NANYANG TECHNOLOGICAL UNIVERSITY

REPORT
ON
INDUSTRIAL ATTACHMENT
WITH
INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE
(INRIA RHONE-ALPES, FRANCE)

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ABSTRACT

This report presents the project done during the Industrial Attachment with the French national research laboratory, Institut National de Recherche en Informatique et en Automatique, Rhone-Alpes, France (INRIA Rhone-Alpes). The project looks into implementing a real-time serial interface between 2 hardware, namely the Motorola MPC555 microcontroller and the SICK LMS (Laser Measurement System), on the Cycab. This is to enable the Cycab to have a real-time laser sensor guiding system. Work was done on programming the MPC555 to communicate with the SICK LMS. Numerous tests were also done to look into the response of the LMS when different sets of telegrams were sent. Once the real-time serial interface was implemented, work was concentrated on writing application programs for the SICK LMS and MPC555. Application programs like Car Following and Obstacle Avoidance are currently in the process of implementation.

This report is divided into 5 Chapters. An introduction of the project with the objectives, work and hardware involved will be given first. After that, the first Chapter will present a more detailed introduction of the main hardware used in the project. In the following Chapter, this report looks into the implementation work done on the serial interface. Then, Chapter 3 will present the application programs being done currently. Comments and discussions are given in Chapter 4. Finally, the report ends with the Summary and Conclusion in Chapter 5.

INTRODUCTION

Since the invention of automobiles, the automobile industry has grown tremendously. Subsequently, the technology involved has also improved by leaps and bounds. The introduction of gears to the once 'single-gear' vehicles and the increase of engine horsepower are just some good examples of technology advancements made in the automotive field. These leaps in the technology not only bring greater convenience to the people, they have also generated other interests. These interests, especially in speed and engine power, have been so great that the industry is now manufacturing faster and more powerful cars. However, power is nothing without control. Lives are lost everyday on the road due to automobile accidents. Even with the latest technology and safety precautions, the legendary World Formula 1 Champion, Artyon Senna died in a fatal crash when his racecar crashed into a concrete wall at 300 km/h. All these have prompted the automobile industry to look more into improving the safety features of a car.

At INRIA Rhone-Alpes, researchers are currently working on an intelligent vehicle named, the Cycab. It is compact, environmental-friendly and can operate autonomously with minimal control from the user. Works on the Cycab involve implementing numerous safe lane-guiding systems, speed control and others. All these are aimed at improving the safety of road transport and also easing the booming population of private cars in the cities.

This Industrial Attachment at INRIA Rhone-Alpes was made possible because of a collaboration tie between NTU and INRIA. During the attachment period of about 6 months, a project with the objective of implementing a real-time serial interface between SICK LMS and MPC555 microcontroller was given. The reason was that a new Cycab equipped with the new generation microcontroller, MPC555, is being built and there was a need to interface the SICK LMS and the MPC555. Subsequently, application programs like Car Following and Obstacle Avoiding are to be implemented too.

The main hardware/materials given for this project were a MPC555 Control Board from Robosoft (manufacturer of Cycab), a SICK LMS 291-S05, a SUN workstation and a LINUX/Windows NT PC for programming and downloading of programs to MPC555. Additional materials include RS232/RS422 cables and user manuals for SICK LMS and MPC555.

During the initial 2 months of the attachment, the main work involved was to have a good understanding of the MPC555, SICK LMS, reviewing of C programming theory and setting up the test environment. Tests were also done on the 2 hardware with programs written in C programming language. The following 2 months were concentrated on programming the serial interface program with numerous tests, troubleshooting and debugging. Finally, upon the completion of the real-time serial interface implementation, application programs on Car Following and Obstacle Avoidance were looked into and are currently in the process of testing and implementation.

This report was written to be as concise and clear as possible to the reader. Please note that hexadecimal numbers are often used in this report. Thus, numbers like 0xXX and XXH that appear in this report are all in hexadecimal format.

ACKNOWLEDGEMENT

During the entire period of this Industrial Attachment, a lot of help and cooperation were rendered by the fellow researchers, supervisors and colleagues in my department, Moyens Robotiques, INRIA Rhone-Alpes. Therefore, I would like to express my sincere gratitude to all of them and especially :

My project supervisor, Mr Gerald BAILLE, Research Engineer, Moyens Robotiques, INRIA Rhone-Alpes, for his precious guidance, time and help in my project and report ;

Dr Hervé MATHIEU, Research Engineer, Chief of Moyens Robotiques, INRIA Rhone-Alpes, for his time and help in my project.

I would also like to thank Mr Fabien LYDOIRE, Project BIP; Mr Kenneth SUNDARAJ, Project SHARP; and Mr Cedric PRADALIE, Project SHARP for their aid in my work at one time or another.

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CHAPTER I

INTRODUCTION TO HARDWARE

In this first chapter, a brief introduction on the main hardware (Cycab, MPC555 and SICK LMS) used in the project will be given. This will enable the reader to have a clear and basic understanding of the hardware before embarking on the next chapter where the main program is explained in detail.

1.1 Cycab

1.1.1 System Description and Specifications

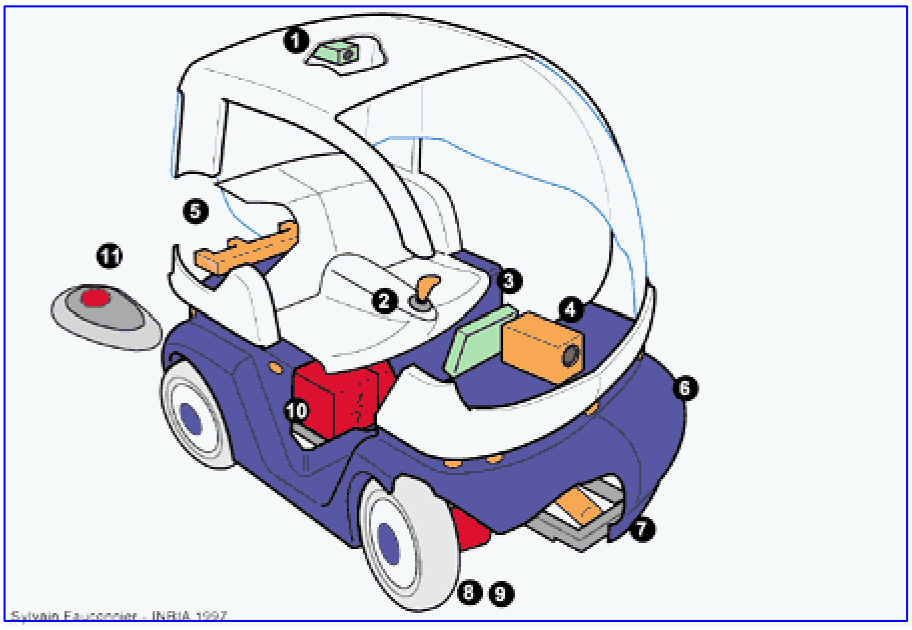
The Cycab is a small intelligent vehicle that runs on electricity. It had been designed to transport up to two persons in downtown areas, pedestrian malls, large industrial or amusement parks and airports, at a maximum speed of 30 km/h.

It offers two new functions, aided driving and autonomous driving. Aided driving relies on the use of a joystick and a finger touch screen. This joystick is connected to the computer, which controls the vehicle and then provides secure and easy driving. In addition, speed may be limited in curves and special areas like narrow lanes, to improve safety of the vehicle. The control of the Cycab is simple and user-friendly and everybody will be able to drive this vehicle without any special skills. The finger touch screen allows the user to communicate with the system in order to get information such as localisation, vehicle autonomy, or even a list of nearby restaurants. One possible application for the Cycab is to form a "virtual car train" of empty vehicles with only one driver in the first vehicle (also known as Car Following). Other autonomous driving modes, like radio-control or light markers guidance may be implemented and research is currently undergoing in INRIA.

The Cycab has been designed with mass production and public use constraints in mind. These considering factors are low cost, compactness, robustness and easy maintenance. The whole design has been oriented in this way, from the mechanics to the computer based system.

Length	1.9 m
Width	1.2 m
Weight	300 kg
Power	4 $\times$ 1 kW Electric Motors
Drive System	4 Wheel-Drive, 4 Wheel-Steering
Maximum Speed	30 km/h
Range	40 km
Capacity	2 adults (+ luggage)
Modes of Operation	• Manual driving with joystick • Fully automated driving • Teleoperated driving
Recharging System	Induction charging
Security	Smart card access

Table 1.1.1.1 : Specifications of Cycab



1. CCD camera for remote control
2. Joystick for manual driving
3. Multimedia terminal
4. Linear camera for platoon driving
5. Infrared targets for platoon driving
6. Ultrasonic sensors for collision avoidance
7. Steering actuator
8. One electric drive motor per wheel
9. One electric brake motor per wheel
10. Four lead-acid batteries and electronic management

Note : The SICK LMS is now attached in front of the Cycab (below the Linear Camera)

Figure 1.1.1.1 : Layout of Cycab

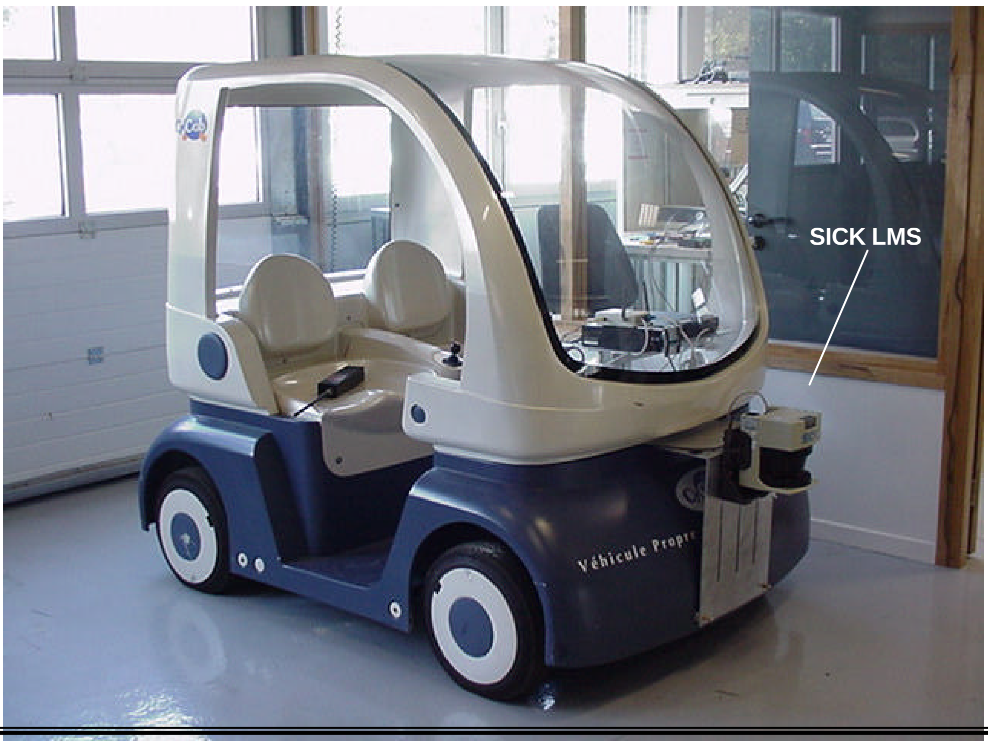


Photo 1.1.1.1 : Cycab (with SICK LMS) at INRIA Rhone-Alpes

From Photo 1.1.1.1, it can be seen that the Cycab at INRIA now has a SICK LMS attached to the front (centralised position).

1.1.2 Mechanics and Electronics of New Cycab

The mechanics is based on a small electrical golf car frame, already produced in small series. The use of four identical wheel motor blocks, allows cost reductions (by re-using identical parts) and volume (four small engines with small power controllers are easier to build and integrate than a big one with a high power controller). Consequently, the architecture is modular and the vehicle is easier to drive (the four wheels are propulsive and directive). The steering is made through an electrical jack mechanically linked to all the wheels. Each wheel motor block has it's own power amplifier, driven by the new Motorola MPC555 microcontroller. This microcontroller is very well suited for motor control in automobiles and is capable of doing real-time data transfer. Each wheel node controls a drive motor and a brake motor, with all their associated sensors (optical encoder, brake torque measurement, temperature etc.) connected. An additional node is attached to the steering jack and the joystick.

Communications between the nodes are made through a CAN (Controller Area Network) serial bus. It has been designed specially for automotive applications and allows safe communications in disturbed environment, with a rate of up to 1Mbits/s. It carries messages of up to 8 bytes length with 50 per cent control and arbitration bits overload. The network consists of 5 nodes and an on-board PC, which drives the screen and the hard disk.

Figure 1.1.2.1 below illustrates the overall network connections and nodes of the new Cycab in detail. All the 3 MPC555 microcontroller are connected to the Linux PC on board the Cycab by the CAN network.

It can be seen that there are 2 MPC555 microcontroller in the network that control the low-level control functions of the motor nodes in real-time. These control functions that

are programmed inside the MPC555 include PID feedback loop control programs. One of the MPC555 is in charge of the front wheels and front steering while the other controls the back wheels and back steering.

The 3rd MPC555 is connected to external sensor equipment like the SICK LMS in this project. It was proposed that the communication with the LMS be made via a real-time serial interface using RS422. This MPC555 is programmed to control the SICK LMS and retrieve all scan data values from it. Then, these data are filtered and only the necessary, required values are sent to the Linux PC via the CAN network. The Linux PC contains all the high-level application control programs like Trajectory Planning and Car Following. When the Linux PC receives the filtered data from the MPC555, the programs will process these vital data and generate results based on its control algorithm. Then, these results are redistributed to the front and back

MPC555 for processing. Finally, these 2 MPC555 will control the motor nodes based on the results.

The network within the dotted zone shown in Figure 1.1.2.1gives a good illustration of the work scope of this project.

