IoT based Driver Information System for Monitoring the Load Securing

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Keywords: Load Securing System, Load Cell Sensor, VL6180X Proximity and Ambient Light Sensing Module, CNY70 Reflective Optical Sensor, Miniature Snap-Action Switch, Wireless Technology, Encryption of Transmitted Data, Development and Analysis of 433 MHz Radio Link, Power Supply of the Electronic Cargo Strap Systems, Back End, Front End, Practical Real World Tests.

Abstract: This paper presents an electronic cargo strap system for monitoring load securing in trucks and car trailers. Various measuring techniques and sensors for measuring the force on lashing belts are investigated. In addition, a data access layer (back end) and a presentation layer (front end) have been developed for the system in order to be able to monitor the load while driving. Moreover, radio data transmission, encryption of transmission data and power supply of the systems has been realized. Furthermore, some prototypes have been created in order to test the developed systems. A series of practical tests have been performed to test the electronic cargo strap systems under real-world conditions.

1 INTRODUCTION

Many accidents and road closures occur due to non-monitored load securing during transportation of loaded goods in heavy goods vehicles, also causing transport damages of the loaded goods, which further increases the costs. To counteract this problem, this paper introduces a system for monitoring the load securing in trucks and car trailers.

Various measuring methods and sensors have been investigated. The sensors for measuring the force on the lashing belt have been analysed and tested. To prove the long-term stability, all sensors were operated in continuous long-term tests. The cost of the individual sensor must be very low for this application because there are many lashing straps used on a typical truck. Monitoring and display of measured data has been implemented as a mobile application running on an Android tablet.

Furthermore, power consumption of our electronic cargo strap systems including sensor and microcontroller has been investigated. Additionally, a power supply suitable for real world use featuring easy replacement of batteries has been developed. Long service life of these systems without replacing the batteries is highly desirable.

The radio data transmission between the data access layer (back end) and the electronic cargo strap systems has been examined. Here it is important that the radio link requires very little energy in order to be able to run the electronic cargo strap systems with the same energy supply for years. A simple encryption of the data has been implemented to address the need not to transmit clear text data via the radio link.

Most of the work in this project was done at the South Westphalia University of Applied Sciences in Iserlohn (Kuzmic A1, 2018). Furthermore, several prototypes of the electronic cargo strap systems were produced in order to test them in real-world deployments.

To the best of our knowledge, there is no other research in this area. For this reason, the references are tutorials and sensor datasheets, and therefore not related scientific work. According to our research, no product exists on the market for monitoring the load securing so far. There is only one patent (Bruhn, 2014) for a similar system which describes other sensors.

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2 SYSTEM ARCHITECTURE OF LOAD SECURING SYSTEM

The system architecture describes the interactions between developed components. Load is secured in the vehicle using lashing belts and is monitored by the electronic cargo strap systems. The data measured by the sensors attached to the lashing belt are transmitted from the truck semi-trailer to a truck cabin via 433 MHz radio link. Data are displayed for the truck driver on a tablet in the cab (Fig. 1). The conversion from raw analog sensor value to force on the lashing belt is performed by the microcontroller of the sensor-transmitter unit. The mechanical DoMess2 force meter (Dolezych, 2018) is used as a starting point for the electronic cargo strap systems.

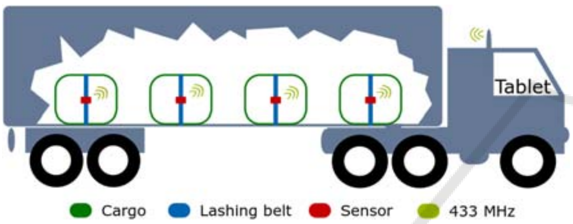

Figure 1: System architecture (interaction between truck semi-trailer and truck cabin).

During development of the electronic cargo strap systems, a hysteresis of measured values was recognized. This is due to the physical assembly of the DoMess2 force meter and the stretching of the lashing belt and the built-in compression springs (Rudolph, 2017). It can be seen in the diagram (Fig. 2) created by the pull-off force machine that the path is not identical during increasing and relieving the force on the lashing straps. When increasing the force on the DoMess2 force meter, the force of 200 daN is reached at a position of about 12 millimetres. However when relieving, the same force is reached at 15 millimetres. The stretching of the lashing strap and the mechanics are included in this diagram. daN is the abbreviation for the unit of force Dekanewton (10 Newtons). This corresponds approximately to the weight of one kilogram (Wikipedia.org A1, 2018).

