Modular Automated Guided Vehicle

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Abstract:
Rover Works is a Modular Automated Guided Vehicle that targets a retail price near two thousand dollars to bring flexible warehouse automation to small facilities that handle light loads. The base unit carries a payload of thirty pounds at four miles per hour for at least two hours on a twelve-volt system and can drive interchangeable top modules, including a pin docking unit and a conveyor module. Power sizing, structural analysis, and subsystem testing confirm adequate torque, stability, and safety margins, showing that low-cost modular warehouse automation is both practical and economically attractive.

Introduction

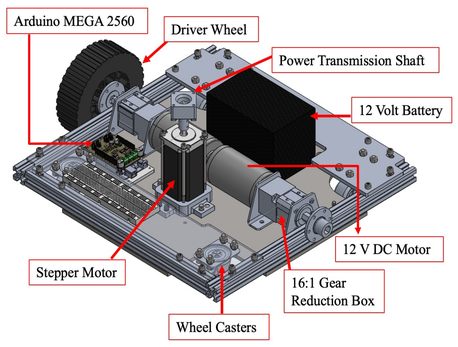
- Many small warehouses still rely on manual carts and labor.
- Existing automation is often too expensive, too complex, and designed for very large facilities.
- Our MAGV is affordable, easy to reconfigure, and simple to integrate into existing warehouse layouts.
- This project demonstrates a low-cost base vehicle with two plug in modules (a conveyor and a pins docking unit) as a proof of concept for scalable modular automation.

Mechanical Design and Methods

Note: CAD models were created in SolidWorks. Parts were manufactured in the Purdue ME machine shop.

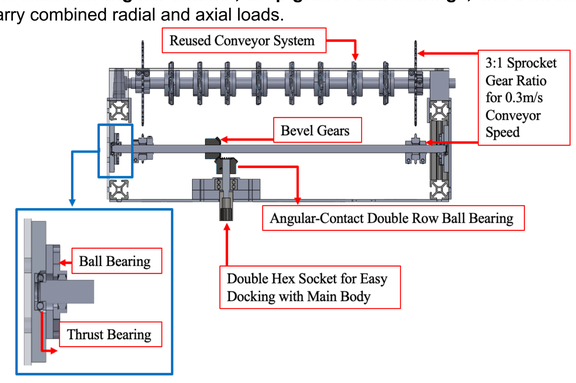
Main Body and Drivetrain:

- **0.25-in hot-rolled steel baseplate** for stiffness and easy fixturing of components.
- **80/20 extrusion frame** for fast assembly, reuse of existing stock, and easy maintenance.
- Two **12-V DC motors with 16:1 gearboxes** drive the wheels; supported by four casters.
- A **NEMA-23 stepper motor** drives a **hexagonal modular shaft** that sends mechanical power to the top modules.
- **Arduino Mega 2560** controls drive motors and stepper while line following and actuating.
- **Five IR line following sensors** and **four ultrasonic sensors** provide navigation and obstacle avoidance.



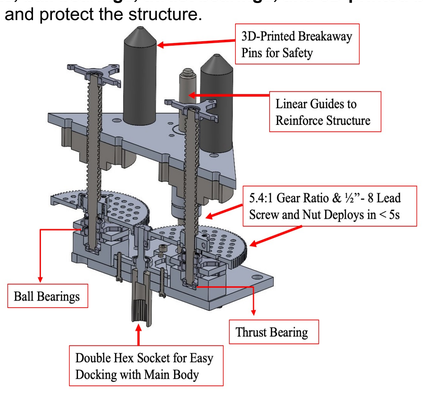
Conveyor Module:

- Reuses an existing **roller/belt conveyor** to reduce cost and fabrication time.
- Uses a **chain and 3:1 sprocket reduction** from the modular shaft to the conveyor shaft, setting belt speed to **0.3 m/s**.
- Supports the shaft with **angular-contact, deep-groove ball bearings, and a thrust-bearing stack** to carry combined radial and axial loads.



