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LoRa® based multi-sensor system for heavy-duty vehicle detection in restricted areas

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Abstract. This paper focuses on the design and implementation of a low cost and low energy consumption system for detecting the access of heavy duty vehicle in restricted areas. Rather than the more common approach of using image acquisition through traffic cameras, the system uses the sound and vibrations generated by the operation of heavy duty vehicles. This approach can be especially useful in areas where the implementation of a conventional traffic monitoring system is extremely cost ineffective due to the lack of an appropriate network infrastructure, LoRaˇ modulation offers great advantages in comparison to other methods regarding the range and power consumption needed for maintaining the communication between the sensors and the back-end infrastructure. Based on the information offered by the vibration and sound sensors a prediction about the presence of a heavy-duty vehicle can be made, the configuration option of the detection thresholds for the measured information allows a fine tuning of the algorithm. Identification of the incident location is done via a unique identifier of the acquisition system present in a database, entry done at installation, to avoid the integration of a GPS receiver. Alerts are displayed on a map upon identification for further measures.

1 Heavy duty vehicle access is restricted areas

1.1 Effects of heavy vehicle access

With a constant growth in the market of transportation based on heavy duty vehicles more and more such vehicles will be present on the roads. One of the problems that arise from an increase of heavy duty traffic is the structural damage caused to the existing infrastructure that might not have been designed to withstand such a heavy load. Figure 1 illustrates fatigue damage caused by the truck movement on the section of the road [1].

Fig. 1. Pavement damage caused by heavy traffic

Besides the damage to the road infrastructure constant traffic can cause damage to residential or historic areas that did not have a consideration for the effects of traffic during their conception. One example of a paper focused on effects of traffic and its effects on historic buildings is described in [2]. While a complete reduction of traffic in certain risk areas is not generally possible a reduction or complete restriction of just heavy traffic is generally possible. An example of such an implementation is presented in figure 2 [3], where the restrictions on heavy vehicles for the Canadian city of Brampton are presented.

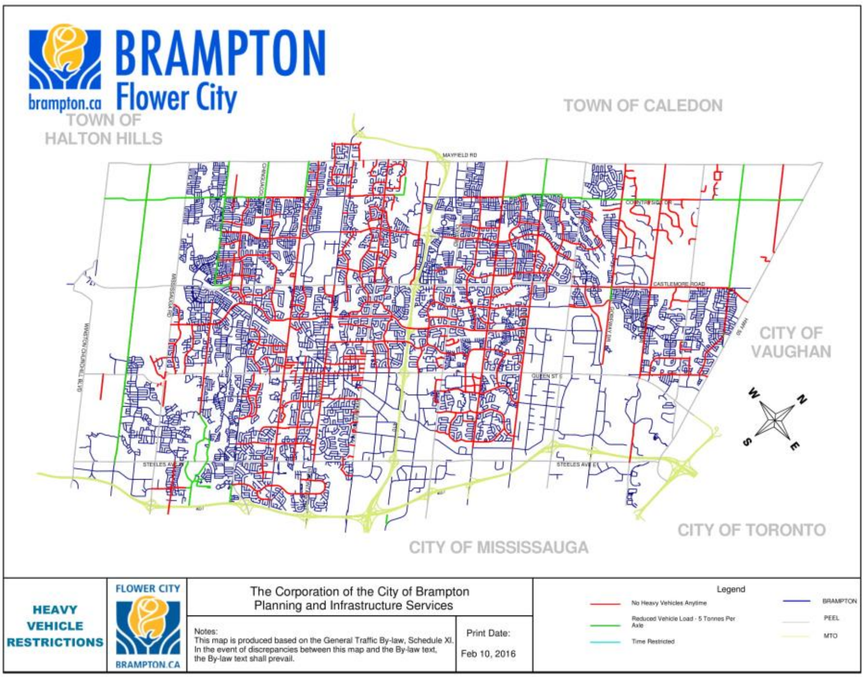

Fig. 2. Heavy vehicle access restriction example

While restrictions are already in place in many cities their enforcement might be difficult sometimes considering the scale of larger cities.

1.2 Detection and enforcement methods

The following detection methods where considered as a comparison to the proposed method.

1.2.1 Non-automated detection through a police filter

This method is the most widely used as it implies no additional systems and existing law enforcement agents can be used. It has the advantage that the detection and the action taken can be done by the same authority. This method is suited for smaller areas or areas in which the access is limited to certain points. Imposing restrictions on weight rather than the vehicle type this method requires an additional equipment for weight verification, the deployment of such a scale might not be feasible in certain areas as most of the system require a considerable amount of space.