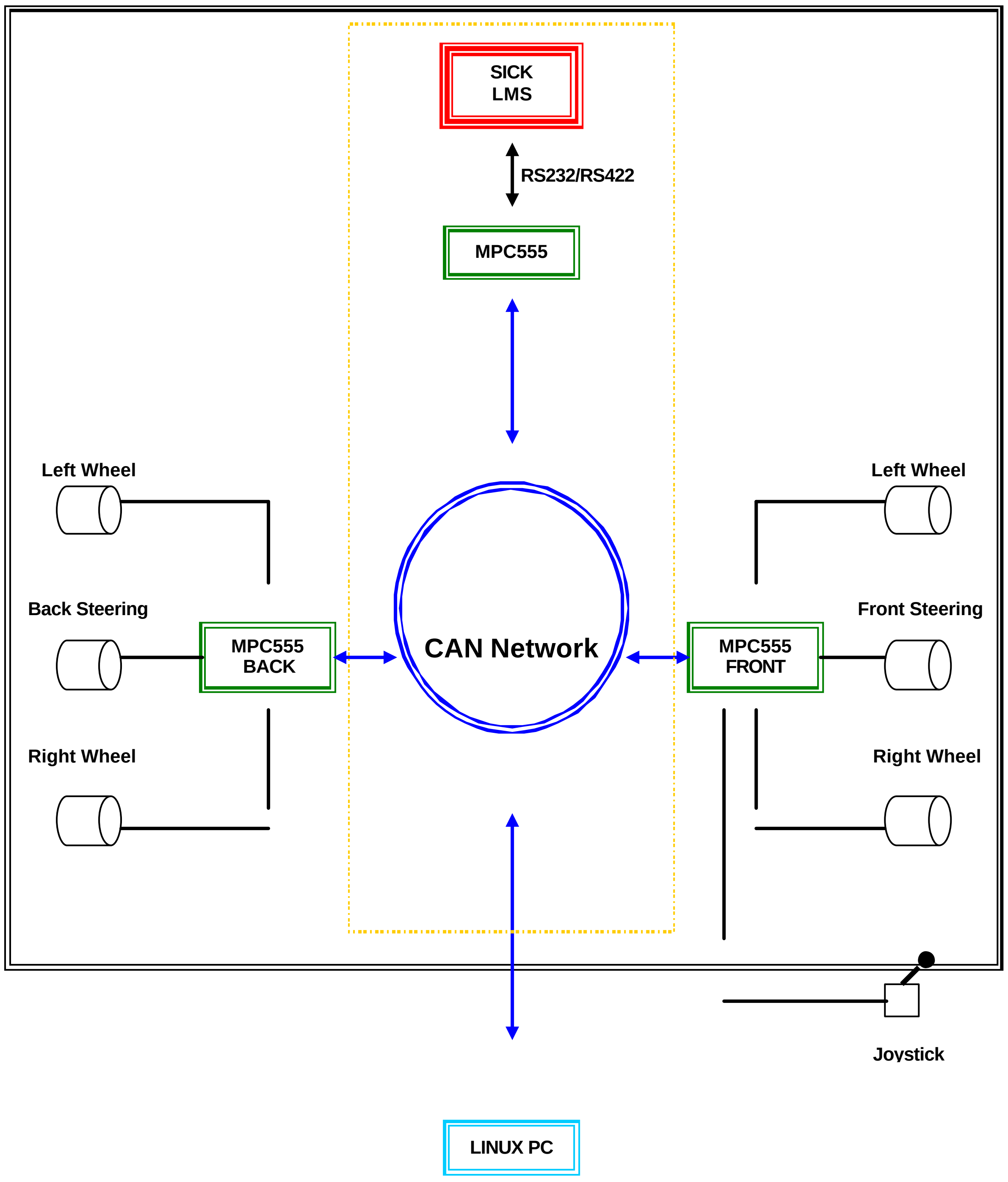


Figure 1.1.2.1 : Network Connections in New Cycab

1.1.3 Goals of Cycab

Researchers at INRIA has been working on this intelligent vehicle project with the following goals in mind:

1.1.3.1 Increase Safety of Road Transportation

It is well known fact that though road transport brings conveniences to people, it is not safe. In fact, this mode kills hundreds of thousands of people each year throughout the world, especially young adults and the elderly. Although safety has improved by one order of magnitude in the last decade through better infrastructure and safer cars, the rate of improvement has tapered off. The techniques to improve drastically the safety are based on four approaches:

- Driver monitoring and warning
- Partial control of the vehicle in emergency situations (e.g. Brake system)
- Total control of some of the functions of the vehicle (e.g. Speed)
- Total control of the entire vehicle

1.1.3.2 Minimisation of Energy Consumption

Fossil fuel is limited and consumption of it has only increased every year, thus threatening the supply. Drastic reductions in the consumption of fossil fuels are one of the challenges for everyone in the next twenty years. Road transportation has always been playing the dominant role in the consumption of these fuels and the trend is going up through two factors: the increase in freight transport by road and a very high increase in car ownership in emerging countries. Without a radical departure from existing technologies and practices, the goals set by the countries cannot be met. Thus, new high technology cars running on electricity can be one of the solutions.

1.1.3.3 Minimisation of Pollutions and Nuisances

In all large cities through the world, air quality is now monitored at frequently unacceptable levels. Noise levels in cities and near highways is the main complain by a large percentage of the population. Besides air quality, soil pollution with large amounts of hydrocarbons going to the sewage system in big cities also poses a problem.

The objective is to study new transportation modes and in particular, to find ways to develop multimodality in order to find the most energy efficient way of satisfying transportation needs. Another approach is to try to influence the needs in order to reduce them.

1.1.3.4 A More Pleasant Living Environment

Space and energy are 2 resources that are scarce and very limited in almost every city. Automobiles take up a lot of space in a city (e.g. car parks, roads, highways) and are one of the highest consumers of energy. Though there is a recent trend towards "car-free cities", not everyone is satisfied with this idea. There will always be people who find driving a car more convenient than taking the public transport. It is well known that public transport is most efficient in terms of space and energy but not very flexible and that the reverse is true for the private automobile. Therefore, the solution is to use public transport approach in places where space is limited and allow private cars in less crowded areas.

1.2 Motorola MPC555

1.2.1 Microprocessor Description

The MPC555 is a high-speed 32-bit control unit that combines high-performance data manipulation capabilities and a large on-chip Flash memory with powerful peripheral subsystems. This MCU (Micro Controller Unit) is built up from standard modules that interface through a common intermodule bus (IMB).

The MPC555 incorporates a PowerPC™ Core with a Floating Point Unit, a 26 Kbytes fast RAM, a 6 Kbytes dual ported RAM for TPU microcode RAM (DPTRAM), 448 Kbytes flash EEPROM with 5 volt programming, a 5 volt I/O system a System Interface Unit (USIU), a Queued Serial Multi-Channel Module (QSMCM), dual CAN 2.0B controller modules (TouCAN™), dual Time Processor Units (TPU3), a Modular I/O System (MIOS1) and dual Queued Analogue to Digital Converters (QADC64). It operates at 40 MHz with dual supply of 3.3 V (for Core), 5 V (for FLASH).

1.2.2 Features

- RISC MCU Central Processing Unit (RCPU)
- Four-Bank Memory Controller
- U-Bus System Interface Unit (USIU)
- Flexible Memory Protection Unit
- 448 Kbytes of CDR MoneT Flash EEPROM Memory (CMF)
- 26 Kbytes of Static RAM
- General-Purpose I/O Support
- Two Time Processor Units (TPU3)
- 18-Channel Modular I/O System (MIOS1)

- Two Queued Analogue-to-Digital Converter Modules (QADC)
- **Two CAN 2.0B Controller Modules (TouCANs)**
- **Queued Serial Multi-Channel Module (QSMCM)**

Though the MPC555 has a lot of useful features, not all were used in this project. The 2 main features that are of special interest to the project are the TouCANs and QSMCM modules (highlighted above).

1.2.3 Queued Serial Multi-Channel Module (QSMCM)

The Queued Serial Multi-Channel Module (QSMCM) provides 3 serial communication interfaces, namely: the Queued Serial Peripheral Interface (QSPI) and 2 Serial Communication Interfaces (SCI1 and SCI2).

The dual, independent SCIs are used to communicate with external devices and other MCUs via an asynchronous serial bus. Each SCI is a full-duplex Universal Asynchronous Receiver Transmitter (UART) serial interface.

For the implementation of a high-speed serial interface between the SICK LMS and MPC555, the UART serial interface function of the MPC555 was used. Robosoft also provided some C libraries specific for MPC555, which aided in the programming part of the implementaion.

The SCI baud rate (bits/sec) can be programmed by writing a 13-bit value to the SCxBR field in the SCI control register. The baud rate can be calculated as follows:

$$\text{SCI Baud Rate} = f_{SYS} / 32 \times \text{SCxBR}$$

Where SCxBR is in the range of {1,2,3,…,8191}.

Nominal Baud Rate	Actual Baud Rate	Percent Error	Value of SCxBR
1250000.00	1250000.00	0.00	1
57600.00	56818.18	-1.36	22
38400.00	37878.79	-1.36	33
32768.00	32894.74	0.39	38
28800.00	29069.77	0.94	43
19200.00	19230.77	0.16	65
14400.00	14367.81	-0.22	87
9600.00	9615.38	0.16	130
4800.00	4807.69	0.16	260
2400.00	2399.23	-0.03	521
1200.00	1199.62	-0.03	1042
600.00	600.09	0.02	2083
300.00	299.98	-0.01	4167

Table 1.2.3.1 : Possible Baud Rate for 40 MHz System Clock

1.2.4 Two CAN 2.0B Controller Modules (TouCANs)

The MPC555 contains 2 CAN 2.0B controller modules (TouCAN). Each TouCAN is a communication controller that implements the CAN (controller area network) protocol, an asynchronous communications protocol used in automotive and industrial control systems. It is a high speed (1 Mbit/sec), short distance, priority based protocol that can run over a variety of mediums (for example, fibre optic cable, an unshielded pair of twisted pair of wires). The TouCAN supports both the standard and extended identifier (ID) message formats in the CAN protocol specification, revision 2.0, part B.

Each TouCAN module contains 16 message buffers, which are used for transmit and receive functions. It also contains message filters, which are used to qualify the received message IDs when comparing them to the receiving buffer identifiers.

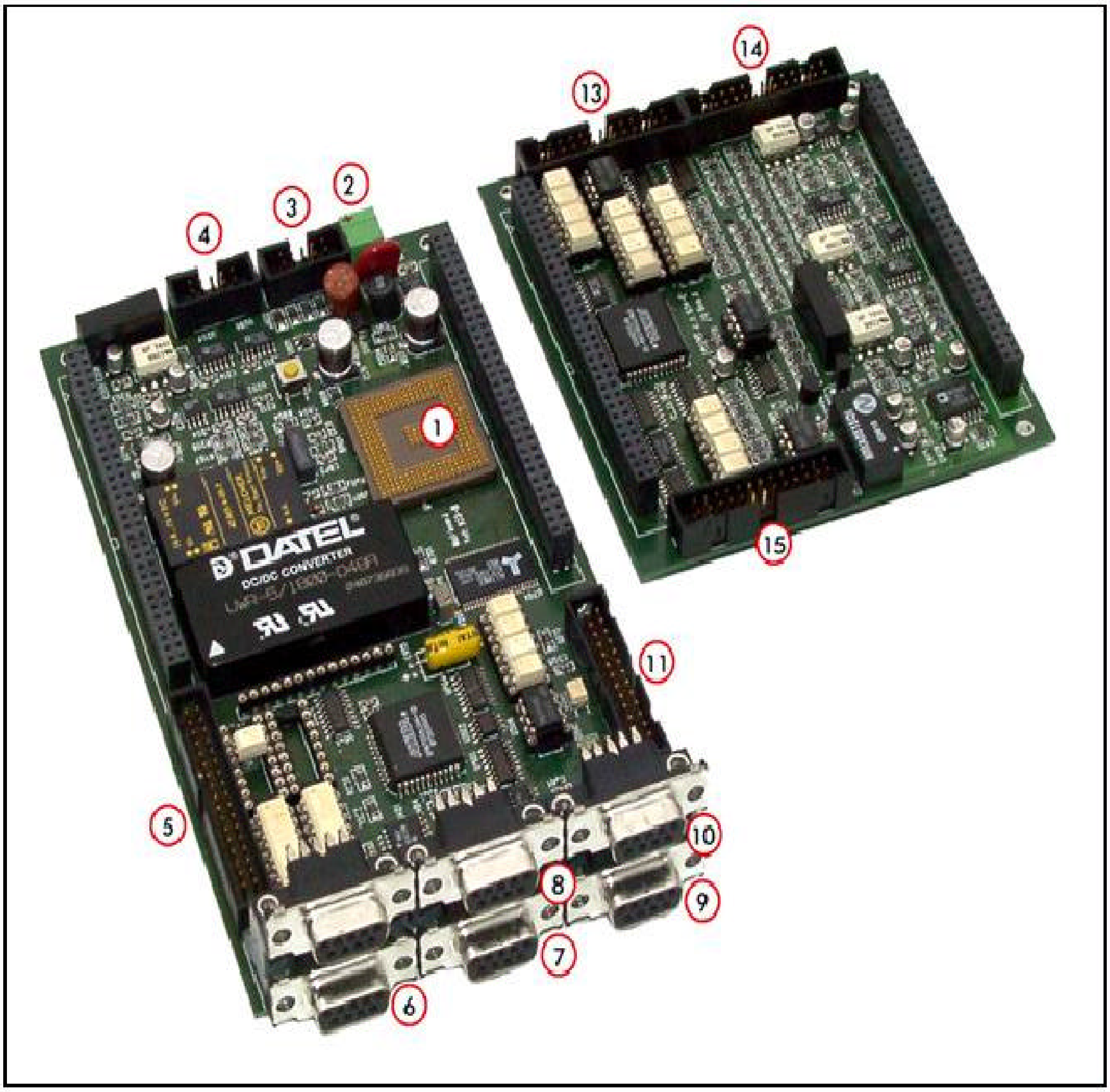


Photo 1.2.4.1 : MPC555 Control Board provided by Robosoft

Figure Label	Description
1	MPC555
2	Power supply: 18-60V DC (from batteries)
3	BDM Interface (Basic Debug Interface)
4	7 analogue inputs
5	16 logical inputs and 20 logical outputs
6	Synchronous serial lines (SPI)
7	Asynchronous serial lines 1 (port number 0)
8	Asynchronous serial lines 2 (port number 1)
9	CAN bus 1 (port number 0)
10	CAN bus 2 (port number 1)
11 – 14	4 connectors dedicated to axis control (including 1 analogue output per axis)

Table 1.2.4.1 : Description of MPC555 Control Board

Photo 1.2.4.1 and Table 1.2.4.1 above describes in detail the MPC555 control board that was used in the project. Take note of the designation of the port number to the CAN bus ports and the serial COM ports, as these designations are crucial during the implementation of the serial interface.

1.3 SICK LMS (Laser Measurement System)

1.3.1 System Description

The LMS (Laser Measurement System) 291-S05 is a divergent laser scanner with a maximum scanning angle of 180° and a lateral resolution of between 0.25° and 1° (variable and definable). Also, the laser scan is a planar scan. The accuracy of measurement in a single shot is about ± 2 cm. With respect to the data transfer rate, the LMS is capable of transferring all measured values in real-time (via serial interface) at a baud rate of 500 Kbauds.

Photo 1.3.1.1 : LMS 291-S05

In this project, the LMS291-S05 used is shown in the above Photo 1.3.1.1.

1.3.2 Operating Principle

The operating principle of our non-contact Laser Measurement System (LMS) is based on time-of-flight measurement. The LMS calculates the distance to the object using the time of flight of pulsed light, i.e. the length of time between sending and receiving the beam of light (Figure 1.3.2.1).

An extremely short pulse of light (infrared laser beam) is transmitted towards an object. Part of the light is reflected back to the unit after a fraction of a second later. A rotating mirror deflects the pulsed light beam to many points in a semi-circle. The precise direction is given by an angular sensor on the mirror (laser RADAR). A large number of coordinates measured in this way are put together to form a model of the surrounding area's contours. Using the serial interface of the unit, measurements are transferred in real time (or other specified rates) to a host PC for further evaluation.

