Application of Solid Freeform Fabrication for using low-cost reconfigurable items to develop actively steered mobile robot platform to experiment with advanced vision and ML based experiments

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Abstract:

Over the last three years under Robotics for Everyone (R4E) initiative, we have presented multiple design ideas that enable low cost, reconfigurable mobile as well as non-mobile robotic systems. Most of the R4E design was limited to basic experiments in Robot navigation, obstacle avoidance, sensor (proximity, touch, ultrasonic) based environment perception and simple pick and place tasks. In this paper we are presenting a platform that can be used for furthering the learning and experimentation in advanced topics such as vision system and machine learning. The system uses reconfigurable parts combined with 3D printed parts to build an actively steered robot. The system allows usage of cost-effective computational platform such as Raspberry Pi and compatible camera. System can also be expanded to use other advanced computing platforms and sensors such as LIDARs. We discussion 3D printed features to sustain dynamic loads as well as accurately steer the robot.

Introduction

Educational and competitive robotics offer invaluable hands-on experimentation, making them effective tools for STEM education. Educational robotics facilitate experimentation with complex ideas, logical thinking, and programming skills. For instance, students can explore physics and geometry principles through verifiable cause-and-effect experimental verifications. They can study motor rotation, mobile robot wheel diameter, and distance covered to gain insights into geometric principles. They can also delve into dynamics by investigating kinematic chains, simple machines, and torque relationships through tasks such as lifting objects with robot arms. Moreover, educational robots enable exploration of advanced topics like programming, machine learning, and artificial intelligence. Students can learn about robot navigation, pathfinding algorithms, and sensor integration for environmental perception.

Recent advancement in technology and significant interest from DIY community has been instrumental in development of many low-cost programmable boards, sensors, computational resources as well as motors and drives. Many open-source control and computation platforms such as Arduino, Raspberry-pi, and Beagle board are very popular in the DIY community and provide significant potential to learn and experiment. Additionally, there is an ecosystem of a range of very cost-effective control, sensing communication, and display modules that is usable with the open-source platforms. Despite many possibilities, the kits are not as comprehensive and easy to work with. Many other kits that are based on open-source platforms are adequate only to build a fixed architecture and single mobile robot. The robots are not designed to expand. Hence opportunities for experimentation are limited.

Authors have developed and successfully demonstrated[1-3] usage of easily available materials, extrusions as well as tubular structures coupled with 3D printable parts to manufacture parts that can be easily assembled and reconfigured for multiple experiments in educational robotics. The work has primarily been limited to structural elements, reconfigurable brackets for rectangular and angular joints, sensor-mounts, microcontroller attachment brackets, microcomputer attachment brackets, motors, drivers and power supply.

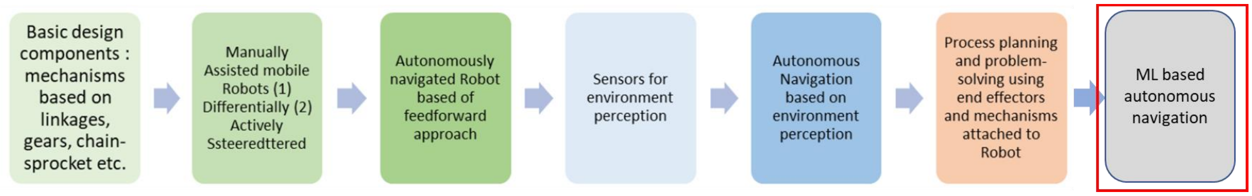


Figure 1 : Path of learning and Experimentation with Robotics for Everyone

Motivated by the initial success and acceptance by the learning community, we are extending the learning platform for advanced experiments. Newer features and items will be added on to the current platforms and will enable experiments in vision and machine learning. The brackets provide platform for mounting single, or multiple camera. Additionally, the module can be expanded to install advanced sensors such as Lidar. Sections below describe unique challenges presented in using a vision-based system for robot navigation. We present unique designs and how we used 3D printing for manufacturing and then testing features for consistent performance of the Robot.

