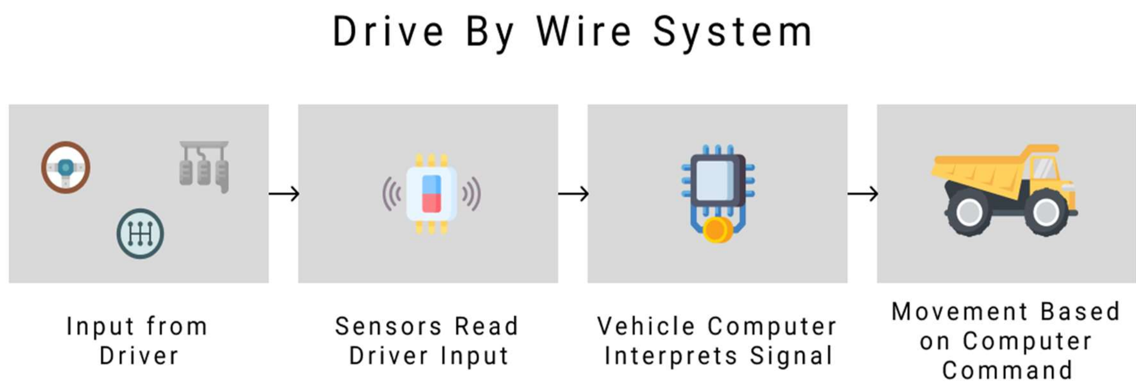
Automating Off-Highway Trucks: A Sensor Fusion with Drive-By-Wire Approach

1.Abstract:

In large open field mines, a large amount of material such as soil, overburden, coal, bauxite etc. in the order of 1,50,000 to 2,50,000 tons of material is moved in a single day. Minerals are dug from the earth using large machines called shovels, they load large scale off highway trucks (dumpers) each with a capacity of roughly 350 tons. Due to the lack of drivers, dumpers remain inoperable and completely shut down the operation of mines, resulting in huge losses even if the operation is stopped for a single day. By ensuring the operation of dumpers even in the absence of drivers, smooth operation of mining activities can be guaranteed. Our proposed solution is a suite of sensors and a compute device that wires into the drive by wire system of these vehicles to convert existing trucks into autonomous trucks.

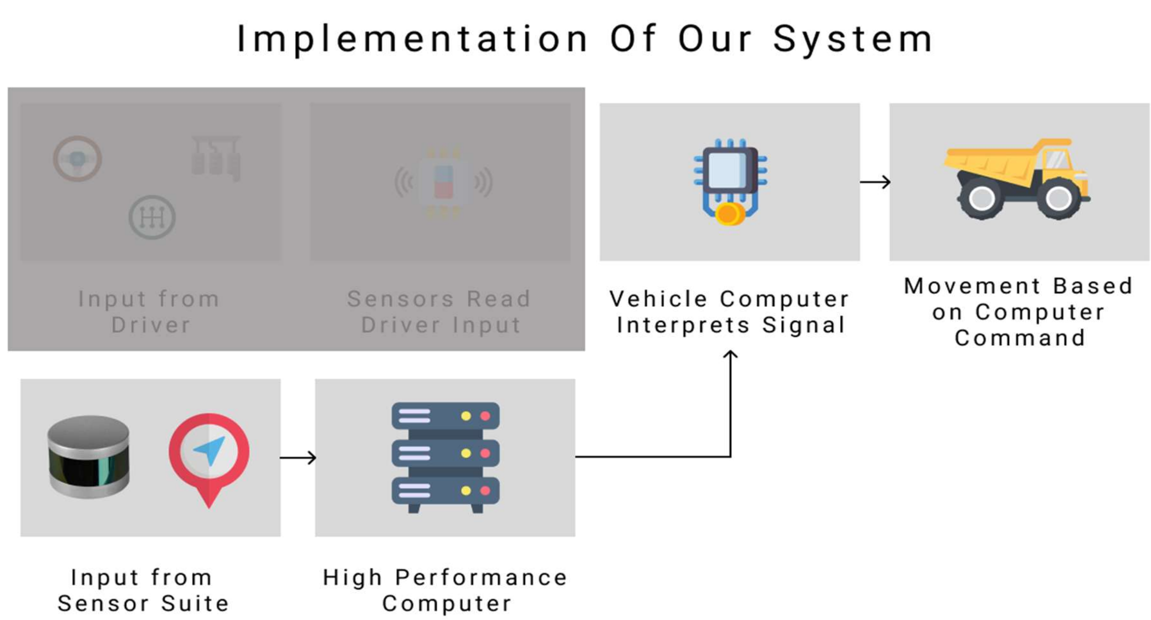
2. Introduction:

Off highway trucks, often referred to as ‘dumpers’ are the backbone of modern open pit mines. Each truck has a capacity of moving 350 to 500 tons of material in one go, each truck has roughly 4000 horsepower and weighs up to 420 tons when fully loaded. Due to the unique challenges presented by such massive machinery, drivers of these vehicles need extensive training and evaluation in operation of these machines before they operate them in mines. When these drivers are absent due to various reasons such as uninformed leave, emergency leave, workers going on strike etc. Each truck that costs ~25,000,000$ goes unused and results in loss for the mines. An existing solution for this problem involves having many drivers on standby (despite the shortage of drivers in the market) however this incurs added costs to the mines. Due to the lack of any robust solution to this problem, we propose that existing trucks can be automated to ensure that productivity is not reduced. Autonomous Vehicles are becoming more prevalent year on year, although they are mostly used only on tarmac due to the challenges offered by offroad scenarios, this technology can be used to greatly improve the productivity of mines. Autonomous vehicles require a suite of sensors that they use in order to see and understand



the space around them. An onboard computer translates the information obtained from these sensors into physical movement of the vehicle using a Mathematical model of the vehicle that contains details such as the wheelbase, turning circle etc. to calculate a kinematically possible instruction. Many algorithms such as SLAM and Navigation algorithms are tied together to make a map of the environment using the vehicle and then drive the vehicle in the same environment. Our solution is a kit consisting of sensors, and an onboard computer that integrates into the drive by wire system of the dumper.

The prototype model uses LiDAR and Cameras to create a map of the environment and to localize within it. It also features a Jetson Orin Nano as



the onboard computer. The software stack consists of Autoware built using ROS2 Humble running on Ubuntu 22.04. Autoware is the largest open source Autonomous Driving Stack that uses ROS2 nodes written in C++ and Python.

As a demonstration of autonomous navigation, we have made a prototype that can map its surroundings and then navigate from point A to point B within the created map.

3.Related works:

A few examples of commercially available autonomous dumpers are listed below

3.1. Hitachi AHS:

3.1.1 The Hitachi Autonomous Haulage System (AHS) is an IoT based system that allows for fully autonomous operation of off highway trucks, it also provides the ability to control the trucks remotely with teleoperation. It integrates seamlessly into the Fleet Management System (FMS), and automatically calculates the most optimal loading and unloading points, as well as the most optimal route between the points, minimizing fuel usage and maximizing efficiency. Their system also allows teleoperation of all types of machinery including shovels.

3.2 Komatsu Frontrunner:

3.2.1 This system runs on a LTE network and has high availability and minimal downtime, it has been implemented in over 400 trucks across the world. It has had a stellar record of 14 years of operation without a single causing a single injury. Trucks with this system can work round the clock and can tackle the harsh environment of mines on their own without endangering a human driver.

3.3 CAT:

3.3.1 Caterpillar's implementation of an AHS uses a GPS and Lidar, performing sensor fusion to accurately estimate the vehicle position within the mine and to navigate along the planned path without meandering. It also uses AI to estimate the optimal speeds and to avoid obstacles in the path.

All autonomous vehicles that are larger than scale models use Model Predictive Control (MPC) and advanced techniques such as using a Digital Twin [1] for simulation before making any physical movements. This principle enhances the safety in operation of these autonomous vehicles [2]. With the help of a proper vehicle model it is possible to assert that the system will only drive in a manner that is kinematically feasible [3]. With algorithms like A* and RRT* ensure path planning can be done with better accuracy [4][5].

4.Objectives:

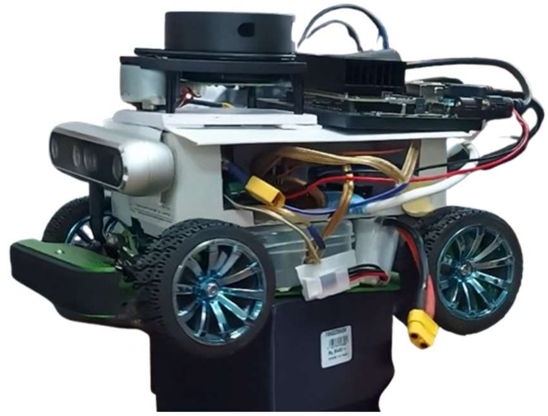
4.1 Ensure continued operation of dumpers even in the absence of drivers
4.2 Improve overall productivity by running machinery on fixed schedule
4.3 Boost profits by enabling 24/7 operation

5.Research methodology:

5.1 Setup

5.1.1 The test platform used to evaluate the model consists of a generic robotics chassis with 2 drive motors, a HW-166 motor driver that takes input from an Arduino Nano, which in turn takes input from the Jetson Orin Nano. The vehicle also has an Rplidar A1 for mapping and localization and has an Intel Realsense Camera for Obstacle Detection and Avoidance. The whole setup is powered by a 2200mah 3S LiPo battery. A photograph of the completed test platform is show to the right of this column.