1.2.2 Automated detection through traffic cameras and image recognition software

This method has the advantage that no ground force is required for detection and sanctions can be issued automatically based on the vehicle registration number. The method requires the presence of physical cameras on key parts of the road and a rather processing heavy hardware either on site of as a centralized structure. Booth paradigms have their advantages and disadvantages while a local processing unit would require a less demanding network connection equipment that is capable of image processing is rather expensive and comes with a high energy consumption. A centralized approach to vehicle detection requires large data centers with high operational costs that might not be feasible on a local level. The mounting of traffic cameras is also a problem that needs to be considered in the deployment of such systems as certain sites might not be suitable.

2 LoRa and LoRaWAN

2.1 LoRa description

LoRa is a proprietary spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth [4]. Semtech Corp is the owner of the patent [5] and the sole supplier of LoRa modulation capable circuits [6]. LoRa defines only the physical layer of the communication and for a complete solution LoRaWAN is used. LoRa modulation features the following key properties [7]:

- Bandwidth Scalable
- Constant Envelope / Low-Power
- High Robustness
- Multipath / fading Resistant
- Doppler Resistant
- Long Range Capability
- Enhanced Network Capacity

2.2 LoRaWAN description

Maintained by the LoRa Alliance, LoRaWAN™ defines the communication protocol and system architecture for the network while the LoRa® physical layer enables the long-range communication link [8].

Figure 3 [9] features an overview of the components defined by the LoRaWAN protocol stack.

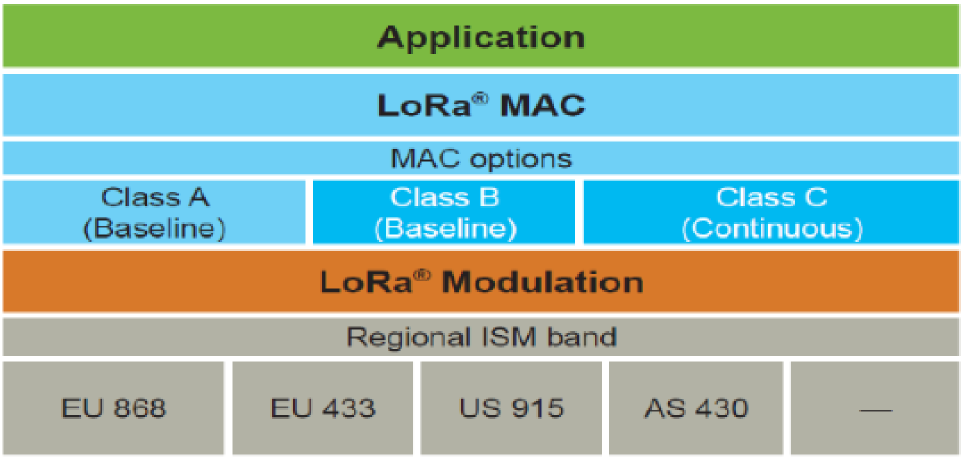

Fig. 3. LoRaWAN protocol stack

As it is visible in the above figure the ISM band is highly dependable on the location, as LoRaWAN utilises non-commercial sub GHz frequencies local legislation will be a key factor in determining the band used. LoRaWAN defines three classes of end devices based on factors like power options, latency, message types etc. The device classes defined are A, B and C. [10] presents in a synthetized manner the various characteristics of the three device classes. A diagram of a LoRaWAN network is presented in figure 4 [11]. The network layout will be used as the starting point for the solution's network design.

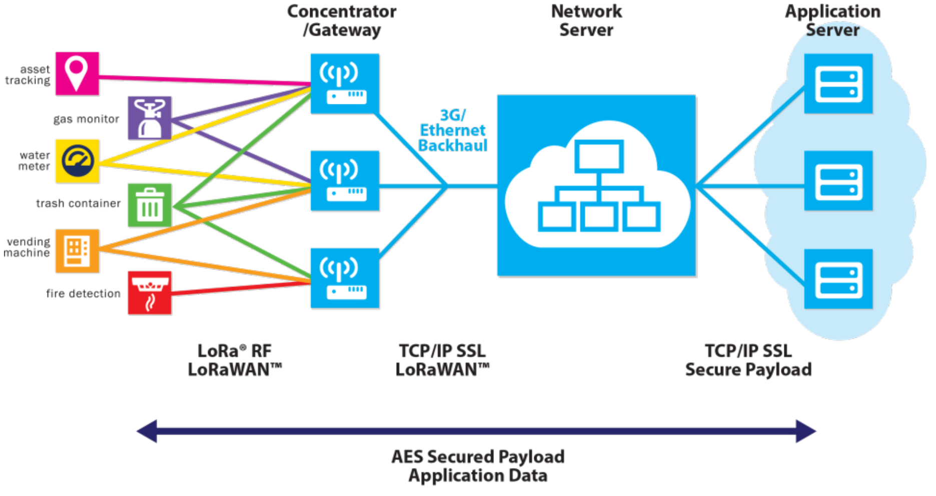

Fig. 4. Network diagram for LoRaWAN

The main components of the network are:

- The LoRa enabled end devices
- The LoRa gateways
- The network server
- The application server

3 Proposed solution

The proposed solution features two sensors (vibration and sound) based system to detect the presence of a heavy-duty vehicle. Rather than using direct observation the system used the two factors of higher vibrations and a higher noise level. This is a low cost low processing power approach.

