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Implementation of an Intelligent Caravan Monitoring System Using a Simple Serial Communication Protocol for Microcontrollers (SSCPM)

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Abstract—Safety applications play an essential role in our daily life. Without them many accidents would have happened. Especially nowadays, where the amount of traffic increases year by year, safety applications have become an important factor for the vehicle industry. Statistics have shown that the amount of accidents could be remarkably reduced for vehicles with safety systems. However, most of the safety systems are implemented on vehicles but not on trailers.

This paper describes the implementation of an Intelligent Trailer Monitoring System which uses a Simple Serial Communication Protocol (SSCPM) for the communication between the vehicle's board computer and the trailer's monitoring system.

I. INTRODUCTION

In recent years, there were several accidents with caravans. According to [1] 80% of the accidents resulted in total destruction of the caravan. The loss of control was the reason for 30% of the insurance claims. One reason, for the loss of control, is overspeeding. It is recommended, not to drive more than 96.5 kph when drawing a caravan, otherwise a slight force might tip the caravan from one way to another.

A further reason, for the loss of control is overloading, or when the load of the caravan is not balanced. A too high coupling load, could lead to a situation, where the front wheels of the car are loosing the road grip, making the car uncontrollable. Furthermore, a too high load at the back of the caravan, could lead to a situation, where the back wheels of the car are loosing the road grip, making the car uncontrollable, too. It is also important, that the weight of the right side is equal or close to the weight on the left side, otherwise the caravan could tilt over, while driving through a dangerous bend. The age of the tires plays also an essential role for the road safety. Tires, older than five years, should be replaced with new ones, even if they do not show any kind of damage or if the profile depth is still good. Old tires can explode or can get flat, causing that the caravan might skid.

Another hazard that could cause a road accident with caravans, are broken light bulbs. In newspapers, it can be read quite often, that a vehicle with a trailer turned left, but due to a broken indicator bulb, another vehicle was just overtaking it at that moment and crashed into it.

In addition, the carried gas bottles could also cause an explosion if they, or if a gas pipe, becomes leaky for a longer time. This could lead to a serious road accident during the ride.

In this paper, an Intelligent Caravan Monitoring System has been implemented in order to reduce the amount of accidents caused by the previous mentioned reasons.

II. FUNCTIONALITY OF THE PROPOSED INTELLIGENT CARAVAN MONITORING SYSTEM

The idea of the Intelligent Caravan Monitoring System is to monitor all kind of electrical devices on board, getting information about the weight, weight distribution, lighting system, temperature, status of the door and the status of windows from the caravan. This system requires, that the car as well as the caravan must be equipped with a board computer that contains a touchscreen. It is to mention, that the board computer of the car acts as a Master while the board computer of the caravan is acting as a Slave. In order to read a certain information (temperature values, lighting issues etc.) or to set certain values, the board computer of the car will send a certain packet type to the caravan's board computer which will then process the packet. The board computer of the caravan is connected with all kind of electrical devices that can be monitored and controlled by the car's board computer. Cars, that have a trailer hitch, are normally equipped with a 13 pole trailer socket but only eleven poles are used. Fig. 1 presents the trailer socket. Table 1 shows the pin assignment of a 13 pole trailer socket. Two poles of the 13 pole trailer socket are used, for the communication between the car's and caravan's board computer [2]. One wire (pole 12) is used for transmitting the packet, the other wire is used for the common ground (pole 13). When transmitting a packet, each byte of a packet is sent separately. SSCPМ [3] has been used to transmit a packet byte-by-byte from the car's board computer to the caravan's board computer and vice versa. Fig. 2 illustrates the transmission of the byte value 129 (0x81). Each byte transmission starts with a 100us high level signal followed by a 500us low level signal

before the eight bits of the corresponding byte are transmitted. It takes around 4.6ms to transmit one byte.

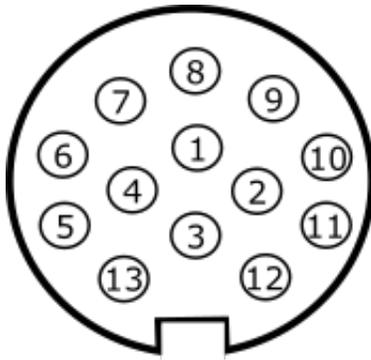


Fig. 1. Trailer Socket.

