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System specification document

for

Project: Test setup for industrial joystick demonstration

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Contents

1 Project Drivers

1.1 Purpose of the Project

1.1.1 Project Effort

- This project is being developed by the request of the company IFM. This product will be used for the purpose of giving out a demonstration to the Sales department of company IFM.
- The intention is to develop the project to best of our ability aligning our goals to the specifications requested by the company IFM
- The project should showcase all the features and demonstrate the full functionality of the Industrial Joystick CR1301

1.1.2 Goals

- We want to demonstrate the complete set of features provided by the Joystick CR1301
- The set of features being demonstrated are in accordance to the requirement criterion specified by the Sales department. We must showcase all the new or differentiating functionalities provided by the Joystick, so that the Clients could recognize the extra set of functions which could be used by them in industrial applications
- This must result in increase in the number of clients looking to replace or buy a new Joystick controller, with an increasing requirement of functionality

1.2 Client, Customer and other Stakeholders

- The Clients: The company IFM and its' Sales Department head Victor Chavez is our initial Clients. The sales department will access the credibility of our product

- The Customers: The customers for the Joystick CR1301 could be Medical, Manufacturing, Electronics and Communication industries. Along with industries, the customers could also be testing engineers and students who could use the product for experimental purposes

- The Stakeholders:
  - Testers should observer that the interfacing systems used are limited by Arduino UNO and MCP2515.
  - Technical operators should be aware of Mechanical inputs of Joystick, which could be understandable from specification document.
  - Marketing experts have to have understanding of the distinguished Marketable functionalities of the developed system.
  - Business analysts should observe a rise in the demand of our product compared to previous iterations.
  - Sponsors need the product to be limited to our budget.

1.3 Users of the Project

1.3.1 Hands-On Users:

- The category of users could vary from Shop workers, Trained-System Engineers, Students, Test engineers and Emergency workers.
- The actors should make themselves aware of the buttons and keys that have programmed functionalities. They should also be wary of making the correct electrical connections between the Joystick, MCP2515 and ESP32.
- The actors should have master's level of marketing to understand the selling points of our project and make attractive to potential customers
- The actors should have technically Journeyman level knowledge in C++ programming and microcontroller technologies
- The actors should be motivated in working with the Joystick and must be above 18 years old to work with the sub-systems connected with our product

1.3.2 Priorities Assigned to Users:

- Key users: They are the customers who will determine the specific functionalities that are required to be made available for all the users. Their feedback is essential to the quality and complexity of our project
- Secondary users: They are the system engineers who can access and test the working of our project. Their feedback will help in finding the correctness of our system
- Unimportant users: They could be the unauthorized and unskilled users who interact with the product rarely

1.3.3 User Participation:

- The participation of sales department during the demonstration would provide valuable information about the marketing aspects of our project

1.3.4 Maintenance Users:

- The developers of the project and system engineers are best equipped to provide value addition to our project and make changes

2 Project Constraints

2.1 Mandated Constraints

2.1.1 Solution Constraints:

- Constraint 1:
  - Description: The project must use the ESP-32 microcontroller for system controls
  - Relational: Client will not pay for new controller /control system
  - Fit criteria: All functional requirement must be delivered along with no system response delay

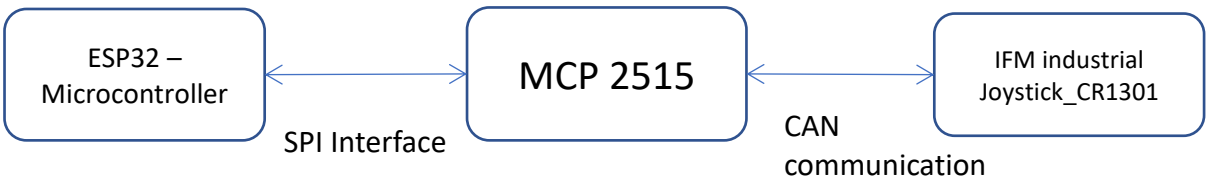
- Constraint 2:
  - Description: The project must use the MCP2515 microcontroller for system controls
  - Relational: Client will not pay for new CAN controller
  - Fit criteria: All functional requirement must be delivered along with no system response delay

- Constraint 3:
  - Description: SAE J1939 communication protocol must be used to for CAN communication
  - Relational: Client has specific requirement regarding the use of CAN communication protocol
  - Fit criteria: The logic and hard wire connections must be compatible with SAE J1939 communication protocol

- Constraint 4:
  - Description: Transmission speed of joystick keys are limited to 30 ms
  - Relational: The product to be tested has a limitation of transmission rate
  - Fit criteria: The software logic must consider the transmission rates in subsequent steps while writing the logic

2.1.2 Implementation environment of the current system:

- Block diagram illustrating the correlation between all processors and the devices:



- ESP32 Microcontroller: A controller to control the complete system, It communicates with MCP2515 according to SPI communication interface.
- MCP2515 – Control Area Network (CAN) Controller, it communicates with ES32 microcontroller via SPI communication interface and with Industrial joystick CR1301 via CAN communication protocol.
- IFM Joystick CR1301: A product for which a client want to develop a test setup under this project

