REMOTE PERIMETER MONITORING FOR AGRICULTURAL APPLICATIONS

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ABSTRACT

A monitoring system has been developed to detect when a large vehicle is gaining access to an area such as an agricultural field or facility through a control gate. The system uses multiple sensors, including Hall-effect, anisotropic magnetoresistor, ultrasonic ranging, and vision. A user is alerted using a conventional cell phone network of the presence of the vehicle. The system is microcontroller based, uses photovoltaic power supply, and leverages commercial off the shelf components wherever feasible. The system detection algorithm was made adaptable, to minimize false alarms and missed detections

Keywords: Remote monitoring, COTS, alternative energy

INTRODUCTION

This paper describes a remote monitoring system that can detect the presence of a land vehicle in the range of 1 to 5 metric tons. The intended application is to provide perimeter monitoring in agricultural applications. In these applications it is often difficult to gain access to an area except through a control point, or gate. We assume the gate can vary in width from approximately 1 to 5 meters. The goal is to determine when a vehicle has approached, or is passing through, this gate. Ideally the device should require little if any training or calibration by the user, be easy to install, operate in a wide range of locations, in all weather conditions, and of course have a low probability of false alarm and missed detection.

To accomplish these goals, an array of inexpensive sensors was integrated into a single device. A Hall-effect sensor is used in conjunction with a common magnet to determine if the gate has moved from its initial position. Since many vehicles contain a substantial amount of ferrous metal, an anisotropic magnetoresistor sensor will monitor changes in the ambient magnetic field, an ultrasonic ranging device will sense when a large object is approaching the gate, and a vision system will observe the area in front of the gate to detect changes that imply a vehicle is present.

Once the device has determined that a vehicle is present, it will notify the end user through a conventional cellular telephone network. The device will also be able to photograph the vehicle for security and monitoring purposes.

To maximize the usability of the device, it will be important that it use a limited amount of power, to allow it to be driven by an inexpensive photovoltaic array. It must also require only minimal installation and calibration operations to be performed by the end user. In addition it must have a very low false-alarm and false-positive rage. These rates should ideally be independent of terrain, weather conditions, and other factors beyond the control of the designers. The design goal is to have a false-positive rate of less than once per calendar year. Self-diagnosis is also performed, and reported to the end user on a weekly basis.

SYSTEM DESIGN

Since the device needs to be powered by a photovoltaic array, and in a location where it can visually see the gate, it will be challenging to make it small enough to be inconspicuous. Rather than trying to hide the device, we chose to make it appear similar to devices commonly found in these applications – and used a commercial solar powered fence charger as a housing for the system. As an added benefit, we were able to use the photovoltaic array and battery supplied with the fence charger to operate the electronic systems of our device.

The next challenge was to develop a method for determining when a gate has been opened. The most obvious choice was to use a conventional contact switch. However this approach has a number of drawbacks. Gate hardware often has very large margins of error, so a small switch may not work in this application. A larger switch would work, but could be cumbersome, expensive, and easy to identify and defeat. We also anticipated that any type of contact switch would have a high failure rate, both with false positives and false alarms. We investigated a number of non-contact switches, such as those that use optical or infrared sensors. While these could be easier to conceal, they were prone to failure due to obstructions from vegetation, dust, and other commonly found objects in this application.

The final decision on the gate sensor was to use a magnetic sensor. A magnetic device is either attached to the gate, or in a more secure setting integrated into the gate structure. A magnetic sensor can then be embedded in the post that the gate is attached to. The sensor is reasonably small, so it could be easily concealed in the post, or again in a more secure system, integrated into the post design.

The next challenge was to find a means to detect when a vehicle is present. One method of doing this was to burry an inductive coil in the ground. When a vehicle passes over the buried loop we expect the inductance of the cable to change. By using the cable as an inductor as part of a tuned circuit in an oscillator, a frequency counter could easily detect when the inductance has changed, indicating a vehicle is present. This approach was widely used in early traffic detection systems, and requires the digging of a small trench to place the wire, and extending the trench to the detection device. We rejected it, because of the installation expense and difficulty of maintaining in many rural environments.

However, just as the vehicle causes a change in the inductance of the wire, it also disrupts the Earth's magnetic field. These changes can be measured directly. A similar approach is used in factory automation requiring precise vehicle positioning and tracking using anisotropic magnetoresistor (AMR) devices [1]. These same devices are specialized to detect the Earth's magnetic field for compass bearing applications.

Machine vision offers another method of detecting vehicles, and is commonly used at intersections monitoring traffic signals [2]. These cameras require significant power due to the computationally intensive continuous image processing, but offer a great deal of flexibility and reliability. In addition it is possible to use both optical, and near infrared wavelengths to give the device more than one way to detect the presence of a vehicle, which in many applications will be significantly warmer than the surrounding environment.