Mobile Robot Architectures and popular vision controlled mobile robots

Most of the mobile robot architecture may fall in following categories:

1. Differential Drive Robots -use differential steering to control movement, with each wheel driven independently[4].
2. Active Steering Robots - use mechanisms to control steering angles actively, enhancing maneuverability [5].
3. Mecanum Wheel Robots- use wheels with rollers set at an angle to achieve omnidirectional movement[6].
4. Omni Wheel Robot- use wheels with rollers mounted perpendicular to the wheel's axis for omnidirectional movement[7].
5. Kiwi Drive Robots- use a combination of three omnidirectional wheels for movement control [8].
6. Tread-Wheel Robots-Tread-wheel robots use a continuous track or tread system for improved traction and stability [9].
7. Synchro Drive Robots- use synchronized wheel movements for enhanced stability and maneuverability [10]

The choice of mobile robot architectures is governed by the application. Vision based control is successfully used in industry to control each type of robot. However, most of the educational mobile platforms [11-14] use actively steered mobile robot architecture. Some of the popular platforms such as MIT-Racer, UW-MuSHR use competitive Small-scale Electric RC cars as starting platforms. Preparing the platform for experimentation require additional drive, controls, power and sensing modules. The platforms are built for high performance and suitable for advance learning and experimentation. The cost to build the vehicles may range $1200-$2500. The cost becomes prohibitive for most of the learners and educators.

UW MuSHR : Approximately $1200

MIT Racecar : Approximately $2800

Figure 2 : Popular platforms used in vision and ML based navigation

Many features within the popular robotic racecar allow performance catering to competitive excellence. The camera vision, stereo vision and Lidars not only enhance the overall complexity of the system but also make the path of entry extremely steep for many learners. The same is reflected in the popularity and access of such kits to college, Industrial DIY enthusiast and limited resourceful high-school students.

Some of the mechanical features such as the rear drive, Ackerman implementation of the steering, suspensions system and BLD motor and controller makes the system expensive. Authors therefore are taking a creative approach to the kit. As described in Figure 3, the features of such as vehicle includes- AWD Drives, Powered by High RPM BLDS, Extremely complex steering and wheel speed adjustments. Suspension system to account for shock isolation.