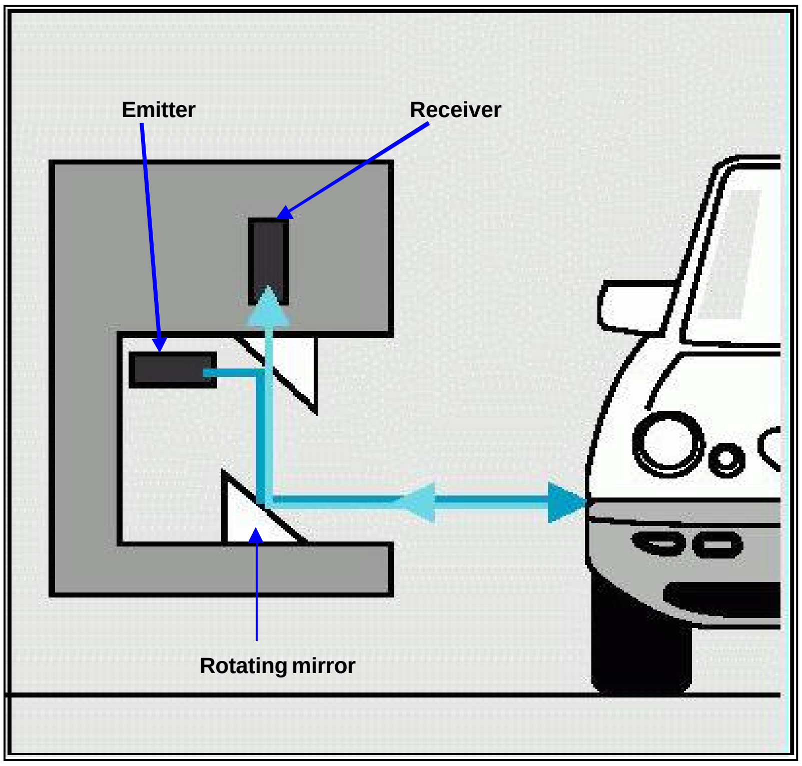


Figure 1.3.2.1 : Operating Principle of SICK LMS

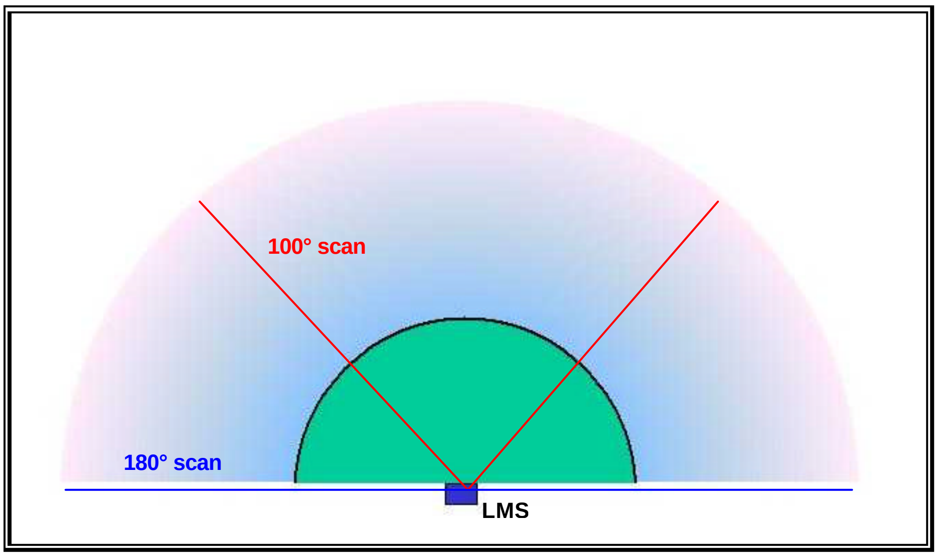


Figure 1.3.2.2 : Scan Angle and Angular Resolution

As seen from Figure 1.3.2.2, the LMS does a planar scan of either 100° or 180° with an angular resolution choice of 0.25°, 0.5° or 1°. This implies that for a 180° scan with 0.5° angular resolution, there will be a total of 361 scan values. ((180$\times$2) + 1(0° value) = 361). Each scan value consists of 2 bytes of data and all these are important as the LMS will send the number of data bytes according to the request.

1.3.3 Specifications (LMS 291-S05)

Dimensions (W´ H´ D)	155×210×156 (mm)
Maximum Range	80 m (outdoor); 150 m (indoor)
Range (without supplementary reflectors)	Up to 30 m
Range with minimum reflectivity 1.8%	4 m
Lateral Resolution (mm)	10 mm
Angular resolution	100° Scan: 0.25°/0.5°/1°, No. Of Scan Values: 401/201/101 180° Scan: 0.5°/1° No. Of Scan Values: 361/181 Configuration by software
Response times	52 ms with angular resolution of 0.25° 26 ms with angular resolution of 0.5° 13 ms with angular resolution of 1.0°
Interfaces	Serial RS-422 or RS-232 switchable
Measurement data	Real-time transfer, binary data
Data transfer rate	9.6 / 19.2 / 38.4 / 500 Kbaud
Voltage supply (electronic)	24 VDC ±15%
Laser Protection Class	1 (Eye-safe)

Table 1.3.3.1: Specifications of SICK LMS 291-S05

1.3.4 Features

- High-resolution measurement system
- Non-contact, optical measurement over long distances
- High scanning frequency allows high speed movement of objects
- An active system, requiring no illumination of the target area
- No reflectors or markings necessary on target objects
- Background and supporting medium have no affect on measurements
- Any orientation of target objects is possible
- Transfer of measurement data in real time available for further processing or control functions
- Self-testing, no external testing procedures required
- Suitable for outdoor use

1.3.5 Possible Applications for SICK LMS

The LMS can be used for standard applications involving measurement of objects and position determination, monitoring areas and vehicle guidance and collision control.

The fundamental ability of laser scanners to offer accurate contour measurement is a very important asset for use in the above applications. Advanced laser technology is relatively straightforward to acquire, install and maintain. It can provide the precision, which adds substantial value to the container handling process.

Collision control is a problem in many areas, for example in the container-handling terminal. The laser scanner's function is to monitor one or more zones in front of the fixed path or mobile equipment and to alert an operator of a potential collision; i.e. it functions as a system designed to avoid collision. This function can be extended to many other areas like car parking guiding and car following applications.

1.3.6 LMI 400

The LMI (Laser Measurement Interface) is the universal evaluation system for the distance measurement values generated by the LMS. One or more LMS can be combined and connected to the LMI to create a single system. It can be flexibly controlled according to the particular application used. The LMI 400 receives the data from the LMS in real-time using an asynchronous serial interface so that every scan can be processed by the LMI. A maximum of 4 LMS sensors can be physically connected to a LMI.

A LMS (stand-alone) can be connected directly, without an LMI, for diagnosis and requests for measured values. Thus, in this project, there is no requirement for a LMI. Figure 1.3.6.1 below illustrates the maximum configuration possible for a LMI management system.

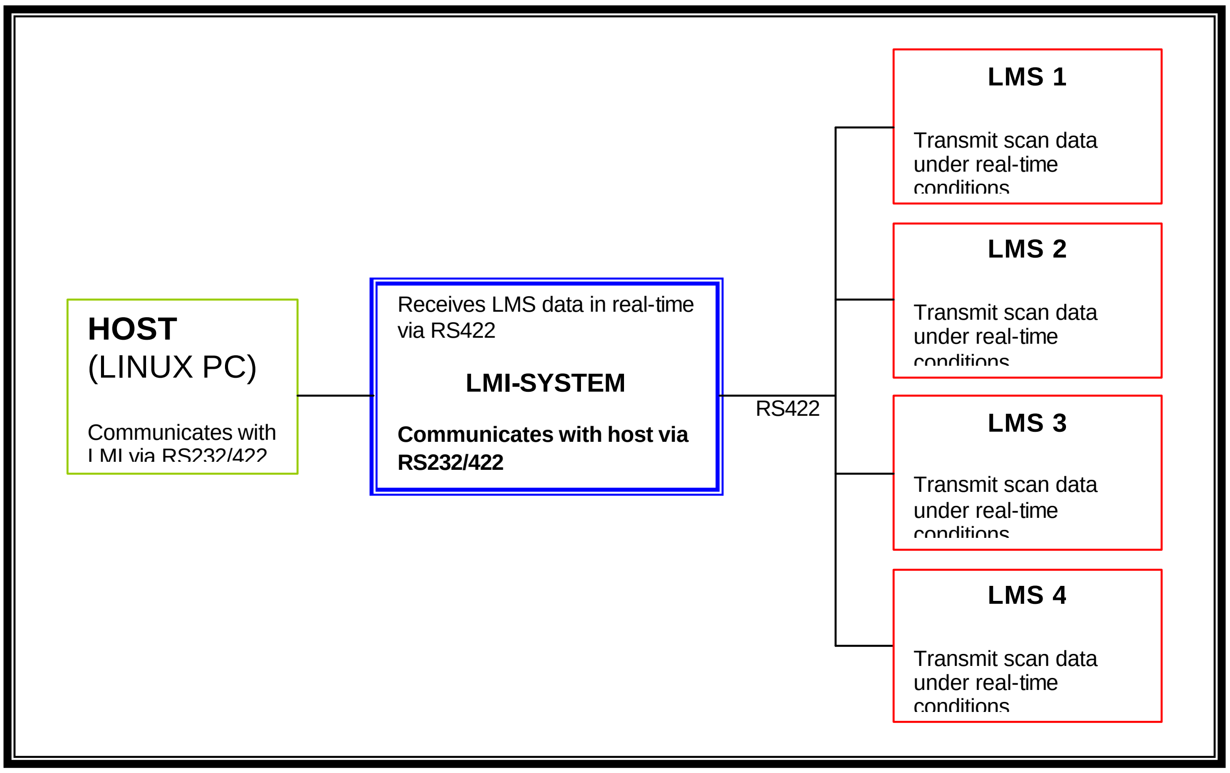

HOST
(LINUX PC)
Communicates with LMI via RS232/422
Receives LMS data in real-time via RS422
LMI-SYSTEM
Communicates with host via RS232/422
RS422
LMS 1
Transmit scan data under real-time conditions
LMS 2
Transmit scan data under real-time conditions
LMS 3
Transmit scan data under real-time conditions
LMS 4
Transmit scan data under real-time conditions

Figure 1.3.6.1 : Maximum Configuration for a LMI System

CHAPTER II

IMPLEMENTATION OF REAL-TIME SERIAL INTERFACE

In this chapter, detailed description and explanation of the implementation of a real-time serial interface between MPC555 and SICK LMS will be given. Basically, it will be split into 3 main parts; the first will explain the real-time serial interface, followed by the explanation of the serial functions of the MPC555. The final part shall look into the description and explanation of programming the SICK LMS.

2.1 Real-Time Serial Interface

The present Cycab based on the older Motorola MC68332 microcontroller (without CAN bus support) is programmed only to handle data transfer rate of 9.6 Kbauds between the equipped LMS and a laptop. Also, the MC68332 microcontroller does not have a CAN bus interface, which limits the number of devices that it, can control. With the new Cycab, the new generation MPC555 microcontrollers can handle up to a maximum data transfer rate of 1250 Kbauds, which is more than sufficient to have real-time data transfer between the MPC555 and LMS. To have real-time data transfer, a minimum baud rate of 500 Kbauds is required.

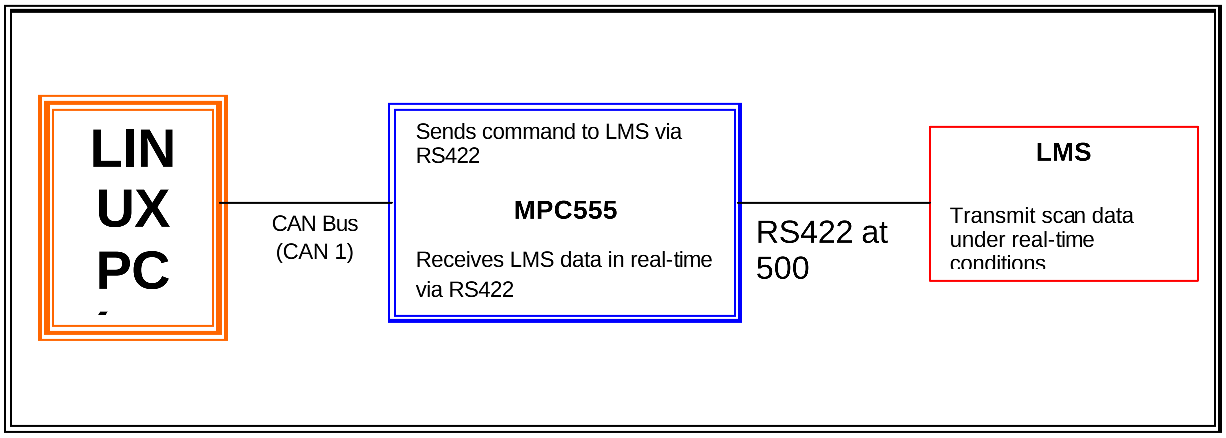

LIN
UX
PC
CAN Bus
(CAN 1)
Sends command to LMS via RS422
MPC555
Receives LMS data in real-time via RS422
RS422 at 500
LMS
Transmit scan data under real-time conditions

Figure 2.1.1 : Configuration of Required Serial Interface

2.1.1 Serial Interface

The serial interface for the real-time data transfer is of type RS422. However, due to a hardware incompatibility problem (refer to MPC555 Interface Port) between the port interface card and the MPC555, RS232 was being used in the project.

RS means Recommended Standard. Both RS232 and RS422 are of full duplex type. Full duplex devices can transmit and receive data at the same time. The maximum data speed for a RS232 is about 115 Kbauds while the RS422 can go up to about 10 Mbauds. The RS232/RS422 serial interface used has a Sub-D 9 pin connector and this is commonly used in interfacing between computer peripherals. Figure 2.1.1.1 shows the front view of a typical Sub-D 9 pin connector that was used.

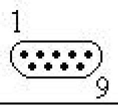
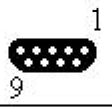
	Male	Female
DB9		

Figure 2.1.1.1 : Sub-D 9 Pin Connector View

2.1.2 Serial Format

Before commencing with the programming of the real-time serial interface implementation, the serial format of the data/message frames that MPC555 and SICK LMS will send/receive must be known. As the 2 hardware are from 2 entirely different manufacturers, there will always be the possibility of hardware incompatibility problems. It is very important that both the receiving and transmitting devices use the same data frame format. With the same data frame format defined, then both hardware can capture and send data successfully based on the defined format.

All data frames must have a start bit and at least one stop bit. The SCI (Serial Communication Interface) in MPC555 provides hardware support for both 10-bit and 11-bit frames. In the case of message frames sent by the SICK LMS, a byte of data consists of **1 start bit, 8 data bits, 0 parity bit and 1 stop bit**. With reference to Table 2.1.2.1 below, the different data frame formats that MPC555 can support is shown. Thus, basically the messages sent between the 2 devices are in 10-bit frame format. With the data frame format known, it can thus be specified in the initialisation of the UART interface in MPC555. Once specified, the MPC555 UART interface will be able to send and capture data successfully to and from SICK LMS. This will ensure that the MPC555 gets the correct data byte position.

10-Bit Frames			
Start	**Data**	**Parity/Control**	**Stop**
1	7	-	2
1	7	1	1
1	***8***	***-***	***1***
11-Bit Frames			
1	7	1	2
1	8	1	1

Table 2.1.2.1: Serial Frame Formats

2.2 MPC555 Control Board

2.2.1 UART Serial Interface Functions in C Language

Robosoft had provided some C language libraries specific for the MPC555 microcontroller. The libraries written for the UART serial interface were utilised in the implementation of the real-time serial interface between the MPC555 and SICK LMS. The figure 2.2.1.1 below lists out the main functions used in the programming.

	Function Declaration	Comments
1	Int UARTInit (int UartNb, int Baud, int nbit, int nstop, int parity, int ButPtr, int Bufsize)	Initialise UART serial interface on MPC555. Return 0 if all is ok.
2	int UARTClose (int UartNb)	Disable UART serial interface when error is detected.
3	Int UARTGetChar (int UartNb, char *C)	Return char read from target (SICK LMS) if any. If no char is in the buffer, then return Err_SCCNoChar.
4	Int UARTGetWaitChar (int UartNb, char *C)	Wait for char read.
5	int UARTPutChar (int UartNb, char x)	Input char to target. Return 0 if all is ok.

Table 2.2.1.1 : MPC555 UART Interface Functions

2.2.2 MPC555 Interface Ports

In order for MPC555 to be able to communicate with the LMS, the MPC555's COM serial port has to be initialised. The MPC555 control board used in this project has 6 ports: 2 CAN Bus ports, 3 serial ports and 1 free port (refer to Photo 2.2.2.2). The written program was downloaded into the MPC555 control board via the CAN port 1. The new Cycab will be based on a Linux PC (Personal Computer) installed with a CAN Interface Card and all the main nodes of the Cycab will be connected by CAN bus to the MPC555.

