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I also take this opportunity to thank our Department of Robotics and Automation for encouraging and strengthening me at all possible means. I will be ungrateful if I fail to thank our faculty guide **Mr. M. Vasanthakumar**, Assistant Professor (Sr. Gr) in helping me at all situations.

I also thank my parents for their continuous support in encouraging in doing the project. Above all, I thank the almighty for the blessings showered on me to complete the project successfully.

SYNOPSIS

The goal of this project is to compute odometry of vehicle using low-level controls combined with inertial measurement unit. The Low-Level control includes design of Drive-by-Wire mechanisms for steering, brake and accelerator systems with appropriate embedded module.

Experimentation with encoders and DC motors of steering and brake has been carried out first with various embedded modules to choose best suitable module. The experimentation has led to choosing BeagleBone Black (BBB). A low-cost, open-source community-supported development platform for real-time analysis provided by the TI Sitara AM3358 ARM Cortex-A8 processor with Linux-based operating system. Using BBB dedicated hardware module for high CPR (Counts per Revolution) encoders, the vehicle position is evaluated. Using BBB serial cape it is interfaced to Roboteq motor controller (used for steering and brake motor) and steering encoder for steering wheel position control. The major task of the project is the evaluation of odometry data acquired from vehicle rear wheel encoders combined with inertial measurement unit.

The project is carried out on a dune buggy; petrol powered motor vehicle with Ackermann drive platform type and mobility. Initially, Drive-by-wire mechanism for steering, brake and accelerator is designed. Autonomous steering control of vehicle is carried out with feedback from steering motor encoder and steering hand wheel encoder connected to axle of steering system. Using IMU (Inertial Measurement Unit) yaw angle and rear wheel axle encoder position value, the odometry of vehicle are computed. Combined with inertial measurement units, they have proven to be a precise and low-cost sensor for vehicle odometry evaluation. The project was proposed by and carried out in AURO ROBOTICS PVT LTD, IIT Kharagpur.

CHAPTER 1

INTRODUCTION

This chapter discusses about the problem definition, study on various papers that relate to the problem, methodologies to solve the problem and the organization of the report.

1.1 BACKGROUND

Auro Robotics Private Limited is a start-up spun-off from **IIT Kharagpur Robotics Research Lab**, has researched and developed the Autonomous Driving Software over four years at IIT Kharagpur and CMU Robotics Institute, and is testing it on a prototype vehicle. Auro Robotics offered an opportunity to do a project on implementation of low-level control in the dune buggy prototype vehicle.

1.2 PROBLEM DEFINITION

The Low-Level control includes design of Drive-by-Wire mechanisms for steering, brake and accelerator and control of low-level systems with appropriate embedded module. The goal of this project is to compute odometry of vehicle using low-level controls combined with inertial measurement unit and integration of x-by wire mechanism.

1.3 LITERATURE SURVEY

A literature survey was conducted on the available systems and methodologies for implementation of Low-Level control in Autonomous Ground Vehicle

Sensor Fusion for Precise Autonomous Vehicle Navigation in Outdoor Semi-structured Environments, *L. Conde Bento, Urbano Nunes; Fernando Moita and Antonio Surreci.* [6]

This paper presents a guidance system for autonomous vehicles navigation in semi-structured outdoor environments. It integrates redundant encoder's data and absolute positioning data provided by landmarks and artificial beacons. Natural features are localized using a laser range sensor, and magnetic sensing rulers were developed to detect magnetic markers buried in the ground. In the first fusion stage,data from four wheel encoders and one steering encoder are fused by means of an EKF, providing robust odometric information, namely in face of undesirable effects of wheels slippage. Next, a second fusion stage is processed for integrating odometric and absolute positioning data. Simulation and real experiments using a four-wheel actuated electrical vehicle are presented.

Visual Odometry : Autonomous UAV Navigation using Optic Flow and Stereo - *Reuben Strydom, Saul Thurrowgood, Mandyam V. Srinivasan.* [7]

Visual odometry is vital to the future of mobile robotics. In this paper, we demonstrate a method that combines information from optic flow and stereo to estimate and control the current position of a quad rotor along a pre-defined trajectory. The absolute translation in 3D is computed by combining the optic flow measurements between successive frames and stereo-based height over ground. The current 3D position, as estimated from path integration of the incremental translations, is controlled in closed loop to follow the prescribed trajectory. The performance of the system is evaluated by measuring the error between the initial and final positions in closed circuits. This error is approximately 1.7% of the total path length.

Autonomous Vehicle-Target Assignment: A Game-Theoretical Formulation – *Gurdal Arslan, Jason R. Marden, Jeff S. Shamma*[8]

We consider an autonomous vehicle-target assignment problem where a group of vehicles are expected to optimally assign themselves to a set of targets. We introduce a game theoretical formulation of the problem in which the vehicles are viewed as self-interested decision makers. Thus, we seek the optimization of a global utility function through autonomous vehicles that are capable of making individually rational decisions to optimize their own utility functions. The first important aspect of the problem is to choose the utility functions of the vehicles in such a way that the objectives of the vehicles are localized to each vehicle yet aligned with a global utility function. The second important aspect of the problem is to equip the vehicles with an appropriate negotiation mechanism by which each vehicle pursues the optimization of its own utility function. We present several design procedures and accompanying caveats for vehicle utility design. We present two new negotiation mechanisms, namely, “generalized regret monitoring with fading memory and inertia” and “selective spatial adaptive play,” and provide accompanying proofs of their convergence. Finally, we present simulations that illustrate how vehicle negotiations can consistently lead to near-optimal assignments provided that the utilities of the vehicles are designed appropriately

Autonomous Vehicle Implementation Predictions Implications for Transport Planning - *Todd Litman Victoria Transport Policy Institute*[9]

This report explores the impacts that autonomous (also called self-driving, driverless or robotic) vehicles are likely to have on travel demands and transportation planning. It discusses autonomous vehicle benefits and costs, predicts their likely development and implementation based on experience with previous vehicle technologies, and explores how they will affect planning decisions such as optimal road, parking and public transit supply. The analysis indicates that some benefits, such as independent mobility for affluent non-drivers, may begin in the 2020s or 2030s, but most impacts, including reduced traffic and parking congestion (and therefore road and parking facility supply requirements), independent mobility for low-income people (and therefore reduced need to subsidize transit), increased safety, energy conservation and pollution reductions, will only be significant when autonomous vehicles become common and affordable, probably in the 2040s to 2060s, and some benefits may require prohibiting human-driven vehicles on certain roadways, which could take longer.

Sharing the Road: Autonomous Vehicles Meet Human Drivers - *Kurt Dresner Peter Stone* [10]

In modern urban settings, automobile traffic and collisions lead to endless frustration as well as significant loss of life, property, and productivity. Recent advances in artificial intelligence suggest that autonomous vehicle navigation may soon be a reality. In previous work, we have demonstrated that a reservation-based approach can efficiently and safely govern interactions of multiple autonomous vehicles at intersections. Such an approach alleviates many traditional problems associated with intersections, in terms of both safety and efficiency. However, the system relies on all vehicles being equipped with the requisite technology — a restriction that would make implementing such a system in the real world extremely difficult. In this paper, we extend this system to allow for incremental deployability. The modified system is able to accommodate traditional human-operated vehicles using existing infrastructure. Furthermore, we show that as the number of autonomous vehicles on the road increases, traffic delays decrease monotonically toward the levels exhibited in our previous work. Finally, we develop a method for switching between various human-usable configurations while the system is running, in order to facilitate an even smoother transition. The work is fully implemented and tested in our custom simulator, and we present detailed experimental results attesting to its effectiveness.

Autonomous Driving in Urban Environments: Boss and the Urban Challenge - *Carnegie Mellon University, General Motors Research and Development, Continental AG, Intel Research*[11]

Boss is an autonomous vehicle that uses on-board sensors (global positioning system, lasers, radars, and cameras) to track other vehicles, detect static obstacles, and localize itself relative to a road model. A three-layer planning system combines mission, behavioral, and motion planning to drive in urban environments. The mission planning layer considers which street to take to achieve a mission goal. The behavioral layer determines when to change lanes and precedence at intersections and performs error recovery maneuvers. The motion planning layer selects actions to avoid obstacles while making progress toward local goals. The system was developed from the ground up to address the requirements of the DARPA Urban Challenge using a spiral system development process with a heavy emphasis on regular, regressive system testing. During the National Qualification Event and the 85-km Urban Challenge Final Event, Boss demonstrated some of its capabilities, qualifying first and winning the challenge. C 2008 Wiley Periodicals, Inc.

Optimal Driveline Robot Base - *Michael Cullen (ME), Stephen Diamond (RBE/ECE), William Dunn (RBE), Kirk Grimsley (RBE)* [12]

Our team has decided that there is currently a need for a driveline system that is capable of performing a zero radius turn and being maneuverable at low speeds while also maintaining traction, stability, and energy efficiency at high speeds. We designed and prototyped a modified Ackermann steering system driven by a single motor, with an extended range of motion. This driveline system will also incorporate all wheels driven in all conditions. The steering system was integrated into a robot chassis that meets FIRST Robotics Competition requirements.