2.1.3 Partner or Collaborative Applications

- Visual Studio Code: An opensource software by Microsoft which is being used in this project for the software development
- Star UML: An opensource system modeling software which is used for the system engineering diagrams (ex.: Sequence diagram, Parametric diagram and state machine diagram)
- CR1301 Simulator: It s an open source simulator which is being used to simulate the IMF joystick product during the initial development stage of the product

2.1.4 Off-the-Shelf Software and hardware:

- ESP32 – It is an opensource hardware which is being used as a microcontroller for the development of this project using opensource Arduino libraries
- MCP 2515: It is an opensource Control Area Network (CAN) controller, it is being used to create the communication interface between ESP32 and CR1301 joystick
- Node-Red: It is an opensource software which is used to check and validate the received CAN frames along with CAN communication protocol
- Logic Analyzer: It is opensource software which is used to validate the CAN communication by validating the CAN frame data (ex. CAN id, Identifier, Length and data.)
- USB CAN (V8.0): It is opensource software which is used to validate the CAN communication by validating the CAN frame send and receive data (ex. CAN id, Identifier, Length and data.)

2.1.5 Anticipated workplace environment:

- The product will be used by sales department to pitch/ sale the product to the customer
- Final product could be a hand held portable device which can be used for the customer demonstration
- Product should be provided with rigid casing to protect it against the harsh environment and damages during the handling

2.1.6 Schedule Constraints:

- The final product must be delivered within the three weeks after the product kick-off
- The sales department schedule to present demonstration to the customers is dependent on the project delivery timeline

2.2 Naming Conventions and Definitions

Definitions of All Terms, Including Acronyms, Used in the Project:

- CAN: Control Area Network
- SAE J1939: Society Of Automotive engineers, CAN communication protocol J1939
- ESP32: Microcontroller developed by Espressif Systems-32

2.3 Relevant Facts and Assumptions

2.3.1 Facts:

- CR1301 Joystick has additional features which are not being tested under the scope of this project

2.3.2 Assumptions:

- It is assumed that there will not be any changes in functional and non functional requirements of the product as considered earlier in the scope of this project
- The Joystick CR1301 must be tested in manual, reset, color change and automatic mode as mentioned in the scope of this project

2.4 Norms and related documents

- The scope of this projects includes SAE J1939 communication protocol standard for CAN communication interface between the MCP and industrial joystick
- The scope of this projects includes SPI communication interface between the MCP and ESP-32
- The scope of this project includes the norms and guidelines of SysML to derive structural, behavioural and requirement diagrams long with the initial operating conditions

3 Functional Requirements

3.1 Scope of the work

3.1.1 The current situation

The sales team of M/s IFM pvt. Ltd does not have a system which can help to demonstrate the features and functionality of the industrial joystick CR1301 to the customers. A team needs a portable system which can assist sales person to demonstrate the functionality and use cases of the joystick CR1301 industrial joystick.

3.1.2 Scope and context of the work

The scope of this project consist of the conceptual development, prototyping and proving out the functionalities of industrial joystick CR1301 to the sales team of IFM pvt. Ltd. The end product will be a portable device which can be connected to the industrial joystick CR1301 to prove all its functionalities to the end user with more interactive and realistic manner. Detailed description about the scope of work is as follow:

- Drawing project functional and non-functional requirement:

  In this phase of the project a conceptual model was developed along with the systematic documentation to understand the functional and non-functional requirements. A systematic structure of system along with subsystem was drawn to elaborate the internal and external communication sequences.
- Prototype development for validation (VP):

  In this phase of the project a prototype was made to demonstrate the functions of the industrial joystick CR1301, A prototype was developed using the open source hardware and software system which are in line with the customer requirements and constraints. A simulator was used to test all the functions of the joystick.

  In this phase of the project, all used cases of the product were tested Ex. Manual mode, Reset mode, Automatic mode and color change mode
- Proposal for improvement of the product:

  In this phase all open issues were listed and collected together to present the customer along with the possible solutions (Just a brief explanation about the possible solutions) to improve the product functionality and appearance
  Ex.: 1. A product can be made portable and easy to use for quick demonstration by developing a carrier case structure

  2. A product can be improved further by including the test cases for the tilt function of the joystick etc.

3.2 Functional and Data Requirements

3.2.1 Use-Cases

Different use cases are prepared and analyzed to understand the functional requirements and different modes of operations. Use cases elaborate all possible

operation modes along with the functional dependencies on internal and external parameters.

