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Characterization and Validation of Telemetric Digital Tachometer based on Hall Effect Sensor

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Abstract: Telemetry field has grown exponentially in recent years. This work presents a simple, easy to implement digital remote tachometer based on a Hall effect sensor. A correct characterization is crucial to properly handle, analyze and interpret signals from any kind of sensor, however, here is presented the whole telemetric system characterization, including sensing stage, wireless transmission and reception under IEEE 802.15.4 standard, data analysis and display through a graphical user interface developed on LabView software. An electric motor is placed remotely, where, using a Hall effect sensor and the adequate signal conditioning, a pulse train proportional to the motor speed is sent to a microcontroller to manage signals and compute speeds before wireless transmission. Once received, data is analyzed and displayed. Both simulation and experimental results under diverse conditions of speed, transmission distances and computation parameters are presented to clearly describe the process of characterization and system validation. Promising results have been achieved and is expected to growth this project to different physical variables oriented to monitor and control a formula SAE automobile.

Keywords: telemetry; wireless; tachometer; hall effect sensor

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1. Introduction

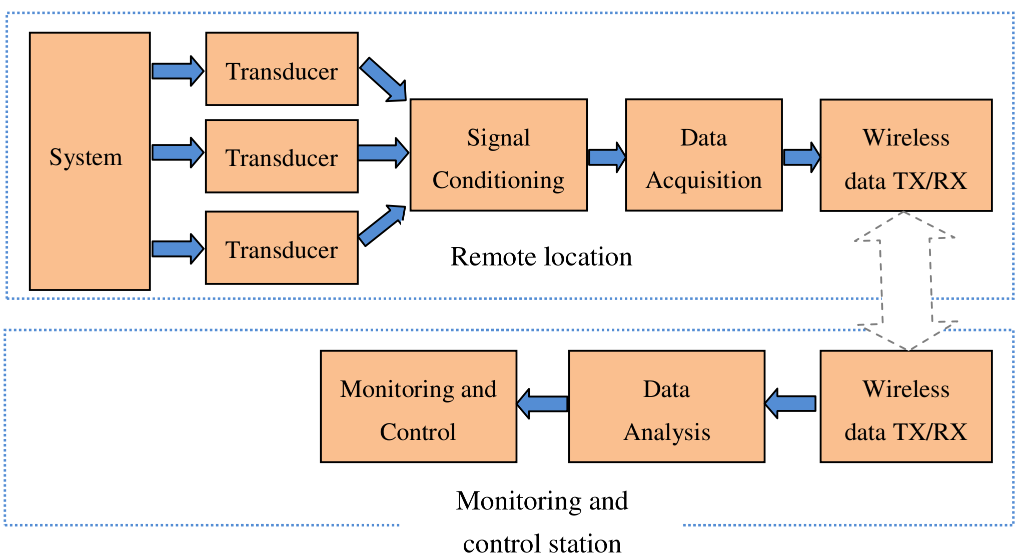
The most accurate information leads the best decision. Either for monitoring or control, is always desirable a reliable measurement system. Due to it is not always possible to have a local measurement; the field of telemetry remains as an actual field of research.

Several applications in telemetry have been reported in literature, including the medicine [1-2], military [3-4] and automotive [5-6] industries to name a few. Regarding to the automotive industry, a formula one car can be considered as one of the most heavily instrumented objects in the world [7]. But this is not exclusive for formula one racing cars, for example, GPS/GPRS tracking systems have become more and more popular among the cars circulating in our cities, transmitting real time information about actual localization, routes and historical speeds. This work reports the design and characterization of a telemetric digital tachometer capable to transmit information wirelessly above the 300 feet in line of sight over the RF standard IEEE 802.15.4 commonly referred as Zigbee protocol. This work is intended to serve as a basis for an automobile instrumentation for the Formula SAE competition with educational purposes.

2. Experimental Framework

In this section we describe the main functional blocks involved in the development of this project. According to Council [8], a telemetric system can be divided as two main functional subsystems: The transmission subsystem and the reception subsystem.

Figure 1. Transmission and reception subsystems in a telemetry system.