Real-Time Stereo Visual Odometry for Autonomous Ground Vehicles, *Adrew Howard.* [13]

This paper describes a visual odometry algorithm for estimating frame-to-frame camera motion from successive stereo image pairs. The algorithm differs from most visual odometry algorithms in two key respects: (1) it makes no prior assumptions about camera motion, and (2) it operates on dense disparity images computed by a separate stereo algorithm. This algorithm has been tested on many platforms, including wheeled and legged vehicles, and has proven to be fast, accurate and robust. For example, after 4000 frames and 400m of travel, position errors are typically less than 1m (0.25% of distance traveled). Processing time is approximately 20ms on a 512x384 image. This paper includes a detailed description of the algorithm and experimental evaluation on a variety of platforms and terrain types.

1.4 PATENTS SEARCH

Autonomous ground vehicle control system for high-speed and safe operation - *Southwest Research Institute*[14]
Patent no: US8180513

The present disclosure relates to a reference yaw rate generator for an autonomous ground vehicle control system. The reference yaw rate generator is configured to generate a reference yaw rate (rr) based on an actual latitudinal position (Y), a desired latitudinal position (Yd), an actual longitudinal position (X), a desired longitudinal position (Xd) and an actual heading (ψ) of the autonomous ground vehicle.

Position estimation for ground vehicle navigation based on landmark identification/yaw rate and perception of landmarks - *Bapiraju Surampudi, Joe Steiber*[15]
Patent no: US8301374

A landmark-based method of estimating the position of an AGV (autonomous ground vehicle) or conventional vehicle, which has an onboard database of landmarks and their location, coordinates. During travel, the AGV looks for and identifies landmarks. It navigates according to position estimations that are based on measured yaw rate and speed. When a landmark is encountered and recognized, its true location coordinates are looked up from the database. These true coordinates are then used to enhance position estimation accuracy between landmarks.

Vision system for an autonomous vehicle – *Brian P*, *Steven Edward*[16]
Patent no: US8139109 B2

A system includes a vehicle management system, and at least a first, a second, and a third video camera in communication with the vehicle management system. The vehicle management system is configured to receive input from a combination of at least two cameras selected from among the first, second, and third video cameras based on an event associated with a vehicle to provide at least a first, a second, and a third visual depth of field.

Autonomous vehicle maintenance and repair system – *Steward shen* [17]

Patent no: US8190322 B2

A system and method for providing autonomous and remote vehicle maintenance and repair. The system employs an on-board diagnosis and prognosis module that monitors one or more vehicle buses to identify trouble codes and other information indicating a vehicle problem. The on-board module causes a telematic device on the vehicle to broadcast a message including a problem code that identifies the problem the vehicle is having. A remote repair center may receive the message and may identify a software upgrade patch associated with the problem that can be transmitted to the vehicle to upgrade its software to correct the problem. Also, the message may be received by another vehicle that is part of a broadcast network that has previously received the software upgrade patch to fix a problem on that vehicle, where the receiving vehicle may transmit the software upgrade patch to the vehicle having the problem.

Autonomous vehicle using fuzzy control – *Bobin helder*[18]

Patent no: US5101351 A

An autonomous vehicle controls the steering of the vehicle on a road by fuzzy control. A camera forms an image of the road, and an image processor processes the image to calculate the deviation dx between a plurality of reference points on a road and the direction in which the vehicle is traveling. Each reference point is associated with a visual point on the road ahead of the vehicle. The product of the deviation dx for each visual point and a membership function μ indicating the degree of importance attached to the visual point is calculated, and a total deviation equal to the sum of the products is calculated. The steering of the vehicle is controlled on the basis of the total deviation. The membership functions μ are varied in accordance with the time rate of change of the deviations dx.

Autonomous vehicle and method for coordinating the paths of multiple autonomous vehicles[19]
Patent no: US 20140081505 A1

A non-transitory processor-readable medium storing code causes a processor at a first vehicle (e.g., a first autonomous vehicle) to generate a first planned path based on a current position of the first vehicle and a mission requirement assigned to the first vehicle. A first planned path associated with a second vehicle (e.g., a second autonomous vehicle), which is based on a current position of the second vehicle and a mission requirement assigned to the second vehicle, is received at the first vehicle. After the first planned path associated with the second vehicle is received, a second planned path is generated based on the first planned path associated with the second vehicle and at least one of the mission requirement assigned to the first vehicle or the first planned path of the first vehicle. The second planned path of the first vehicle is transmitted to the second vehicle.

Modeling of Autonomous Vehicle Operation in Intelligent Transportation Systems - *Mark Woodard, Sahra Sedigh*[20]
Patent no: US 28441085810 B1

The past decade has seen autonomous vehicles become the subject of considerable research and development activity. The majority of these advances have focused on individual vehicles, rather than the interactions that result when autonomous (unmanned) and conventional (manned) vehicles come together in an intelligent transportation system. The robustness of autonomous vehicles to contingencies caused by unpredictable human behavior is a critical safety concern. Assuring the reliability, availability, security, and similar non-functional attributes of autonomous vehicles is just as critical.

The doctoral research proposed in this paper centers on developing models capable of accurately representing environments where manned and unmanned vehicles coexist. An established macroscopic transportation model serves as the basis for the proposed work, and will be extended to differentiate between manned and autonomous vehicles. Stochastic methods will be applied to reflect the non-determinism of the operating environment, especially as related to driver behavior, and will facilitate analysis of robustness. The goal is to capture both basic operation of autonomous vehicles, as well as advanced capabilities such as platooning and robotic adaptation. The insights gained from these models are expected to facilitate the design of intelligent transportation systems that are both safe and efficient

Multi-purpose autonomous vehicle with path plotting - Louis S. McTamaney[21]
Patent no: US 5170352 A

An autonomous vehicle for operating in a predetermined work area while avoiding both fixed and moving obstacles. A plurality of laser, sonic and optical sensors detect targets and obstacles in the work area and provide coded signals to processors and controllers which direct the vehicle over a most expedient route to a target while avoiding any obstacles. The vehicle is especially useful in moving around the deck of an aircraft carrier to deliver ammunition to aircraft from an ammunition magazine.

Autonomous vehicle for working on a surface and method of controlling same - *Jr. Pong, Joseph F. Engelberger, John M. Evans, Jr., William S. Kazman*[22]
Patent no: US 4962453 A

A means and method for control of an autonomous vehicle while working on a surface, specifically for operation of an automatic floor cleaning machine using power derived from line power through a wall plug and cord. The vehicle uses information derived from contact between bumpers and objects in the environment to sense the geometry of its environment and utilizes a recursively applied algorithm to systematically and efficiently cover the floor area.

Autonomous vehicle with an easily set work area and easily switched mode - Nobukazu Kawagoe[23]
Patent no: US 5066014 B2

An autonomous vehicle for operating in a predetermined work area while avoiding both fixed and moving obstacles. A plurality of laser, sonic and optical sensors detect targets and obstacles in the work area and provide coded signals to processors and controllers which direct the vehicle over a most expedient route to a target while avoiding any obstacles. The vehicle is especially useful in moving around the deck of an aircraft carrier to deliver ammunition to aircraft from an ammunition magazine.

1.5 Organization of the Report

- Chapter 1 deals about the basic outline of the project (overview) and study of various published papers which were related to our current methodologies
- Chapter 2 explains various concepts that is to be dealt with the current scenario are explained for the better understanding.
- Chapter 3 describes the software architecture of the project is formulated and the required theoretical and practical concepts are explained
- Chapter 4 describes the chapter deals interfacing BeagleBone Black with low-level controls with procedures, and configuration steps.
- Chapter 5 describes the chapter deals with development of power supply board for encoders and motors with detailed specifications of various modules
- Chapter 6 describes the chapter provides a detailed discussion on implementation and validation of odometry of autonomous vehicle
- Chapter 7 describes the chapter provides information on combining IMU for evaluation of odometry and its test results

CHAPTER 2

VEHICLE ARCHITECTURE

This chapter details about the vehicle architecture that is used in the project implementation and details about the steering and drive mechanisms

2.1 DUNE BUGGY VEHICLE

The dune buggy vehicle is petrol powered motor vehicle with Ackermann drive platform type and mobility. The vehicle has two DC motors each for steering and brake. It is auto clutch system with forward and reverse system. A servomotor is connected to throttle for speed control. Two encoders are connected to rear wheel axle for position estimation. Battery and UPS are also provided for powering electronic circuit boards and processors. The Fig. 2.1 is the illustration of the vehicle with sensors and processors positioned at appropriate places.