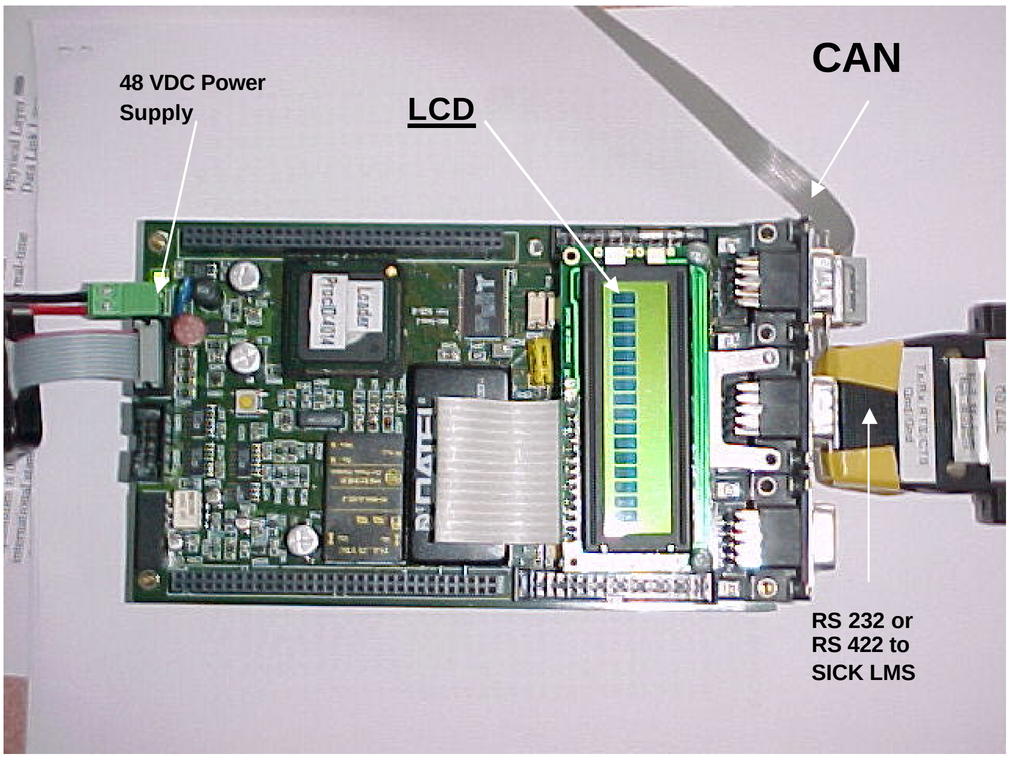


Photo 2.2.2.1 : MPC555 Control Board with Connections (Top)

However, due to hardware incompatibility between the port interface card and MPC555, the maximum baud rate that the port can handle is about 250 Kbauds whereas the minimum baud rate for real-time data transfer must be at least 500

Kbauds. Thus, the serial interface was being tested at 19.2 Kbauds instead (until Robosoft provides a new port interface).

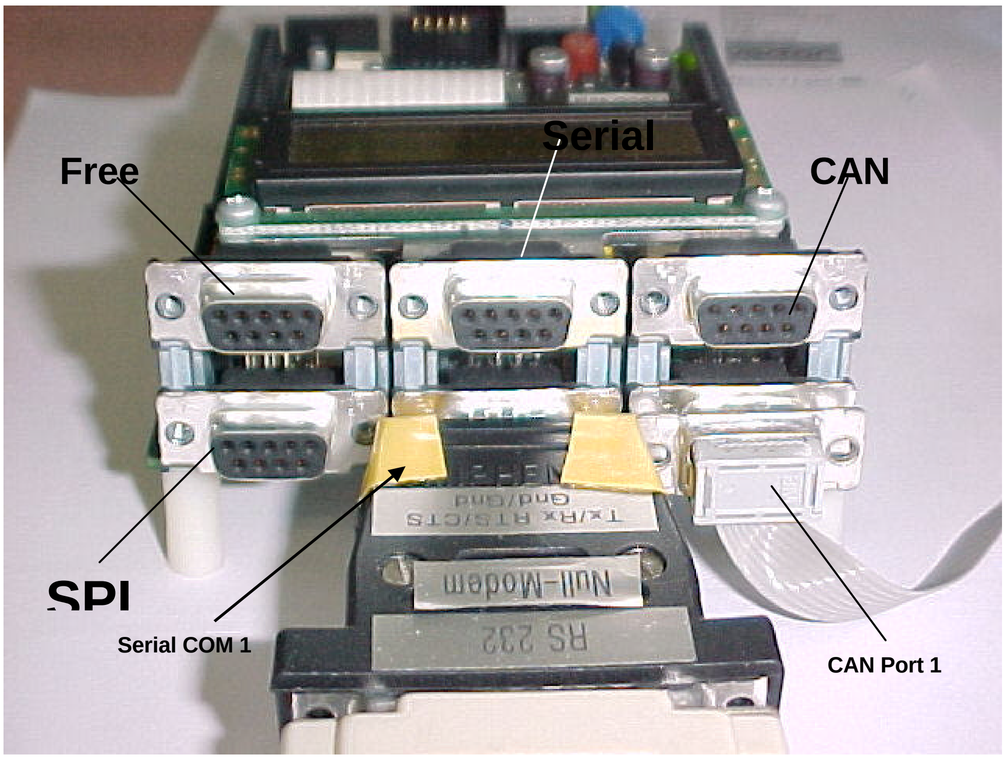


Photo 2.2.2.2 : MPC555 Control Board with Connections (Front)

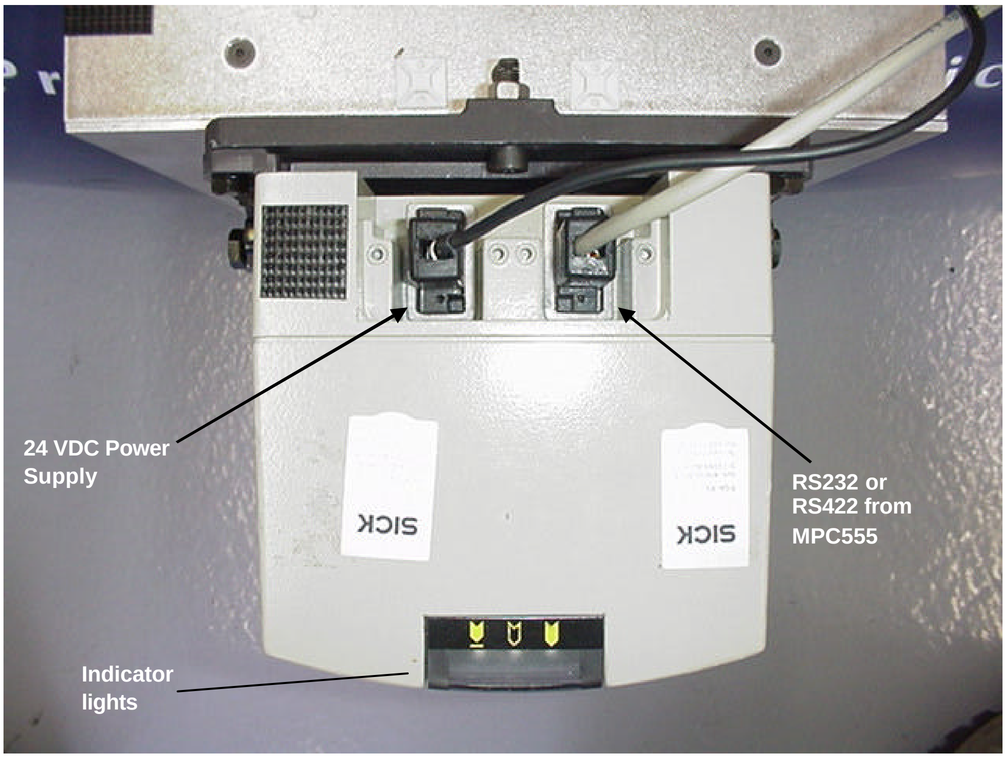


Photo 2.2.2.3 : SICK LMS with Connections (Top)

Photo 2.2.2.3 above shows a top view of the SICK LMS attached to the Cycab. It can be seen that the RS232/RS422 cable from the MPC555 are connected to the right port of the SICK LMS.

2.3 SICK LMS

2.3.1 LMS Telegram Structure

The SICK LMS requires pre-defined telegrams for communication with the Host, which can either be a computer or in this case, a microcontroller (MPC555). Data is transferred in binary format (but written and displayed in hexadecimal format) and transfer is initiated by the STX byte (start of text), 02H. In addition, the transferred data is also in INTEL data format. This implies that word transfer takes place with the lower address and the least significant byte first, followed by the bytes of higher address and significance. The structure of the telegrams sent and received must comply with the pre-defined telegram structure throughout the entire program. Otherwise, errors will occur and make troubleshooting difficult. Table 2.3.1.1 below shows a typical LMS telegram structure and Table 2.3.1.2 describes the structure in detail.

STX	ADR	Len		CMD	Data ……(N bytes)	Status	CRC	

Table 2.3.1.1 : LMS Telegram Structure

Designation	**Data width (bits)**	**Description**
STX	8	Start byte (02H)
ADR	8	Address of the LMS to be contacted. Note: The LMS adds the value 80H to the address when responding to the Host Computer.
Len	16	Number of data bytes (CMD+Data+Status)
CMD	8	Command byte sent to the LMS. When responding, LMS will send the original command byte with the addition of 80H to the value.
Data	$N \times 8$	Optional, depends on the previous command.
Status	8	Optional, the LMS transmits the status message only when it is sending out data. When sending command to LMS, no status message is transmitted.
CRC	16	CRC checksum for entire data.

Table 2.3.1.2 : Description of LMS Telegram Structure

With reference to the above tables, it can be seen that a typical telegram sent to LMS consists of the following bytes in sequence: STX, ADR, LEN Low, LEN High, *CMD, N × Data, Status*, CRC Low, CRC High. One very important definition to note is the 2 Len bytes, which describes the length of the following data bytes except the CRC bytes. That means the Len bytes refer to the total number of bytes in CMD, Data and Status only. Caution must be taken not to confuse these data bytes with the actual N × Data bytes. As the number of Data bytes, N, sent is different every time, thus it is necessary to read the Len bytes and minus off 2 bytes (CMD and Status) in order to get the number of Data bytes. In this project, the defined address ADR of the SICK LMS is 0x01 (01H = 1).

2.3.2 Organisation of Telegrams

In order to establish a good communication interface between the SICK LMS and a Host system (MPC555 in this project), a comprehensive list of different telegrams doing different functions is required. These telegrams can be organised into 2 main categories by their direction of data transfer: Host to LMS and LMS to Host. Subsequently, the telegram list can be furthur categorised into the following different sub-categories:

- **Telegrams from Host to LMS**

♦ Initialisation and Reset of the LMS

♦ Select/Change of operating mode of the LMS

♦ Select/Change of configuration of the LMS

♦ Request for measured (scan) values

♦ Request for LMS status data

♦ Request for LMS configuration data

- **Telegrams from LMS to Host**
    - ♦ Response telegrams by LMS with respect to telegrams sent by Host

In addition, when request telegrams are sent from Host to LMS, a software handshake will be initiated by the LMS. Upon the receipt of a correct request, the LMS will send out a character ACK (06H) before the entire response message. However, in the case that an error is detected, the LMS responds with a NAK (15H).

For synchronisation purposes, the time interval allowed between 2 bytes of data in a telegram is between a minimum of 55 µs and a maximum of 6 ms. When violated, the telegram will be ignored. For a more complete list of telegrams for the LMS, refer to Appendix A.

2.3.3 Structure of LMS Status Byte

The status byte consists of 8 bits. As seen from the figure below, the status byte gives useful information like Error encountered if any or other problems like Pollution.

Bit Position	Description
0	Combination of bits 0,1 and 2 are used to produce values 0 – 4.
1	
2	Value — Meaning 0 — no error 1 — info 2 — warning 3 — error 4 — fatal error
3	Bits 3 and 4 produce data source designators.
4	00 — LMS –xx1 to –xx4 01 — LMI 10 — LMS –xx6 11 — Reserved
5	State of RESTART input: 1 – HIGH, 0 – LOW
6	Implausible measured value.
7	Pollution

Table 2.3.3.1: Description of LMS Status Byte

With the above Table 2.3.3.1, the LMS telegrams sent or received can be interpreted and verification functions can also be written.

2.3.4 Example of Telegram Transfer

To have a clearer picture of the telegram structure, an example of a sent telegram and a received telegram, extracted from one of the serial interface test programs done, is described here.

2.3.4.1 Command sent from MPC555 (Host) to LMS

STX	**ADR**	**Len**		**CMD**	**Data**								
		LOW	HIGH			S	I	C	K	_	L	M	S
02H	00H	0AH	00H	20H	00H	53H	49H	43H	4BH	5FH	4CH	4DH	53H

CRC	
LOW	HIGH
BEH	C5H

Table 2.3.4.1 : Command Telegram sent from MPC555 to LMS

2.3.4.2 Interpretation of Command Telegram

02H	Start character for intialisation of transmission.
00H	LMS address (Broadcast addr to all LMS)
000AH	Length of data bytes = 10 (CMD+Data)
20H	Command byte for Select/Change of Operating Mode
00H	Operating Mode = Installation mode for config and setting parameter

53H … 53H	Installation mode default password = *SICK_LMS*
C5BEH	CRC16 Checksum return value

Table 2.3.4.2 : Interpretation of Command Telegram

2.3.4.3 Response sent from LMS to MPC555 (Host)

ACK	**STX**	**ADR**	**Len**		**CMD**	**Data**	**Status**	**CRC**	
		(+80H)	LOW	HIGH				LOW	HIGH
06H	02H	80H	03H	00H	A0H	00H	10H	16H	0AH

Table 2.3.4.3 : Response Telegram sent from LMS to MPC555

2.3.4.4 Interpretation of Response Telegram

06H	Acknowledge character when response is received correctly within 60 ms. Otherwise, 15H (NAK = Not Acknowledged) will appear.
02H	Start character for intialisation of transmission.
80H	LMS address (Broadcast addr to all LMS) + 80H
0003H	Length of data bytes = 3 (CMD+Data+Status)
A0H	Command byte for Response to Select/Change of Operating Mode
00H	Response Status = Oper Mode change successful
10H	Status byte
0A16H	CRC16 Checksum return value.

Table 2.3.4.4 : Interpretation of Response Telegram

An important point to note and remember is that no Status byte is transmitted when a request command is sent to LMS. The Status byte is included only when the LMS is transmitting response messages. Also, for responses from LMS, an ACK byte will be included before the STX byte. The Len bytes when converted from hexadecimal to decimal give the number of data bytes that are enclosed within the 2 red lines.

2.3.5 CRC16 Checksum and Other Verification Methods

In ensuring transfer reliability, a block check is done at the end of the telegram with a CRC checksum over the entire data package with CRC 16 polynomial generator. CRC, Cyclic Redundancy Check is a common method for detecting data transmission errors. The CRC will perform a mathematical calculation on the data block to be sent and generates a unique checksum value that represents the content and organisation of that data. Subsequently, the receiving station also generates a checksum value of the received data based on the CRC algorithm. Then, both CRC checksum values at the sending and receiving stations are compared to make sure that they are the same. If they are different, it can be concluded that errors occurred during the sending process.

During the software handshake (refer to Chapter 2.3.2, Organisation of Telegrams), the LMS does nothing if the wrong ADR is used. When the ADR is correct but the CRC checksum is incorrect, a NAK will be sent. Finally, in the case where both ADR and CRC checksum is correct, the LMS will respond with ACK.

Another verification method used was to obtain the return values (0 or 1) of certain functions. For example, in the initialisation of the UART serial interface of the MPC555, the function UARTInit will return a value 0 if there is no error. Thus, a simple ‘if’ verification statement in the program can help test if the UART is initialised properly. These verification measures when implemented in the program will help in easing the task of troubleshooting or debugging as the user will know at which step the program encountered the error.

2.3.6 The Makefile

A makefile is like an instruction book that tells the compiler which library to look for, which .c program files and .o object files to compile. Also, it indicates the name of the target files and the executable file that is to be compiled.

In order to download a program into the MPC555, the C program file with extension .c must first be converted into a format understandable by the downloader. The Makefile and some libraries provided by Robosoft contain specific functions for compiling a program to work in MPC555.