Pins Docking Module:

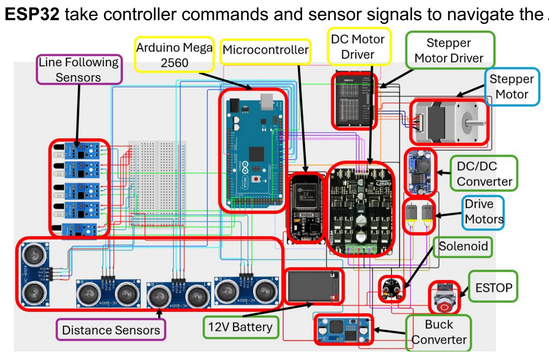
- Four docking pins actuated by **5.4:1 gear ratio** and **½″-8 lead screws**, achieving **55 mm stroke in < 5 s**.
- **Linear guide shafts, ball bearings, thrust bearings, and 3D-printed breakaway pins** maintain alignment and protect the structure.



Electrical Design & Controls

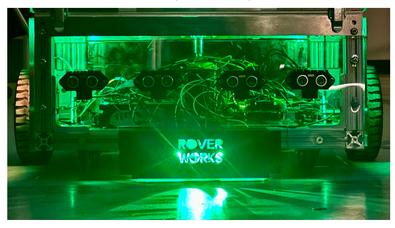
Electrical Design:

- **12V Battery** supplies power to all 5V, 12V, and 48V components through buck converters and DC-DC converter.
- **Arduino and ESP32** take controller commands and sensor signals to navigate the AGV.



Controls Logic Design:

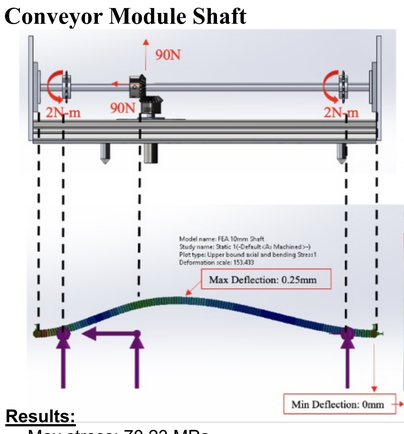
- **PID Controller** reads line sensors to follow black line while stopping for sonar sensors.
- **"T Nodes"** coupled with **Integer Array** tell the AGV when to perform predetermined tasks.
- **Communications Protocols** allow for Manual-to-Automatic states swap while enhancing features such as a dead-man switch and manual driving/actuating.
- **Human Machine Interface (HMI)** allows for simple programming of robot tasks.
- **1116 Lines of Code** (818+298)




```
// PID
integral += error * dt;
if (integral >  INTEGRAL_LIMIT) integral =  INTEGRAL_LIMIT;
if (integral < -INTEGRAL_LIMIT) integral = -INTEGRAL_LIMIT;

float derivative = (error - lastError) / dt;
lastError = error;

float correction = Kp * error + Ki * integral + Kd * derivative;
if (correction >  MAX_CORRECTION) correction =  MAX_CORRECTION;
if (correction < -MAX_CORRECTION) correction = -MAX_CORRECTION;

int leftPWM  = baseSpeedPWM + (int)correction;
int rightPWM = baseSpeedPWM - (int)correction;

leftPWM  = constrain(leftPWM,  MIN_PWM, MAX_PWM);
rightPWM = constrain(rightPWM, MIN_PWM, MAX_PWM);

setMotorSpeeds(leftPWM, rightPWM);
delay(5);
}
```

Structural Analysis

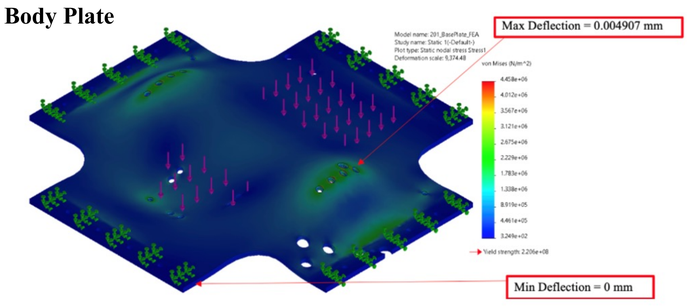
Conveyor Module Shaft



Setup
- Shaft fixed at both ends.
- 90 N upward and axial load due to Bevel Gear.
- Tangential Tension Force applied 55N.
- Two applied end moments: 2 Nm each.