TABLE I
PIN ASSIGNMENT OF A 13 POLE TRAILER SOCKET

Pole Number	Consumer
1	Indicator (left)
2	Rear Fog Light
3	GND of Poles 1 to 8
4	Indicator (right)
5	Back Light (right)
6	Brake Light
7	Back Light (left)
8	Backup Lamp
9	Positive Pole
10	Positive Pole for Charging
11	not assigned (GND of Pole 10)
12	not assigned
13	GND of Poles 9 to 12

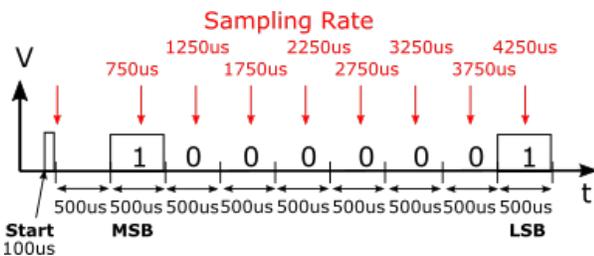


Fig. 2. SSCPM Signal for the transmission of one byte (value 0x81).

In the proposed system there are nine different packet types. Control Packets with and without value, Authentication Packet, Safety Packet, Reply Packets, Trailer Info Packet, Trailer Weight Packet, Trailer Supply Packet and Driver Assistant Packet. The Control Packets and the Authentication Packet are sent from the car's board computer to the caravan's board computer. Based on the request of the received Control Packet, the caravan's board computer replies either with a Safety Packet, Reply Packets, Trailer Info Packet, Trailer Weight Packet or Driver Assistant Packet. Fig. 3 shows the format of the packets. A Control Packet is used to request a Safety Packet in certain time intervals or when an indicator is set.

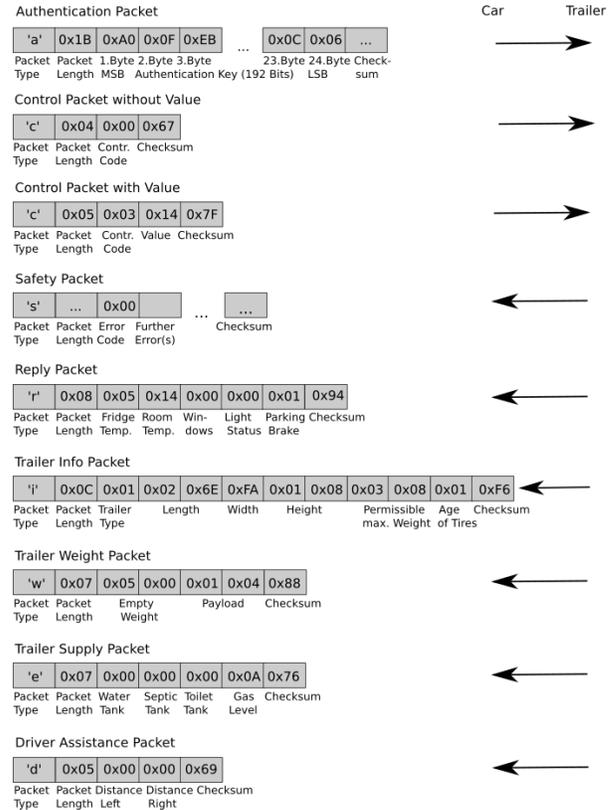


Fig. 3. Packet Formats.

In case of lighting and tire problems, such as an open door or open window(s), the Safety Packet contains the error code(s) which will be sent to the car's board computer in order to inform the driver about the problem. It displays the safety warning message on the screen and generates an acoustic warning signal. Through the Control Packets the driver can also send control commands to the caravan's board computer. Typical control commands are the adjustment of the fridge temperature, air conditioning, turning on/off the light in the caravan as well as opening and closing electronic windows. The Reply Packet contains all the control values of the caravan and it will be sent from the caravan's to the car's board computer after a request from a Control Packet. There is also a Trailer Info Packet, that contains information about the dimensions of the trailer, the maximum permissible weight and the age of the tires. In addition, there is also a Trailer Weight Packet that includes the empty trailer weight and the trailer payload. The Trailer Supply Packet delivers the water tank level, septic tank level, toilet tank level and the amount of gas. Furthermore, the Driver Assistance Packet transfers the values received from the parking sensors. It is to mention, that the Reply Packet, Trailer Info Packet, Trailer Weight Packet and the Driver Assistance Packet are also requested by the Control Packet. As soon as the driver puts the car into reverse, the board computer of the car will request continuously a Driver Assistance Packet from the caravan's board computer.