The final sensor used was an ultrasonic ranging device, which can sense the presence of an object by generating an acoustic signal above the audible range of humans, and then sense a reflection. The device is normally used to measure distances, and in our application it will help us determine not only if a vehicle is present, but if it progressing toward the control point.

We initially considered implementing a custom processor for this application. However the limited design time, and availability of powerful and low-power development systems, led us to select a commercial off the shelf solution. The particular device we chose to base our design on was a Raspberry Pi [3]. It is physically small enough to fit in the enclosure we chose, has a power consumption low enough to allow powering using a small photovoltaic array, it has the necessary communication ports for both the sensor and cell phone network interface, and has ample documentation and example code which we could leverage.

COMPONENTS

ENCLOSURE / POWER MANAGEMENT

As mentioned above, the enclosure of the device was a COTS electric fence charger. The particular device we selected was 30 x 15 x 10 cm. It included a 7 Ahr, 6 volt battery which weighted approximately 1 kg and could be recharged in 12 hours of direct sunlight by the photovoltaic array. Once fully charged, the battery could power the device for approximately 72 hours of normal operation. For the proof-of-concept model we used a linear regulator, as shown in figure 1. The final design will use a DC-DC converter to avoid the inefficiency of linear regulators.

GATE MOVEMENT SENSOR

To detect the movement of the magnetic gate device, use used a Honeywell SS41 Hall Effect senor [4]. This is an inexpensive three lead analog device. The sensor had a range of approximately 0.5 meters, which allowed for a wide spacing in the gate. The output of the sensor could be connected to a general purpose input/output pin on the processor if binary detection is sufficient, or it could be used to drive an analog to digital converter to allow for additional processing of the signal to try to minimize errors.

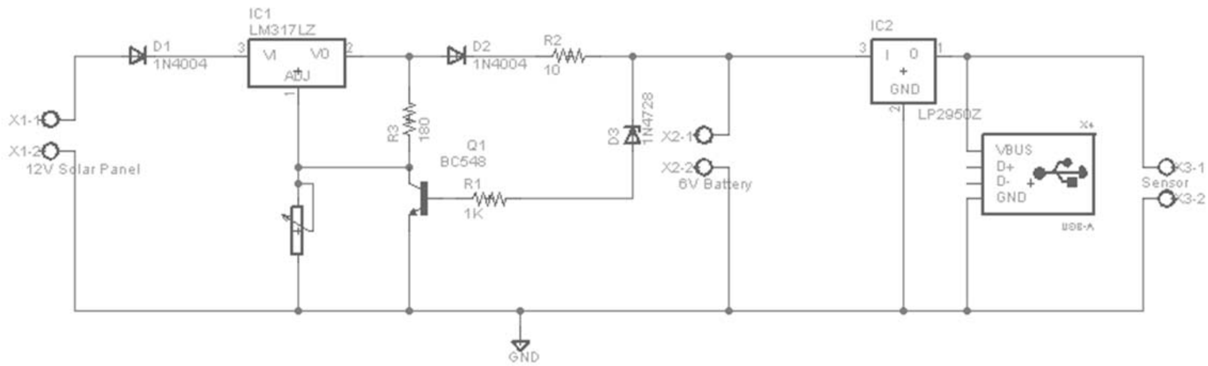

Figure 1. Power Supply

VISION SYSTEM

Since the device is based on a Raspberry Pi, it was possible to run the Linux operating system, and use open source libraries such as OpenCV [5]. This increased the capabilities of the device, and streamlined the development process. We chose to use an Airlink101 AWCN200 Infrared Night Vision Webcam for the vision system. This gives the device the ability to capture images both during day and night. The camera has built-in infrared LEDs to improve visibility in low light. Higher cost/quality cameras were considered, but experimental results indicated that this particular camera works well enough for our purposes.

The detection algorithm used for the project was to train the system by periodically recording the background image. We expect the image will change slowly with weather, lighting, and other factors. The background image is then compared to the most recently sampled image, to determine if a large object has suddenly come into view. The vision algorithms were implemented with the OpenCV image processing library. Using this open source library reduced the development time significantly, although it was still necessary to develop algorithms to reliably determine when a vehicle was present.

This detection algorithm divides an image into regions, and examines each for a significant deviation from the background data. A function was used to combine all of the pixels contained in a region into a single value per channel to simplify training and comparisons. This function was the average of all the pixels but other functions may be tested to see if they give better results. From the values collected through training over a number of captured images, a mean value and standard deviation was calculated to determine if the region had changed.

Images are compared to the training data by determining if the calculated values for each region fall within some given number of standard deviations of the mean found during training. When using a color image, there will be multiple channels and the results of each will need to be combined for each region. This potentially gives us the ability to ignore or give low weight to unreliable data such as lightness of the image, which may change considerably between training and detection during operation in outdoor environments with continually varying cloud cover.