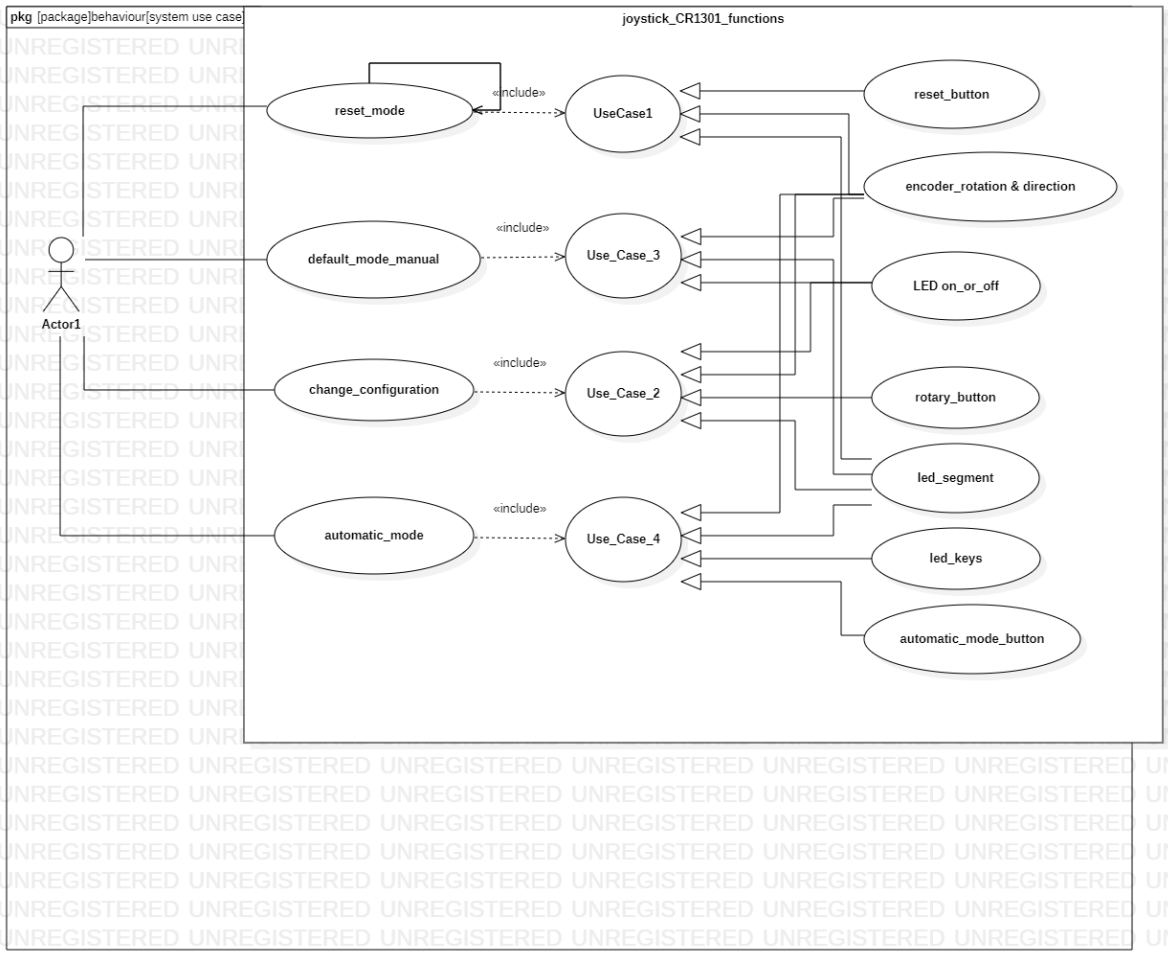


Figure 1: Use case diagram – Elaborates the different use case scenarios and the possible operating states of the system

3.2.2 Block diagram of the System

A parametric block diagram was prepared to understand the basic structure of complete system and the subsystem of the product. A relation was established to understand the constraints of different block elements and corresponding parameters. Following diagram illustrates the parametric block diagram of the product:

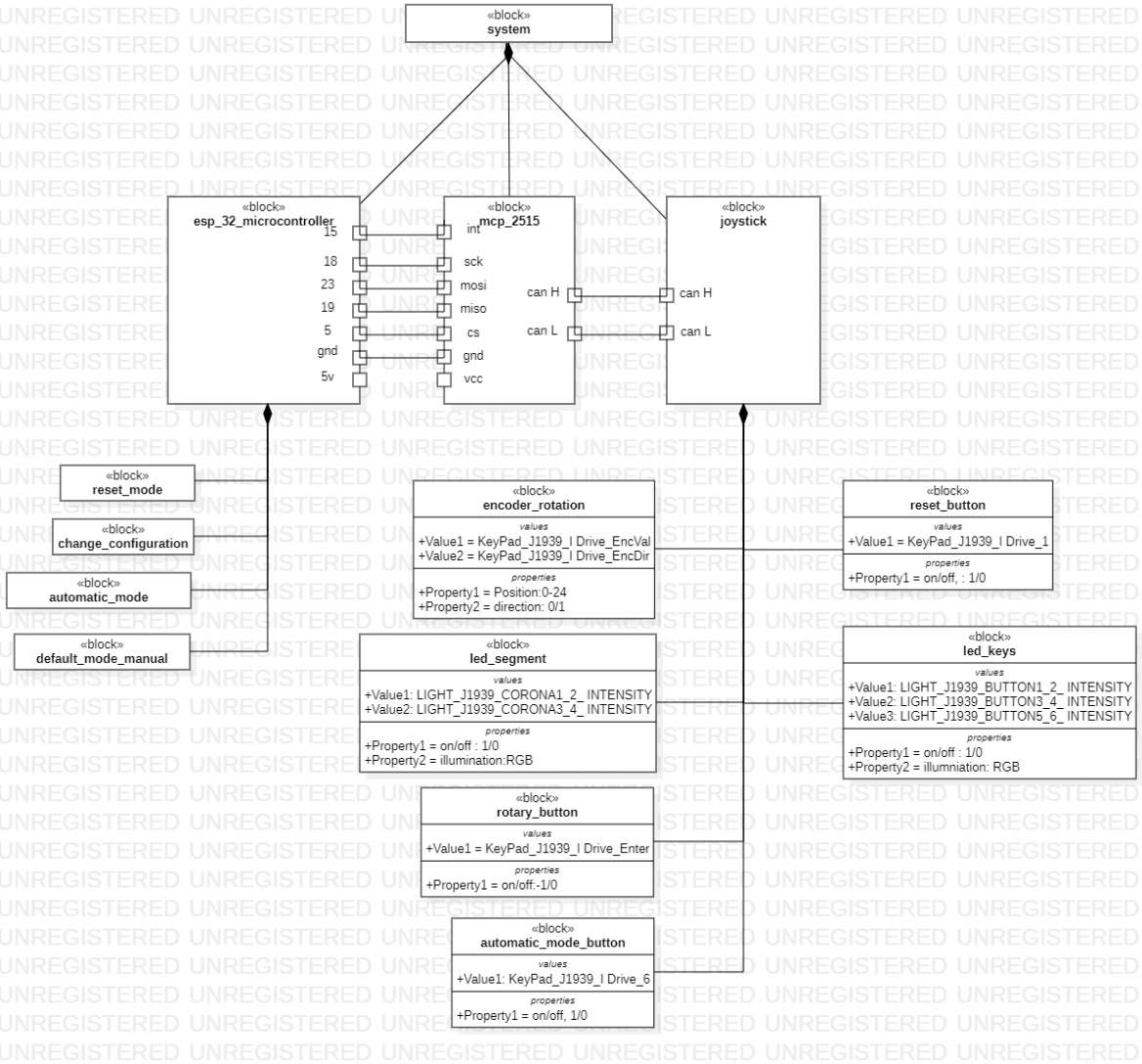


Figure 2: SysML: Block diagram – elaborates the structure of the system

3.2.3 Sequence diagram for communication

A sequence diagram was prepared to understand the basic structure of complete system and to elaborate the communication sequence between different structural components of the system in different mode of operation. Following diagram illustrates the sequence diagram of the product:

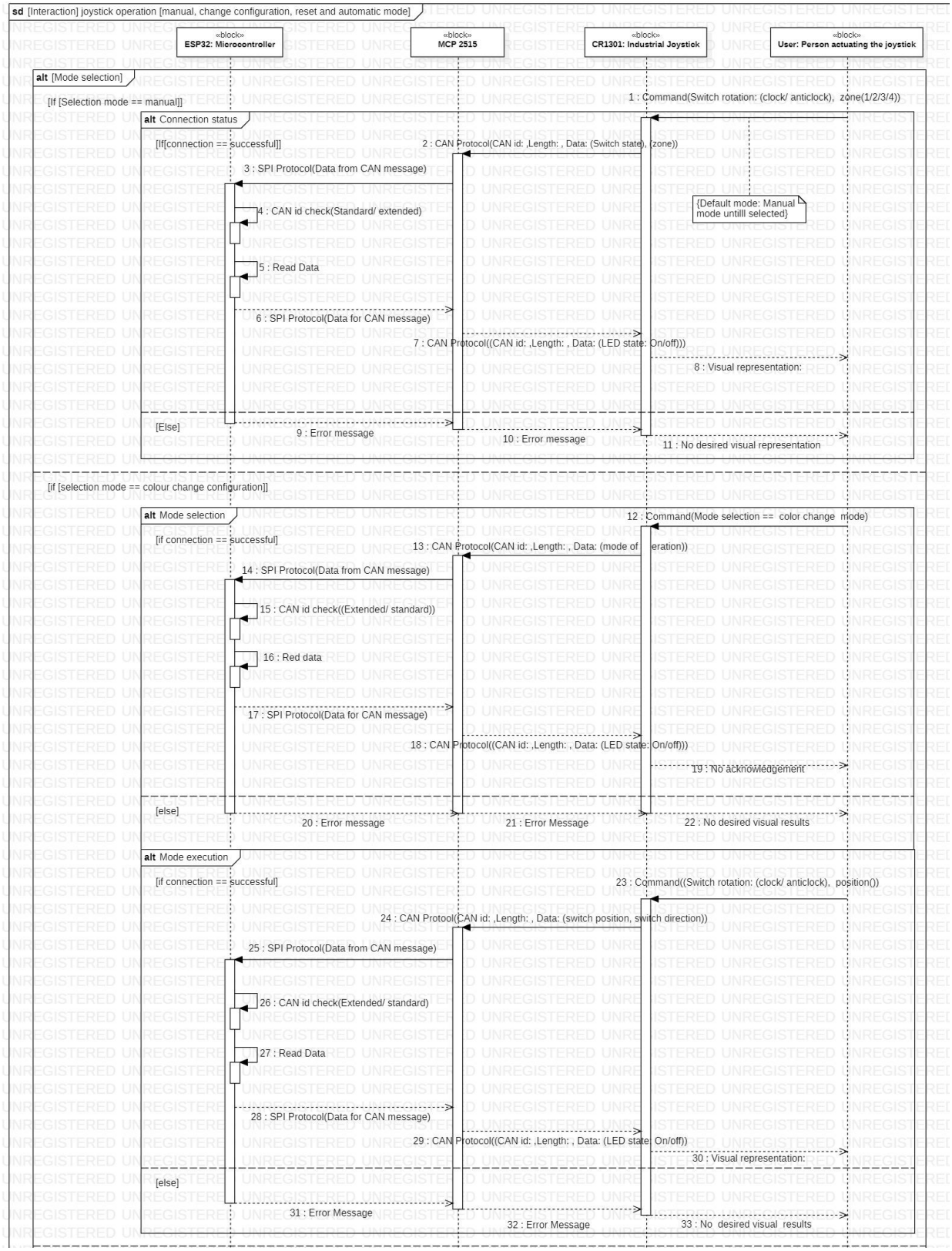


Figure 3: Sequence diagram – elaborates the communication sequence between the subsystems - Part 1/2

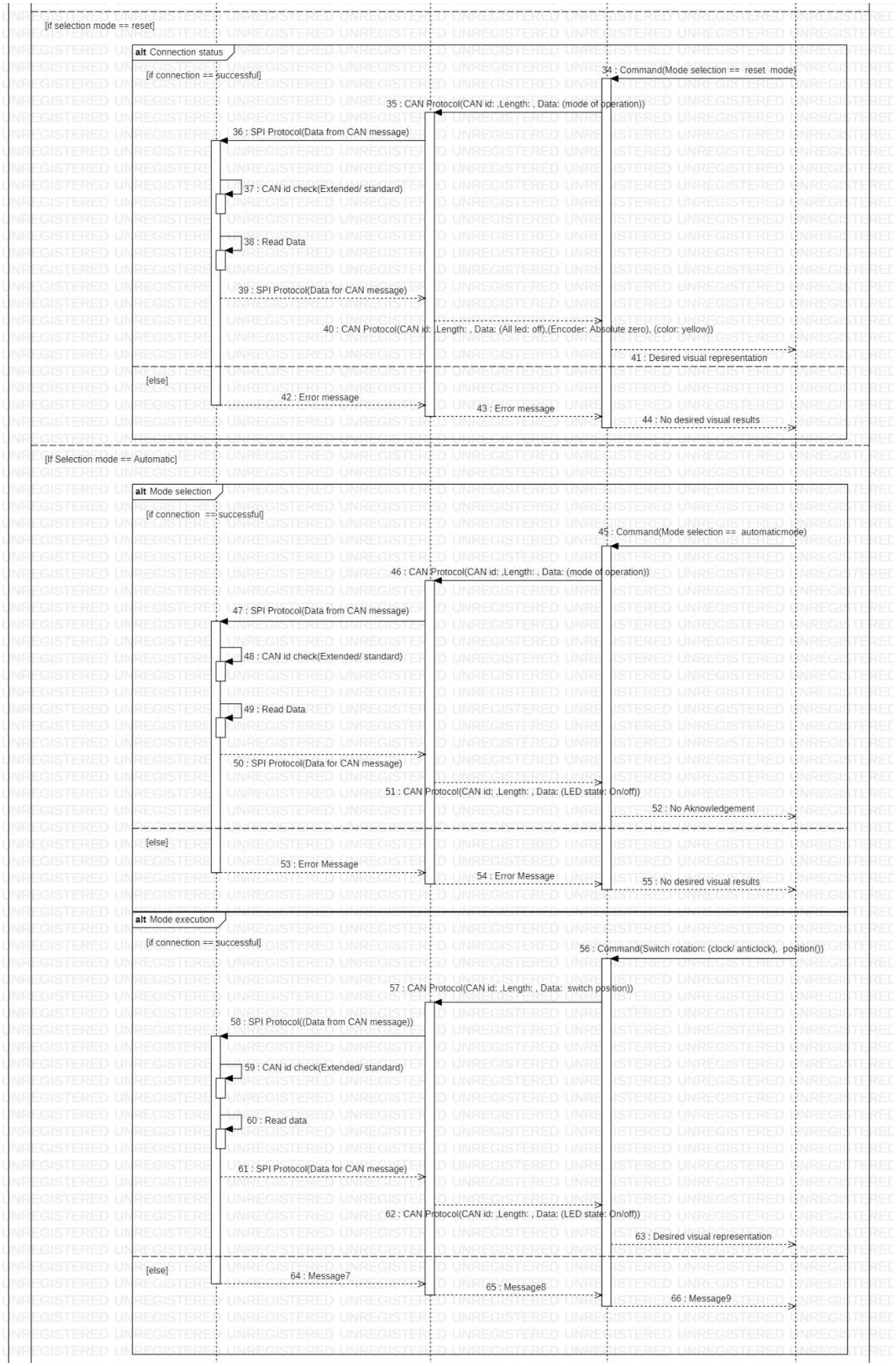


Figure 4: Sequence diagram – elaborates the communication sequence between the subsystems - Part 2/2

3.2.4 State diagram for program flows

A state machine diagram was prepared to identify and analyse the different states of the machine. Following figure illustrates the state machine diagram prepared for this project.