Fig. 2.1 Autonomous vehicle

2.2 ACKERMANN DRIVE MECHANISM

Ackermann steering geometry is an arrangement of linkages in the steering of a designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radius. The intention of Ackermann geometry is to avoid the need for tires to slip sideways when following the path around a curve. The geometrical solution to this is for all wheels to have their axles arranged as radii of a circle with a common center point. As the rear wheels are fixed, this center point must be on a line extended from the rear axle. Intersecting the axes of the front wheels on this line as well requires that the inside front wheel is turned, when steering, through a greater angle than the outside wheel. The Fig. 2.2 shows the Ackermann geometry and approximation of the system

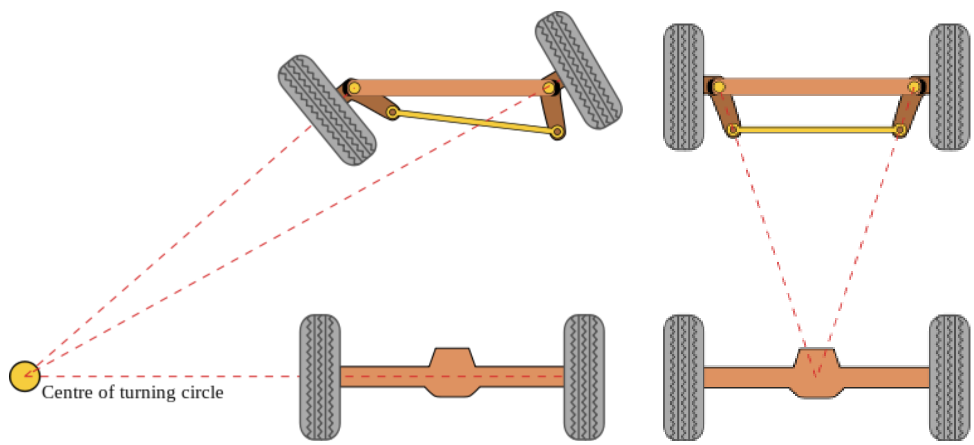

Fig. 2.2 Ackermann geometry

Rather than the preceding "turntable" steering, where both front wheels turned around a common pivot, each wheel gained its own pivot, close to its own hub. While in complex system, this arrangement enhances controllability by avoiding large inputs from road surface variations being applied to the end of a long lever arm, as well as greatly reducing the fore-and-aft travel of the steered wheels. A linkage between these hubs pivots the two wheels together, and by careful arrangement of the linkage dimensions the Ackermann geometry could be approximated. This was achieved by making the linkage not a simple parallelogram, but by making the length of the track rod (the moving link between the hubs) shorter than that of the axle, so that the steering arms of the hubs appeared to "toe out". As the steering moved, the wheels turned according to Ackermann, with the inner wheel turning further. If the track rod is placed ahead of the axle, it should instead be longer in comparison, thus preserving this same "toe out".

2.3 ACKERMANN ANGLED STEERING ARMS

The steering arms in the Fig. 2.3 is angled inwards to create a means for the wheel angles to change at a different rate. This is the basis of the Ackerman Steering Principle and creates this unequal angular movement of the wheels. This unequal angular movement occurs because of the relative position of the steering arm pivot point (A) around how the steering arm pivot point moves around the king pin pivot point (B). The Fig. 2.3 shows the Ackermann angled steering arms.

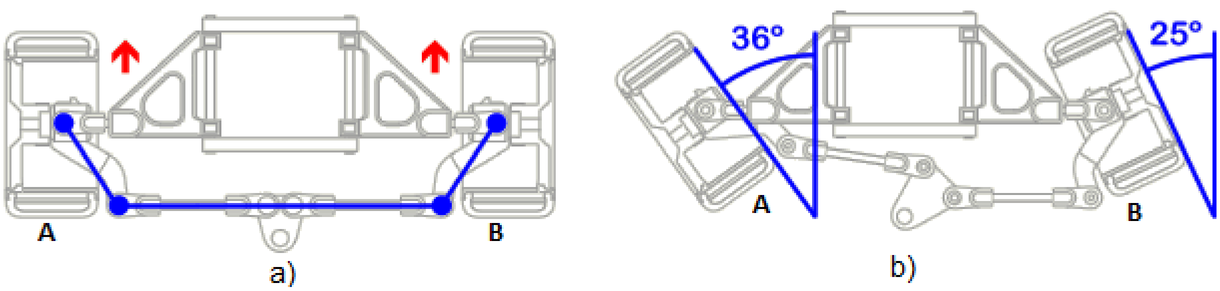

Fig. 2.3 a) Steering arms b) Front wheel steering angle

As the steering arms are angled, the pivot point (A) is not vertically aligned and is, in a straight ahead position, part way round the circle. Because of this, a Right movement of the steering arm will cause the pivot point to move a greater distance in the forward direction than a Left movement of the steering arm.

2.4 ODOMETRY

Odometry is the use of data from motion sensors to estimate change in position over time. The change in position data are evaluated from encoders connected to rear wheel axle. The encoder output pulses are converted to distance travelled and are used for position evaluation. The orientation of vehicle is determined through steering wheel angle. The determination of steering wheel angle involves a mapping function between steering hand wheel and steering wheel. As steering hand wheel has 360 deg rotation and steering wheel can rotate at 25 deg alone as according to vehicle Ackermann drive model. The Fig 2.4 shows the Ackermann drive model.

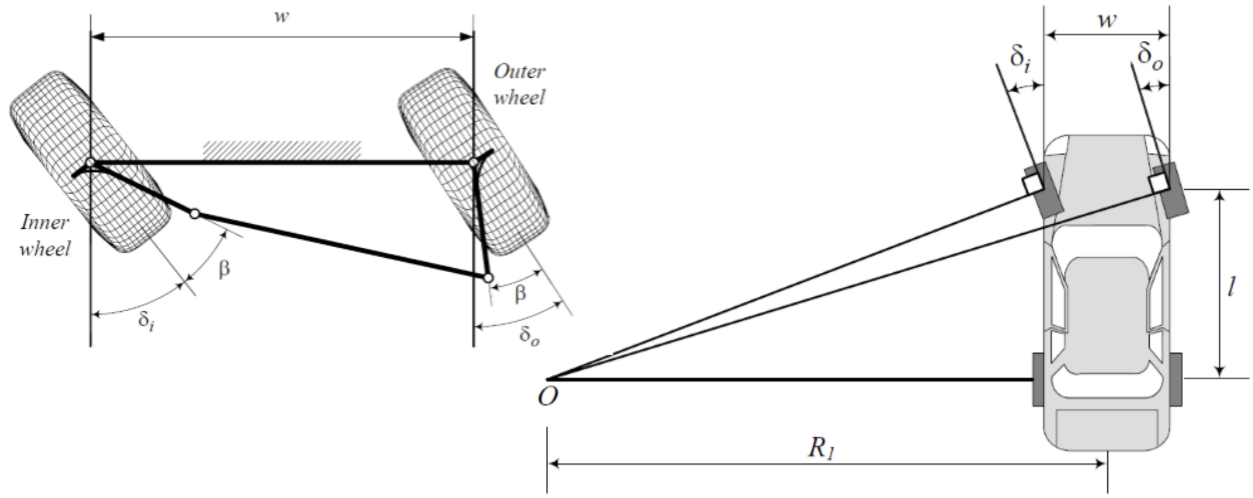

Fig. 2.4 Ackermann math model

Consider a front-wheel-steering of a 4 Wheel Steer vehicle that is turning to the left, as shown in Fig 2.4 When the vehicle is moving very slowly, there is a kinematic condition between the inner and outer wheels that allows them to turn slip-free. The condition is called the Ackerman condition and is expressed by

$$\cot\delta_o - \cot\delta_i = \frac{w}{l} \tag{2.1}$$

Where, δ i is the steer angle of the inner wheel, and δo is the steer angle of the outer wheel. The inner and outer wheels are defined based on the turning center O. The distance between the steer axes of the steerable wheels is called the track and is shown by w. The distance between the front and rear axles is called the wheelbase and is shown by l. Track w and wheelbase l are considered as kinematic width and length of the vehicle.

A device that provides steering according to the Ackerman condition (2.1) is called Ackerman steering, Ackerman mechanism, or Ackerman geometry. There is no four-bar linkage steering mechanism that can provide the Ackerman condition perfectly. However, we may design a multi-bar linkages to work close to the condition and be exact at a few angles.

