Documentation of Lab work for group 8

Wiktor Kochanek
Electronic Engineering
Hochschule Hamm-Lippstadt
Lippstadt, Germany
wiktor.kochanek@stud.hshl.de

Vytaras Juraska
Electronic Engineering
Hochschule Hamm-Lippstadt
Lippstadt, Germany
vytaras.juraska@gmail.com

Given Name Surname
dept. name of organization (of Aff.)
name of organization (of Aff.)
City, Country
email address or ORCID

Given Name Surname
dept. name of organization (of Aff.)
name of organization (of Aff.)
City, Country
email address or ORCID

***Abstract*—This document is a record of our group activity and progress in a lab assignment - build an autonomous car.**

I. Introduction

Motivated by a class assignement our group was tasked with creating a self-driving vehicle. We achieved this by using line tracking sensors and ultrasonic sensors controlled by an Arduino and also implemented a video stream using Raspberry Pi and its external Raspberry Pi Camera V2.

II. Analyzing the specifications

Our assignment came with clearly defined specifications:

- Line tracking system
- Ultrasonic sensor integration
- Camera streaming system

We split these objectives into two sections: car focused - line tracking and ultrasonic sensors systems - and camera focused - the streaming. We then split the tasks inside our group so that each member can focus on a specific objective to bring the best possible results.

III. Car focused specifications

A. *Line tracking system*

The car was supposed to be able to follow a line around a track using two line tracking sensors. The specific implementation of such function was left to our own choice. We decided to make a system that would allow the car to drive when it doesnt detect a line and react when it does detect a line.

B. *Ultrasonic sensors system*

The car was supposed to integrate a system using three ultrasonic sensors - what said system would influence was left to us to decide. we settled on an obstacle avoiding system that would co-operate with the line tracking system - if there was an obstacle on the track the car would attempt to drive around the obstacle and drive back onto the track.

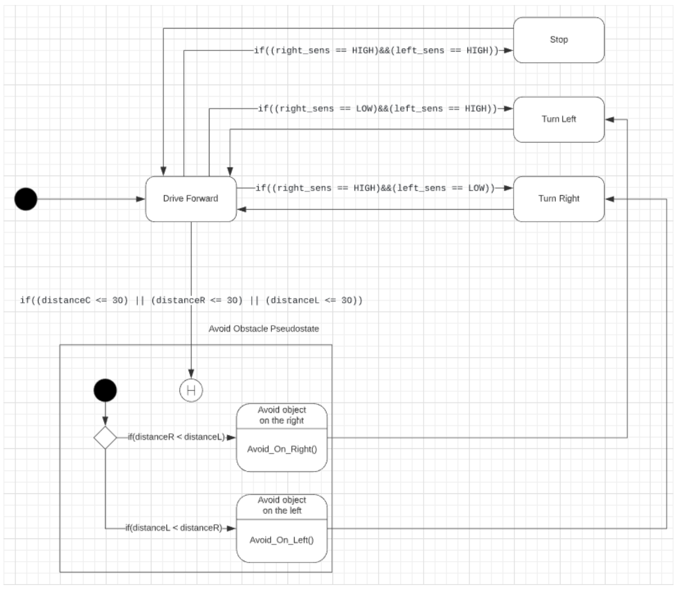
IV. Camera focused specification

The car was supposed to integrate a camera and a system, that would allow it to stream the video from the camera to an external device. The methods of implementation were left to us to decide. For this task we used a Raspberry Pi with a camera module as a client sending frames and a Mac computer as a server receiving frames and opening them in a format of a picture one by one.

V. System Design

A. *Car focused System Design*

The car will operate within 4 states for line tracking system and a pseudostate for the ultrasonic sensors sytem. Different enviromental inputs will influence the behaviour of the car. The car will always begin in the line tracking state attempting



Stop
if((right_sens == HIGH)&&(left_sens == HIGH))
Turn Left
if((right_sens == LOW)&&(left_sens == HIGH))
Drive Forward
if((right_sens == HIGH)&&(left_sens == LOW))
Turn Right
if((distanceC <= 30) || (distanceR <= 30) || (distanceL <= 30))
Avoid Obstacle Pseudostate
H
if(distanceR < distanceL)
Avoid object on the right
Avoid_On_Right()
if(distanceL < distanceR)
Avoid object on the left
Avoid_On_Left()

Fig. 1. UML State Diagram

to go forward. When one of the line tracking sensors detects that it has gone onto the line it will steer the car to get the sensor back off the line - Turn Right and Turn Left states. If it happens that both sensors are on the line at the same time the car will stop. Should the cars ultrasonic sensors detect an obstacle it will enter into the Avoiding Obstacles Pseudostate. It will then decide if the obstacle is closer to its right or left side and will attempt to avoid the obstacle on the other side. When it succesfully returns to the track the line tracking sensors will exit the car from the pseudostate and will reutrn line tracking functionality.