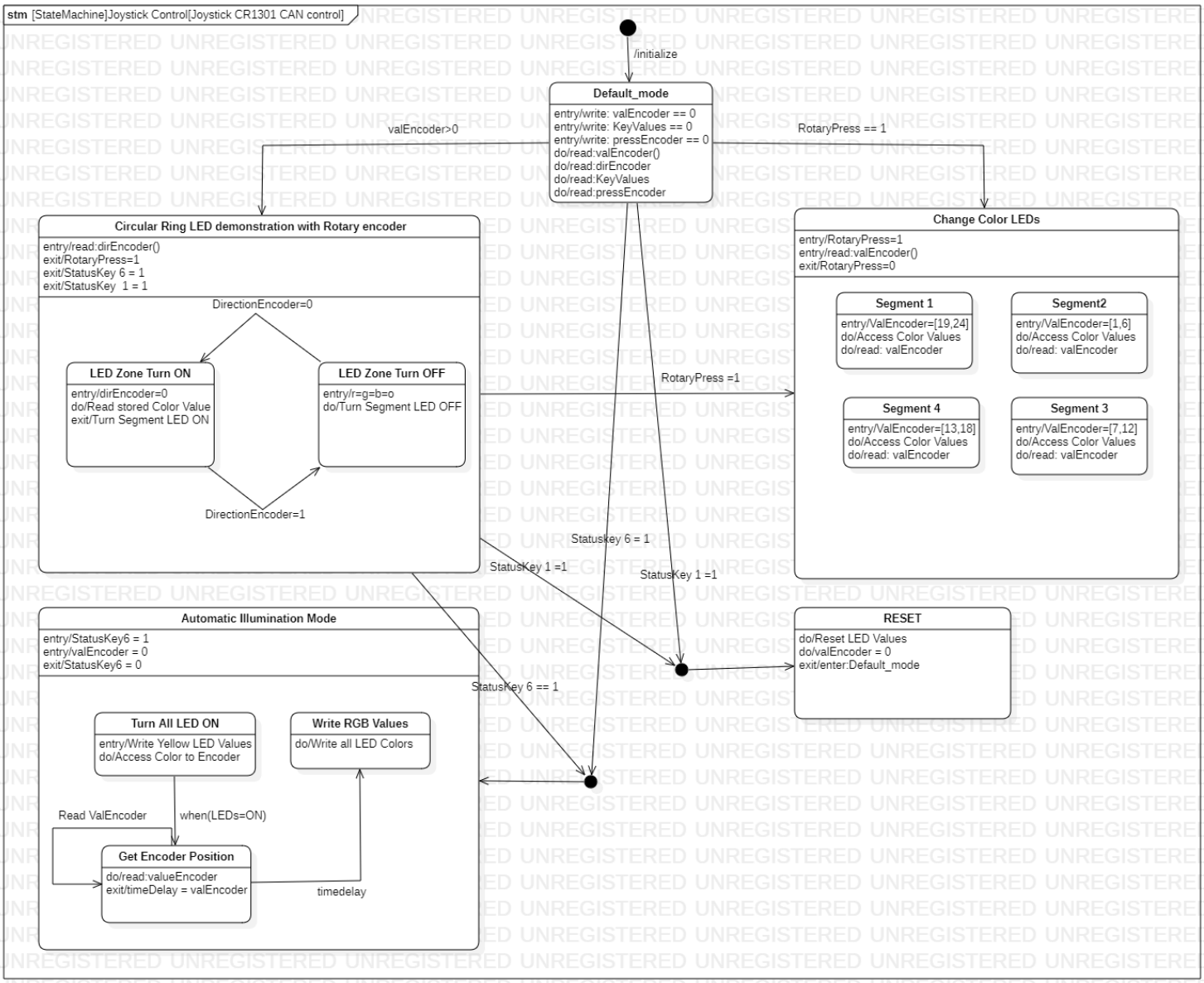


Figure 5: State machine diagram – elaborates the communication sequence between the subsystems

3.2.5 Communication protocols

The scope of this project consists of two communication protocols (CAN: SAE J1939 and SPI) to establish the successful communication between the microcontroller (ESP32), CAN controller (MCP2515) and the industrial joystick.

- **SPI communication protocol: (Serial peripheral Interface)**

  This protocol is being used for the communication between the CAN controllers MCP2515 to microcontroller ESP-32. Devices communicating via SPI are in a master-slave relationship. The master is the controlling device (usually a microcontroller), while the slave (usually a sensor, display, or memory chip) takes instruction from the master. The simplest configuration of SPI is a single master, single slave system, but one master can control more than one slave.
  Protocol requires 4 port connection between the master and slave to be established for successful communication which are described as follow:

  - MOSI (Master Output/Slave Input) – Line for the master to send data to the slave.
  - MISO (Master Input/Slave Output) – Line for the slave to send data to the master.
  - SCLK (Clock) – Line for the clock signal.
  - SS/CS (Slave Select/Chip Select) – Line for the master to select which slave to send data to.

  Cock signal (SCLK):
  The clock signal synchronizes the output of data bits from the master to the sampling of bits by the slave. One bit of data is transferred in each clock cycle, so the speed of data transfer is determined by the frequency of the clock signal. SPI communication is always initiated by the master since the master configures and generates the clock signal.