3.1 System overview

The system is mapped on the LoRaWAN network and utilizes the protocol to transmit information from the nodes to the main application. Figure 5 presents a system overview

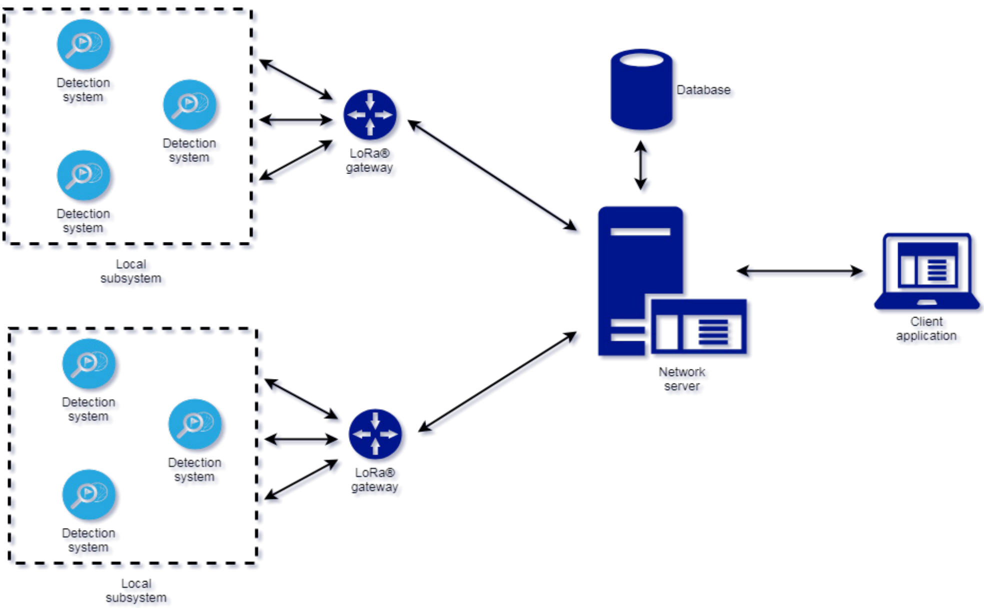

Fig. 5. Detection system overview

The LoRa enabled device is presented in figure 6. The most important components of the system are the sensors used for detection, the processing unit for the algorithm and the LoRa transceiver.

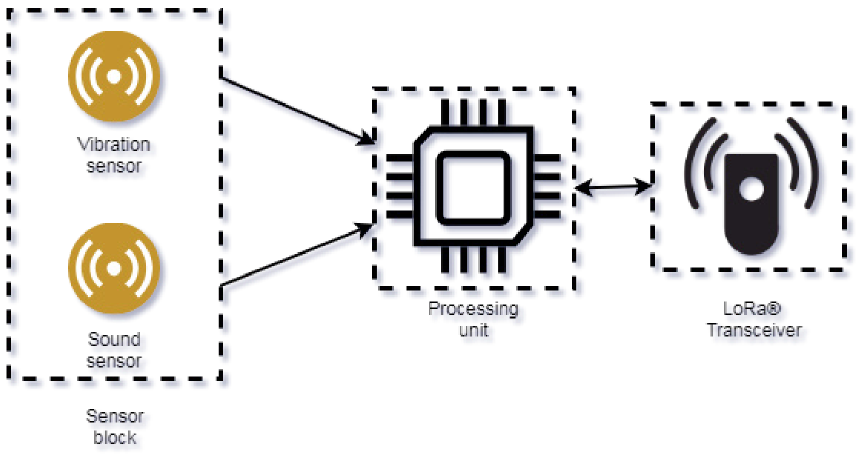

Fig. 6. End device block diagram description

The algorithm used for the vehicle detection is presented in figure 7.