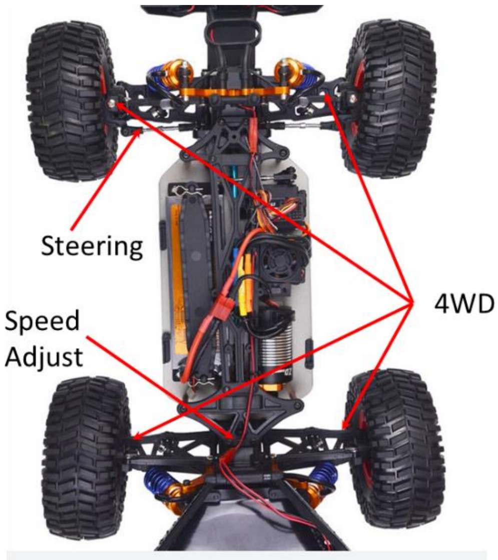


Figure 3 System features for the ML based autonomously navigated vehicles

Robotic for Everyone Simplified Design and hardware features

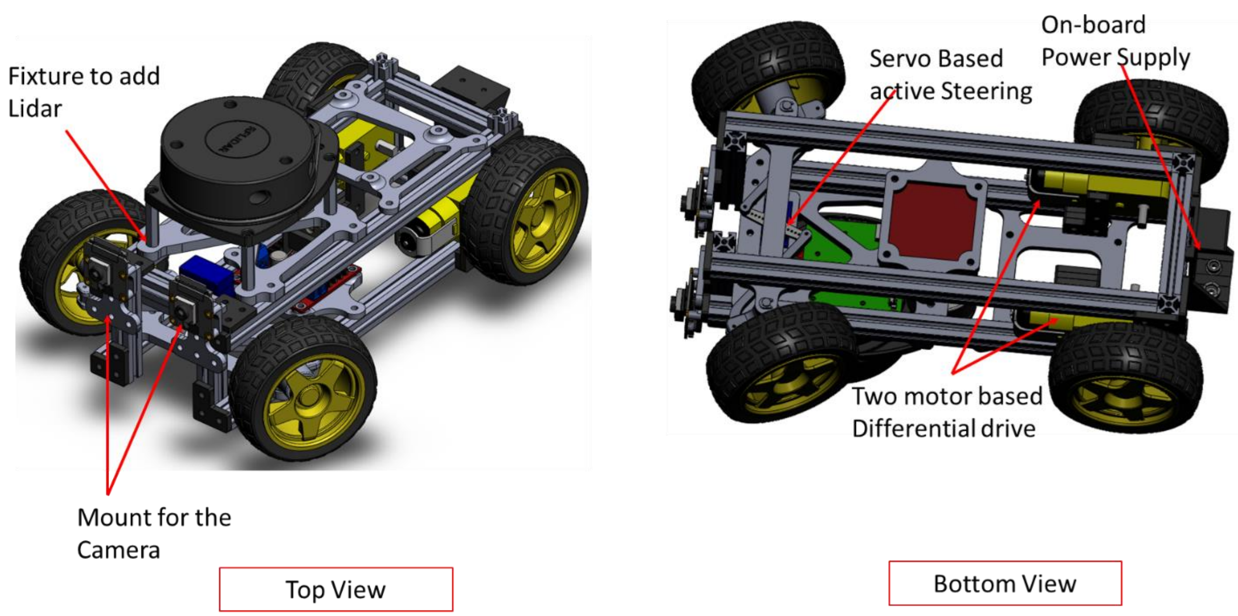


Figure 4 : Cost effective, simpler design by Robotics for Everyone team

The experiment vehicle for ML implementation is an extension of the Robotics for Everyone platform as presented in [1-3]. As described in Figure 4. The steerable robot is extrusion based. Brackets are designed for 3D printing and assembly. The system includes servo driven implementation of Ackerman steering. The steering is servo motor driven. One or more camera will be added for vision control. The rear drive for the robot uses the two DC motor for differential adjustment of the speed. To ensure quick response and accuracy we are using a unique approach. The onboard controller determines the stroke for servo motor. Speeds of rear motors are adjusted to coordinate with the required turning angle. As described in the schematic (Figure 5, Figure 6). The required turning radius for the vehicle and speed are used to estimate a differential multiplier parameter. The differential multiplier parameter calculates the speed for rear wheel. The adjustment to the speed ensures that between the steering and differential speeds, the robotic vehicle maintains a common center of rotation.

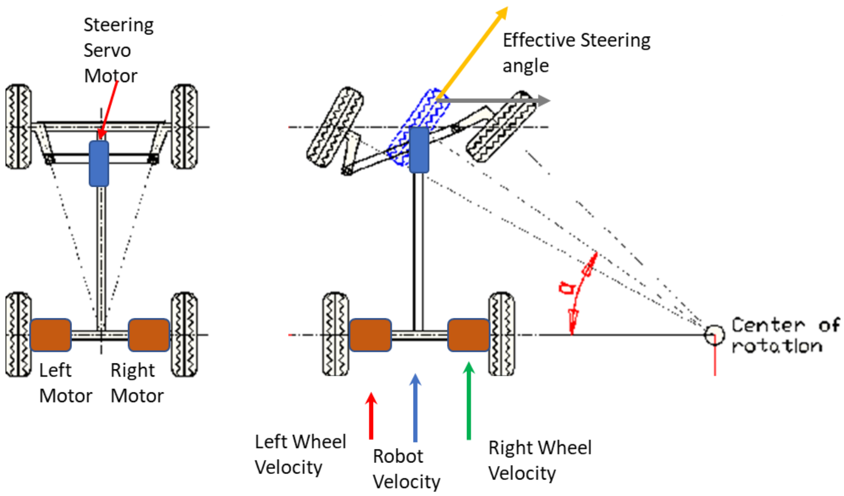


Figure 5 : Kinematics for vehicle navigation

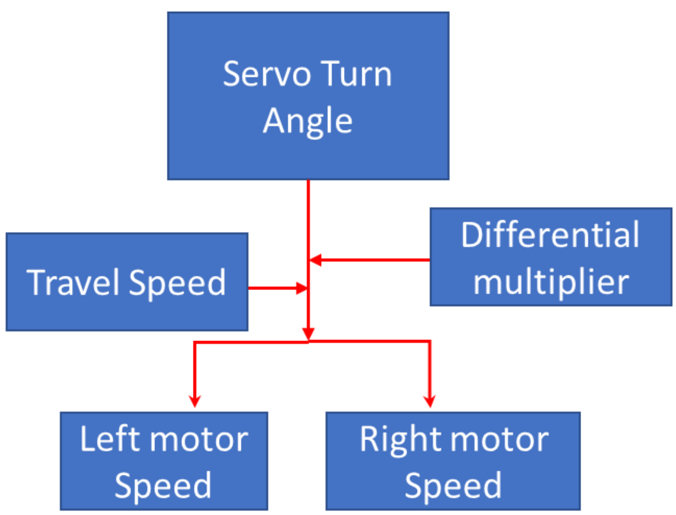
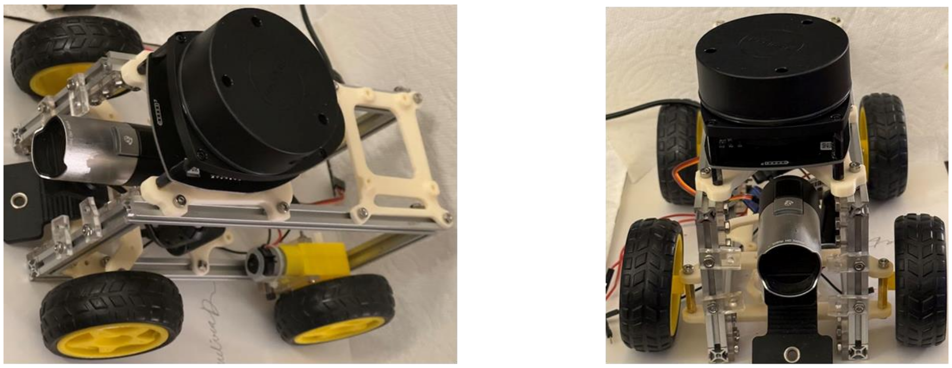