To find the vehicle's turning radius R, we define an equivalent bicycle model, as shown in Fig. 2.5. The radius of rotation R is perpendicular to the vehicle's velocity vector v at the mass center C. Using the geometry shown in the bicycle model, we have

$$R^2 = a^2 + R^2 \tag{2.2}$$

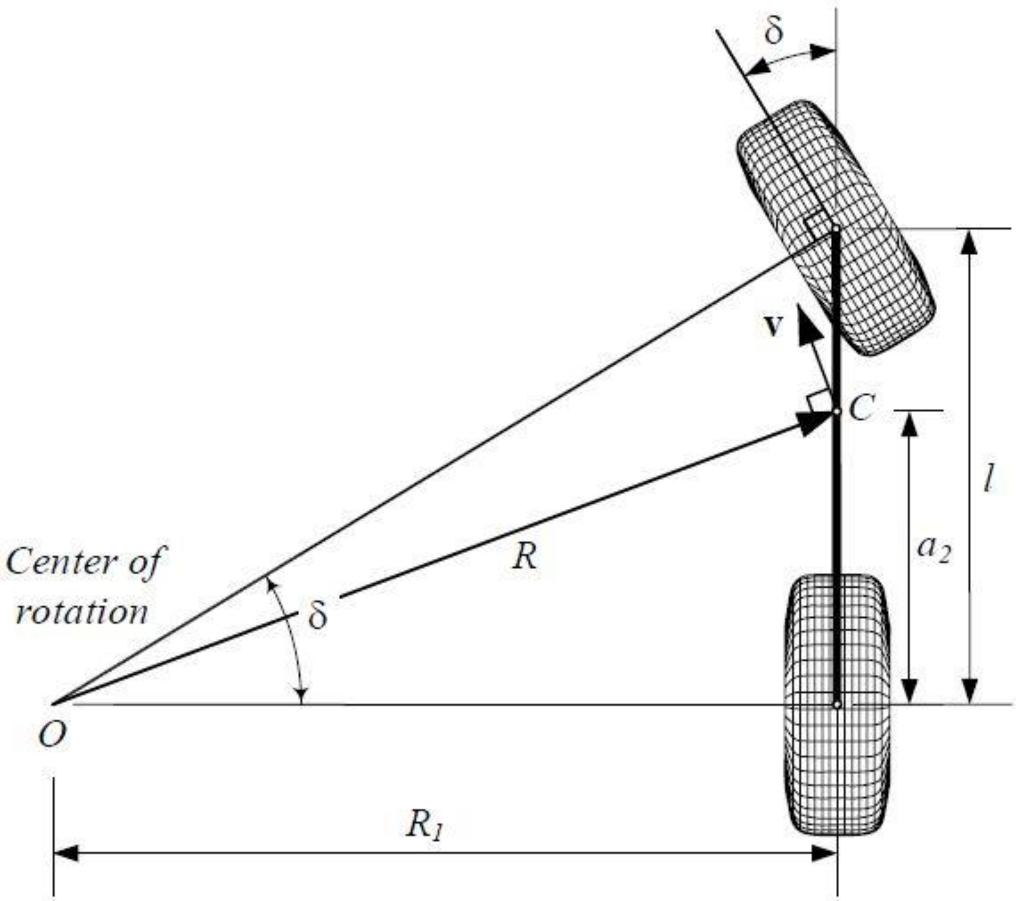

Fig. 2.5 Equivalent bicycle model of front wheel steering vehicle

CHAPTER 3

DESIGN OF DRIVE-BY-WIRE MECHANISM

This chapter explains design of Drive-by-wire mechanism for steering, brake and accelerator, its usage and functions. It has been explained for steering, brake and throttle. A high count CPR encoder has also been discussed about its implementation.

3.1 DRIVE-BY-WIRE MECHANISM

Drive-by-wire mechanism is a fast-growing area, and software-based systems are increasingly replacing the mechanical and hydraulic ones. The reasons for this evolution are technological as well as economical. On the one hand, the cost of hardware components is decreasing while their performances and reliability are increasing. On the other hand, electronic technology facilitates the introduction of new functions whose development would be costly, or not even feasible, if using mechanical or hydraulic systems alone. This evolution, formerly confined to functions such as motor control, wipers, lights, or door controls, now affects all car domains, even for critical functions such as throttle, brake, or steering control. This trend resulted in the introduction of the concept X-by-Wire, where mechanical or hydraulic systems embedded in an automotive application will be replaced by fully electric/electronic ones.

Drive by wire (DbW), Steer-by-wire (SbW), or x-by-wire technology in the automotive industry is the use of electrical or electro-mechanical systems for performing vehicle functions traditionally achieved by mechanical linkages. This technology replaces the traditional mechanical control systems with electronic control systems using electromechanical actuators and human-machine interfaces such as pedal and steering feel emulators. Components such as the steering column, intermediate shafts, pumps, hoses, belts, coolers and vacuum servos and master cylinders are eliminated from the vehicle.

Traditional hydraulic brakes make use of a master cylinder and several slave cylinders. When the driver pushes down on the brake pedal, it physically applies pressure to the master cylinder. In most cases, that pressure is amplified by a vacuum or hydraulic brake booster. The pressure is then transmitted via brake lines to the brake calipers or wheel cylinders.

Anti-lock brake systems were early precursors of modern brake-by-wire technologies. Most vehicles that are equipped with ABS still use hydraulic brakes, but the brakes can also be pulsed without any input from the driver. That is accomplished by an electronic actuator. Electronic stability control, traction control, and automatic braking systems are also related to brake-by-wire technology.In vehicles that use true brake-by-wire systems, there are no mechanical connections between the brake pedals and the brakes.

3.2 STEER-BY-WIRE MECHANISM

The steer-by-wire mechanism is built with chain sprocket and idler systems. A steering encoder – Danfoss Steering Angle Sensor Absolute is connected to steering column shaft. It provides steering angle information. It is CAN data type output which is parsed and used as 360 deg hand wheel angle rotation. A feedback from steering motor is used for accurate steering wheel position and calibration to steering front wheel according to Ackermann Drive model. The Fig. 3.1 shows the steer-by-wire mechanism implemented.

Fig. 3.1 Steer-by-Wire mechanism

The first advantage lies in the decreased risk of the steering column entering the cockpit in the event of a frontal crash. Furthermore, the variable steering ratio of the Steer-by-Wire system brings remarkably increased comfort to the driver. This function enables the steering ratio between the hand wheel and the wheels to adapt according to the driving conditions. In parking and urban driving, this ratio should be smaller in order to reduce the amplitude of the hand wheel rotation. Another facility for steering functionality, brought by software-based technology, is the m-split braking, which consists of applying a dissymmetric torque to the wheels in case of a dissymmetric adherence. Finally, the steering column is one of the heaviest components of the vehicle and removing it significantly decreases the weight of the vehicle and thus reduces fuel consumption.

In a steer-by-wire system, there is no mechanical coupling between the steering wheel and the steering mechanism, i.e., the vehicle's steering wheel is disengaged from the steering mechanism during normal operation. Even though the mechanical linkage between the steering wheel and the road wheels has been eliminated, a steer-by-wire steering system is expected not only to implement the same functions as a conventional mechanically linked steering system, but it is also expected to provide the advanced steering functions.

3.3 BRAKE-BY-WIRE MECHANISM

In the Brake-by-wire mechanism a dc motor is fixed to the brake pedal. The Brake pedal is connected to DC motor shaft by links and couplings. The DC motor is controlled in torque mode of Roboteq motor controller, where the amount of current drawn by motor governs the brake pressure and as shown in Fig. 3.2.

Fig. 3.2 Brake-by-Wire mechanism

A Brake-by-Wire system implemented with a single processor and an actuator per wheel can significantly increase the quality of the braking, in particular by reducing the stopping distance. Moreover, this technology provides more precise braking by adapting to the pressure the driver puts on the pedal. Like Steer-by-Wire, there is a significant decrease in the weight of the vehicle in removing the hydraulic braking system, and therefore significantly lower costs.

Brake-by-wire technology in automotive industry represents the replacement of traditional components such as the pumps, hoses, fluids, belts and vacuum servos and master cylinders with electronic sensors and actuators. Drive-by-wire technology in automotive industry replaces the traditional mechanical and hydraulic control systems with electronic control systems using electromechanical actuators and human-machine interfaces such as pedal and steering feel emulators.

3.4 THROTTLE-BY-WIRE MECHANISM

In throttle-by-wire mechanism a servomotor is fixed to carburetor. The servomotor is actuated using pwm signal from an embedded module. The Fig. 3.3 shows the throttle by wire mechanism.

Fig. 3.3 Throttle-by-wire mechanism

With throttle by wire a servomotor is attached. The complete control of the throttle opening things like idle speed control, cruise control, and traction control can easily be integrated using in-vehicle PC. Because automatic transmissions are also usually controlled by the computer it can adjust the throttle during forward and reverse maneuvers. It also allows the addition of eco or sport buttons to change the way the throttle reacts when pressed, increasing fuel economy or throttle response.

Throttle–by-wire systems enables the control of the engine torque without touching the gas pedal, steer-by-wire systems allow autonomous steering of the vehicle, brake-by-wire systems delivers distributed brake force without touching the brake pedal, shift-by-wire systems enables the automatic selection of the proper gear.

For providing highly automated vehicle functions the intelligent actuators are mandatory requirements. For example for a basic cruise control function, only the throttle-by-wire actuator is required, but if we extend the functionality for adaptive cruise control the brake-by-wire subsystem will also be a prerequisite. Electronic throttle control enables the integration of features such as cruise control, traction control, stability control, pre-crash systems and others that require torque management, since the throttle can be moved irrespective of the position of the driver's accelerator pedal. Throttle-by-wire provides some benefit in areas such as air-fuel ratio control, exhaust emissions and fuel consumption reduction, and also works jointly with other technologies such as gasoline direct injection.