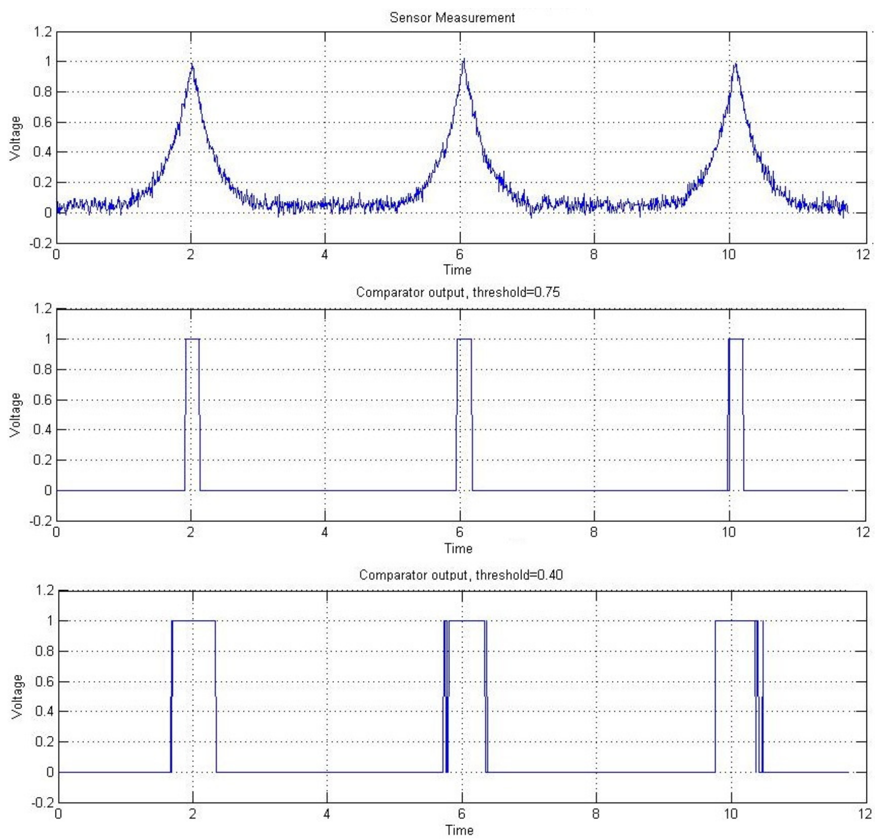


2.1. Sensing and signal conditioning

Hall effect sensors have been used in a wide variety of applications for years. These applications include them as proximity switching, positioning and speed detection. A Hall effect sensor bases its operation on the generated transversal voltage of a conductor under the presence of a magnetic field.

In order to detect the speed of the motors' shaft, there are placed three permanent magnets equally spaced at 120°, whose magnetic fields can be detected by a fixed Hall effect sensor. Because of the magnetic field can be detected from a certain distance before the magnet crosses in front of the sensor, and after it crosses it, it is necessary a signal conditioning stage to transform this variable voltage output to a pulse train, which can be processed by a micro controller. This conditioning task is performed by a single operational amplifier comparator with a reference signal used as threshold.

Figure 2. Simulation for sensor measurements and signal conditioning. **(a)** Simulation of sensor measurements adding a normal noise with $\mu = 0$ and $\sigma = 0.3$, **(b)** Comparator output with threshold = 0.75, **(c)** Comparator output with threshold = 0.40



From figure 2 can be noticed the result from changing the threshold in the comparator. By increasing it, it is obtained a thinner pulse train, while when it is decreased, a wider pulse train is observed.

Once a usable pulse train is obtained, it is counted by a microcontroller PIC 16F887, which, through a technique of constant sample time [9] assesses the shaft speed of the electric motor and send this information serially to the RF transmission module. The speed computation is reached by:

$$n = 60 * \frac{C}{3T} \tag{1}$$

Where *n* denotes the speed given by revolutions per minute, *C* is the count performed by the micro controller and *T* is the sample time in seconds.

2.2. Wireless Transmission and Reception

Wireless transmission and reception is done by two Xbee RF modules working in transparent mode, this implies that, all UART data received in the transmission module is queued for RF transmission. When RF data is received by the reception module, it is transmitted to the data analysis block to later be displayed.

Data analysis block applies a median filter in order to eliminate the higher and lower values caused by noise or errors in the transmission-reception process. A median filter is a non linear technique that applies a sliding window to a sequence, replacing the center value in the window with the median value of all the points within the window.