Results:
- Max stress: 70.23 MPa
- Yield strength: 283 MPa (4130 Steel)
- Factor of Safety (FOS) = 4
- Peak deflection **0.25 mm** → meets strength and stiffness targets

Main Body Plate

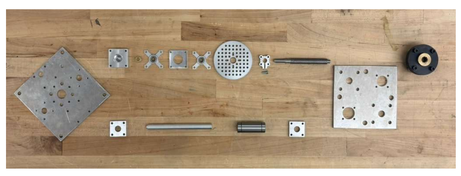


Setup
- Fixed Supports (80/20)
- **Forces:** 200N on Wheels, 30N on Stepper Motor Mount, 50N on the Battery and 100N on the Vertical Supports.

Results
- Max stress: 4.6 MPa
- Yield strength: 220 MPa (4130 Steel)
- Factor of Safety (FOS) = 47

Manufacturing & Assembly

- **127 Parts Manufactured** using 98% recycled raw materials from ME resources.
- **21 Electrical Components** using 80% recycled components in a cost-basis.
- **100% reused fasteners, cables, and 80/20 components.**
- **250+ hours in machine shop** using lathe, mill, water jet, laser cutter, CNC, and others.
- **218 total components** assembled and tested (not including fasteners).



Testing & Results

Testing & Functions:

- **HMI Relays Instructions to MAGV** accurately and intuitively.
- **PS5 Controller Allows for Manual Operation** and switch to Autonomous mode.
- **MAGV Understands Nodes** by accelerating, turning, and actuating.
- **MAGV Follows Line and avoids obstacles** while achieving 4MPH speeds.
- **Up to 50lbs** payload capacity tested for both module configurations.
- **0.3m/s** conveyor speed and **3.2s** for full pins deployment.

Results and Market Feasibility:

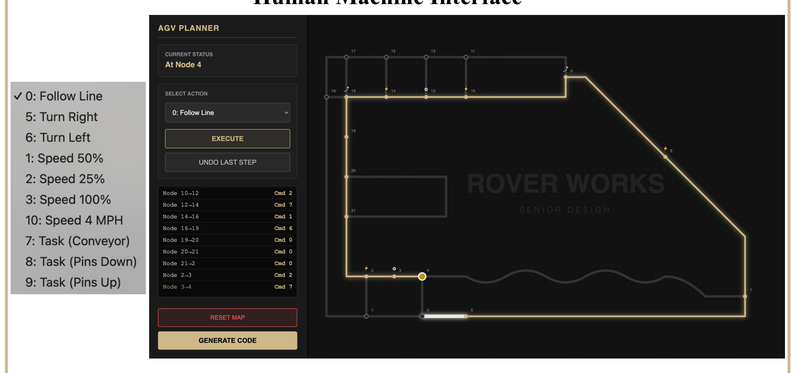
- **$1750 BOM** achieves affordability targets.
- **Net $734.35 budget** greatly efficient due to strong repurposing and recycling mentality.
- **$2,000 selling price** after manufacturing costs and economies of scale.
- **Function, speed, endurance, and all other engineering requirements achieved.**
- **Price over 10 times lower** than the nearest competitor.

The Rover Works MAGV proves that small warehouses can commence the adoption of Industry 4.0 technology through accessible engineering solutions, rather than through high-cost traditional automation.

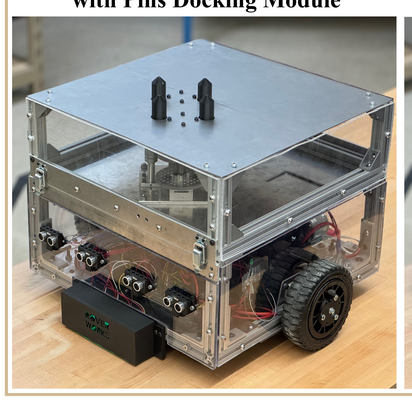
Future Improvements:

- **Direct upload of robot planning** without the need to physically connect to robot.
- **Use of Wiring Harnesses** for simple assembly and product lifetime improvements.
- **Use of highly resistant Magnetic Tape** designed for warehouse environments.
- **Improved Sonar Sensors** for further detection and more accurate readings.
- **More Robust Bearings** for easier assembly and product lifetime improvements.
- **Ease of Assembly Improvements** such as less bolts, easier to access electronics, and quickly removable panels.