There are several reasons why electronic throttle actuation is preferable to a conventional throttle cable:

- The vehicle’s on board electronic systems are able to control all of the engine’s operation with the exception of the amount of incoming air.
- The use of throttle actuation ensures that the engine only receives the correct amount of throttle opening for any give situation
- The optimisation of the air supply will also ensure that harmful exhaust emissions are kept to an absolute minimum and drivability is maintained, regardless of the circumstances. Coupling the electronic throttle actuation to the adaptive cruise control, traction control, idle speed control and vehicle stability control systems also means finer control can be achieved.
- The use of such a system has advantages over the conventional cable version by:
- Eliminating the mechanical element of a throttle cable and substituting it with fast responding electronics, reduces the number of moving parts (and associated wear) and therefore requires minimum adjustment and maintenance.
- Greater accuracy of data improves the driveability of the vehicle, which in turn provides better response and economy.

3.5 REAR WHEEL AXLE ENCODERS

The high CPR encoder is 5VDC operated 3200 pulses per revolution encoder. The encoder is interfaced to embedded module and upon processing of input pulses provided by encoder the vehicle velocity is computed by the embedded module. The encoder is connected to both rear wheels. In the Fig. 3.4 shown the high CPR encoder connected to rear axle.

Fig. 3.4 High CPR encoder at rear wheel axis

CHAPTER 4

EMBEDDED AND DRIVE ARCHITETCURE

This chapter discusses software architecture of low-level control implementation and selection of suitable embedded module. Below is the Fig. 4.1 that illustrates the developed embedded system architecture. The In-Vehicle PC is the upper-level control which runs navigation and planners for determination of path and sends steering angle and vehicle speed command to Low-Level control module – Microprocessor which takes care of actuators and sensors.

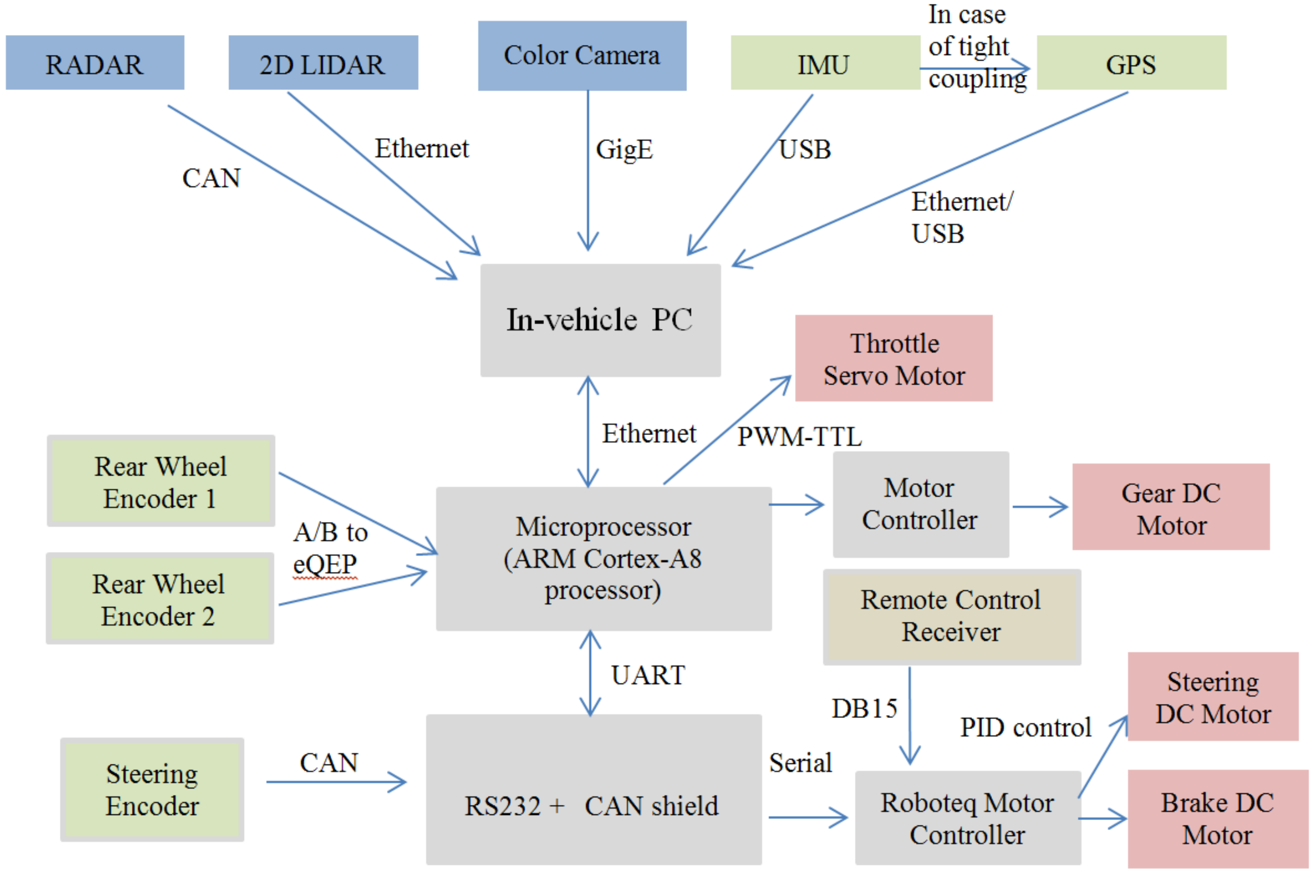

Fig. 4.1 Block diagram

4.1 EXPERIMENTATION OF VARIOUS EMBEDDED MODULES.

In order for determining suitable embedded module for the implementation of low-level controls. Following embedded modules have been experimented.

4.1.1 INTEL GALILEO

Galileo is a microcontroller board based on the Intel Quark SoC X1000 Application Processor, a 32-bit Intel Pentium-class system on a chip. It's the first board based on Intel architecture designed to be hardware and software pin-compatible with Arduino shields designed for the Uno R3. Digital pins 0 to 13 (AREF and GND pins), Analog inputs 0 to 5, the power header, ICSP header, and the UART port pins (0 and 1), are all in the same locations as on the Arduino Uno R3. This is also known as the Arduino 1.0 pinout.

Galileo is designed to support shields that operate at either 3.3 V or 5 V. The core operating voltage of Galileo is 3.3 V. However, a jumper on the board enables voltage translation to 5 V at the I/O pins. This provides support for 5 V Uno shields and is the default behavior. By switching the jumper position, the voltage translation can be disabled to provide 3.3 V operation at the I/O pins.

The Intel Galileo embedded module is interfaced to high CPR encoder of 3,200 pulses per revolution. The Intel Galileo is programmed using its dedicated IDE to compute velocity from encoder pulses. Experimentation of interfacing and examining with encoder. Evaluating the velocity showed that at higher acceleration of vehicle and rear wheels rotating at high speed the output velocity data overflows and doesn't give output.

The Intel-provided integrated development environment for the Galileo looks exactly like the Arduino IDE on the surface. Under the Boards menu, you'll see addition of the Galileo under "Arduino X86 Boards". The modified IDE also is capable of upgrading the firmware on the board.

4.1.2 ARDUINO UNO

Experimenting with Arduino Uno interfacing the high CPR encoder. Output data overflow and switching of values randomly have been found out. It has been found out that interrupt capability of Arduino Uno is not dedicated module for the high CPR encoders.

The Arduino Uno is a staple for the maker community. Arduinos come in various sizes and flavors, but we chose the Arduino Uno as an example of the prototypical Arduino. It has an easy to use development environment, an avid user base and is designed to be easy to interface all sorts of hardware to. For applications that interface to external sensors Arduino boards are useful. The Arduino makes it the easiest of any of the boards to interface to external sensors. The Arduino is a flexible platform with great ability to interface to most anything. It is a great platform to learn first and perfect for many smaller projects.

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 V. If supplied with less than 7 V, however, the 5 V pin may supply less than five volts and the board may be unstable. If using more than 12 V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 V.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

4.1.3 BEAGLEBONE BLACK

The BeagleBone Black -4G is a low cost, high-expansion focused BeagleBoard using a low cost Sitara AM3358 ARM Cortex-A8 processor from Texas Instruments. BBONE-BLACK-4G ships with the Ångström Linux distribution preinstalled on the onboard FLASH, ready to start evaluation and development. Many other Linux distributions and operating systems are also supported by BeagleBone Black including Ubuntu, Android, and Fedora. Like its predecessors, the BeagleBone Black is designed to address the Open Source Community, early adopters, and anyone interested in a low cost ARM Cortex-A8 based processor. It has been equipped with a minimum set of features to allow the user to experience the power of the processor and also offers access to many of the interfaces and allows for the use of add-on boards called capes, to add many different combinations of features. A user may also develop their own board or add their own circuitry. The BeagleBone is a great combination of some of the interfacing flexibility of the Arduino with the fast processor and full Linux environment.