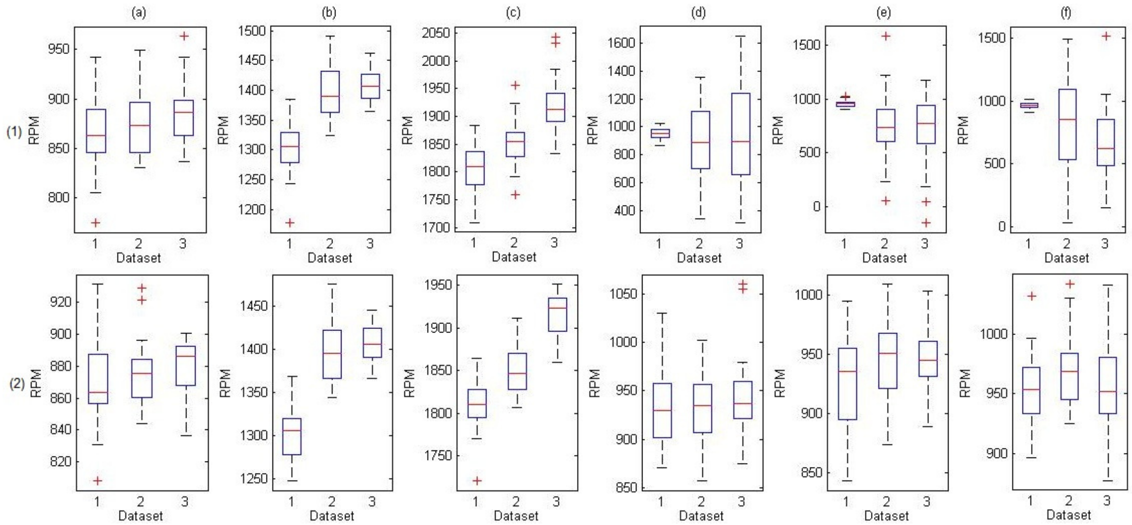
Finally, the monitoring interface developed in the graphical LabView software gives the user the possibility to observe the instant speed through a sliding gauge, the historical speeds displayed in a waveform chart as well as the channel to properly establish communication between the computer and the RF reception module.

Figure 3. Monitoring station front panel showing instant and historical speeds

3. Results and Discussion

To validate the presented work, various measurements were performed, varying principally three variables: Speed given in revolutions per minute (n), distance of transmission (d), and sample time (T). In order to have statistical validity, there were taken 30 samples of every variable combination, then, this data was fitted into a normal distribution to obtain the mean and standard deviation of the dataset. In figure 4 it is shown a concentrate of all obtained datasets in the form of box plots before median filtering (shown in row 1) and after median filtering (row 2). Columns a-c corresponds to speeds of 900, 1500 and 2000 RPM, measured at 20' with different sample times. Dataset1: T=500ms, Dataset2: T=1s, Dataset3: T=2s. In columns d-f are shown the data for sample times at 50ms, 1s and 2s respectively, constant speed at 1000 RPM, and different measure distances. Dataset 1: d= 50', Dataset 2: d=300', Dataset 3: d=400'.

Figure 4. Box plots of recollected data. **(a)** n = 900 RPM, d = 20'. **(b)** n = 1500 RPM, d = 20'. **(c)** n = 2000 RPM, d = 20'. **(d)** n = 1000 RPM, T = 500ms. **(e)** n = 1000 RPM, T = 1s. **(f)** n = 1000 RPM, T = 2ms.



From the figure 4, can be notice that the data spreading in columns d-f is considerably larger than presented in columns a-c. This is caused by the occurrence of fails of data transmission-reception. When a data is not received, this is reported as a zero, which, at the moment to be fitted to a normal distribution, increases greatly the standard deviation and decreases the mean as observed in row1 of columns d-f, principally in datasets 2 and 3. Dataset 1 does not have this problem because the missing data occurs when the measurement distances crosses the transmission distances endorsed by the manufacturer.

In columns a-c are noticed the consequences of changing the sample time. By increasing the sample time, the mean value approaches the real speed, but the system response is slower. In the other hand, by decreasing the sample time the response is faster, but the mean value departs from the real value, according to the measurements taken by a commercial optical tachometer model DT-2234C. Getting an error correspondence between the real speeds and computed speeds in a given sample time it is possible to obtain a correction function to compensate this difference, while preserving useful time response.

4. Conclusions and further work

In this study, a low cost digital tachometer has been characterized. Important achievements have been reached to implement this methodology in the research of other physical variables oriented to monitor and control diverse variables in a Formula SAE automobile. Has been validated the reliability and repeatability of the whole system, including sensing, signal conditioning, wireless transmission-reception, data analysis and data display functional blocks. Diverse experiments were performed, documenting the consequences of changing speeds, distances and sample times.

As further work is still pending the research of other wireless technologies and/or communication protocols that can be useful in greater distances and adverse conditions. It is important to note that until this point all experiments were done in a laboratory with controlled conditions and may vary when applied to an automobile.

Conflicts of Interest

The authors declare no conflict of interest.

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