  Slave Select (C):
  The master can choose which slave it wants to talk to by setting the slave's CS/SS line to a low voltage level. In the idle, non-transmitting state, the slave select line is kept at a high voltage level. Multiple CS/SS pins may be available on the master, which allows for multiple slaves to be wired in parallel. If only one CS/SS pin is present, multiple slaves can be wired to the master by daisy-chaining.

  Data Transmission via MISO/MOSI ports:
  The master sends data to the slave bit by bit, in serial through the MOSI line. The slave receives the data sent from the master at the MOSI pin. Data sent from the master to the slave is usually sent with the most significant bit first.
  The slave can also send data back to the master through the MISO line in serial. The data sent from the slave back to the master is usually sent with the least significant bit first

- **CAN communication protocol: (Controller Area Network) – SAE J1939**

  Controller Area Network (CAN) is a serial network technology that was originally designed for the automotive industry, especially for European cars, but has also become a popular bus in

industrial automation as well as other applications. The CAN bus is primarily used in embedded systems, and as its name implies, is a network technology that provides fast communication among microcontrollers up to real-time requirements, eliminating the need for the much more expensive and complex technology of a Dual-Ported RAM.

CAN is a two-wire, half duplex, high-speed network system, that is far superior to conventional serial technologies such as RS232 in regard to functionality and reliability and yet CAN implementations are more cost effective.

J1939 is a higher-layer protocol based on Controller Area Network (CAN). It provides serial data communications between microprocessor systems (also called Electronic Control Units - ECU) in any kind of heavy-duty vehicles. The messages exchanged between these units can be data such as vehicle road speed, torque control message from the transmission to the engine, oil temperature, and many more.

Even though extremely effective in automobiles and small, embedded applications, CAN alone is not suitable for projects that require a minimum of network management and messages with more than eight data bytes.

As a consequence, higher layer protocols (additional software on top of the CAN physical layer) such as SAE J1939 for vehicles were designed to provide an improved networking technology that support messages of unlimited length and allow network management, which includes the use of node IDs (CAN supports only message IDs where one node can manage multiple message IDs).

Brief summary of the SAE J1939 communication protocol:

- Is a standard developed by the Society of Automotive Engineers (SAE)
- Defines communication for vehicle networks (trucks, buses, agricultural equipment, etc.)
- Is a Higher-Layer Protocol using CAN as the physical layer
- Uses shielded twisted pair wire
- Applies a maximum network length of 40 meters (~120 ft.)
- Applies a standard baud rate of 250 Kbit/sec
- Allows a maximum of 30 nodes (ECUs) in a network
- Allows a maximum of 253 controller applications (CA) where one ECU can manage several CAs
- Supports peer-to-peer and broadcast communication
- Supports message lengths up to 1785 bytes
- Defines a set of Parameter Group Numbers (PGNs, predefined vehicle parameters)
- Supports network management (includes node IDs and an address claiming procedure)

In the scope of this project the CAN communication is being used to established a communication between CAN Controller (MCP2515) and the industrial joystick CR1301.

4 Nonfunctional Requirements

4.1 Look and Feel

4.1.1 Style & Appearance Requirement:

- The case is made out of Polycarbonate/Acrylnitril Butadien Styrol. There is a Silicone coating of Polyamide 66 over the Joystick
- The Joystick has IP65 protection
- The Joystick should have a rugged Matte Black finish

4.1.2 Usability & Humanity Requirements:

- The project is descriptive and shall easily be usable by any person with no previous training on the said product
- The project is developed to minimize the error rate of incorrect input from the users
- The project allows users from any country and language to understand and use the product with relative ease
- An engineer will be able to use all the functionalities of the product after at least 2 hours of hands-on training with the joystick. The learning curve is small and does not require extensive training to execute the functionalities of the project
- The product is easily understandable and has only 2 button keys and 1 rotary encoder with functionalities

4.2 Performance

- Speed and latency requirements: The speed of data transfer between the Joystick and controller is limited by the CAN baud rate of 250 kBaud. The response of the keys is cyclically every 30 ms. The CAN controller MCP2515 has system frequency of 8 MHz

- Safety-Critical requirements:
  - The product is certified of fatigue resistance by the ISO 16750-3 standard
  - It has also passed the EN 60068-2-52 Salt mist spray test
  - It has passed the ISO 16750-3 Review VII of vibration test
  - It has UN/ECE-R10 Emission and immunity certification to electromagnetic radiation

- Precision & Accuracy requirements: The project has very high precision and accuracy standard as the output of the LED are displayed within <30ms

- Reliability & Availability requirements: The product will be available to run for 24 hours per day, 365 days per year. It has been designed to be used continuously without any point of failure.

- Robustness requirements: The project is designed to be able to reset by press of a key to recover from any faults or abnormal happenings.

- Capacity requirements: The project has been designed to be used by one person at any point of time. Number of sub-systems attached to the product could be increased depending upon the field of application.

- Scalability requirements: The number of users of the product can be expected to increase to 50,000 customers in one year.

- Longevity requirements: The expected lifetime of our back-end software is expected to last for minimum of 5 years and maximum lifetime can be further increased subject to development and changes.