Table of all the parts used on the test platform is given below.



5.2 Flow

5.2.1 Once the Jetson is powered on and the ROS nodes are run, the LiDAR starts sending distance data in the form of an array. This array arrives on the /scan topic at the scan rate of the LiDAR(10Hz). Upon running slam toolbox, this data along with wheel odometry is used to create a map of the environment. Once this map is moved into the Autoware map folder and a planning simulation is launched using this map, we have to set the initial pose of the vehicle. After the initial pose is set, a localization algorithm like Adaptive Monte Carlo Localization (AMCL) determines the estimated pose of the vehicle in the given environment. Once a goal pose is set, Autoware plans a path to the goal using a combination of path planning algorithms like A*, RRT, MPC etc.

Sno.	Part Name	Quantity
1	Robotics Chassis	1
2	DC Motor	2
3	3S Lipo Battery (2200mah)	1
4	HW-166 Motor Driver	1
5	Arduino Nano	1
6	Jetson Orin Nano	1
7	Rplidar A1	1
8	Intel Realsense Camera	1
9	XT60 connector	1
10	USB Micro B Cable	1
11	USB C Cable	1
12	Male to Male Jumpers	16

Once a path is planned, the vehicle is ready to move along the planned path, when the control is set to autonomous mode, the vehicle starts to move along the planned path, it will avoid obstacles and also come to a halt when it encounters a dangerous situation like a blockade formed by falling material. This movement is translated into actual movement by sending a drive message that commands the motors to turn at the required speed, this will enable the vehicle to move in a straight line as well as make turns. When the vehicle is in motion, there is a possibility of an error arising between the intended path and actual path. These sources of error can be excessive slip between the wheel and road surface, error in encoder reading, error in lidar reading, change in voltage supplied by the battery, etc. The various sources of error, their intensities, some ways to mitigate these errors and the resultant change in the error term are listed below.

Source of Error	Initial Error (%)	Improvement Method	Expected Impact	Estimated error after improvements (%)
Encoder Drift	1-5%	Utilization of higher resolution encoders, periodic calibration	Better odometry accuracy, more precise measurement	0.5-2%
Slip	2-10%	Use softer rubber tires, reduce rate of acceleration	Better traction on slippery surfaces	1-3%
Mapping and Localization	2-5%	Use Extended Kalmann Filters (EKF), or advanced particle filters	Increased accuracy in mapping and localization	1-2%
Voltage fluctuation	1-3%	Use voltage regulator to ensure stable output	Consistent motor rpm, reduced error in speed	0.5-1%

5.3 Architecture

5.3.1 The Jetson onboard the vehicle runs a version of jetpack based on Ubuntu 22.04. Setup up ROS2 Humble on the Jetson and Create a ROS2 workspace. Install all necessary packages as site-packages. Clone this repository into the workspace. Build all packages with colon. Run slam toolbox when creating a map of the environment, after a map is obtained, move it to the autoware_maps folder. Start planning simulation with the given map, set the initial pose of the vehicle and the goal pose of the vehicle, you will be able to see a green color path being planned in the map, once the path planning step is over, the entire route turns a solid green color, this indicates that the system is ready to proceed. Once the drive mode is selected as auto, you will be able to see the vehicle move from the initial pose to the goal pose and also see it avoid obstacles in its path.

5.4 Steps

5.4.1 After making the connections and ensuring that they are in the proper order, plug in the battery into the XT60 connector.

5.4.2 Boot up the Jetson Orin Nano, this will power on the Arduino Nano as well as powering the other devices such as the Motor driver, Rplidar and the Intel Realsense camera.

5.4.3 After booting the Jetson, navigate to your ROS2 workspace and run the required nodes.

5.4.4 Use SLAM Toolbox to create a map of the environment.

5.4.5 Upload the created map into the Autoware Maps folder.

5.4.6 Launch a planning simulation in Autoware with the given map.

5.4.7 Set the initial pose of the vehicle

5.4.8 Set the goal pose of the vehicle

5.4.9 Set the navigation mode to Auto, the vehicle should start to move along the planned path

6.Conclusion:

With the help of autonomous vehicles, we can ensure that the operation of mines is not hindered. By converting the existing fleet of trucks into autonomous trucks, the mines can save on capital cost and retain their current schedule of operations, extending the working hours for the trucks as necessary. The use of an open-source project like Autoware also ensures that the insights gained in operating large scale autonomous vehicles can be shared among the community, leading to better algorithms in Mapping, Localization, Vehicle Control and Navigation. The extreme environment presented by mines also serves as a hot testbed for new innovations in lidar and computer technology.