However hysteresis plays a minor role in the development of the electronic cargo strap systems. Because the relieving curve is relevant when verifying force during transport, only the relieving curve must be examined. Furthermore Figure 2 shows, that while relieving the DoMess2 force meter the distance from 200 to 300 daN is only about 0.9 millimetres. This means that the sensor must be very sensitive in order to be able to perceive minimal changes of the distance. Optimizing the larger spring forces may reduce the hysteresis, but this was not tested. The steps in the relieving curve diagram result from stopping at different levels of force on the pull-off force machine. The force was held in these conditions for ten seconds at each step.

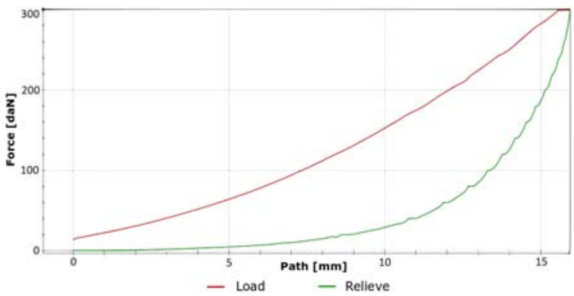

Figure 2: Hysteresis of load and relieve the lashing strap.

3 ANALYSIS OF SENSORS

The following sections examine four possible sensors for measuring the force on the lashing belts. Arduino Pro Mini microcontrollers (Rohner, 2015) are used to read the sensors.

3.1 Load Cell Sensor

The load cell sensor is the standard measuring device installed in commercial digital personal scales (Instructables.com A1, 2018). This sensor contains two strain gauges, which change their resistance during compression or stretching (Al-Mutlaq, 2018). This type of sensor needs a load cell amplifier, because the changes of resistance are very small. The breakout board HX711 (Forum.arduino.cc, 2018) can be used for this. It contains all components required for amplification of the resistance changes. To obtain correct readings for two load cell sensors, two half Wheatstone bridges (dual half bridge) have to be constructed (Youtube.com, 2016). This type of circuit is commonly used to measure small ohmic resistance changes. After some short-term measurements, the question arises as to whether the load cell sensors are long-term stable. To answer this question, a continuous operating test was run for about two weeks. The starting weight in this test was 410 grams. As can be seen in next figure (Fig. 3), the reading values vary significantly over time. The deviation in this case is up to 76 percent. Although these sensors are ideal for a short measurement in a digital personal scale, they can not be used for continuous operation. For this reason, load cell sensors are inappropriate for measuring forces on lashing belts.

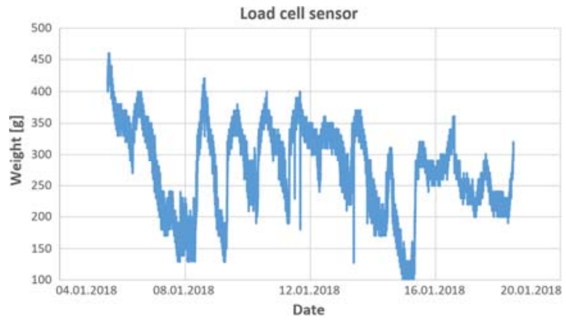

Figure 3: Continuous operating test of load cell sensor.

3.2 VL6180X Proximity and Ambient Light Sensing Module

The next type of sensor investigated was the VL6180X Time-of-Flight proximity and ambient light sensor. Because the VL6180X uses infrared pulses for measurement, it is widely independent of colour and surface properties of the target (Pololu, 2018). After wiring and programming (Github.com, 2016) of the components, a distance measurement test was performed with this sensor. From this test, it was found out that the VL6180X sensor is suitable for measuring distances in the mm range. It provides a digital read out of the distance to the object in millimetres. To determine whether this sensor can be used permanently for the electronic cargo strap system, a continuous operating test with three sensors for about two weeks was carried out (Fig. 4).

Figure 4: Continuous operating test of one of three VL6180X sensors.