B. Video steam focused System Design

Since specifications did not define what methods of implementation had to be used, we really wanted to implement OpenCV into our video streaming system, hence our system design was focused more on the implementation methods with OpenCV. After some reaserch of how does the main concept of video streaming look like, we decided to settle on our finalised base concept of our video streaming system design. The idea

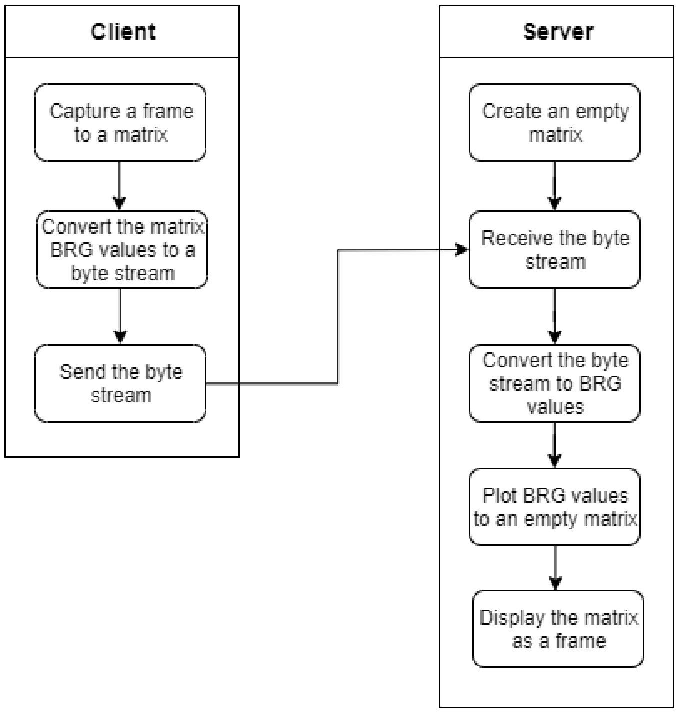

Client
Capture a frame to a matrix
Convert the matrix BRG values to a byte stream
Send the byte stream
Server
Create an empty matrix
Receive the byte stream
Convert the byte stream to BRG values
Plot BRG values to an empty matrix
Display the matrix as a frame

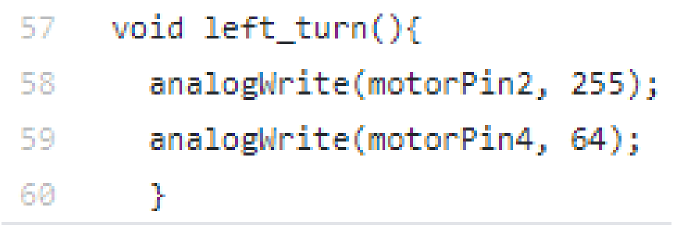
Fig. 2. Video Streaming System Design

for the client was to portray frames as matrixes, in which every single pixel would be a component with 3 channels in the sequence of Blue, Red and Green. We portray each channel in a byte value with a limited amount of bits dedicated to each channel component. So our client has to store each frame in a matrix, convert every single matrix component channel into a byte stream and send the byte stream over to the server. From the server side the process is a bit lengthier, first it has to create an empty matrix, as a template. After the server receives the byte stream from the client, it has to convert the byte stream back to the channels, which would resemble each component in the matrix. After plotting each component sequentially back to the matrix template, we would receive a whole frame, which we finally can open up as an image.

VI. Implementation of the system

A. Line tracking system

The line tracking system was the first thing tackled in the car functionality. The first implementation was a simple use of ”if” and ”if else” functions - depending on which line tracking sensor was tirggered, speeds of motors would change to make the car drive forward, turn the correct way or stop completely. Later implementation made use of interrupts, which changed the motor speed in the interrupt service routine. [1] While the



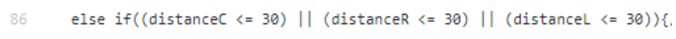
```
void left_turn(){
  analogWrite(motorPin2, 255);
  analogWrite(motorPin4, 64);
  }
```

Fig. 3. used interrupt service routine[1]

interrupt solution was a great way to make the source code easy to understand and the car ran very smoothly, it was scrapped during integration with ultrasonic sensor code as there were compatiblity problems. As such we settled on a ”if” and ”if else” functions solution.