The BBONE-BLACK-4G features TI's Sitara AM3358AZCZ100 microprocessor, which is based on ARM®Cortex-A8 core with enhanced image, graphics processing, peripherals and industrial interface options such as EtherCAT and PROFIBUS. The board is equipped with 256Mb x16 DDR3L 4Gb (512MB) SDRAM, 32KB EEPROM, and 4GB embedded MMC (eMMC) Flash as the default boot source. The board is also populated with a single microSD connector to act as a secondary boot source for the board and, if selected as such, can be the primary boot source. The BeagleBone Black supports four boot modes, including eMMC boot, microSD boot, serial boot, and USB boot. A switch is provided to allow switching between the modes.

BeagleBone Black has an Enhanced Quadrature output type encoder decoder module (eQep) which can seamlessly output velocity without overflow and data interruption. It has a support for connecting additional module to able to interface with serial port devices and CAN devices. Hence it is an appropriate module for the various elements in low-level control of Autonomous Ground Vehicle.

4.2 EMBEDDED MODULE

Embedded module is the low-level processor that provides commands to motor controller. Embedded module is interfaced to high CPR encoders to process and output the velocity of vehicle. Using cape – extended embedded modules it is interfaced to motor controller through serial communication. Steering hand wheel encoder is also interfaced to embedded module. The embedded module receives control commands from top-level control the In-vehicle PC.

4.2.1 ROBOTEQ MOTOR CONTROLLER

Roboteq's MDC22xx controller is designed to convert commands received from an RC radio, Analog Joystick, wireless modem, PC (via RS232 or USB) or microcomputer into high voltage and high current output for driving one or two DC motors. Designed for maximal ease-of-use, it is delivered with all necessary hardware and is ready to use in minutes.

The controller features a high-performance 32-bit microcomputer and quadrature encoder inputs to perform advanced motion control algorithms in Open Loop or Close Loop (Speed or Position) modes. The MDC2230/MDC2250/MDC2260 features several Analog, Pulse and Digital I/Os which can be remapped as command or feedback inputs, limit switches, or many other functions. The controller's two motor channels can either be operated independently or mixed to set the direction and rotation of a vehicle by coordinating the motion of each motor. Numerous safety features are incorporated into the controller to ensure reliable and safe operation.

The controller's operation can be extensively automated and customized using Basic Language scripts. The controller can be reprogrammed in the field with the latest features by downloading new operating software from Roboteq. Roboteq controllers are high performance, microcontroller-based motor controllers, loaded with numerous features and operating modes. Yet, for all their sophistication, the controllers are very simple to install and operate. Their many configuration options are programmed using PC utility with a convenient Graphical User Interface. Once programmed, the configuration data are stored permanently in the controllers' nonvolatile memory, eliminating the need for cumbersome and unreliable jumpers.

The Roboteq controllers are fitted with many safety features ensuring a secure power-on start, automatic stop in case of command loss, overcurrent protection, and overheat protection. Temperature sensors automatically adjusts the Amps limit in case of overheating.

Roboteq motor controller feature a convenient 15-pin or 25-pin connector is used for the following low voltage connections:

- Digital Inputs which may be used for emergency stop, invert direction, limit switch, etc.
- Pulse/RC inputs for Radio or for sensors with PWM output
- Analog inputs for connecting joystick and/or position/speed feedback sensor
- 1A solid-state switched output(s) for controlling a brake, clutch, weapon, field excitation relay or other device.
- A regulated 5V supply output for powering an R/C radio (Battery Eliminator Circuit), potentiomenters, encoders or other sensors.
- Often, an input can be used as Analog, Digital or RC input. Details of quantity, types and possible use is shown in the product datasheet.

4.2.2 STEERING CONTROL

The RoboteQ is the high current motor controller. It is used to control two DC motors connected to Brake and Steering. The Roboteq is a dedicated motor controller developed specially for the application of motor control. Using RoboteQ GUI – Roborun Utility various control configurations can be set. In the application of Steering control, the configuration Closed-loop position relative is used and in Brake control Closed-loop torque control are used. Each configuration modes are explained below.

In closed loop position relative mode the controller accepts a command ranging from -1000 to +1000, from serial/USB, analog joystick, or pulse. The controller reads a position feedback sensor and converts the signal into a -1000 to +1000 feedback value at the sensor's min and max range respectively. The controller then moves the motor so that the feedback matches the command, using a controlled acceleration, set velocity and controlled deceleration. This mode requires several settings to be configured properly but results in very smoothly controlled motion.

4.2.3 BRAKE CONTROL

In closed loop torque mode of motor controller, the motor is driven in a manner that it produces a desired amount of torque regardless of speed. This is achieved by using the motor current as the feedback. Torque mode is mostly used in electric vehicles since applying a higher command gives more “push”, similarly to how a gas engine would respond to stepping on a pedal. Likewise, releasing the throttle will cause the controller to adjust the power output so that the zero amps flow through the motor.

4.2.4 THROTTLE SERVOMOTOR

The throttle servomotor is interfaced to embedded module and controlled by pwm (pulse-width-modulation) of embedded module. The servomotor is a 180 deg high torque motor. The pwm pulses are determined by duration of pulses corresponding to angle of servomotor shaft.

4.4 REAR WHEEL ENCODERS

Rear wheel encoders are used for velocity feedback of vehicle. The rear wheel encoders are 5 V DC operated 3 200 pulses per revolution encoder. The encoders are interfaced to embedded module and upon processing of input pulses provided by encoder the vehicle velocity is computed by the embedded module. The RS232 + CAN cape module is connected to embedded system. It provides the embedded system to interface to devices that has serial port communication only available. In the software architecture the RS232 + CAN cape help to interface with RoboteQ motor controller and steering encoder.

CHAPTER 5

INTEGRATION OF SYSTEM

This chapter discusses how the BeagleBone Black is interfaced to low-level controls. This chapter walkthroughs the following subtasks in order to execute the main task.

- Enabling eQEP module of BBB
- Enabling BBB serial interface pins
- Enabling BBB pwm pins
- Enabling DCAN of BBB to interace with CAN output type devices

5.1 INTERFACING BBB WITH REAR AXLE ENCODERS:

Interfacing BeagleBone Black with rear axle encoders involved following sub tasks such as enabling eQEP modules in BeagleBone Black.

5.1.1 ENABLING EQEP MODULE:

The BeagleBone Black is an ARM based microprocessor. It is an operating system based file system management. As BBB can also run on Linux, the kernel is the communication between user code and System-on-a-chip (SOC). The Kernel of BBB is modified to 3.8 versions from factory default kernel to enable eQEP's (enhanced Quadrature-Encoder Pulse). The BBB has device tree overlays which are an indentification to find components of SOC. The kernel module acts as a driver to get the device tree working. To enabe eQEP, it is first patched and compiled along with kernel and enabled through device tree overlays.

A common way to read a rotational input is with a quadrature encoder such as these rotary encoders from SparkFun and Adafruit. BeagleBone Black has an Enhanced Quadrature Encoder Pulse (eQEP) Module (See section 15.4 of the TRM) that makes reading encoders easy.

The processes of enabling eQEP are mentioned as steps below

- Patch and compile kernel along with eQEP
- Enable eQEP on device tree overlays
- Test with code and validate velocity.

5.2 INTERFACING BBB WITH STEERING ENCODER:

Interfacing BeagleBone Black with steering encoders involved following sub tasks such as interfacing with plug-in boards and retrieving data from BBB.

5.2.1 INTERFACING USING PLUG-IN BOARDS FOR BBB

The BeagleBone has support for CAN output type devices. Using plug-in boards called – cape, the BeagleBone is interfaced to steering encoder CAN output type device. The cape has EEPROM which automatically enabled CAN in device tree overlay of BBB whenever the cape is connected to BBB.

The processes of enabling eQEP are mentioned as steps below

- Connecting cape to BBB
- Connecting encoder to cape screw terminals
- Enabling CAN module in BBB is through a command

ip link set can0 up type can bitrate 290000

The command ip link set is used to enable can0 type in BBB. The frequency of bits per second transmitted by the encoder device is 290kbps.

- The steering encoder CAN output data format is encoded in program and steering angle is provided as output.

5.3 INTERFACING BBB WITH ROBOTEQ MOTOR CONTROLLER

The BeagleBone Black is interfaced to Roboteq motor controller using plug-in device of BBB called cape. The cape has RS232 support and can help in interfacing with motor controller.

The processes of enabling eQEP are mentioned as steps below

- Enabling corresponding UART using device tree overlays of BBB
- Connect the motor controller serial connector to cape serial communication pins
- The corresponding commands for Roboteq motor controller is programmed and validated.

5.4 SERIAL CAPE FOR BEAGLEBONE BLACK

This BeagleBone Serial Cape is the most flexible way to connect to other devices with a serial connection. This cape allows for simultaneous use of up to two RS232 ports and one isolated CAN bus, RS232, or one RS485.

- Two RS232 ports with optional flow control
- Half-duplex RS485 transceiver
- Isolated CAN transceiver with external connections for isolated 5V power supply

In the application, the serial cape as shown in Fig. 5.1 is used to interface with Roboteq motor controller through serial communication. Also in interfacing with CAN output type steering encoder. The Fig. 5.2 shows the embedded module in the autonomous vehicle.