The three continuous operating tests were executed in parallel. All three VL6180X sensors fluctuate between 4-7 millimetres. The minimum resolution of the sensor is one millimetre, which is within the requirements for measuring lashing belt forces. Nevertheless, the discovered fluctuations make these sensors too inaccurate with regard to long-term stability. The VL6180X sensors are therefore not suitable for measuring the force on lashing belts because the maximum lift of the mechanical DoMess2 force meter used is only ten millimetres and the fluctuations of the sensors were 4 mm, equivalent to 40% of the measuring range. However, the measuring range is in centimetres, VL6180X sensors may be used.

3.3 CNY70 Reflective Optical Sensor with Transistor Output

This chapter investigates the usability of the CNY70 reflective optical sensor with transistor output (Mischnick and Mischnick, 2007) for the electronic cargo strap system. In order to check whether the sensor is suitable for measuring, it was installed in a syringe in the first step. The syringe was taped with black tape, so that the outside light did not affect the light from the sensor's LED. Because each of these analog sensors shows different measured values with the same applied voltage, they must be calibrated before measuring. In principle, these sensors are suitable for measuring distances. They passed the continuous operating tests very well, showing excellent long-term stability (Fig. 5).

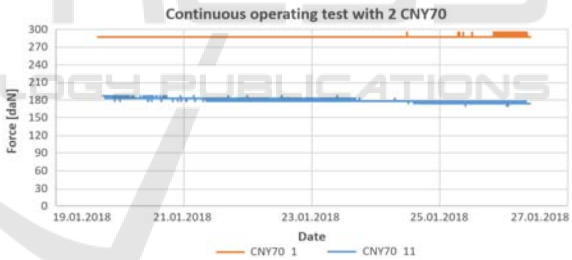

Figure 5: Continuous operating test of two CNY70 sensors.

An average function is used to convert the raw analog value of the sensor voltage to the force on the lashing belt (Dekanewton). Because the curve progression of the sensors is identical, the measured ratio of the sensor can be represented on a percentage basis on this average curve. For this only the start and end values of the measurement range determined during calibration of the sensor are required. During test measurements and continuous operating tests it turned out that although CNY70 sensors are suitable for measuring the distance in the DoMess2 force meter, they are very sensitive to external light and mechanical impact. Furthermore, it has been noticed that material and colour of the reflective surface play a major role in the measurement. However, because of the good results of test measurements and continuous operation tests, several prototypes were produced for field tests in the real world.

3.4 Miniature Snap-action Switch

Another possibility for monitoring load securing is the miniature snap-action switch known from electrical engineering. These switches are nowadays a standard component in many electrical appliances. A great advantage of micro switches is their working temperature range between - 25°C and + 85°C. In addition, they support up to a million operations (Produktinfo.conrad.com, 2018). Micro switches can be used in different ways. Using all three existing connections, the electrical switch can be wired as a changeover contact. If only two connections of the micro switch are used, it acts as a NO (normally open) or NC (normally closed) (Wikipedia.org A2, 2018) device. In the electronic cargo strap system, the micro switch is used as a normally open switch.

Because the micro switches behave like security contacts, and load security requires a certain minimum force on the lashing belts, they are well suited for monitoring load securing when their trigger point is set to this minimum force. This point can be adjusted on a pull-off force machine. For this reason, two such prototypes are created.

4 WIRELESS TECHNOLOGY

The 433 MHz wireless technology was chosen as radio technology for the system. WLAN (wireless local area network) wireless technology was used successfully in a previously created prototype (Kuzmic A2, 2017) with ESP8266 microcontrollers (not discussed in this paper). Based on this, it was known that a WLAN connection is indeed stable and secure due to WPA2 encryption, but it requires a lot of energy. Therefore, WLAN wireless technology with the ESP8266 can not be used when operating with batteries as in this paper. Another alternative investigated was Bluetooth wireless technology. Previous projects revealed that this technology has range problems using less transmission power (powering with batteries), but this was not explicitly tested in this project. Therefore, it can not be used in the development of the electronic cargo strap system. In the two previously presented wireless technologies, a permanent connection between transmitter and receiver is established. Thus, the transmission process lasts longer and uses a lot of energy. In 433 MHz wireless technology, however, no connection between the transmitter and the receiver is established. Messages are sent without knowing whether they have actually arrived at the receiver, like User Datagram Protocol (UDP). Therefore, 433 MHz radio technology requires much less energy and can achieve long range in optimal conditions. For this reason, this wireless technology was used in our system.