B. Obstacle avoidance system

Implementation of the ultrasonic sensors was not specifically defined in the project requriements. Our design used them in a way to detect and obstacle in the way and attempt to drive around it. First the car had to know that there was an obstacle in front of it. This was achieved simply using an ”if” function - if any of the three sensors detect an obstacle within 30cm of the car they will trigger the if condition and enter the car in the pseudostate of ”avoid obstacle”. After the car enter



```
else if((distanceC <= 30) || (distanceR <= 30) || (distanceL <= 30)){
```

Fig. 4. if condition detecting the obstacle

this pseudostate we have to choose which way is best to avoid the obstacle on - meaning that if theres a wall on our right, we want to turn to the left to clear it and vice versa. This is simply done by comparing the distance values on the right and left ultrasonic sensors - distanceR and distanceL respecitvelly. In this case we don’t care about the centre distance as it doesnt influence our choice of side to avoid on. After the choice is made the car enters a loop that lets it go around an obstacle - in this example we will be avoiding an obstacle on the right (distanceL $<$ distanceR). After starting the avoiding algorithm

[1]lines of code in Fig. 2 do not represent actual content in the final source code

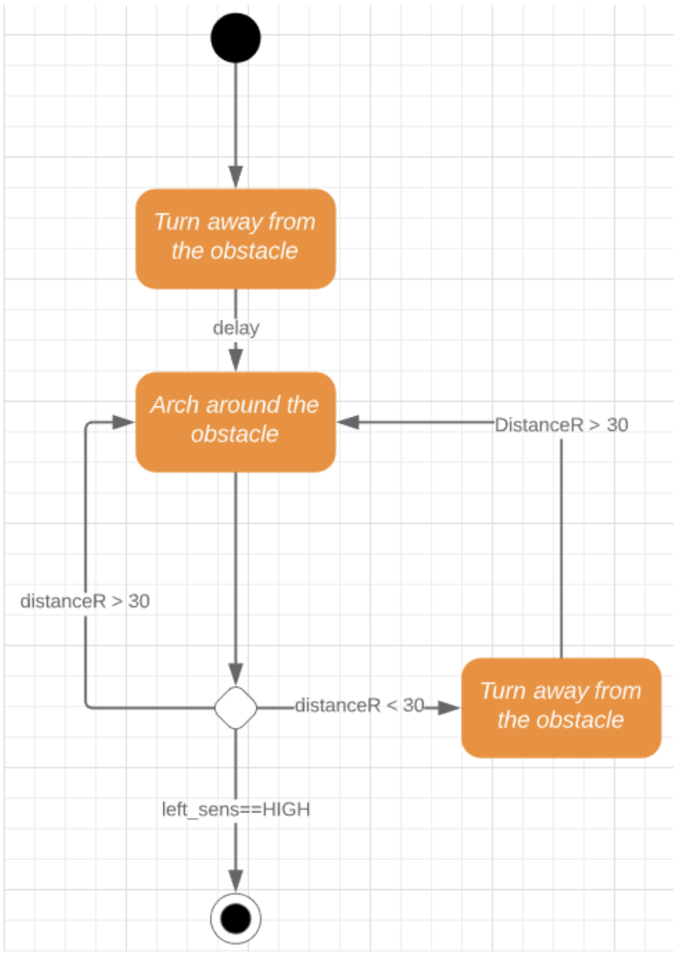


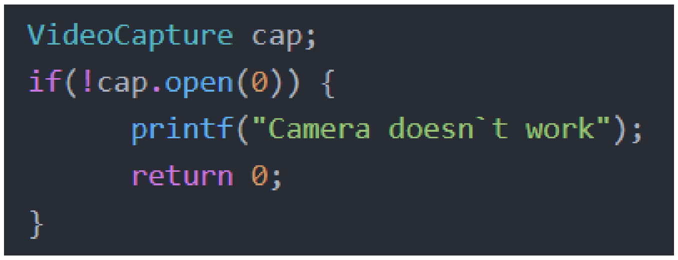
Fig. 5. Activity diagram of the avoiding algorithm

the car will slowly arch around its obstacle. it is possible that the obstacle is longer than the arch diameter, so the car is able to detect obstacles in this mode and turn away again if needed. This algorithm was designed to allow the car to leave its line in order to avoid the obstacle and detect when it is supposed to once again follow said line. In order to do that we had to have the car ignore one of the line tracking sensors for the duration of avoiding algorithm - in this case the right line tracking sensor - and then respect the sensor again when it gets back on the line. This was simply done by running the algorithm in a subfunction and including a simple if condition in the loop. The car arching around the obstacle is implemented using a while loop that relies on a variable set after the car decides on which side is the obstacle. The only way to stop that while loop is the active line tracking sensor - in this case the left one - to cross onto the line. The sensor triggering ends the while loop and the avoidance algorithm returning the car to its line tracking functionality.