The Authentication Packet contains a 192 bit authentication

TABLE II
CONTROL CODES FOR THE CONTROL PACKET

Description	Control Code
Request Safety Packet	0x00
Request Reply Packet	0x01
Request Trailer Info Packet	0x02
Request Trailer Weight Packet	0x03
Request Trailer Supply Packet	0x04
Request Driver Assistance Packet	0x05
Adjust fridge temperature	0x06
Adjust temperature of air conditioning	0x07
Radiators (on/off)	0x08
Window Control (left side)	0x09
Window Control (right side)	0x0A
Window Control (front side)	0x0B
Window Control (rear side)	0x0C
Window Control (roof)	0x0D
Light Control	0x0E
Tighten/release electrical brake	0x0F
Release Reversing Lock for the brake	0x10
Fresh Water Tank Level	0x11
Septic Tank Level	0x12
Toilet Tank Level	0x13
Gas Bottle Monitoring	0x14

TABLE III
ERROR CODES FOR THE SAFETY PACKET

Description	Error Code
No fault	0x00
Indicator (left)	0x01
Indicator (right)	0x02
Brake light (left)	0x03
Brake light (right)	0x04
Back light (left)	0x05
Back light (right)	0x06
Rear Fog light (left)	0x07
Rear Fog light (right)	0x08
Backup Lamp (left)	0x09
Backup Lamp (right)	0x0A
Electrical parking brake (tighten)	0x0B
Reversing Lock (released)	0x0C
Tire pressure (left)	0x0D
Tire pressure (right)	0x0E
Tire pressure (2nd tire left)	0x0F
Tire pressure (2nd tire right)	0x10
Window opened (left side)	0x11
Window opened (right side)	0x12
Window opened (front side)	0x13
Window opened (rear side)	0x14
Window opened (roof)	0x15
Door opened	0x16
Gas Sensor Alarm	0x17
More Weight on Corner (Left Front)	0x18
More Weight on Corner (Right Front)	0x19
More Weight on Corner (Left Rear)	0x1A
More Weight on Corner (Right Rear)	0x1B
More Weight on Front	0x1C
More Weight on Back	0x1D
More Weight on Left Side	0x1E
More Weight on Right Side	0x1F
Overweight of Trailer Coupling Load	0x20
Problem with the Brakes	0x21

code which is sent to the trailer's board computer. Only when the transmitted authentication code matches with the stored authentication key in the caravan's board computer, then a

Trailer Info Packet will be sent to the car's board computer. Furthermore, the caravan's board computer is then ready for processing the received Control Packets. If the car's board computer will not receive a Trailer Info Packet after sending the authentication message, then the authentication failed. In Table 2, the control codes from the Control Packet are listed. Table 3 contains the error codes.

The authentication process is needed to protect a parked caravan from data manipulation or thieves. Without an authentication process, almost every person could connect the vehicle with a parked caravan and could change the temperature settings, turning off the fridge or even opening the windows through the car's board computer. To ensure that this will not happen, the board computer of the caravan generates a 192 bit random number, the so called authentication number, and displays it. This number must be edited and saved in the car's board computer, to establish the communication with the board computer of the caravan. The authentication number is valid until a new authentication number is generated on the caravan's board computer. In case, the caravan's board computer receives three wrong authentication numbers in a row, it will not process any authentication packet until the warning message displayed on the screen is confirmed with the caravan's board computer password. It is important to emphasize, that different packets are used because some information, the caravan dimensions for example, is only needed once.

To this system belongs also a Weight Monitoring System that warns the driver, if the load in the caravan is not balanced. This system is described in the next section.

III. WEIGHT DISTRIBUTION SYSTEM

In order to achieve a safe driveability, the load of the caravan must be distributed in a certain way.