7.Future work:

The existing test platform serves as only a proof of concept on a small scale, it proves that a specific algorithm or model can be implemented, but requires further testing and evaluation before doing so. Some changes that can be made in the future are:

7.1 Use of a larger test platform, both width and wheelbase.

7.2 Using a 3D Lidar like a Velodyne model instead of a 2D Lidar used [6].

7.3 Addition of GPS/GNSS to increase the accuracy of both mapping and localization.

7.4 Addition of more cameras to enable 360-degree vision [7].

7.5 Use of a mode powerful pc, with an Nvidia Graphics Cards.

7.6 Inclusion of air brakes like the ones used in trucks.

7.7 Consider a planner for the different modes of operation of trucks within an open pit mine [8].

Such a larger platform could be used to evaluate the models that have proved to be correct in the simulator as well as on the small test platform. It also serves as a closer to real life example of the dumper that the algorithms are going to be implemented on.

8.Societal Impact:

The use of autonomous dumpers ensures that humans are not exposed to the high temperatures and harsh conditions of an open pit mine, it reduces the number of humans present on the field in dangerous conditions, with advancements in autonomous driving, humans can remain in a safe environment and take control only when the situation cannot be handled by the algorithms in place. Timely operation of mines also ensures that other industries such as iron and steel, power etc. that depend on the raw material obtained from mines are not affected, further delays in the supply chain can be reduced or completely avoided with automation.

9.Acknowledgement:

The successful completion of our project titled **"Automating Off-Highway Trucks: A Sensor Fusion with Drive-By-Wire Approach"** was made possible by the collaborative efforts of all the members of the team and the unwavering support of our mentors. We would like to express our sincere gratitude toward KGiSL Institute of Technology for giving us the opportunity to present this project at the Smart India Hackathon 2023 under the problem statement SIH1336. I would also like to thank them for providing us with the hardware and time to develop this project. I am deeply grateful to my mentors Mr.Navaneeth M and Mr.Sathish R for their unshakable belief in our team.

10.Annexure:

10.1 The Autoware Project - https://autoware.org/

10.2 Video of Test Platform - https://youtu.be/l6k6AmtQ01A?si=jwHjOIDBvYTuZ_Mp

11.References:

[1] J. P. Allamaa, P. Patrinos, H. Van der Auweraer, and T. D. Son, "Sim2real for Autonomous Vehicle Control using Executable Digital Twin," in *IFAC-PapersOnLine*, vol. 55, no. 24, pp. 385-391, 2022. doi: https://doi.org/10.1016/j.ifacol.2022.10.314.

[2] W. Liu et al., "A systematic survey of control techniques and applications in connected and automated vehicles," in *IEEE Internet of Things Journal*, vol. 10, no. 24, pp. 21892-21916, 2023. doi: https://doi.org/10.1109/jiot.2023.3307002.

[3] L. Wang, X. Xu, Q. Su, Y. Song, H. Wang, and M. Xie, "Automatic gear shift strategy for manual transmission of mine truck based on Bi-LSTM network," in *Expert Systems with Applications*, vol. 209, 2022, Art. no. 118197. doi: https://doi.org/10.1016/j.eswa.2022.118197.

[4] D. Wang, S. Zheng, Y. Ren, and D. Du, "Path planning based on the improved RRT* algorithm for the mining truck," in *Computers, Materials and Continua*, vol. 71, no. 2, pp. 3571-3587, 2021. doi: https://doi.org/10.32604/cmc.2022.022183.

[5] P.-F. He, P.-F. Fan, S.-E. Wu, and Y. Zhang, "Research on path planning based on bidirectional A* algorithm," in *IEEE Access*, vol. 12, pp. 109625-109633, 2024. doi: 10.1109/ACCESS.2024.3411872.

[6] A. Gupta, S. Jain, P. Choudhary, and M. Parida, "Dynamic object detection using sparse LiDAR data for autonomous machine driving and road safety applications," in *Expert Systems with Applications*, vol. 255, 2024, Art. no. 124636. doi: https://doi.org/10.1016/j.eswa.2024.124636.

[7] W. Lyu, Z. Zhou, L. Chen, and Y. Zhou, "A survey on image and video stitching," in *Virtual Reality & Intelligent Hardware*, vol. 1, no. 1, pp. 55-83, 2019. doi: https://doi.org/10.3724/SP.J.2096-5796.2018.0008.

[8] S. Teng, L. Li, Y. Li, X. Hu, L. Li, Y. Ai, and L. Chen, "FusionPlanner: A multi-task motion planner for mining trucks via multi-sensor fusion," in *Mechanical Systems and Signal Processing*, vol. 208, 2024, Art. no. 111051. doi: https://doi.org/10.1016/j.ymssp.2023.111051.