4.1 Encryption of Transmitted Data

To ensure that messages are not transmitted in plain text over the 433 MHz radio link, the transmission data is encrypted with an enhanced Caesar encryption. This should show in principle the possibility of cryptography. Of course, in the next step the primitive Caesar algorithm needs to be replaced with a state of the art encryption like the Rabbit stream cipher, which requires only a rather small extra amount of code.

4.2 Analysis of 433 MHz Radio Link

To understand what really happens on the 433 MHz radio link between transmitter and receiver, the 433 MHz radio link was analysed (Instructables.com A2, 2018; Rtl-sdr.com, 2013) using software-defined radio (SDR) technology. This analysis uses digital signal processing. Coding of the bits in a 433 MHz connection is as follows: 0 = 100 and 1 = 110 (Pérez, 2013). The 433 MHz transmitter and the 433 MHz receiver modules (FS1000A and XD-RF-5V) for Arduino use amplitude-shift on-off keying (ASK-OOK) (Mietke, 2018). This is a form of amplitude modulation (AM) (Wikipedia.org A3, 2018). To check what the binary code on the radio link looks like, a test message is sent. The bit sequence of this message looks like this: "1111010111011011000111001".

After demodulating the signal, the same bit pattern can be successfully detected from the air. The next figure (Fig. 6) shows this demodulation (Rascagnères, 2015).

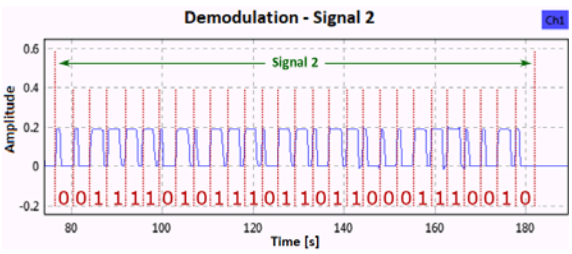

Figure 6: Diagram of bit sequence from signal two.

During testing the transmission range of the systems, the messages of all ten test systems could be received at a distance of ten metres from the transmitter to the receiver. This test was carried out without any obstacles between transmitter and receiver. To increase the transmission distance, professional antennas could be installed. If this does not solve this problem, 433 MHz repeaters can be installed on the truck semi-trailer.

5 POWER SUPPLY

According to a market analysis, the Arduino Pro Mini microcontrollers are known to consume very little power and are often used as microcontrollers for powering with batteries (Wikipedia.org A4, 2018). Due to the fact that these microcontrollers consume very little energy in sleep mode (Deep Sleep) compared to other microcontrollers, they can be operated for years without changing batteries (Home-automation-community, 2018). For this reason, these microcontrollers were chosen for the electronic cargo strap system. Of course, the final power consumption is also affected by the connected sensors and actuators. Furthermore, Arduino Pro Mini microcontrollers do not require an external low-dropout (LDO) regulator. This is already installed on the standard demo board (Cdn.sparkfun.com, 2018). The following table (Tab. 1) illustrates the key data for an example calculation of continuous operation.

Table 1: Key data for battery life.

Battery type	NiMH
Capacity of a battery (mAh)	2500
Power consumption in sleep mode (mA)	0,03293
Power consumption in normal mode (mA)	21,08
Interval duration (s)	600
Duration in sleep mode (s)	598
Duration in normal mode (s)	2

The following shows an example of the theoretical calculation of the battery life:

$$\frac{2500\ mAh * 600\ s}{21.08\ mA * 2\ s + 0.03293\ mA * 598\ s} = 24261.4\ h \approx 33.2\ months \quad (1)$$

Every ten-minute interval (600 seconds), the microcontroller switches from sleep mode to normal mode. In normal mode two seconds are needed for reading the sensor and transmitting the sensor's value via the 433 MHz interface. During the remaining 598 seconds of a 600 second interval the microcontroller is in sleep mode (Deep Sleep). This calculation (Eq. 1) refers to the CNY70 sensors currently installed in the electronic cargo strap system. This also shows that theoretical battery life is approx. 3 years in continuous operation.