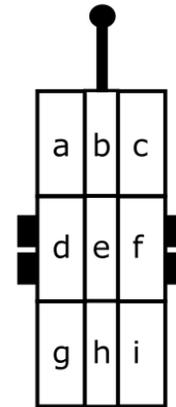


Fig. 4. Trailer Weight Distribution.

According to [4], experiments have shown, that a caravan has the highest driving stability, when the coupling load is close to the maximum and when the weight at the left side is close to the weight at the right side. For that reason, a Weight Distribution System (WDS) has been developed. The bottom

of the caravan is split into nine parts as shown in Fig. 4. It is assumed, that each of the nine parts are equipped with sensors that can determine the weight. In order to determine if the load is equally distributed, the following algorithm has been developed. It is also to mention, that the load of the caravan cannot be exactly equally distributed because not everywhere are storage compartments available or they are already full or too small for a certain load.

The idea of the WDS is to build a 3x3 Weight Distribution Matrix (WDM) from the caravan bottom that is split into nine parts.

$$WDM = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

The following Pseudocode describes how the Weight Distribution Algorithm works.

```

balanced ← false
while balanced ≠ true do
    diagonalBalance ← true
    if ((| ∑ row1 − ∑ row3 | ≤ mawd) and
    (| ∑ column1 − ∑ column3 | ≤ mawd)) then
        the load of the trailer is equally distributed
        balanced ← true
    else
        if (| wa − wi | > mawd) then
            if (wa > wi) then
                too much load on a
            else
                too much load on i
            end if
            diagonalBalance ← false
        end if
        if (| wc − wg | > mawd) then
            if (wc > wg) then
                too much load on c
            else
                too much load on g
            end if
            diagonalBalance ← false
        end if
        if ((∑ row1 > ∑ row3) and
        (diagonalBalance = true)) then
            too much load on b
        else
            too much load on h
        end if
        if ((∑ column1 > ∑ column3) and
        (diagonalBalance = true)) then
            too much load on d
        else
            too much load on f
        end if
    end if
end while

```

The variable *mawd* stands for the maximum allowed weight deviation and *w*_a, *w*_i, *w*_c and *w*_g are the variables for the load in the area a, i, c and g.

First, the system will check if the load on the front and back side is equal or in the range of the maximum allowed weight deviation. The same procedure will be done for the left and right side. In case the weight is not equally distributed, the diagonal weight distribution is determined and if it is not equally distributed it will display a warning message on the car's and caravan's board computer. If the diagonal weight distribution is okay, but the weight distribution between the front and back side as well as the weight distribution between the left and right side is not okay, further warning messages are sent and displayed.

IV. IMPLEMENTATION OF THE SYSTEM

The proposed Intelligent Caravan Monitoring System has been tested on an own implemented system (see Fig. 5). Java has been used for the implementation of the car's board computer and the caravan simulator. Both applications, the car's board computer and the caravan simulator have been running on the same Personal Computer (PC). The SSCPM has been implemented on two MSP-EXP430G2 LaunchPad Development Boards in order to realize the one wire communication between both applications. For the testing, both LaunchPads have been connected with the PC via Universal Serial Bus (USB). Two wires have been used to connect the LaunchPads with each other. One wire is used for the communication and the other wire is used for the common ground. As already mentioned, the Car's Board Computer Application acts as a Master, while the Caravan Simulator Application acts as a Slave. To get information from the trailer, the Car's Board Computer Application will send a Control Packet with the control code to the Caravan Simulator Application, which replies with the corresponding packet.

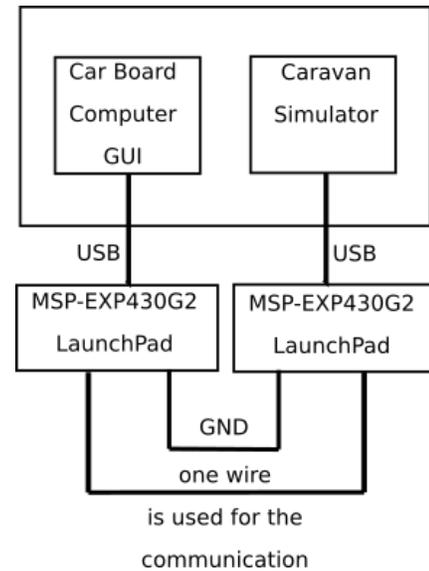


Fig. 5. Overview of the Implemented System.