Having determined which of the regions have changed since training, and attempt can be made to determine the nature of the cause. If the change had resulted from variations in lighting, wind, etc. the system should ignore it. This can be accomplished by examining the size, and shape, of the clusters of changed regions. By simply specifying a minimum width and height for what can be considered a potential positive detection, we can ignore much of the inevitable noise that will be experienced.

A sample test of the vision system is shown in figure 2. The image on the left is what the camera sees. The image on the right shows the area in red that is considered to be a substantial change from the background image recorded prior to the vehicle approaching.

Figure 2. Detection of Vehicle by Vision System

MAGNETIC FIELD SENSING

The Earth's magnetic field near the surface of the Earth in populated areas currently varies from approximately 250 to 650 mG. The target vehicles for this application can cause a variation in this field on the order of 1 mG for up to 10 meters from the vehicle. Typical AMR magnetic sensors are sensitive enough to detect these changes. Since the devices are often used in devices which need an electronic compass, they are reasonably low cost and easy to obtain. In the initial design, a Honeywell HMC1001 was chosen, since it has 27 µG resolution, well better than needed for this application. Unfortunately this device requires external circuitry that complicated the design, so a Honeywell HMC588L was used instead. The sensor was purchased on a breakout board which also contained the necessary communication electronics. The sensitivity was 2 mG, which we anticipated would be sufficient for detection of a vehicle up to 5 meters from the sensor.

When the device gain was set to maximum sensitivity, the measurement noise was noticeable. To combat this problem, the sensor was set to sample at the fastest rate possible, in this case 75 Hz. When the device is calibrated, a large number of samples are taken and both the mean and standard deviation are found. Then during use, 8 samples are averaged before making a measurement. If this average deviates by more than one standard deviation from the calibration mean, then the sensor declares that a vehicle is present. The system must be periodically recalibrated to account for natural variations in the naturally occurring magnetic field strength of the Earth's magnetic field.

ULTRASONIC SONAR SENSOR

Another means to detect the presence of a vehicle is with an ultrasonic sonar range finder. We chose to use a Maxbotix I2CXL-MB1202 sensor. This particular device has an approximately 60 degree beam width, and claims an accuracy of 1 cm to a range of at least 7 meters for large objects. In our detection algorithm the detection range was divided into 4 approximately equal size intervals. Once an object is detected in the farthest region, monitoring begins for reading the next closest region. This progresses until the nearest region is reached and a positive approach is detected. If a reading is taken equal to the maximum measurable distance at any point in this process, detection is reset to monitoring the far end region. If a reading is taken closer than this far end region, it is ignored. This allows for the rejection of vehicles or animals passing near the detection region.

EXPERIMENTAL RESULTS

Each sensor was first tested individually before being tested as a whole system to confirm baseline operation. With the magnetic sensor gate sensor a small magnet was held in close proximity to the Hall Effect sensor, and then removed. For the magnetic field sensor, a steel water bottle was held close to it, to confirm it could sense the changes in the magnetic field. It was apparent that the device would be operating at the limit of its noise threshold if adequate range was to be achieved. The sonar rangefinder was similarly configured and tested by approaching the sensor and conforming readings were accurate. Further testing took place in a similar manner as the respective operating algorithms were developed for each sensor.

A sample output of the sensor array is shown in figure 3, where the horizontal axis represents the distance from the vehicle to the gate, with the distance being the greatest at the left side of the graph, and the vehicle approaching the gate as we move to the right. The magnetic field readings were offset so that the minimum reading taken during initialization corresponds to the zero along the axis. This allows the field plot to overlay accurately with the distance plot. The sonar sensor reports a maximum distance of 7.65 meters when there is no object reflecting the ultrasonic pulse used for measurement. When an object comes within the maximum distance, the approach is tracked. The smooth nature of this decreasing curve is essential to the current approach detection algorithm. As shown, the vehicle is tracked at every point in its approach, passing through each of the four regions monitored. Once the distance measured is less than the set approach trigger distance (gray dotted line in figure 3), an approach is confirmed.