C. Video stream system

Since we wanted to implement OpenCV into our video streaming system, we decided to make it in C++ programing language. As a method of communication, with no doubts we chose TCP Internet Protocol and it's implementation in C++ programming - Berkeley Sockets, which we, at the time, recently learned from the lectures and were really motivated to implement it into our video streaming.
The first problem we encountered, was what to use, to compile OpenCV and Berkeleys Sockets in C++. After trying out many popular IDE's (Integrated Development Enviroment) on a Windows based device, we decided to start the development purely on our Raspberry Pi, which was running on Raspbian, Debian-based opperating system. Since we finally started working on Raspbian, all we had to do, was to install OpenCV libraries, dedicated for Raspberry Pi, and compiling was not an issue anymore. After we could finally compile our code properly, we started learning how Berkeley Sockets worked and how to implement a client and a server successfuly, since we had implementation in our lectures, the process was not complicated, but fully understanding it and changing properties in a way, that the communication would function as intended was challenging. Once we understood the basics of Berkeley Sockets, we started implementing OpenCV to Berkeley Sockets. Since we had a bit of prior experience with OpenCV, we did not have to learn it from the basics, so we instantly went for implementation. After countless trial and error, we finally got it to work:

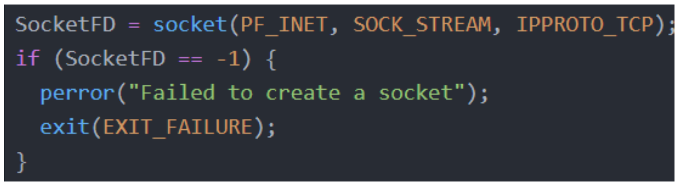
1) Client system: Before any task was performed, the client has to check if the camera was aviable. That was easily done by implementing OpenCV class, called "VideoCapture" which



```
VideoCapture cap;
if(!cap.open(0)) {
        printf("Camera doesn`t work");
        return 0;
}
```

Fig. 6. Camera access check

has many functions dedicated for camera access. One of the functions is called "open", which if parameters of the funcion "open" are not zero, that means there was no access to the camera or there was an error.
Going forward the code enters an infinite loop, which would be the whole process of connecting, capturing frames, converting to byte stream, sending byte stream. First we begin from creating a Socket. We define what a socket is and all of its

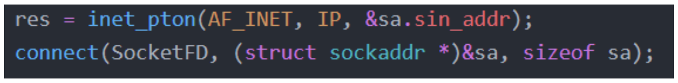


```
SocketFD = socket(PF_INET, SOCK_STREAM, IPPROTO_TCP);
if (SocketFD == -1) {
  perror("Failed to create a socket");
  exit(EXIT_FAILURE);
}
```

Fig. 7. Socket creation in Client

properties are, simply put, referring to the type of protocol,

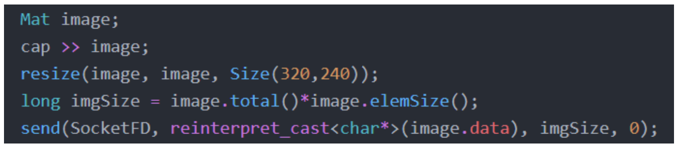
which has to be used, which in our case is TCP. Later on we check, if we were successful in creating a socket.
Afterwards, using ”inet_pton” function, we have to connect to the server knowing the socket address, port and it’s IP (Internet Protocol). Just then we can finally connect our socket using the ”connect” function



```
res = inet_pton(AF_INET, IP, &sa.sin_addr);
connect(SocketFD, (struct sockaddr *)&sa, sizeof sa);
```

Fig. 8. Connecting to Server and connecting the Socket

And if we finally have connected to the server, we can start capturing the frame, converting it and sending it to the client. First we create a matrix, which we use to store the frame,

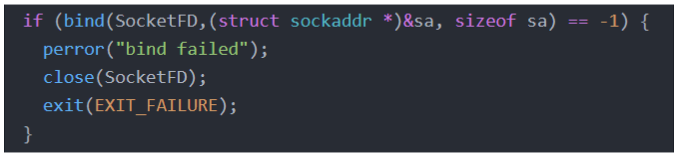


```
Mat image;
cap >> image;
resize(image, image, Size(320,240));
long imgSize = image.total()*image.elemSize();
send(SocketFD, reinterpret_cast<char*>(image.data), imgSize, 0);
```