Figure 6 : Navigation schematics

The vehicle includes mounting features for adding single or two (for stereo vision) cameras compatible with microcomputers such as raspberry Pi. The brackets can be removed and alternate bracket can be attached if user wishes to use other commercial off the shelf camera. The system can be expanded to add hobby grade LIDAR. The platform allows integration of range of controllers such as RPI, Beagleboard or Jetson. The placement of power supply and different components is done to ensure that the center of gravity is within the span of 4 wheels and system is stable through the acceleration, deceleration and turns.

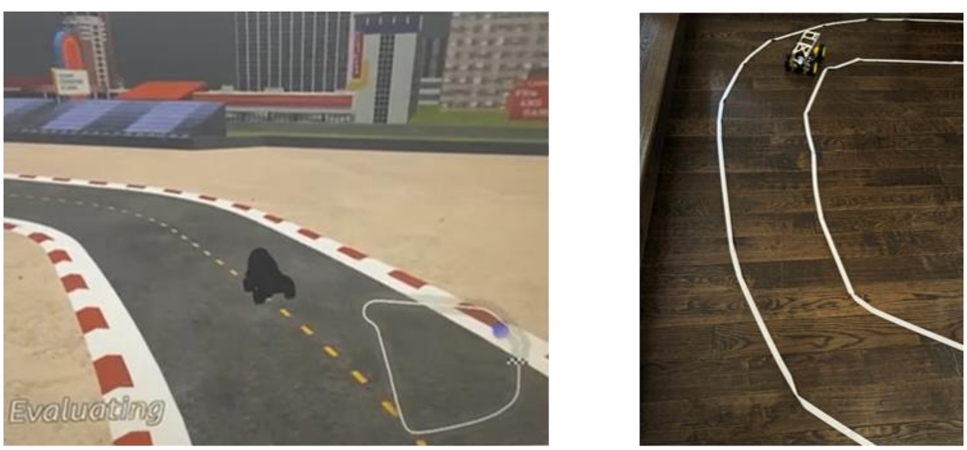
Manufacturing and testing of the platform



1. The controller board and power supply is not assembled to show the features
2. Single commercially assembled MS-HD Camera is used for vision

Figure 7 : Robotics for Everyone platform built using extrusions and 3D printed parts

The parts were manufactured using Stratasys Fortus 450mc. We used ASA material with different tip thickness for different parts. We used T40, thick tip for the sensor mounting brackets and other structural elements. We used T16, thin tip for manufacturing smaller parts such as connecting rods for the steering.



a. Virtual Environment b. Testing

We adjusted the parameters and implemented an ML based path following algorithm using the AWS DeepRacer console (An AWS Machine Learning). We trained a custom reinforcement learning model for autonomous racing by using the AWS DeepRacer console integrated with SageMaker. Additionally, we have implemented the use of machine learning to adapt to various environments. These models communicate with the vehicle's onboard computer to plot various trajectories across the environment, allowing for the vehicle's efficient navigation. Onboard computer is directly networked to the cameras. The camera captures real-time images of the track which are then processed using a Convolutional Neural Network (CNN) to identify key features of the track layout. We borrowed from the Amazon DeepRacer platform and utilized deep reinforcement learning to navigate autonomously. We implemented Proximal Policy Optimization (PPO) which uses small step-by-step procedures to produce more consistent results. The robot is awarded points for staying within bounds, minimal breaking, and a high average speed. It will also be penalized for leaving track bounds or frequently breaking. Through many iterations of these simulations, the robot used previously high scoring runs as a basis for newer runs, allowing the robot to recursively build upon itself to achieve the most accurate and efficient path.

Conclusions

Continuing from the original vision of Robotics 4 Everyone, we developed and demonstrated means to implement ML and vision based learning platforms. The Platform is an extension of the existing modules and uses the same parts. The Camera, high end control boards, and LIDAR can be mounted using 3D printable parts.Current implementation uses rather complex and computationally intensive AWS ML. We plan to customize and implement simpler libraries in order to make it available to learners.

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