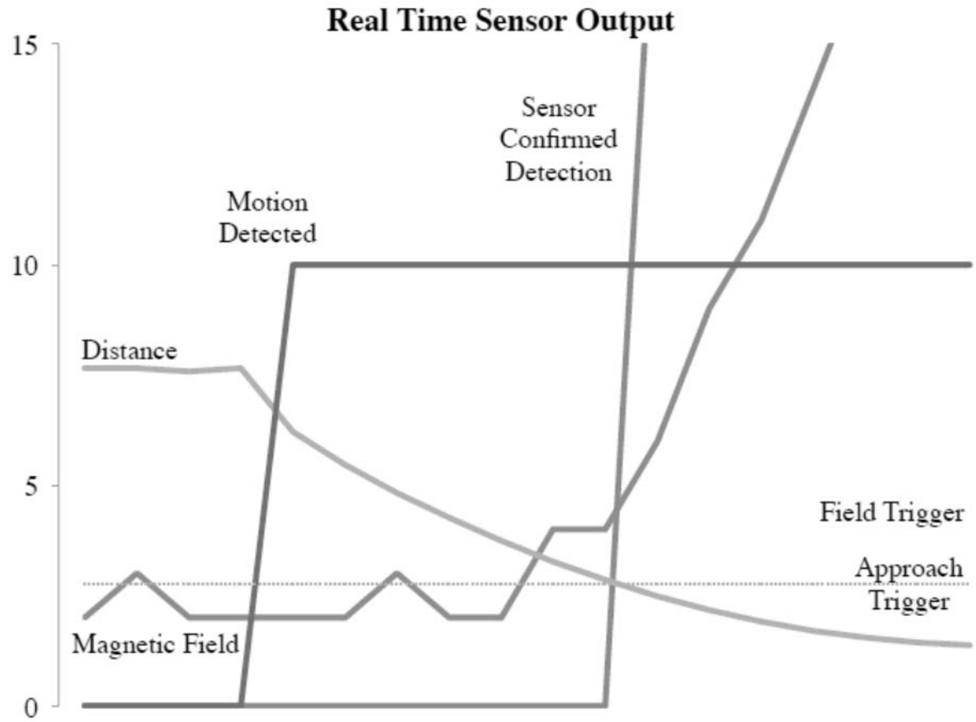

Figure 3. Sample Senor Outputs

Failed detections were easily detected during testing. Sources of these corresponded to the sensitive nature of the sonar sensor or the inopportune timing of motion sensor output. Anomalies occurred at seemingly random points that caused the sonar sensor to fluctuate wildly in its readings, most likely the result from small reflections off of the detailed features of the vehicle grill. If this occurred during an approach, it almost certainly led to a failed detection. Out of the 50 logged approaches, there were two failed detections.

CONCLUSION

A multi sensor data fusion device was fabricated, which combined a magnetic gate sensor, video camera, magnetic field sensor, and sonar range finder, to detect when a vehicle is approaching a control point such as an agricultural gate. Two photographs of the prototype are show in figure 4. By combining the outputs of the sensors, it was possible to reliably detect when a vehicle is approaching

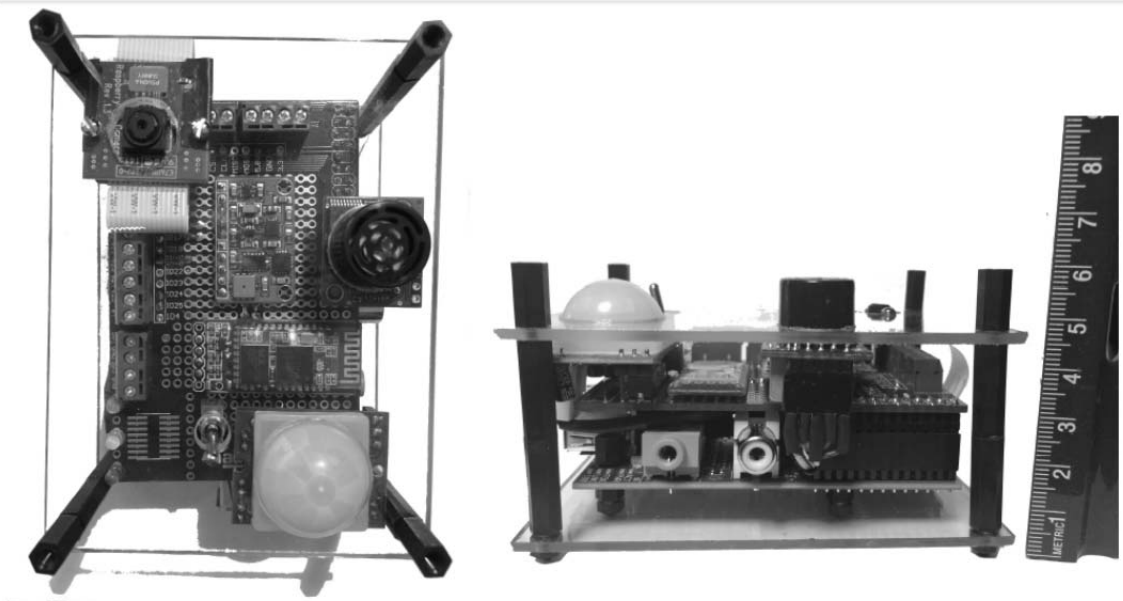

Figure 4. Prototype

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