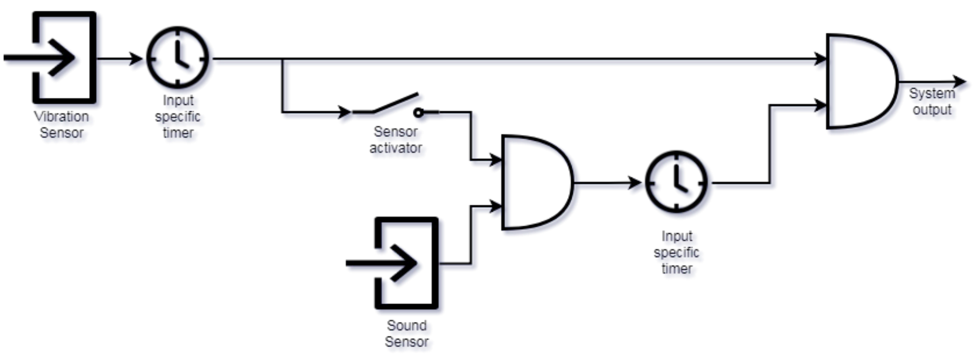

Fig. 7. Vehicle detection algorithm

The algorithm reduces the processing necessities by considering the sensor input as a digital signal associated with a specific timer for denounce to reduce false positives. Only one sensor is periodically read until the first stimuli appears. If the first sensor detects a signal for a given time frame it will determine the system to read the secondary sensor reading. If both sensors have an active signal for the specific time frame the presence of a vehicle is determined and the message is forwarded. If the stimuli disappear the counters will be decremented and if the counters reach zero, the system enters the normal low power operation mode. This method was used to minimize the traffic on the network and increase the battery life of the device.

3.1 Hardware prototype

For the system proof of concept, the following components where used: vibration sensor with adjustable sensitivity and a digital output, sound sensor with adjustable sensitivity and a digital output, Raspberry Pi model 3 B+, 868MHz RN2483 LoRa(TM) Technology Mote.

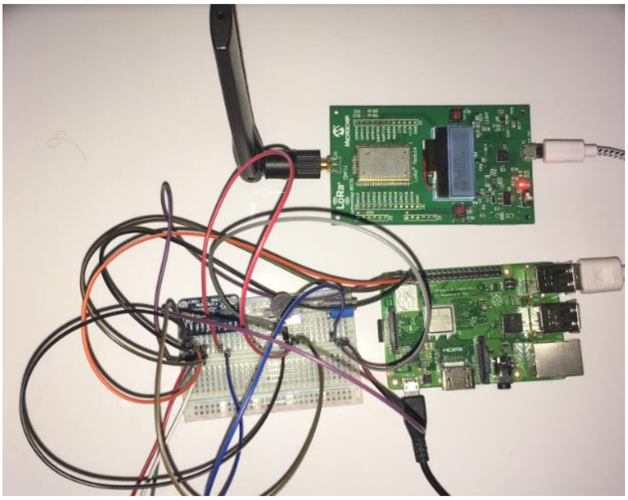

Fig. 8. Hardware prototype

As a LoRa gateway the SENTRIUS™ RG1XX was used. For the network and application servers a generic PC was used. While the hardware choice is not nearly optimal for a commercially viable product in terms of power consumption, excess features or cost it offered the fastest prototyping solution for the designed system.

3.2 Results

Using the HW prototype presented in figure 9 and having the input stimuli (read as a digital input) presented in figure 10 the system was capable to detect the presence and display the alert on the application presented in figure 11. The equipment position was marked in a database therefore the positioning problem is reduced to a simple database query. The parameter calibration can be changed based on future research even on existing devices trough the downlink possibility.

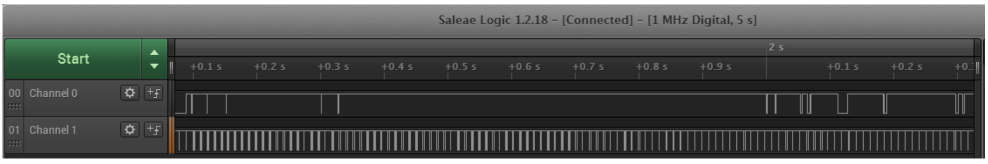

Figure 10 Input signals used

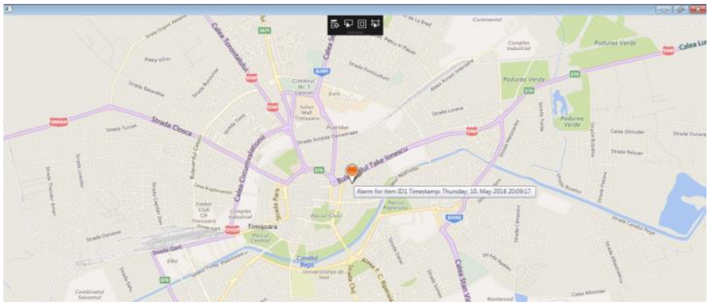

Figure 11 Application output for new detection

4 Conclusions

Compared with the solutions presented in chapter one the solution proposed offers a cheaper alternative that can be easily deployed even in areas with limited access to a network connection. The solution has its shortcomings regarding the accuracy of the prediction as false positives might be generated but this can be reduced with the addition of a sensor to measure also the vehicle height. For industrialization cheaper and more protected hardware needs to be used.

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