6 SOFTWARE ARCHITECTURE

Software architecture (Fig. 7) describes the interaction of the sensors with the presentation layer (front end) and the data access layer (back end).

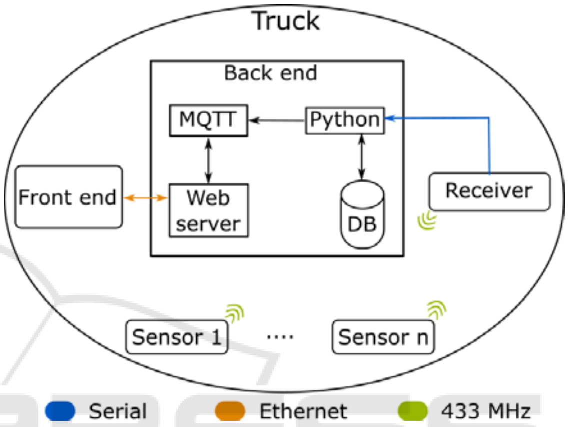

Figure 7: Software architecture of the monitoring system.

The electronic cargo strap systems transmits the measured data over a 433 MHz radio link. Data are received by a 433 MHz receiver connected to the data access layer (back end). Next, the received data are streamed to a Python script in the back end. Received data are evaluated in this Python script and stored in the database. Furthermore, the analysed data and alarm messages are passed from the Python script to the MQTT broker and thus to the presentation layer (front end). In the next step, incoming data are displayed in an Android application via the web server.

Communication between back end and front end is realized via a REST interface, working via Ethernet over USB (Universal Serial Bus), because a cable connection is more stable and less susceptible to interference. Of course, this connection can also be a wireless connection.

6.1 433 MHz Receiver

The microcontroller for the 433 MHz receiver (XD-RF-5V) uses the demo board NodeMCU ESP8266. This board contains all components necessary for Plug and Play (PnP). The internal serial adapter provides access to the back end via USB.

6.2 Back End

The back end of the software includes the components Apache HTTP server, MariaDB relational database, Mosquitto MQTT broker and a Python script. These run on a Raspberry Pi 3 with a solid-state drive (SSD) (Raspberry.tips, 2017). After the back end system is started, the Python script is executed as a service (Wiki.ubuntuusers.de, 2018). This service connects to the MQTT broker and in the next step checks using an endless loop whether data have arrived from the 433 MHz receiver via the serial interface.

Once data are available, they will be reviewed first. After review and evaluation of the message, metrics and alerts are forwarded to the front end. If errors occur in the function, in the receiver or in the transmitter, these are sent to the surface additionally. Moreover, each measured value, alarm message and error message is stored permanently in the database for possible further evaluations.

6.3 Front End

The user interface of the front end consists of an Android application that displays the data in a WebView (Fig. 8). The data for the display are provided by the HTTP web server.

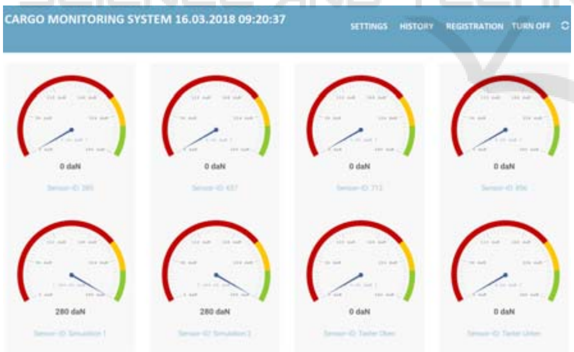

Figure 8: User interface of the monitoring system with eight monitored sensors (translation from German).

As soon as measured values of the electronic cargo system arrive on the monitoring page, a new JavaScript gauge for this system is created and displayed. If the JavaScript gauge exists already for a particular sensor, the measured values of this sensor are updated and displayed as daN. If an error message is forwarded from the back end to the front end, it will appear on the monitoring page immediately. As soon as measured values of a lashing belt fall below the minimum allowable force predefined in the settings, an alarm message appears on the monitoring page (Fig. 9) including the system's sensor identification number. If a name was manually set when registering the electronic cargo strap system, this name will be displayed on the monitoring page instead of the sensor identification number.