The first part of the Makefile works like a normal Makefile. It first compiles the .c program files into .o object files. Then, the .o object files are furthur compiled into an ELF binary executable file format. A function, *elf2sdxbin*, will convert the ELF binary executable file into a SynDEX binary file format (.bin) understandable by the downloader. Then, the downloader function, *dwnbin*, will download the .bin file into the MPC555. MPC555 will run the program upon receiving the .bin file.

Makefile function	**Description**
elf2sdxbin	elf2sdxbin [input file] [output file]
dwnbin	dwnbin [input file] [SID]

Table 2.3.6.1 : Description of Makefile Functions of MPC555

Table 2.3.6.1 gives a good description of how the command lines in the Makefile were written. SID is the ID number of the MPC555 microcontroller. The MPC555 given in this project has an ID of 4014H. However, the Makefile requires the user to input the SID as a decimal value, so SID is actually 16404.

```
# Sample Makefile Commands
Download :
            elf2sdxbin   TEST       TEST.bin
            dwnbin       TEST.bin   16404
```

Figure 2.3.6.1 : Example of Makefile Commands for MPC555 Program

From Figure 2.3.6.1, the sample in this case was taken from one of the test programs done during the attachment. The C program that was written was TEST.c and after the initial normal compilation, an ELF binary executable file, TEST, was created. This was the input file name for the command line elf2sdxbin and the name given for the output file was TEST.bin. After the SynDEX binary file TEST.bin was created, the downloader command line, dwnbin, was inserted with the input file name of TEST.bin and subsequently, the MPC555 ID in decimal. This entire process will take place when the user does a Make Download command or Makefile command. For the complete Makefile program, please refer to Appendix E.

2.4 The Simulated Environment

The SICK LMS is connected to the MPC555 via RS232/RS422 cable to port COM 1. The Figure 2.4.1 below illustrates the overview of the entire setup. In the case of this project, a Linux PC was used in programming, compilation and downloading of the completed software into the MPC555. Thus, the simulated environment is in fact the same as the actual environment on the new Cycab.

A FALCO Infinity series computer was used during the testing and simulation process of the serial interface program. It is mainly used for inputting responses to the MPC555 and viewing responses from the LMS.

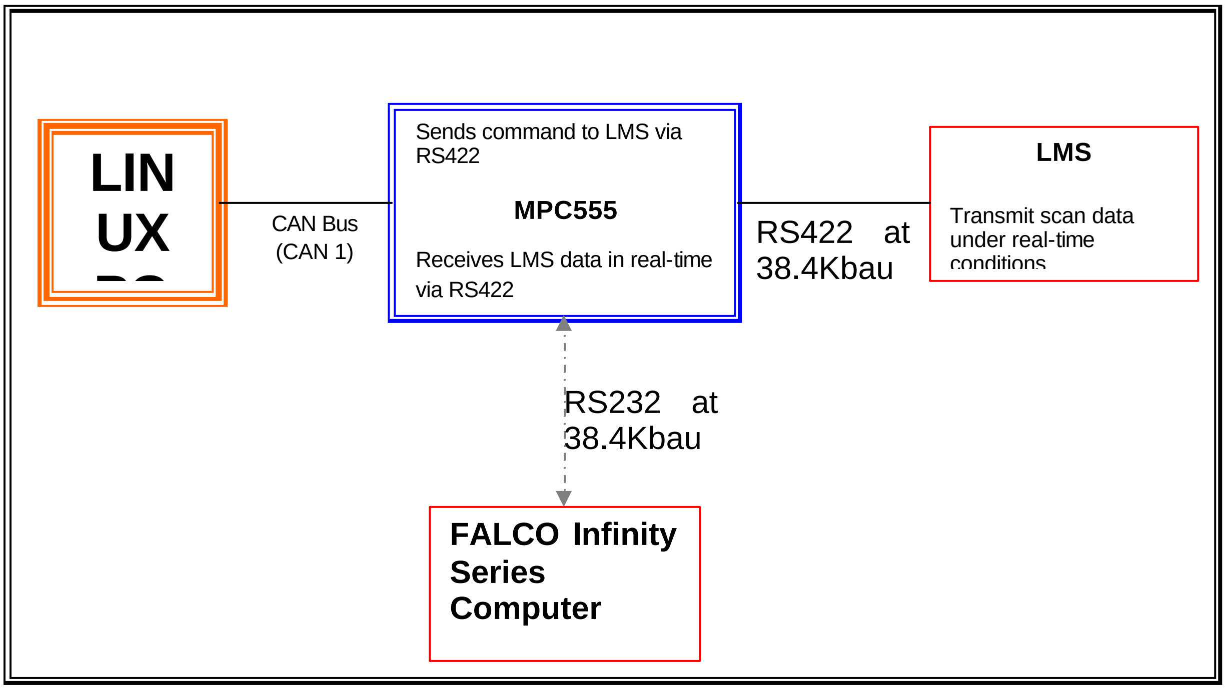

LIN UX
CAN Bus (CAN 1)
Sends command to LMS via RS422
MPC555
Receives LMS data in real-time via RS422
RS422 at 38.4Kbau
LMS
Transmit scan data under real-time conditions
RS232 at 38.4Kbau
FALCO Infinity Series Computer

Figure 2.4.1 : Overview of Simulated Environment

2.5 The Flow of Program

2.5.1 Data Exchange between SICK LMS and MPC555

In this C program of the implementation of a real-time serial interface, there are a lot of data flow between the LMS and the MPC555. These exchanges of data may be confusing and the LMS is programmed in an orderly manner such that the initialisation, request and receipt of data are in a proper sequence. Basically, the data exchanges are categorised into the following parts in sequence in the program.

1) The configuration/operating mode data of LMS
2) The specification parameters of LMS measurement
3) The scan values data

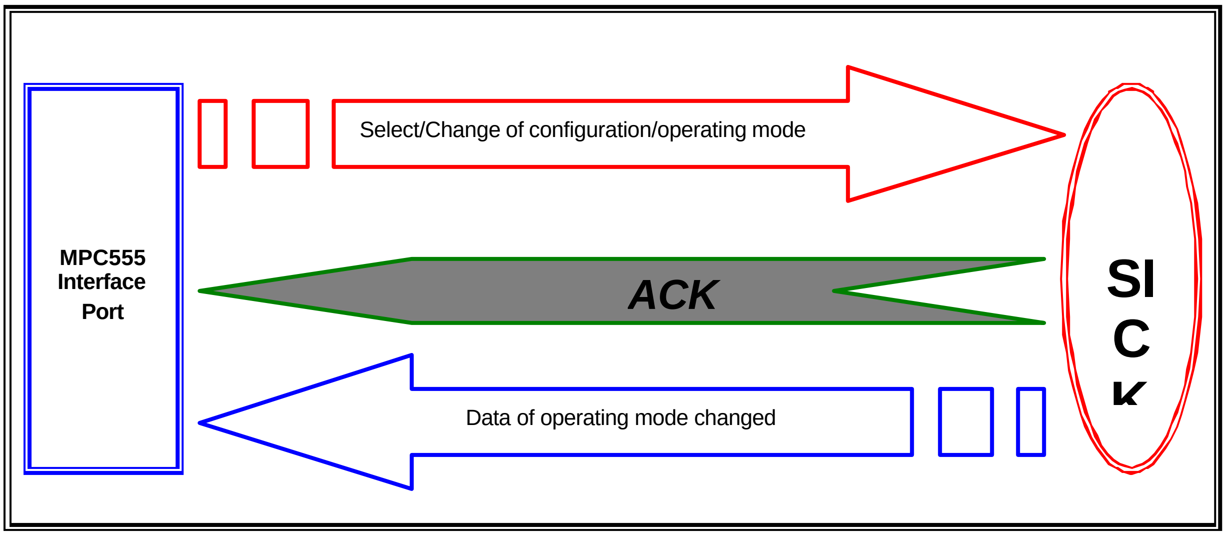

MPC555 Interface Port
Select/Change of configuration/operating mode
ACK
Data of operating mode changed
SICK

Figure 2.5.1.1 : Request for Change in Operating Mode with Response

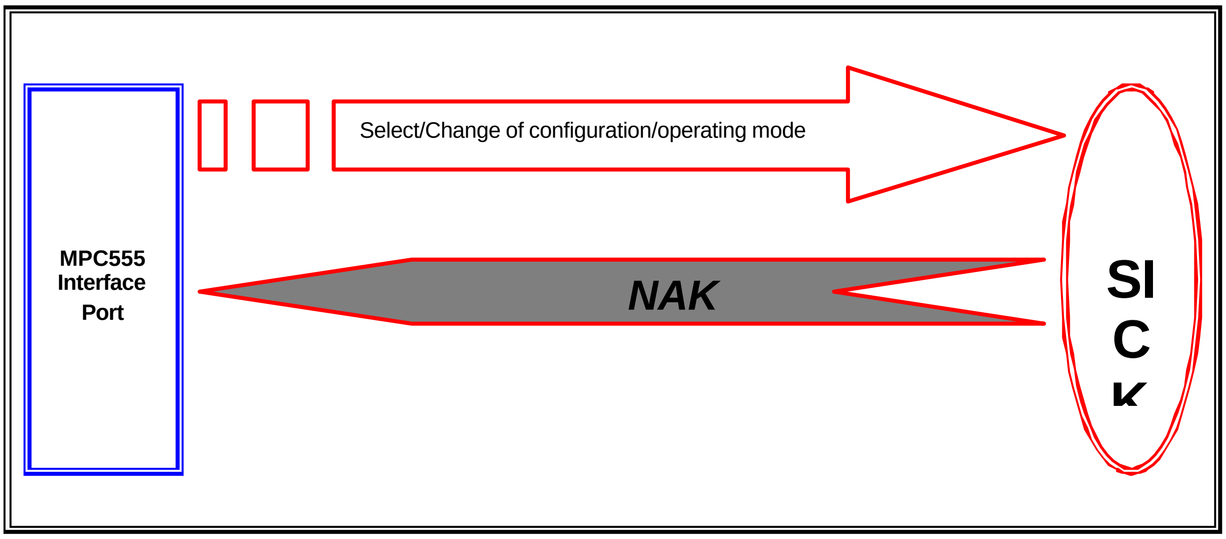


Figure 2.5.1.2 : Request for Change in Operating Mode without Response

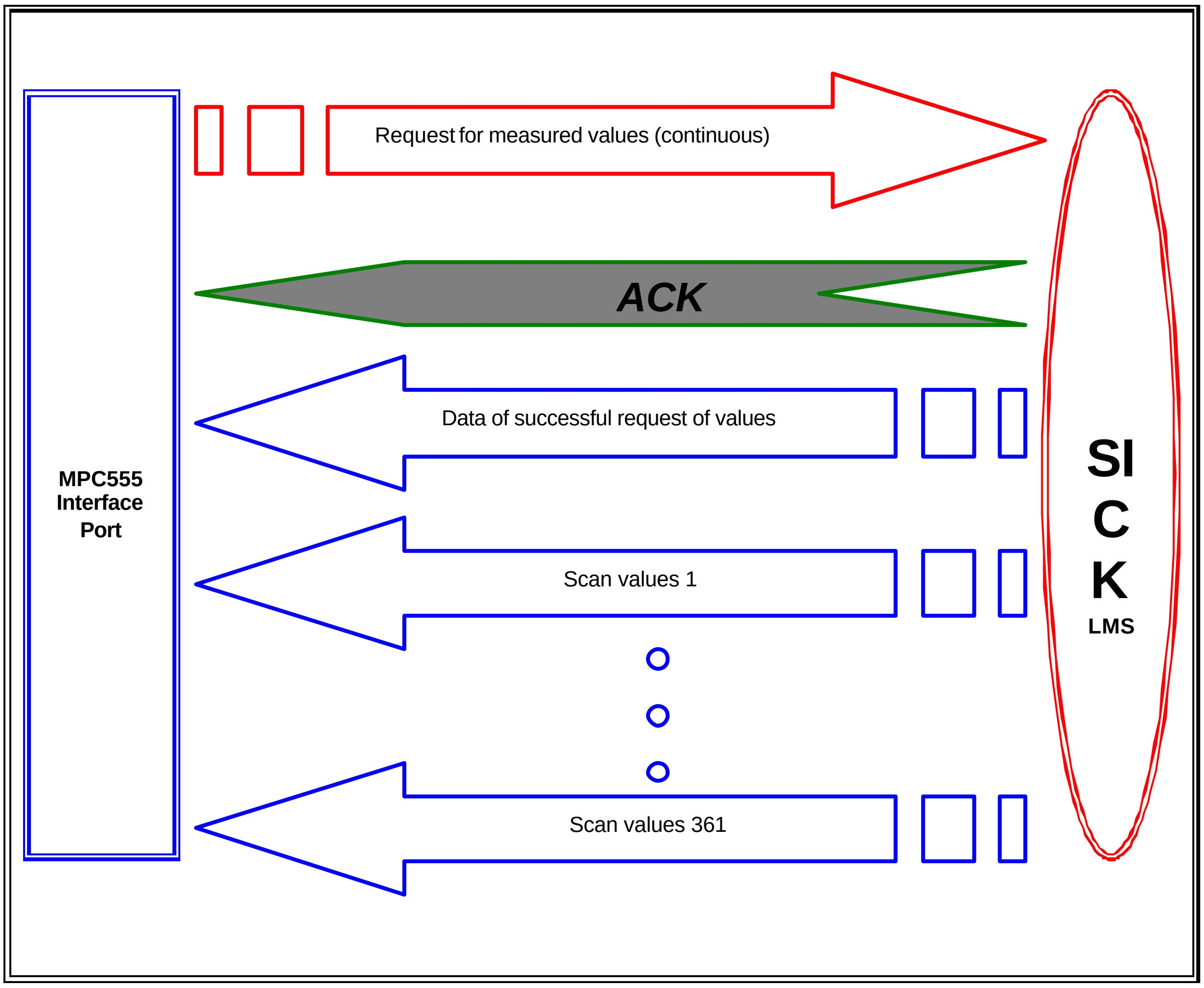

MPC555
Interface
Port
Request for measured values (continuous)
ACK
Data of successful request of values
Scan values 1
Scan values 361
SI
C
K
LMS

Figure 2.5.1.3 : Request for Scan Values (continuous)

Figure 2.5.1.1 shows a flow diagram of a good request for Select/Change of Configuration/Operating Mode. Upon verifying that the request is good, an ACK byte is sent followed by the mode changed data. An example of a bad request (with incorrect CRC) is shown in Figure 2.5.1.2. No data is transferred after the NAK byte is sent.

For the Request of Scan Values (continuous), the normal procedure takes place (Figure 2.5.1.3) with the request sent to LMS and after verification, ACK is sent back to MPC555. Following the ACK, the normal response message describing a successful request for scan values is sent. After that, the scan values will then be sent. Depending on the scan angle and the angular resolution chosen, the number of scan values will differ. For this project, the default scan angle of 180° and angular resolution of 0.5° was chosen. Thus, 361 scan values will be sent. Refer to Table 1.3.3.1 for details of number of scan values. The retrieving of the 361 values (after a request for the scan values) will be explained in more detail in the next section 2.5.2, Main Program Flow.