Quickly and cleanly add an RS-232 serial level converter to your BeagleBone Black with this "micro" cape. Fits completely inside the BeagleBone Black or Orange enclosure (sold separately), giving a sleek solution for BeagleBone serial port integration. Micro cape leaves all P8 and most of P9 I/O pins available for other applications.

CBB-TTL-232 micro-cape is configured as a DTE (Device Terminal Equipment) similar to a standard PC. The DB9-male pin-2 is an input to the BeagleBone (RxD). The DB9-male pin-3 is an output (TxD).Changing configuration from UART0 (default) to UART4 requires soldering (see Manual for more details).

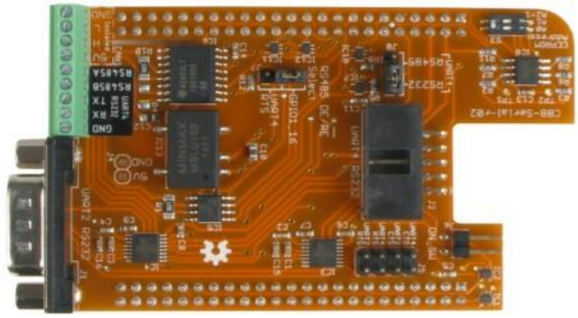

Fig. 5.1 Serial cape

Fig. 5.2 Serial cape in interface with motor controller

5.5 INTERFACING BBB WITH SERVOMOTOR

The BeagleBone Black is interfaced to servomotor using vero board and connected to BBB through stackable pins. The function of vero board is to provide supply voltage for servomotor for it to operate. The throttle servomotor is interfaced to embedded module and controlled by pulse-width-modulation (pwm) of embedded module. The servomotor is a 180 deg high torque motor. The pwm pulses are determined by duration of pulses corresponding to angle of servomotor shaft.

The processes of enabling eQEP are mentioned as steps below

- The pwm pin is enabled in device tree overlay
- The period, duty and polarity of pwm are set. The corresponding pwm value are set through program and are validated on the operation.

The position of the servomotor is set by the length of a pulse. The servo expects to receive a pulse roughly every 20 milliseconds. If that pulse is high for 1 millisecond or less, then the servo angle will be zero, if it is 1.5 milliseconds, then it will be at its centre position and if it is 2 milliseconds or more it will be at 180 degrees.

This example uses the PWM feature of the GPIO library to generate the pulses for the servo. The PWM frequency is set to 60 Hz so that the servo will receive a pulse roughly every 17 milliseconds. The length of the pulse is changed by adjusting the duty cycle over the fairly narrow range of 3 to 14.5 percent. The Fig. 5.2 were estimated and then tweaked a bit to give a maximum range of the servo being used. If you wanted to, you could attach three more servos to the GPIO pins P8_19, P9_14 and P9_16. They could all share the same external 5-6VDC power supply without any problem.

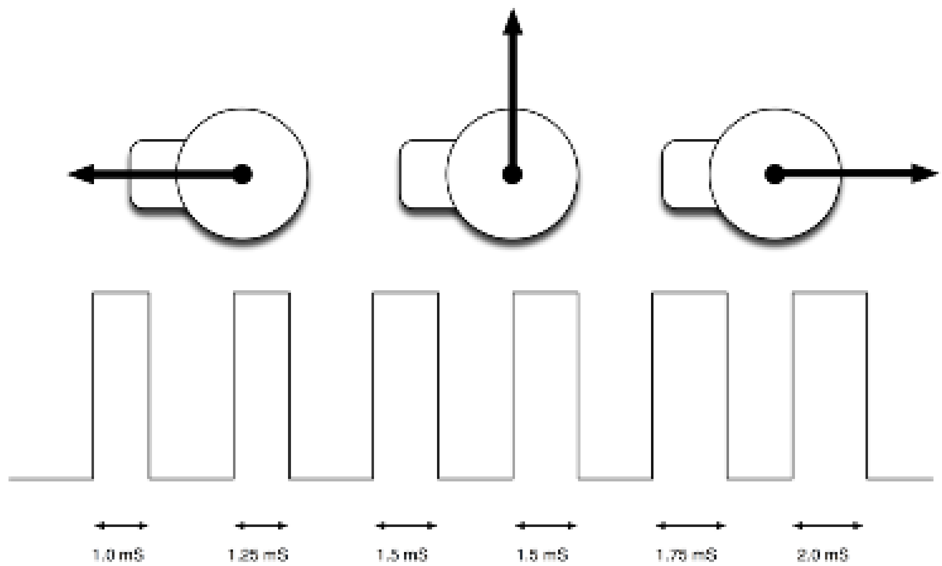

Fig. 5.3 Servomotor control using BBB

5.6 DESIGN OF POWER CIRCUIT BOARD

In the design of circuit board for encoders and motor, the electrical specifications of BeagleBone Black are to be considered first. The BeagleBone Black is operated at 3.3 V stage. The encoders are operated at 5 V and a voltage conversion should take place to convert the encoder output to 3.3 V. The steering encoder operates between 9 V and 30 V is also powered.

5.6.1 ENCODER POWER DESIGN

In the design of power circuit for encoder. The encoder operates at a voltage range of 5 V. In the embedded board using voltage regulators the 12 V source supply is converted to 5 V range to supply encoders. The BBB operates at 3.3 V and hence input pins should be provided at the specified voltage range. The encoders output which are also 5 V is converted to 3.3 V by voltage divider circuit made of appropriate resistor values. The 3.3 V output are then connected to BBB through stackable pins

5.6.2 SERVOMOTOR POWER DESIGN

In the design of power circuit for servomotor. The voltage regulator used for powering the encoder is connected parallel to second voltage regulator to able to provide approximately 2 Amps current. As two encoders and a servomotor can consume to approximately 1.5 Amps. The servomotor signal pin are connected to BBB pwm pin through stackable pins.

Servomotor has three wires. They are power, ground, and signal. The power and ground are connected to vero board. The signal is connected to BeagleBone Black pwm pin. The pwm device tree overlay is enabled using pwm device tree overlay file.

In the Fig. 5.3 the power circuit is shown. In the power circuit board. There are stackable pins, voltage regulator IC's, capacitors and voltage divider circuit. The stackable pins are used to connect to BBB. The voltage divider circuit powers two encoders and a servomotor. The supply voltage is 12V and output voltage is 5V at a current of 2Amps.

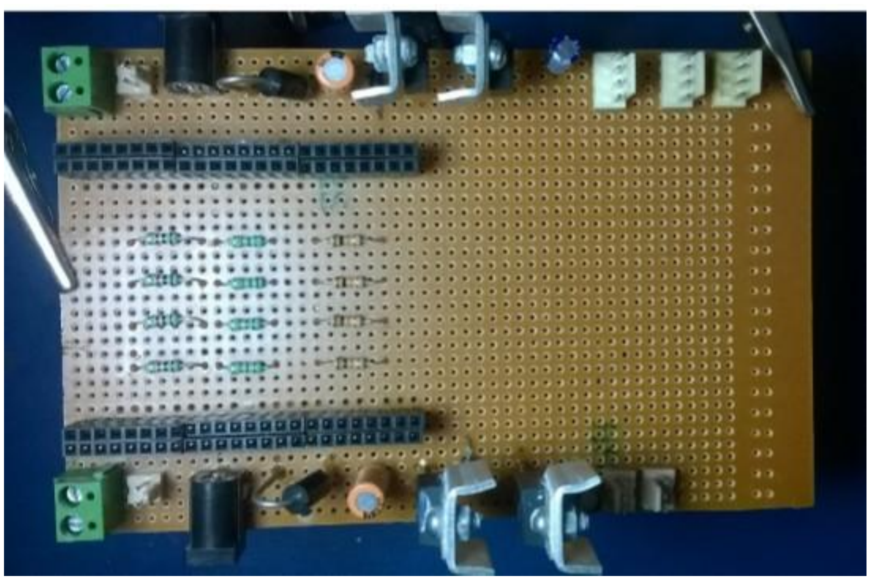

Fig. 5.4 Power circuit board

In the Fig. 5.4 the embedded system for low-level control is shown. The embedded system is placed on the front tray of vehicle. A 12V supply of battery is converted to AC power supply using Inverter.The power circuit board, BeagleBone Black and motor controller get power through the inverter.

Fig. 5.5 Embedded system for Autonomous Ground Vehicle

CHAPTER 6

RESULTS AND DISCUSSION

The previous chapters depicted the flow of the process and components involved in the project. This chapter portrays results and observations obtained from the odometry of vehicle using low-level controls with x-by-wire mechanisms.

6.1 EVALUATION OF ODOMETRY DATA

The implementation of odometry evaluation technique involves analyses of Ackermann drive model and vehicle design. Odometry is the use of data from motion sensors to estimate change in position over time. The change in position data are evaluated from encoders connected to rear wheel axle. The encoder output pulses are converted to distance travelled and are used for position evaluation. The orientation of vehicle is determined through steering wheel angle. The determination of steering wheel angle involves a mapping function between steering hand wheel and steering wheel. As steering hand wheel has 360 deg rotation and steering wheel can rotate at 25 deg alone as according to vehicle Ackermann drive model.