Fig. 6. The Car Board Computer GUI Application.

Fig. 6 shows the Graphical User Interface (GUI) developed with JavaFX. The GUI displays all the trailer information mentioned in section II. The Caravan Simulator Application is currently a console application which will be further developed into a GUI application. Both applications get the information about the car's or caravan's dimensions, empty weight, maximum permissible weight etc. from text files. The GUI will also inform the driver about the distribution of the load (see section III).

V. FEATURES OF THE PROPOSED INTELLIGENT CARAVAN MONITORING SYSTEM

The implemented system has several features that are relevant for safety driving. In addition to the the safety features introduced in section II and the weight distribution introduced in section III, this section describes the functionality of how the system determines the required driving license, the maximum allowed driving speed with the trailer, as well as the amount of gas in a gas bottle.

All member countries of the European Union issue the European Driving License. For cars, there are three different driving licenses available B, B96 and BE [5]. All of them (B, B96 and BE) allow the owner to drive a car up to 3500kg but the driving licenses B and B96 limit the total permissible weight of the car and the trailer. Owner's of driving license B can drive a car with a trailer of more than 750kg as long as the total permissible weight of the car and trailer does not exceed 3500kg, otherwise they can only tow a trailer with a maximum permissible weight of 750kg. Owner's of driving license B96 are allowed to drive a car with a trailer whose permissible weight is more than 750kg, if the total permissible weight of 4250kg is not exceeded. The driving license BE allows to tow trailers up to 3500kg. The developed system determines the

required driving license based on the maximum permissible weight of the car, the maximum permissible weight of the trailer and the total weight of the trailer. First, the maximum permissible weight of the trailer is checked. If the maximum permissible weight of the trailer is equal or below 750kg, then the car with the trailer can be driven with all driving licenses (B, B96 and BE). Otherwise, the maximum permissible weight of the car and the maximum permissible weight of the trailer are added together. Based on the result, the system will ascertain, if the car with the trailer can be driven with the driving license BE only, B96 and BE only or with all three driving licenses (B, B96 and BE). The system considers also the total weight of the trailer in its decision because due to an overloaded trailer, the next higher driving license could be required.

The maximum allowed driving speed for cars with trailers is 80km/h. However, a driving speed of 100km/h is allowed when certain conditions are fulfilled[6].

- the total permissible weight of the car must not be more than 3500kg
- the car must have an Anti-lock Braking System (ABS)
- the trailer must be suitable for a speed of 100km/h
- the tires must have the speed index "L" (max.speed 120km/h)
- the tires must not be older than six years
- total permissible weight of the trailer $\leq y \times$ empty weight of the car

It is assumed that the factor y is provided by the trailer manufacturer. The factor depends on the shock absorbers and the brakes of the trailer. Usually the factor has a value between 0.3 and 1.2. This factor must be entered in the car's board computer.

While driving, the driver can also check via the car's board computer, the water tank, septic tank, toilet tank and the amount of gas.

The amount of the gas in the bottle can be determined according the following formula, where t is the total weight of the gas bottle, e is the empty weight of the gas bottle and x is the maximum filling weight of propane [7].

$$\text{amountOfGas} = \frac{t - e}{x} \quad (1)$$

VI. CONCLUSION

In this paper, we have introduced the implementation of an Intelligent Caravan Monitoring System using a Simple Serial Communication Protocol. The main idea of this research, was to build an Intelligent Caravan Monitoring System that informs the driver about the weight, weight distribution, state of the trailer's lighting system, tire pressure and other features. This system gives the driver the opportunity to access and control certain electronic devices such as fridge, air conditioning and so on. The simulators for the car's and caravan's board computer were implemented with Java, while the SSCPM was implemented in C Language. The vehicle's board computer communicates with the caravan's board computer over the SSCPM, that uses two of the free wires of a 13 pole trailer

socket. One wire is used for the common ground and the other wire is used for the signal transmission. Furthermore, it is to emphasize, that the Controller Area Network Bus (CAN-Bus) has not been used because the developed system should be easily integrated into the current car and caravan systems without major changes.

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