2.5.2 Main Program Flow

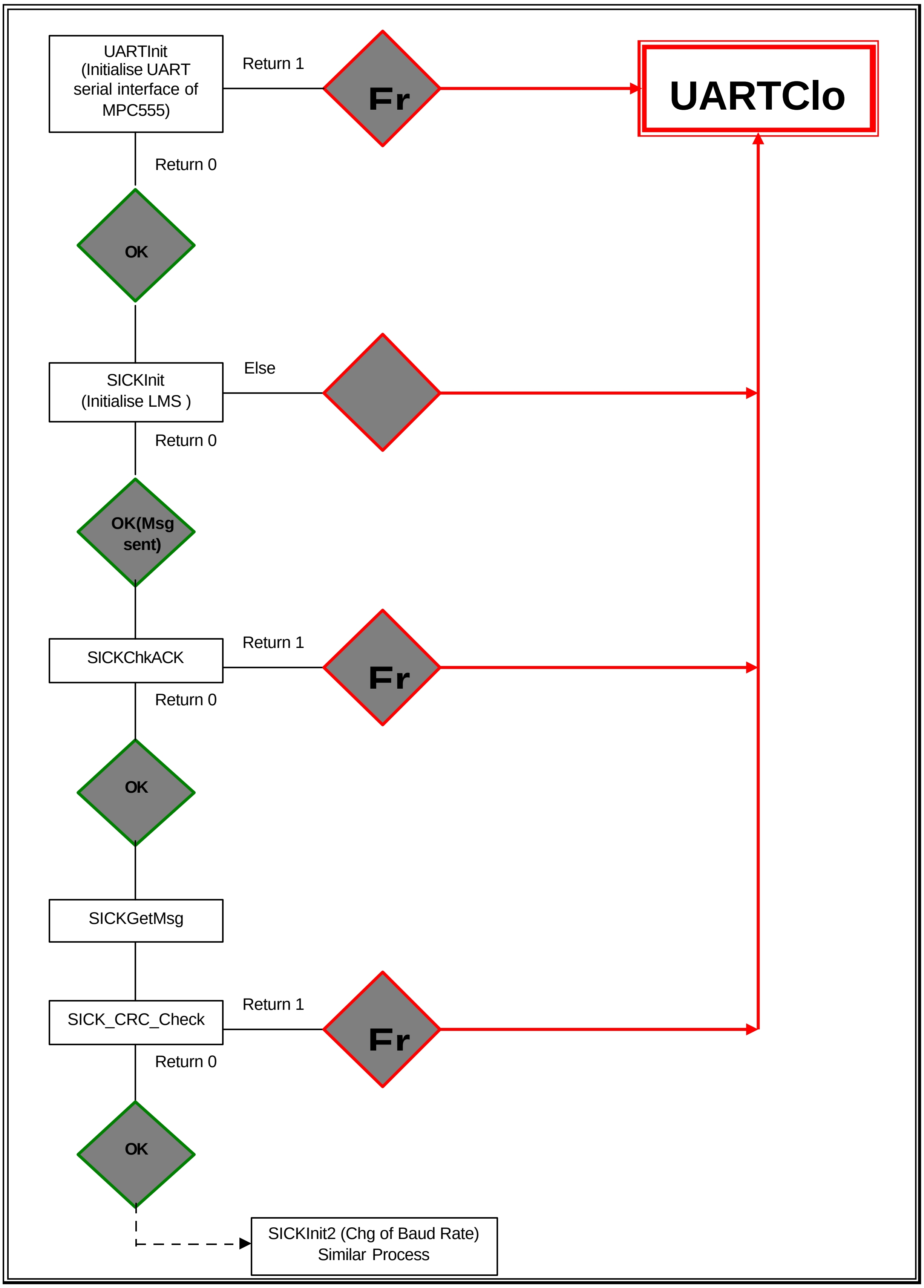


Figure 2.5.2.1 : Initialisation Flow of Main Program

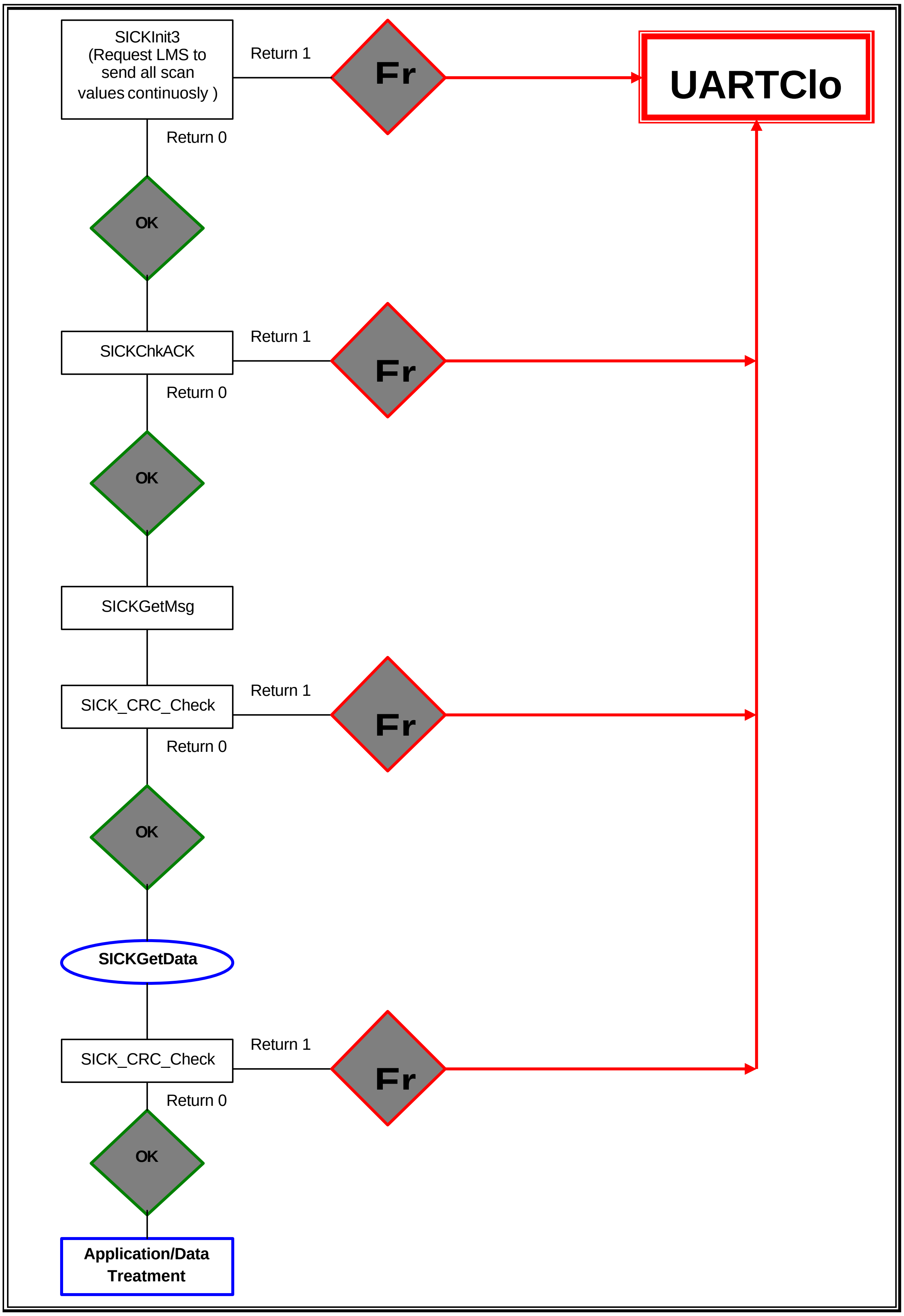


Figure 2.5.2.2 : Capturing of Scan Values in Main Program

As mentioned earlier in Chapter 2.5.1, the data exchange between SICK LMS and MPC555 can be categorised into 3 categories and the main program can also be categorised in the same way. In Figure 2.5.2.1, the initialisation of the UART interface of MPC555 and SICK LMS is shown and this is the first part of the main program. The UART was first initialised (by UARTInit) and if the return value is a 0, it means that the UART was initialised properly. From the program, the function declaration is UARTInit (0, 19200, 8, 1, 0, &Buffer, BufSize). In sequence, 0 refers to the serial COM 1 port number of the MPC555 control board; 19200 refers to the desired baud rate; 8 is the number of data bits; 1 is the number of stop bit and finally 0 is the number of parity bits. &Buffer is the pointer to the declared buffer while BufSize is the size of the buffer which had been declared to be 128 bytes in the beginning of the program.

After the UART was initialised, the program continues to the next step of sending a command string, SICKInit, to the LMS. This is to initialise the LMS with specifications corresponding to that of the MPC555 UART serial interface. With reference to the program, the LMS telegram structure (Table 2.3.1.2) and the LMS telegram list, the initialisation telegram SICKInit can be interpreted. However, the array init[16] was declared with a size of 16 bytes but only 14 bytes were included. The reason is the last 2 bytes are reserved for the CRC bytes and they are created by the function SICKCreateCRC. The block of data from the 1st byte to the 14th byte are included in the SICKCreateCRC calculation. After that, the CRC Low byte is put into init[14] and CRC High byte into init[15]. This is because data is transferred in INTEL data format for SICK LMS.

The next step in the program is the function SICKChkACK where it will capture the 1st response byte and determine if it is an ACK byte. If so, it will continue capturing the rest of the message by SICKGetMsg. Otherwise, if it is a NAK or rubbish, error has occurred and the program will proceed to UARTClose (0) where the UART interface of the MPC555 will be closed. After getting the entire message, the function SICK_CRC_Check will create a CRC value based on the entire message block except the received CRC bytes. Then, the received CRC bytes will be converted into decimal format (CRCL + (CRCH x 256)). Both received and created CRC values will be compared and if they are the same, the program will continue.

Following command strings are sent to control the LMS to commence with a scan (180° scan and 0.5° angular resolution by default) and to send back the scan data (361 values) to the MPC555.

Figure 2.5.2.2 shows the process of capturing the 361 scan values in the main program. First of all, SICKInit3 is sent with the request of all the scan data values (continuous). The same process as the earlier functions is run though: SICKChkACK, SICKGetMsg and SICK_CRC_Check. This time, after the MPC555 receives the message that the request for all 361 scan values was successful (by SICKGetMsg), the sending will not stop there. The LMS will proceed to send another string of data beginning with STX (no ACK or NAK byte for this) and this string contains all the 361 values. Also, since each scan value consists of 2 bytes, the total length of the entire string is (361x2)+4 = 726 bytes. The additional 4 bytes are the CMD, Status, LENL and LENH.

After getting the entire string of scan values, a CRC check is done again and then the program will go to the next part: treatment of the scan values for Application programs like Car Following and Obstacle Avoidance. The complete program on the serial interface can be found in Appendix D.

CHAPTER III

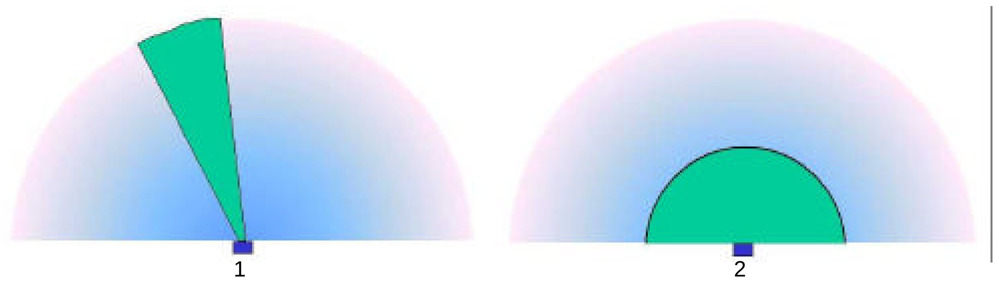
PROCESSING OF SCAN DATA AND APPLICATION PROGRAM

In this third Chapter, the report will focus on the method of data extraction for processing and the application programs : Obstacle Avoidance and Car Following. A researcher did before some previous work on the above for the old Cycab equipped with the MC68332 microprocessor. The objective now is to translate these into a suitable format for the MPC555 microcontroller installed in the new Cycab.

3.1 Obstacle Avoidance

3.1.1 LMS Programmable Scanning Field

As explained earlier in the Chapters 1 and 2, the SICK LMS can be requested to change its operating mode, baud rate, type of data to be sent, method of data sending (e.g. continuous) and many others. In fact, the LMS can be instructed to define its scanni ng field. Figure 3.1.1.1 below illustrates 4 possible configurations of scanning field. Configuration 1 is the normal configuration where the laser from LMS makes either a 100° or 180° scan. Configuration 2 and 4 are a defined scanning field where a desired area is 'marked-out'. The LMS can be programmed to define the scanning field in a rectangular field or a semi-circular field. Furthermore, up to 3 scanning fields can be configured active simultaneously and this is shown as configuration 3.



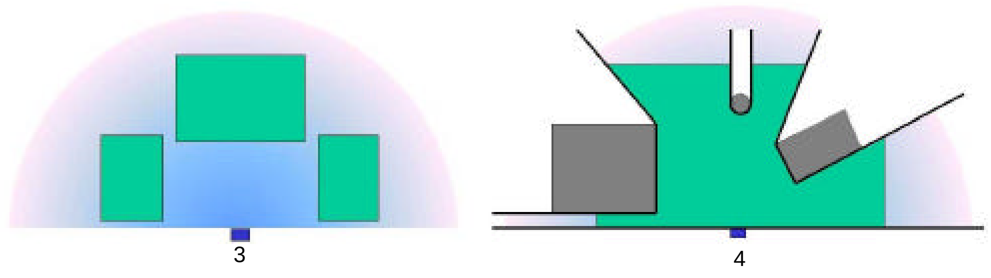


Figure 3.1.1.1 : Possible Configurations of LMS Scanning Field

3.1.2 Implementation of Obstacle Avoidance

The purpose of an Obstacle Avoidance application is to implement a safety feature to the Cycab, where it will either stop or move out of the way when an obstacle is detected. This application is simple in terms of data extraction and processing, as it does not need special processing of the scan data.

It can be seen in configuration 4 of Figure 3.1.1.1 above, the LMS was programmed to scan a designated area in front of it. For example, an area of 5 m by 5 m can be defined and to increase the safety distance of the Cycab, a bigger field can be defined. The size of the field can be easily defined by sending the request telegram to the LMS.

Then, the Obstacle Avoidance will be programmed to check for a change in the scan data received. As soon as an obstacle is within the defined field boundary, the program will detect a change and send a request to the MPC555 subsequently to either stop the vehicle or steer away.

3.2 Car Following

3.2.1 Extraction and Processing of Data

For sophisticated and complicated application like Car Following, it is necessary to retrieve and process the scan data values. When the LMS sends the scan values back to the Host (MPC555), it is capable of sending the data in different format/type.

All the measured data sent by the SICK LMS come from the following information :

- The angle of emitting laser beam
- The distance
- The level of intensity of the reflected beam

The data processing by the LMS will provide the following information :

- Data values of 1 complete scan in polar coordinates and the intensity level of the reflected beam
- Averaged values
- Partitioned values
- Averaged partitioned values
- The shortest perpendicular distance with respect to the radius of the scan
- The shortest distance value in each segment
- Cartesian coordinates

Figure 3.2.1.1 below illustrates a typical process of the extraction and processing of scan data by the LMS.

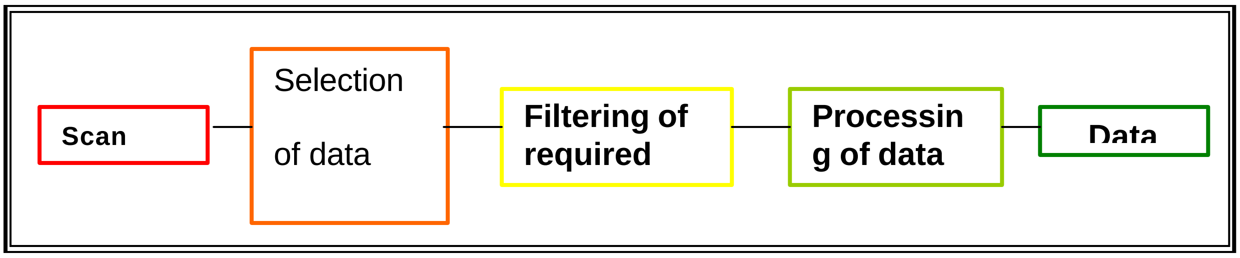


Figure 3.2.1.1 : Extraction and Processing of Data

3.2.2Detection of Reflector Target

The SICK LMS detects the distance of objects in front of it by the principle of time-of-flight as explained in Chapter 1.3.2. This implies that the total time taken for the emitted laser beam to reach the target and for the reflected laser beam to return to the captor, multiplied by the speed of light constant will produce the distance. Though the SICK LMS is able to detect most objects in front of it, the intensity of the reflected laser beam detected by it is much weaker than the emitted laser beam. This also implies that the SICK LMS may not be able to detect objects of certain material very well. Thus, poor reflectors of light may not be well detected and do not make good targets.