In the implementation the position x and y are determined from encoder connected to rear wheel axle. The orientation is determined through steering wheel angle. The steering wheel angle is provided by mapping function between steering hand wheel and steering wheel. As the vehicle is accelerated the odometry of vehicle i.e. the position and orientation of the vehicle are been published through the program.

The evaluation of odometry technique is the most reliable way to compute and measure vehicle position, coupled with sensors which inform the navigation system of the positions of obstacles or landmarks. Such systems often involve preprogramming the vehicle with information about the geometric layout of the environment, and the positions and characteristics of key landmarks.

In the validation process of odometry data, the encoders of rear wheel which are computed to vehicle position data is published. The mapping function between steering hand wheel and steering wheel publishes the steering wheel angle. The combination of both the data provides the position values x and y, rotation value z.

The odometry data is validated with the fixed steering wheel angle to form a circle to complete one revolution. The shift from start position is used to evaluate the data. The odometery data is acquired encoder data are received as counts from rear wheel encoders and steer angle from steering wheel encoder using steer-by-wire. The Fig. 6.1 shows the position x, y calculated from the odometry data and steering angle data.

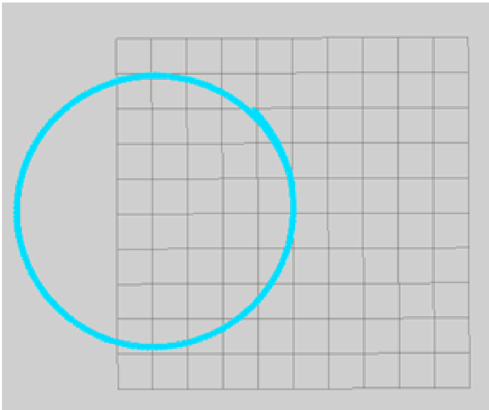

Fig. 6.1 Odometry validation

In Odometry test results, the hand wheel angle is set at 155 degree right and vehicle start position have been noted. In a completion of circle with 155 degree the odometry data’s x, y positions are back to zero position and theta 360 degree has +/-2degree.

In the results it has been found out that as the vehicle makes a circle the x, y and z values change and after completion of circle the position and orientation retain back to as zero as in initial start position state.

6.2 EVALUATION OF ODOMETRY DATA COMBINED WITH IMU

In the implementation of IMU, for yaw data the registers of IMU are accessed and are used for the evaluation of odometry. The following sub-topics explain about the implementation tasks. The Inertial Measurement Unit (IMU) is configured to get Roll, Pitch and Yaw values.The IMU serial cable is connected to BeagleBone Black cape serial port and the pitch, roll and yaw values are published. Using ROS the yaw topic is subscribed and used in odometry function as orientation of vehicle.

The IMU is initially calibrated with 2D calibration utility using IDE of IMU. Several visual odometry approaches use a non-uniform prior on the motion estimate to guide the optimization towards the true solution. These priors can be derived from assumptions about the motion, e.g. small motion or constant velocity [27]. Alternatively, measurements from other sensors (e.g., an IMU) or predictions from a filter (e.g., a Kalman filter) can be used. In contrast to all previous work on dense direct motion estimation, we provide a probabilistic derivation of the model. This formulation allows us to choose a suitable sensor and motion model depending on the application. In particular, we propose to use a robust sensor model based on the t-distribution, and a motion prior based on a constant velocity model.

The relative rotation priors from the IMU are obtained by a fast integration of the high frequency gyroscopic measurements. Typically, common low-cost IMUs already accomplish this integration internally using a complementary filter along with the gravity direction obtained from the acceleration signals. Experience has shown that the resulting orientation of the IMU is only affected by a slowly changing drift term and that short-term relative orientation of the system can hence be recovered safely, directly from consecutive orientation information delivered by the IMU.

The calibrated IMU provide accurate and precise roll, pitch and yaw which are useful in providing precise orientation of vehicle.

```
z: 119.467
---
x: 1.731
y: -6.76
z: 119.465
---
^Cshuttle@shuttle-Precision-M2800:~$ rostopic echo /vectornav/rpy
x: 1.8
y: -6.505
z: 119.454
---
x: 1.803
y: -6.506
z: 119.453
---
```

Fig. 6.2 IMU Roll,Pitch,Yaw

In the program for evaluation of odometry the orientation of vehicle is subscribed from the IMU yaw angle. For validation of orientation the vehicle is set to make a circle from and start position and after completion return back to same position. It has been found that orientation of vehicle was accurate and precise.

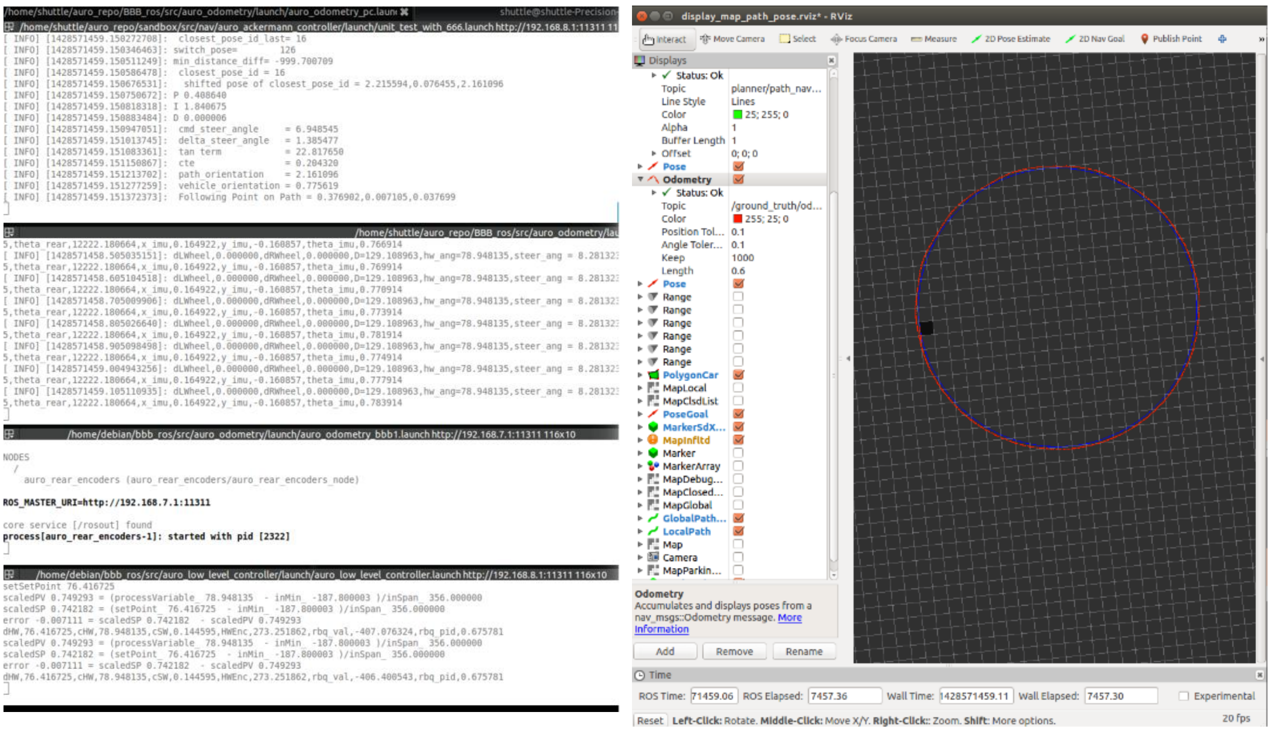

Fig. 6.3 IMU validation

CHAPTER 8

CONCLUSION AND FUTURE WORK

The project titled “Implementation of Low-level control in Autonomous Ground Vehicle” has helped to leverage the knowledge of electrical and computer science engineering disciplines by providing an insight into the scope and feasibility of the Autonomous Ground vehicles. This project helped to gain a thorough knowledge on the interpretation of autonomous vehicles software and hardware architecture.

Process study was a part of the odometry evaluation phase, which helped to learn the various operations involved in the determination of autonomous vehicle odometry, and also identify the various techniques involved.

Design of Drive-By-Wire mechanism (DBW) was also an essential step in the project. Several conceptual designs were proposed before finalizing the ultimate design of the DBW systems. This endeavor helped understand the various parameters to be considered in designing a mechanism for steering, brake and accelerator. Circuit design and building is indispensable for implementation of low-level control. Through this study, a better knowledge of embedded modules was obtained. This exercise helped to aggravate the interests in research and analysis of emerging trends in autonomous ground vehicles.With robust and sophisticated embedded module, the project on the implementation of low-level control in autonomous ground vehicle will prove to serve in real-time applications in automotive industry.

Future developments can be made with sophisticated and rugged embedded module, using Electronic Control Unit (ECU) for autonomous ground vehicle to be built in automotive industry standard.

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