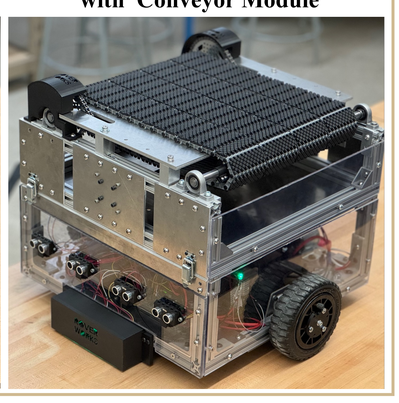
Human Machine Interface



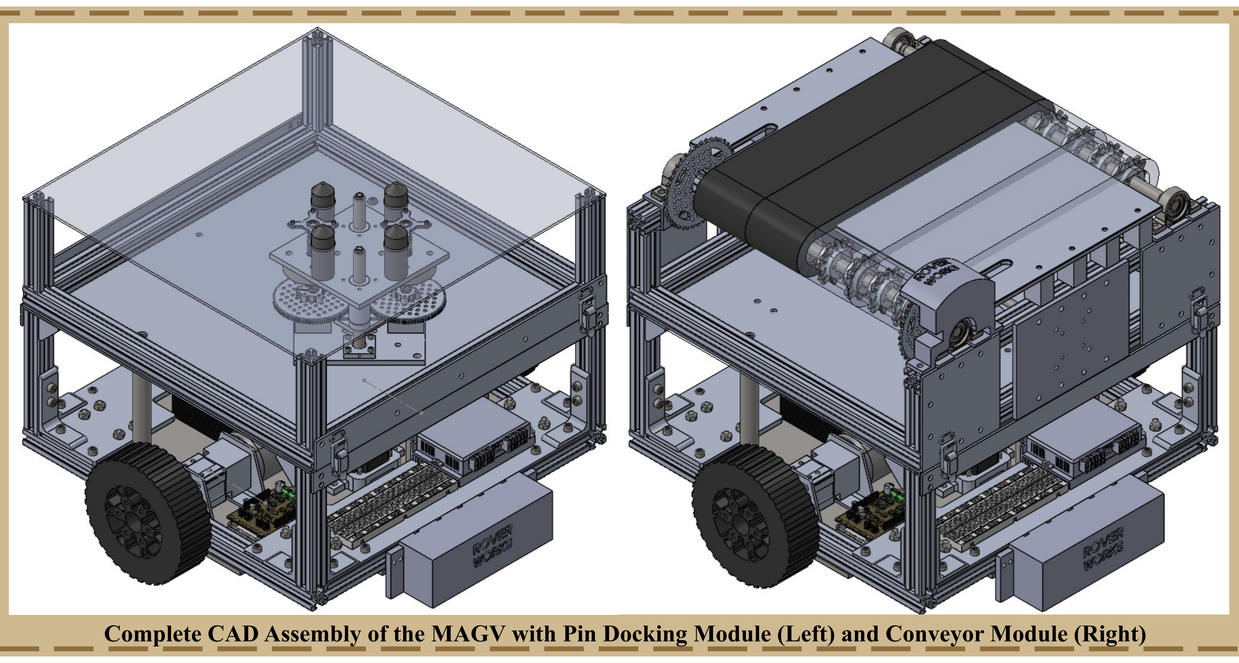
Assembly of the MAGV with Pins Docking Module



Assembly of the MAGV with Conveyor Module



Low-cost Modular Warehouse Robot with Swappable, Motorless Payload Modules



Complete CAD Assembly of the MAGV with Pin Docking Module (Left) and Conveyor Module (Right)