For the Car Following application, the objective is to program the SICK LMS to detect another Cycab in front, so that the 2nd Cycab will follow the leading one. In order to have a higher intensity reflected laser beam, 2 special light reflecting targets were placed behind the Cycab. Then, the position of the 2 reflector targets (back of the Cycab) can be easily detected, as they will produce a very high intensity of reflected laser beam compared to the surrounding environment.

3.2.3Mathematical Algorithm

For the application program of Car Following, the following 3 data are necessary :

- Angular position a of the target (centre of the Cycab)
- Distance d of the target
- Angle ?, the relative orientation of the axis of the 2 vehicles

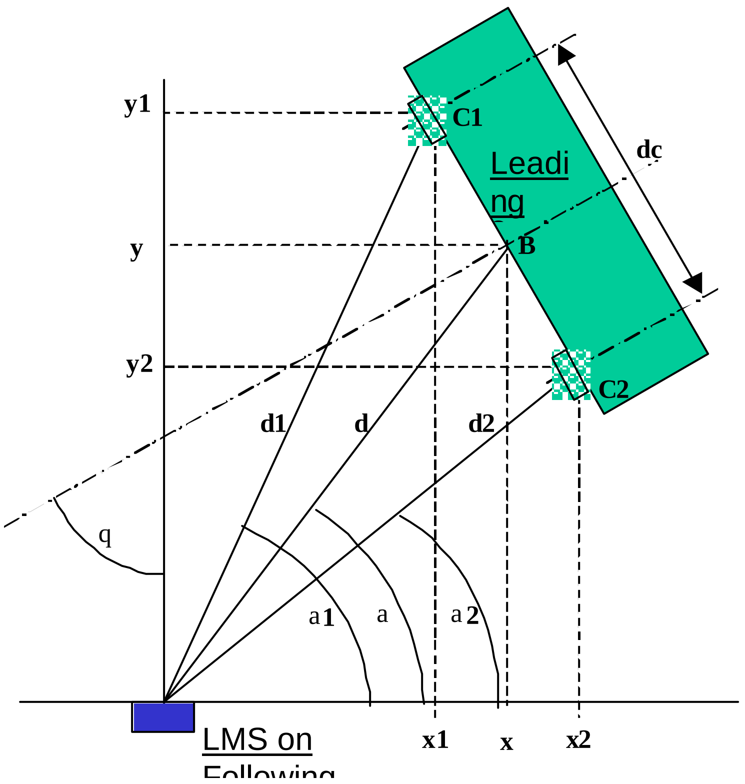


Figure 3.2.3.1 : Mathematical Diagram Representation of Car Following

As illustrated in Figure 3.2.3.1, C_1 and C_2 are the centres of the 2 reflector targets fixed to the back of the leading Cycab. In order to obtain the 3 data a, d and ? for the Car Following application, the following equations derived from Figure 3.1.2.1 were used.

$x_1 = d_1(\cos a_1)$ $\qquad$ $x_2 = d_2(\cos a_2)$

$y_1 = d_1(\sin a_1)$ $\qquad$ $y_2 = d_2(\sin a_2)$

$dc = v[(x_1 – x_2)^2 + (y_1 – y_2)^2]$

$x = (x_1 + x_2)/2$ $\qquad$ $y = (y_1 + y_2)/2$

$a = (a_1 + a_2)/2$

$? = -\text{argsin}[(y_2 – y_1)/dc]$

where

x and y : Cartesian coordinates of the leading vehicle (relative to the following vehicle)

d : Direct distance between the 2 vehicles (with respect to the centre of the vehicle)

? : Angle between the longitudinal axis of each vehicle

a : Angular position of the leading vehicle with respect to the front of the following vehicle

dc : Distance between the 2 reflector targets, C_1 and C_2

The program will filter aside all the required values like the Cartesian coordinates in order to get the 3 required values for Car Following application.

Both applications are currently in the process of implementation.

CHAPTER IV

COMMENTS AND DISCUSSIONS

4.1 Limitations of SICK LMS

The current laser sensor used, SICK LMS, conducts a scan of up to 180° and a high angular resolution of 0.25°. It is configurable from the type of scanning field required to the type of scan data value the user wants to retrieve. However, its drawback is that the scan is only in planar form. Thus, the laser scanning zone is like a flat piece of paper cutting across the area in front. This may pose some problems like the height of obstacles or reflecting beacons must not be too short or too high. They must coincide with the line of sight of the LMS laser beam. This problem was actually encountered when tests were done on the Cycab. The securing screws on the SICK LMS that attaches the LMS to the front of Cycab are not tight enough.

This problem, along with the weight of the LMS, pulls and tilts the LMS down. Though the range of tilt is not big (less than 1 cm) at the point of attachment, this difference in height is greatly magnified at a further distance from the Cycab. This caused the inability of the laser to reach the desired target. If the tilt height difference is greater than the height of the reflector target (of the leading Cycab) in a Car Following application, the LMS will not be able to detect the reflectors and the application will fail.

Therefore, a proposed solution would be to increase the overall reflector height or to implement a more secure attachment system for the SICK LMS.

Furthermore, with scan data from a planar scan, it is only possible to plot out a 2-Dimensional (2D) plan of the specified scanning field. Though a 2D plan may prove just sufficient for Obstacle Avoidance application, the user will not be able to know the obstacle's size, shape and other features that may allow the user to have more decision making choices. For example, if a large truck is in front of the Cycab, the user may either want the Cycab to slow down and keep a longer safety distance, or take another available route. Thus, a simple 3-Dimensional (3D) plan model of the specified scanning field can provide much more data and extend the uses of the application further. Pattern comparison (e.g. compares the shape, size of obstacle) can then be incorporated and provide information like the nature of the obstacle. These shall be feedback to the Cycab, which will make decisions based on it.

4.2 Processing Time

Time is a very important factor in decision-making and it applies to the application programs of the Cycab as well. The SICK LMS does a scan within a certain time and this time depends on the scan angle and angular resolution. For example, in this project where the LMS is requested do a 180° scan with an angular resolution of 0.5°, the time taken to complete a scan is 26 ms. However, the time required increases as the angular resolution increases.

The overall objective of the Cycab is to have application programs that guide it safely and yet fast enough to satisfy the needs of people for public transport. Thus, if the response time for MPC555 to complete a task (e.g. To avoid an oncoming obstacle) is too long (> 500 ms), the vehicle may not perform as predicted to avoid the obstacle in time. In order to curb this problem of long processing time, it will be better to keep the program in MPC555 to a suitable length.

4.3 Addition of a User Menu

The current program done for the serial interface between MPC555 and SICK LMS is a simple one. As can be read from the report, the LMS has a lot of functions and each request and response corresponds to a different telegram, so it will be better if a user menu with all the different requests is included in the program. With this menu, the program will be user-friendlier and running of the application programs can also be included in the menu.

4.4 Minor Problems Encountered

During the course of work with the SICK LMS, there were often instances of insufficient power to power the LMS. In fact, the LMS is a big consumer of energy and this actually shortens the life span of the battery run time. Thus, it is suggested that the battery of the Cycab be recharged after it is being used for a fixed period of time.

For the MPC555, it has a problem of hardware reset not working. Sometimes, when a program 'hangs' midway while processing in the MPC555, doing a hardware reset of the MPC555 will not reset and clear all the buffers. Power to the MPC555 has to be cut off completely for a few minutes before the MPC555 can operate again. This problem will be reported to Robosoft for their action.

CHAPTER V
SUMMARY AND CONCLUSION

For this period of Industrial Attachment with INRIA Rhone-Alpes, the project given was very good with a clear objective and direction. Till this moment, the goal of implementing a high-speed serial interface between the MPC555 and the SICK LMS had been achieved. Although tests at the initially proposed 500 Kbauds were not carried out (due to problems with the MPC555 board provided), tests at lower baud rates were done under the direction of my supervisor. Also, the program written to implement the serial interface works well at the other lower baud rates, so there should not be much problem for real-time interfacing.

The next objective of implementing application programs (Obstacle Avoidance and Car Following) for the Cycab is currently being carried out. These applications involve programming the MPC555 and the SICK LMS to conduct and collect different scan data, thereby making use of the implemented serial interface too. These implementations of application programs will be achieved by the end of the attachment.

Due to the numerous functions that the SICK LMS can do, there were a lot of confusion and doubts over the functions of the telegrams. However, tests done while implementing the serial interface provided results that helped clear some of the doubts and they were documented in this report as well.

On the whole, this project involving both hardware and software implementation has been very fruitful. A lot of experience was gained in working with hardware interfacing and the hardware/software implementation. Due to the different nature of the hardware involved, it was necessary to have a clear basic understanding of them in a very short time. This taught me the skills of filtering out the more important theory and information whenever there is a need to work with new hardware. In addition, the importance of good and clear documentation of hardware specifications, theory and correct procedures was also appreciated. A good documentation will be very useful to fellow researchers working on follow-up projects.

Working as a junior researcher also allowed me to experience the working environment of a researcher. Everyone in the same project group contributes to the final goal of the project. For example, the Cycab is quite a big project that involves many researchers. From the mechanics and electronics of the vehicle, linear camera guiding to the serial interfacing of the SICK LMS, all these contributions are all made by different researchers with the same final aim. Therefore, teamwork is very important in research.

Finally, this report was written to be as clear and concise as possible, with the aim of serving as a guide to anyone who will be working on similar or follow-up projects.

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APPENDIX A

Telegram Number	Description
0x10	Initialisation and reset of LMS
0x20	Select/Change of LMS operating mode
0x30	Request for measured values
0x31	Request for sensor status
0x32	Request for error telegram
0x36	Request for averaged measured values
0x37	Request for partitioned measured values
0x3A	Request for LMS type
0x3B	Change of LMS variant
0x3F	Request for averaged partitioned measured values
0x40	Configuration of LMS capture fields
0x41	Change of active field group
0x45	Request for configured field
0x74	Read LMS configuration
0x76	Request for measured values in cartesian coordinates
0x77	Define LMS-2xx-xxx06 configuration

Table A1 : Telegram List for Data Exchange from Host to LMS

Telegram Number	Description
0x90	Message sent by LMS after Power On
0x91	Confirmation of software reset telegram
0x92	Not acknowledged, NACK (for invalid commands)
0xA0	Response to change of operating mode
0xB0	Response to request of measured values
0xB1	LMS sensor status
0xB2	Error message/test message
0xB6	Send averaged measured values
0xB7	Send partitioned measured values
0xBA	Information on LMS type
0xBB	Response to change of LMS variant
0xBF	Send averaged partitioned measured values
0xC0	Response to field configuration
0xC1	Change active field group
0xC5	Configuration data for programmed fields
0xF4	Current LMS configuration
0xF6	Response to request for measured values in cartesian coordinates
0xF7	Response to definition of LMS-2xx-xx06 configurartion

Table A2 : Telegram List for Data Exchange from LMS to Host

APPENDIX B

Initial Set-Up Test Program provided by Robosoft

```
/*************************************************************************************  */
/* Test.C :Test de l'ensemble TPU, PWM, etc...                                           */
/* channel number to test (0..3); the procedure will measure an average on               */
/* the channel. (Set with nMoy)                                                          */
/*-------------------------------------------------------------------------------------  */
/* Version: 1.00,   22/10/1999                                                           */
/*-------------------------------------------------------------------------------------  */

void InterruptHandlerCAN0(void)
{
}

void InterruptHandlerCAN1(void)
{
}

void InterruptHandlerSPI(void)
{
}

void InterruptHandler2(void)
{
}
void InterruptHandler6(void)
{
}

void InterruptHandler7(void)
{
}

void InterruptHandlerPIT(void)
{
/* Blink the LED as SetLED will return the previous LED state */
  SetLED(!(SetLED(0)));
}

/*-------------------------------------------------------------------------------------  */
/* Interrupt handler reserved for EXTERNAL IRQ lines                                     */
/*-------------------------------------------------------------------------------------  */

void InterruptHandlerIRQ0(void)
{
}
```

```
void InterruptHandlerIRQ1(void)
{
}

void InterruptHandlerIRQ2(void)
{
}

void InterruptHandlerIRQ3(void)
{
}

void InterruptHandlerIRQ4(void)
{
}

void InterruptHandlerIRQ5(void)
{
}

void InterruptHandlerIRQ6(void)
{
}

void InterruptHandlerIRQ7(void)
{
}

/*---------------------------------------------------------------------------------------------------------  */
/* UART Routine : To put a string of char via UART                                                           */
/*---------------------------------------------------------------------------------------------------------  */

/* Error, the combination Parity + nBit + nStop is not equal to 9 or 10 */
/* (10 and 11 bit frame with Start bit)                                 */
#define err_UARTFrame    -1
#define err_UART         -2      /* Error UART number must be 0 or 1 */
#define err_UARTNoChar -1        /* NO Char present in the buffer */

int UARTPutString(int UartNb, char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0)) {
    Result = UARTPutChar(UartNb, St[0]);
    St++;
  }
  return (Result);
}
```

```
/*----------------------------------------------------------------------------------------------------  */
/* LCD Routine : To display a string of char on LCD screen                                               */
/*----------------------------------------------------------------------------------------------------  */
int LCDPutString(char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0)) {
    Result = LCDPutChar(St[0]);
    St++;
  }
  return (Result);
}


/*----------------------------------------------------------------------------------------------------  */
/* LCD Command: see documentation of HDD44780                                                            */
/*----------------------------------------------------------------------------------------------------  */

#define lcd_Clear               0x01
#define lcd_CursorHome          0x02
#define lcd_SetAddress          0x80
#define lcd_SetAddrL1Home       0x80
#define lcd_SetAddrL2Home       0xC0
#define err_ErrorLCD            -1
/* Error returned when busy flag is ALWAYS set */

/*----------------------------------------------------------------------------------------------------  */
/* ADC channel assignment: see schematic for more detail                                                 */
/*----------------------------------------------------------------------------------------------------  */

#define adc_VAxe1               8
#define adc_VAxe2               9
#define adc_VAxe3               10
#define adc_VAxe4               11
#define adc_Temperature1        12
#define adc_Temperature2        13
#define adc_Temperature3        14
#define adc_Temperature4        15


/*----------------------------------------------------------------------------------------------------  */

#define  BufSize  16         /* Buffer Size */
#define  nMoy     64         /* Average number */

int main()
{
  char Buffer[BufSize];        /* For RX */
  char Ch;
  char St[31];
```

```
int VMoy[nMoy];
int Val, Value;
int I, J;
int chAdc;
int axis;
int EncVal;
short int pwmcmd = 0;
int direc;

ADCInit();
LCDInit();
TPU3Init();
PWMInit();
//  InitInterrupt(0x800);

UARTInit(0, 9600, 8, 1, 0, &Buffer, BufSize);
UARTPutString(0, "\n\rUART 9600 Baud, ADC Chain calibration by Robosoft SA");

LCDPutString("PoKkIaM & MpC555!");

chAdc = 0;

for (I = 0; I < nMoy; I++) {
  VMoy[I] = 0;
}
Value = 0;

I = 1;

while (1) {

  DACWrite(0, I);
  DACWrite(3, (-I & 0xFFF));
  DACWrite(1, 0x0400);
  I = I + 10;
  I = I & 0xFFF;

  ADCRead(chAdc + adc_VAxe1, &Val);

  Val = Val - 512;
  Value = Value - VMoy[nMoy - 1];

  for (J = nMoy - 1; J > 0; J--) {
    VMoy[J] = VMoy[J - 1];
  }

  VMoy[0] = Val;
  Value = Value + VMoy[0];

  Val = Value / nMoy;
```

```
    if (UARTGetChar(0, &Ch) != err_UARTNoChar) {
      if (Ch == '+')
        POTSet(chAdc, +1);
      if (Ch == '-')
        POTSet(chAdc, -1);
      UARTPutChar(0, Ch);
    }
    direc = 0x0F;
    EncRead(0, &EncVal);

    if (EncVal != 0)
      UARTPutChar(0,'X');
    if (UARTGetChar(0, &Ch) != err_UARTNoChar) {
      if (Ch == '1')
        pwmcmd++;
      if (Ch == '2')
        pwmcmd--;
      if (Ch == 'd')
        direc = ~direc;
      WritePWMIO(direc);
      UARTPutChar(0, Ch);
      PWMWrite(0, &pwmcmd);
    }
  }
  return 0;
}
```