Fig. 9. Capturing the frame, converting and sending to Server

when we capture it with already predefined ”VideoCapture” class variable. We resize the image to 320 by 240 pixels to improve the speed of sending the byte stream and calculate the final image size, which is later on needed in the ”send” function. The final function ”send” is a bit more tricky, first we dedicate the already connected socket as a socket for sending, dedicate the message property, which in our case are matrix components converted to a long byte stream, and shortened by ”reinterpret_cast”, define the already calculated size of the message, which is the size of the frame, and declare the flag, which we never needed to play around with, so we left it at zero. The tricky part of ”send” function is the ”reinterpret_cast”, because this type of operator is not safe, it does not check if pointer type and the data, which the pointer is pointing at, are the same or not, which can harm the device, if an error in pointers occur, or the types of variables in the code are mixed up.
That is where a single cycle of the loop ends and this is the core of the client system.

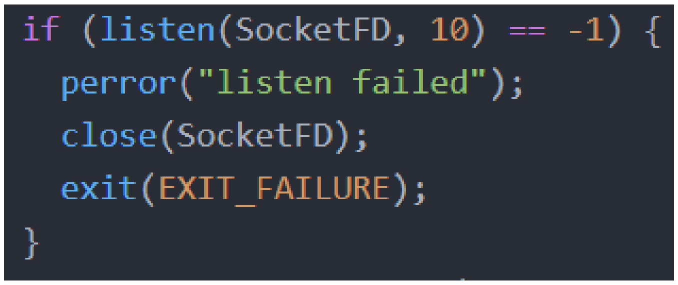
2) Server System: Majority of functions, which are in the client system, are reused in the server system as well. Firstly (same as in Fig. 7), we create a TCP socket and check, if the creation was successful. Then we try to bind the socket to the socket address and the dedicated port, through which our client will try to connect to the server. If the binding has failed (for



```
if (bind(SocketFD,(struct sockaddr *)&sa, sizeof sa) == -1) {
  perror("bind failed");
  close(SocketFD);
  exit(EXIT_FAILURE);
}
```

Fig. 10. Binding the socket

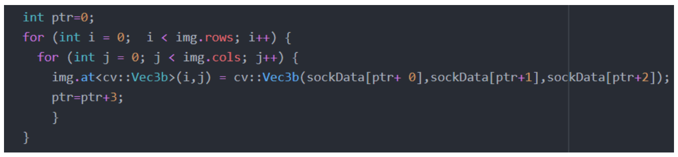
example the port is in use), then we close the socket, we’ve been trying to open, and terminate the program.
This is where the infinite loop from the server side starts and its starts of with the function ”listen”. It’s properties, are the socket, which to check for incoming connections, and the maximum incoming connections allowed at a single time period. If ”listen” function returns negative one, it means, that some sort of error has been made and the socket has to be closed, and the program has to be terminated for security reasons.



```
if (listen(SocketFD, 10) == -1) {
  perror("listen failed");
  close(SocketFD);
  exit(EXIT_FAILURE);
}
```

Fig. 11. Listening error check

Then we create the zero matrix, which is a template with components, which are all empty. We calculate an estimate size of the matrix, to have an exact expected maximum byte stream size, when the server receives it. Before communication both client and the server have to agree on the resolution of the frames, for the frame to be recollected properly from the byte stream. Then we store the recieved data to a variable with a function ”recv”, which properties are: socket from where it recieves the byte stream, the byte stream itself, the estimate size of the byte stream from the predetermined zero matrix.
One of the last steps of the loop is the byte stream conversion to the matrix components channel values. The byte stream is stored in a corresponding sequence of channels: Blue, Red, Green. We divide the whole byte stream into segments, where one segment represents one channel value, three of those channels represent a single component of the matrix, which in the end is just a pixel in a frame. So this exact part of the loop divides a byte stream to pixels and sorts them row by row, column by column back into a single frame.



```
int ptr=0;
for (int i = 0;  i < img.rows; i++) {
  for (int j = 0; j < img.cols; j++) {
    img.at<cv::Vec3b>(i,j) = cv::Vec3b(sockData[ptr+ 0],sockData[ptr+1],sockData[ptr+2]);
    ptr=ptr+3;
    }
}
```

Fig. 12. Byte stream conversion to BRG values

And the last part of the loop is opening up an already prepared frame with a function ”imshow”, after a single frame is shown, it has to close after some time, so we have to implement a function ”waitKey”, which waits for a specified time in miliseconds or completely terminates the program if any key on the keyboard was pressed. If ”waitKey” wouldnt be implemented, more and more frames would stack on each other, taking up all the recourses of the device, so this function is necessary.