4.3 Operational and Environmental

- Expected physical environment: The product shall be used in temperatures between -40-to-85-degree Celsius and up to 90% humidity conditions. It can functional normally till 4000m above sea level

- Interfacing requirements with adjacent systems:
  - All CAN messages for the illumination have a data length of 8 bytes and a value range of 0...255
  - The physical connection has 2 wire CAN High/Low communication
  - The frequency of data transfer is 1 Megabit per second
  - The volume of data transfer is 250 kilo Baud rate

- Production requirements: The product shall be distributed in package of dimensions 140*90*75 mm. The packaging should have air-filled cushioning to protect from any impact damage

- Release requirements: The new releases will be offered every 5 years. The product will always be backwards compatible. The product shall always maintain the list of features from previous releases

4.4 Maintainability and Support

4.4.1 Maintenance requirements:

- Product can be maintained easily. As the work is mostly done on open-source technology, so it is economical as well as easy to maintain the product and its associated documents
- Product does not as well require more maintenance, unless there are some changes done in the program

4.4.2 Supportability requirement:

- Product can be supported through the entire life cycle. Few standard conditions are applicable, which can be reads above
- To add new features to the product, support can be provided and product can be given more features at the later stage, with the discussions

4.5 Legal

- The embedded software is highly configurable and provides a variety of interfaces. Therefore, it is possible that certain configurations and deployment scenarios that are planned, foreseen and/or determined by customer may not comply with applicable laws, statues, regulations, and standards, including but not limited to motor vehicle emission, IT security and data protection. It is customer responsibility to configure and use the embedded system in such a way that it is applicable to the legal requirements

5 Project Issues

5.1 Open Issues

- Time delay for changing LED color in automatic mode:
  The time delay for changing LED color in automatic mode is not defined, it is left on developer interpretation.
- Tilt (Left- right) functionality is not defined.
  Both in manual and automatic mode the function of tilt is not defined.
- Remaining Keys functionality not defined.
  There are 6 keys and only 2 are used in program development, therefore 4 keys are left for user interpretation
- End testing of the program using the micro-controller.
  The micro-controller used at user end is not clear. The system is developed for Arduino based micro-controller

➔ Further Motivation and considerations:

• Here ESP 32 and RS2515 are used, there are no promises if it will be used with the the other micro-controllers such as Raspberry Pi, Jetson Nano or with a PLC.

• The time- delay is not specified properly so that is developer based and hence might vary with the user expectations.

• The purpose of the tilt in the joystick and the few keys have not been mentioned by the user, so there are no special conditions provided to it and hence that can be added later.

5.2 Off-the-Shelf solutions

5.2.1 Ready-made Products:

- There are the few software solution companies which provide platform to test the joystick. Hence those can be used as alternative.
- Some of the companies include:
- https://gamepad-tester.com/
- https://www.infineon.com/cms/en/product/microcontroller/

5.2.2 Reusable components:

Libraries Used	Hardware Used
Arduino library	MCP 25215
J1939 library	ESP-32
MCP-CAN communication library	CAN analyzer
SPI communication library	Logic Analyzer
	Jumper cable
	J1939 cable

5.2.3 Products that can be copied:

- As mentioned above there are few companies providing solution, but they are not specific to the requirements. So the joystick can be tested for basic functionalities but particular software has to be developed. Hence no solutions.
- Hardware is easily available and can be bought as stock products but it is suggested to buy the products specified in the document.

5.3 Risks

- Different function linked with different keys:
  Different key value assigned for different functions (such as Manual mode or automatic mode) might cause few uncertainties

- LED color may vary:
  Different colors for different sectors are assigned by the user but it might vary based on base code. But that can be improved

- Client requirement not met:
  There might be differences in user expectation and developer interpretation, which can be later solved during discussion stages

5.4 User Documentation and Training

5.4.1 User documentation:

Document name	Purpose	People seeing this	Maintenance
Use case diagram	To show different modes and cases demanded by the customer.	user, stakeholders	product maintenance team or product managing team
Parametric diagram	Different values, properties of the parameters in the product and its association with other devices	user, stakeholders	product maintenance team or product managing team
Sequential diagram	to show the sequence of different operations, associations and time taken for the action to complete	user, stake-holders	product maintenance team or product managing team
State machine diagram	to show different stages/features of product which will be triggered with respect to the customer demands and requirements	user, stake-holders	product maintenance team or product managing team

5.4.2 User training:

- Training initially will be given by the developer to the sales department and product management team. The process is fairly easy.
- Later project management team can pass on the training to others.
- The change request and change of the parameters concerning the functionalities and codes should be discussed and can also be allowed to make changes only after discussions.

6 References

- For Sys ML diagrams and documentation:
  - SysML Distilled A Brief Guide - Lenny Delligatti.pdf
  - volere-template.pdf
  - 2022 Project Requirements Documentation.pdf
  - NASA Systems Engineering Handbook
- For communication protocol:
  - A Comprehensible Guide to SAE J1939` (copperhilltech.com)
  - https://www.circuitbasics.com/basics-of-the-spi-communication-protocol
- Technical specification of joystick:
  - 80296590UK.pdf (ifm.com)