In addition to the visual notification, the user is warned by an audible warning signal from the Android device. If this alarm is ignored or not confirmed, the notification will be displayed again when the next measured value of the system is received.

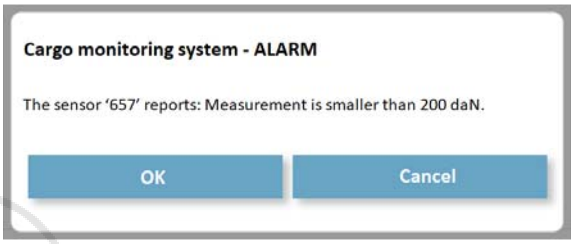

Figure 9: Alarm message on the monitoring page (translation from German).

7 PRACTICAL TESTS

For practical tests of the developed systems, four real-world deployments were carried out.

7.1 Lashing Belt Elongation Test

For this test a metal box weighing about 600 kilograms and filled with scrap metal, was fastened on a car trailer using the developed electronic cargo strap system. Because the metal box can not be compressed by the lashing strap, it was possible to measure the elongation of the lashing strap successfully while driving. After about 1.3 kilometres, the lashing strap had completely extended and had to be retightened. It had also been proven that driving in curves and acceleration has an effect on the measured force on the lashing belt.

7.2 Crucial Test

To detect whether the developed electronic cargo strap system notifies users even when the lashing belt tear (Lasiportal.de, 2018), a successful emergency test was performed (Fig. 10).

Figure 10: Alarm message during the crucial test. Left: Intact lashing belt. Right: Torn lashing belt.

7.3 Pressure Test

Another possible scenario (Fig. 11) for load securing is the transport and attachment of pallets with soft material. Because in these cases the load seems to be secured at first glance, but over the time of driving, the soft material may compress and the cargo will no longer be secured.

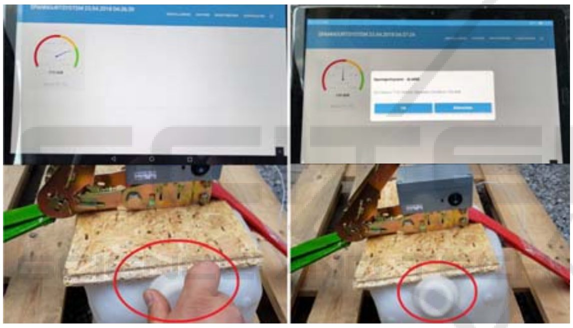

Figure 11: Alarm message during the pressure test. Left: Closed cap of the canister. Right: Opened cap of the canister.

7.4 Transmission Test

A final and important practical test for the electronic cargo strap systems was the transmission test. In this test, it was observed that vehicle speed have a negative effect on the transmission of the sensor data. The use of more professional antennas would significantly improve the result in our opinion.

8 CONCLUSIONS

Overall, the driver information system for monitoring the load securing worked well. The CNY70 reflective optical sensors were used successfully. However, it was noticed that they are very sensitive to the colour and the material of a reflective surface. It was also noticed that ambient light and slight impact affect the measurement.

In order to achieve a greater range for the transmission of the measured data, more professional antennas are recommended. These should point to different directions. The antennas could look like a wireless router, which usually contain three antennas for sending and receiving from different directions. An alternative would be to install 433 MHz repeaters on the truck semi-trailer. Another option for wireless data transmission could be Zigbee (Wikipedia.org A5, 2018). This data transfer technology can achieve long ranges and is often used on various Internet of Things (IoT) devices. For improved receipt in the cab of the truck, the receiver antenna should be mounted outside the cab. It should be noted that the maximum cable length of USB connection is not exceeded. If necessary, it makes more sense to extend the 1-Wire connection (Maxim Integrated Products, 2008) to the Arduino receiver module rather than the USB connection (Wikipedia.org A6, 2018) from the receiver to the back end system.

A second option for the sensor for the electronic cargo system is a miniature snap-action switch. The fact that this micro switch can be installed in a simple mechanical device can quickly turn this prototype into a product. In addition, the micro switches do not respond to ambient light, temperature and slight impact like other analysed sensors. However, it is still a long way to a successful product.

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