APPENDIX C

Serial Interface Test Program

```
/******************************************************************************************  */
/*   Test_Serial.c : UART Interface Test Platform                                           */
/*   Author : Tan Pok Kiam, Moyens Robotique                                               */
/*   INRIA Rhone-Alpes                                                                      */
/*   To test send request, receive response & determine response byte position    */
/******************************************************************************************  */

#include <math.h>
#define BufSize 128

int UARTPutString(int UartNb, char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0)) {
    Result = UARTPutChar(UartNb, St[0]);
    St++;
  }
  return (Result);
}

int LCDPutString(char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0)) {
    Result = LCDPutChar(St[0]);
    St++;
  }
  return (Result);
}

int main () {
  char Buffer[BufSize];
  char c = 0;
  double d;
  int i,res;
  unsigned char init [7] = {0x02,0x00,0x01,0x00,0x10,0x00,0x00}; /* Test Request */

  UARTInit(0, 19200, 8, 1, 0, &Buffer, BufSize);
  LCDInit();
  LCDPutString("Part1 OK");       /* MPC555 UART Initialisation OK */
  for(i=0;i<10000;i++)
    d = cos(d);

  LCDInit();
  for (i=0; i<16; i++)
    {
      res = UARTPutChar (0, init [i]);
      if (res != 0)
            {
              LCDPutString("Request ERROR");
            }
    };

  LCDInit();
  LCDPutString("Part2 OK");                  /* Test Request Send Successful */
```

```
   for(i=0;i<10000;i++)
    d = cos(d);

   LCDInit();
   for (i=0; i<10; i++)
     {
       LCDPutChar('-');
       res = UARTGetWaitChar(0, &c);        /* Receive Test Response */
       if (res != 0)
             {
               LCDPutString("Receive ERROR");
             }
         LCDPutChar (c);
     }
   LCDInit();
   LCDPutString("Part 3 OK");                   /* Message Receive Successful */
   for(i=0;i<10000;i++)
   d = cos(d);
 }
```

APPENDIX D

Completed Program for Serial Interfacing MPC555 and SICK LMS

```
/*************************************************************************************** */
/*:::::::::::::::SERIAL INTERFACE BETWEEN MPC555 & SICK LMS:::::::::::::::::::*/
/*::::::::::::::::::::::::::::::::FOR REAL-TIME DATA TRANSFER:::::::::::::::::::::::::::::::::  */
/*:::::::::::::::::::::::::::::::::::::::::::Tested At 19200 Bauds::::::::::::::::::::::::::::::::::::::::::  */
/*        Filename : Serial1.c                                                          */
/*        Author  : Tan Pok Kiam, Moyens Robotique, INRIA Rhone-Alpes          */
/*        Created : 04/2001                                                             */
/*                                                                                      */
/*************************************************************************************** */

#include <math.h>
#define BufSize 500
#define Max_Length 1000

int i,res;
char msg[Max_Length];
char data[Max_Length];
unsigned char CrcL,CrcH;
unsigned char LenL,LenH;
unsigned int Len,Crc_Create_Send;

/*************************************************************************************** */
/*        UARTPutString : To send a string of char using MPC555 UART             */
/*************************************************************************************** */

int UARTPutString(int UartNb, char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0))
    {
    Result = UARTPutChar(UartNb, St[0]);
    St++;
    }
  return (Result);
}

/*************************************************************************************** */
/*        LCDPutString : To send a string of char to LCD screen of MPC555 board */
/*************************************************************************************** */

int LCDPutString(char *St)
{
  int Result = 0;
  while ((St[0] != 0) && (Result == 0))
    {
    Result = LCDPutChar(St[0]);
    St++;
    }
  return (Result);
}

/*************************************************************************************** */
/*        LCDClear : Clear LCDScreen (Modification Required)                    */
/*************************************************************************************** */
```

```
void LCDClear()
{
  char c = 0;
  while(c != 4)
    {
      UARTGetWaitChar(1,&c);
      UARTPutChar(1,c);
    }
  LCDInit();
  LCDPutString("                ");
  LCDInit();
}

/*****************************************************************************************   */
/* SICKCreateCRC : Create CRC16 CHECKSUM for response msg from LMS     */
/*****************************************************************************************   */

#define CRC16_GEN_POL 0x8005
#define MKSHORT(a,b) ((unsigned short)(a)|((unsigned short)(b)<<8))

unsigned short SICKCreateCRC(unsigned char *CommData,unsigned int uLen)
{
  unsigned short uCrc16;
  unsigned char abData[2];

  uCrc16 = 0;
  abData[0] = 0;
  while (uLen--)
    {
      abData[1] = abData[0];
      abData[0] = *CommData++;
      if(uCrc16 & 0x8000)
{
              uCrc16 == (uCrc16 & 0x7fff)<<1;
              uCrc16 ^= CRC16_GEN_POL;
            }
      else
            {
              uCrc16 <<= 1;
            }
       uCrc16 ^= MKSHORT (abData[0],abData[1]);
    }
  return(uCrc16);
}

/*****************************************************************************************   */
/*        SICK_CRC_Check : CRC checking function for responses from SICK      */
/*****************************************************************************************   */

int SICK_CRC_Check()
{
  unsigned int Crc_Create,Crc_Recvd;

  Crc_Create = SICKCreateCRC(&msg[0],(Len+4));// Create CRC for msg from STX  - Status
  Crc_Recvd = CrcL + (CrcH*256);
  if (Crc_Recvd == Crc_Create)
    {
      LCDPutString("CRC_Check Correct");
      LCDClear();
      return 0;
    }
  else
    {
      LCDPutString("CRC_Check ERROR!");
      LCDClear();
      return 1;
    }
}

/*****************************************************************************************   */
/*         SICKInit : SICK LMS Initialisation. Change to "installation mode".                  */
/*         Default Password = SICK_LMS                                                         */
/*         20H--Select/change operating mode.                                                  */
/*****************************************************************************************   */

int SICKInit()
{
  for(i=0;i<16;i++)
    {
      unsigned char init [16] = {0x02,0x01,0x0A,0x00,0x20,0x00,0x53,0x49,0x43,
                                               0x4B,0x5F,0x4C,0x4D,0x53};
      Crc_Create_Send = SICKCreateCRC(&init[0],(14));
      init[14] = (unsigned char)(Crc_Create_Send & 0xFF);
      init[15] = (unsigned char)(Crc_Create_Send >> 8);
      res=UARTPutChar(0,init[i]);
      if (res == 0)
            {
              LCDPutString("Msg Sent to SICK");
              LCDClear();
            }
      else
            {
              LCDPutString("Msg Send Error");
            }
    }
  return res;
}

/*****************************************************************************************   */
/* SICKInit2: SICK LMS Command String2. Change baud rate to 19200 Baud.      */
/*****************************************************************************************   */

int SICKInit2()
{
  for(i=0;i<8;i++)
    {
      unsigned char init2 [8] = {0x02,0x01,0x02,0x00,0x20,0x41};
      Crc_Create_Send = SICKCreateCRC(&init2[0],(6));
      init2[6] = (unsigned char)(Crc_Create_Send & 0xFF);
      init2[7] = (unsigned char)(Crc_Create_Send >> 8);
      res=UARTPutChar(0,init2[i]);
      if(res == 0)
            {
              LCDPutString("Msg Sent to SICK");
              LCDClear();
            }
      else
            {
              LCDPutString("Msg Send Error");
            }
    }
  return 0;
}

/******************************************************************************************  */
/* SICKInit3: SICK LMS Command String3. Request LMS to send all scan            */
/* continuously.                                                                          */
/******************************************************************************************  */

int SICKInit3()
{
  for(i=0;i<8;i++)
    {
      unsigned char init3 [8] = {0x02,0x01,0x02,0x00,0x20,0x24};
      Crc_Create_Send = SICKCreateCRC(&init3[0],(6));
      init3[6] = (unsigned char)(Crc_Create_Send & 0xFF);
      init3[7] = (unsigned char)(Crc_Create_Send >> 8);
      res=UARTPutChar(0,init3[i]);
      if(res == 0)
            {
              LCDPutString("Msg Sent to SICK");
              LCDClear();
            }
      else
            {
              LCDPutString("Msg Send Error");
            }
    }
  return 0;
}

/******************************************************************************************  */
/* SICKChkACK: To check the 1st byte of the response message for ACK            */
/******************************************************************************************  */

#define ACK 0x06
#define NAK 0x15

int SICKChkACK()
{
  unsigned char ack;

  ack = 0x00;
  UARTGetChar(0,&msg[0]);
  ack = msg[0];
  while ((ack != ACK) && (ack != NAK))
    {
      LCDPutString("ChkACK Err:XX");
      LCDClear();
      return 1;
    }
  if (ack == NAK)
    {
      LCDPutString("ChkACK Err:NAK");
      LCDClear();
    }
  else                              //ack == ACK
    {
      msg[0] = 0;
      return 0;
    }
}


/*****************************************************************************************  */
/*          SICKGetMsg: To get the entire response message from LMS                        */
/*****************************************************************************************  */

void SICKGetMsg()
{
  UARTGetChar(0,&msg[0]);       // STX
  UARTGetChar(0,&msg[1]);       // ADR
  UARTGetChar(0,&msg[2]);       // LENL
  UARTGetChar(0,&msg[3]);       // LENH

  LenL,LenH,Len = 0x00;
  LenL = msg[2];
  LenH = msg[3];
  Len = LenL+(LenH*256);        // Convert HEX to DEC
  for(i=0;i<Len+2;i++)          // CMD+(N x Data)+Status+CRCL+CRCH
    UARTGetChar(0,&msg[i+4]);
  CrcL = msg[Len+5];
  CrcH = msg[Len+6];
}

/*****************************************************************************************  */
/*          SICKGetData: To get the useful scan data values (361 values)                   */
/*****************************************************************************************  */

#define STX 0x02

int SICKGetData ()
{

  UARTGetChar(0,&data[0]);              // STX
  if(data[0] != STX)
    {
      LCDPutString("GetData Err:STX");
      LCDClear();
      UARTClose(0);
    }
  UARTGetChar(0,&data[1]);              // ADR
  UARTGetChar(0,&data[2]);              // LENL
  UARTGetChar(0,&data[3]);              // LENH
  if((data[2] != 0xD6) && (data[3] != 0x02))
    {
      LCDPutString("GetData Err:Len");
      LCDClear();
      UARTClose(0);
    }
  LenL,LenH,Len = 0x00;
  LenL = data[2];
  LenH = data[3];
  Len = LenL+(LenH*256);
  UARTGetChar(0,&data[4]);              // CMD
  for(i=0;i<Len-1;i++)
    UARTGetChar(0,&data[i+5]);          // data
  UARTGetChar(0,&data[Len+5]);
  UARTGetChar(0,&data[Len+6]);
  CrcL = data[Len+5];
  CrcH = data[Len+6];
}

/*****************************************************************************************  */
/*--------------------------------------------------------------------------------------------------  */
/*                                          Start of main program                                    */
/*--------------------------------------------------------------------------------------------------  */
/*****************************************************************************************  */

int main ()
{
  char Buffer[BufSize];
  int Response;

  UARTInit(1,19200,8,1,0,&Buffer,BufSize);
  /* For communication with another terminal to show certain responses */

  Response = UARTInit(0, 19200, 8, 1, 0, &Buffer, BufSize);
  if (Response == 0)
    {
      LCDInit();
      LCDPutString("UARTInit OK");
      UARTPutString(1,"\n\rHello, UART Serial Interface PERFECT!");
      UARTPutString(1,"\n\rPress Ctrl-D to continue");
      LCDClear();
      LCDPutString("Start SICKInit");
      LCDClear();
    }
  else
    {
      LCDInit();
      LCDPutString("UARTInit Error");
      UARTClose(0);
    }

  /**********        Commence SICK Initialisation and Recv Data ***************       */
  if(!SICKInit())
    {
      LCDPutString("Part1 ok");    //Trial For FALCO
      if(!SICKChkACK());
      SICKGetMsg();
      LCDPutString("Part2 ok");    //Trial For FALCO

      if(SICK_CRC_Check() == 0)            //CRC16 Check
            {
              LCDPutString("Rep1 Rcvd OK");
              LCDClear();
              if(!SICKInit2());
              if(!SICKChkACK());
              SICKGetMsg();
              if(SICK_CRC_Check() == 0)
                {
                  LCDPutString("Rep2 Rcvd OK");
                  LCDClear();
                  if(!SICKInit3());
                  if(!SICKChkACK());
                  SICKGetMsg();
                  SICK_CRC_Check();
                  if(SICK_CRC_Check() == 0)
                        {
```

```
                    LCDPutString("Rep3 Rcvd OK");
                    LCDClear();
                    SICKGetData();
                   if(SICK_CRC_Check() == 0)
                     {
                       LCDPutString("Scan Values Rcvd");
                       LCDClear();
                     }
                   else
                     {
                       LCDPutString("Val rcvd error");
                       LCDClear();
                       UARTClose(0);
                     }
                  }
             else
                  {
                    LCDPutString("Rep3 Error!");
                    LCDClear();
                    UARTClose(0);
                  }
           }
          else
           {
             LCDPutString("Rep2 Error!");
             LCDClear();
             UARTClose(0);
           }
        }
    else
        {
          LCDPutString("Rep1 Error!");
          LCDClear();
          UARTClose(0);
        }
  }
}
```

APPENDIX E

The Makefile

```
# ****************************************************************************************
# (c) ROBOSOFT (pierre@robosoft.fr)
#
# This is a Makefile used to compile programs for MPC555 targets.
# Modified : Tan Pok Kiam, Moyens Robotique, INRIA Rhone-Alpes
# ****************************************************************************************

SHELL = /bin/sh
.SUFFIXES = .s .c .o

RM = rm –f
ROBOTIQUE=/local/projets/robotique
# Specify MPC555 cross GCC compiler.
#XGCC = ppc-elf32-gcc
XGCC = ${ROBOTIQUE}/bin/linux/ppc-elf32-gcc

# Set libraries path and the list of libraries to be passed to the linker.
LIBDIR = -L${ROBOTIQUE}/MPC555/lib
#LIBDIR = -L/home/ciney/lydoire/local/lib
LIB     = -lm -lc -lnode555

# Linker options passed from compiler to linker.
LDSCRIPT = script.ld
LDFLAGS = -Wl,-T,$(LDSCRIPT),-Map,$@.map

# Hardware configurations. Target related options.
CFLAGS = -mpowerpc -mhard-float -gdwarf

# SRC (source filess) and OBJ (object files) variables
# list the files needed to generate the `main.elf' executive.
SRC = Serial1.c

TMP = $(SRC:.c=.o)
OBJ = $(TMP:.s=.o)

# Makefile commands.
all :
	make Serial1
	make download

%.o : %.c
	$(XGCC) -O2 -c $< -o $@

%.o : %.s
	$(XGCC) -O2 -c $< -o $@

Serial1 : $(OBJ) crt0.o $(LDSCRIPT)
	$(XGCC) $(LDFLAGS) $(CFLAGS) $(OBJ) -o $@ $(LIBDIR) $(LIB)

clean :
	$(RM) *.o Serial1 Serial1.map Serial1.bin *~

download :
	${ROBOTIQUE}/bin/linux/elf2sdxbin Serial1 Serial1.bin
	dwnbin testall.bin 16404
```

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