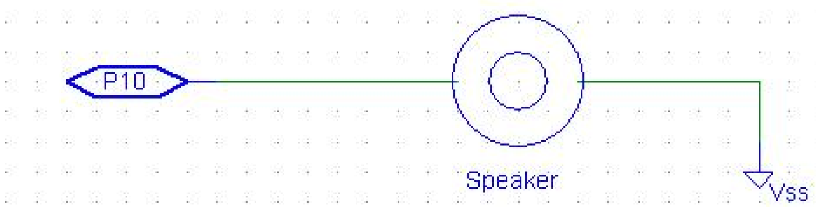
Temperature Sensor with ADC0831



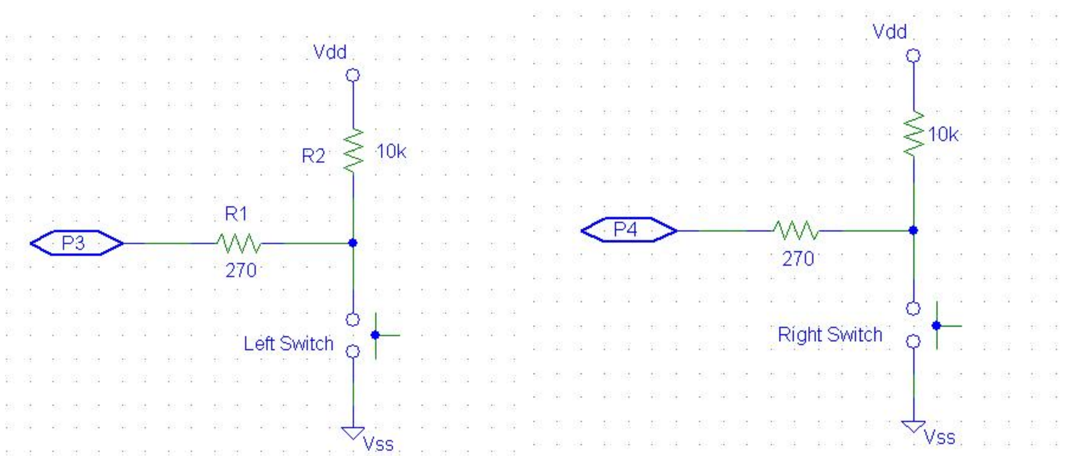
LED's



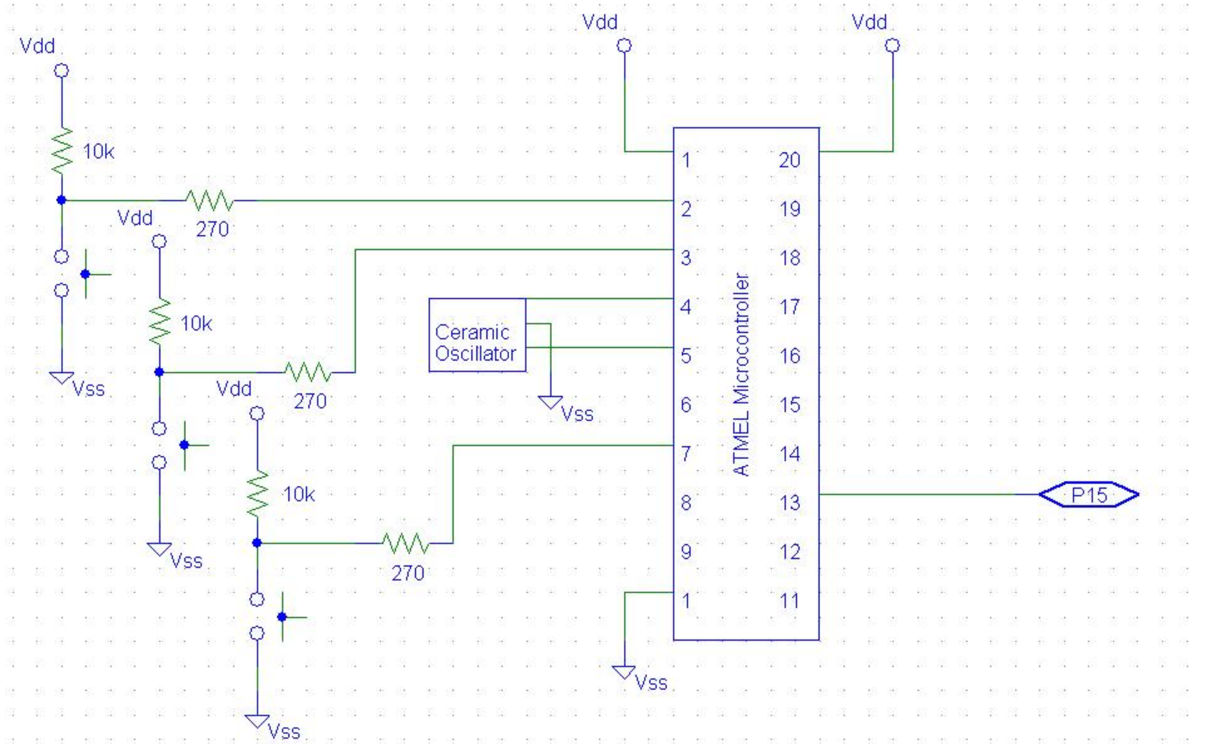
Speaker



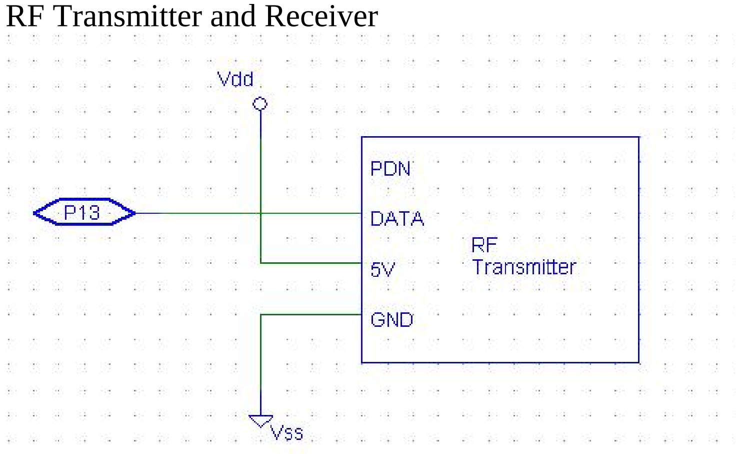
Switches

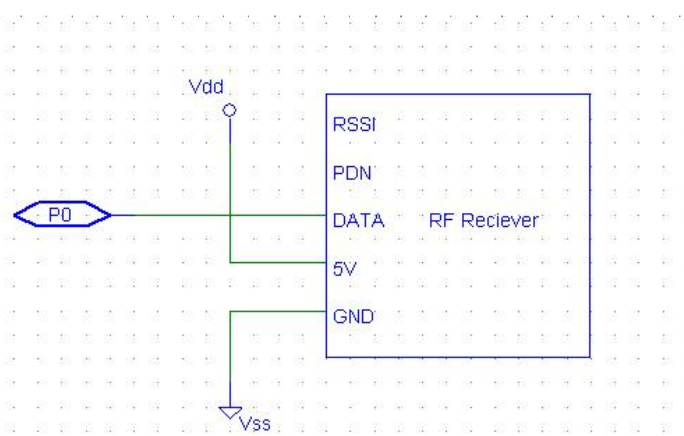


ATMEL PIC Microcontroller with 3 buttons



RF Transmitter and Receiver





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