Team 3: RolloCycle

4800 Calhoun Rd

Houston, TX 77004

281-773-4491

December 5, 2016

Subject: Final Report

Dr. Jose Contreras-Vidal

Dr. Steven Pei

4800 Calhoun Rd

Houston, TX 77004

Dear Dr. Contreras-Vidal and Dr. Pei:

On behalf of team 3, I am submitting the enclosed final report, “RolloCycle”, for our capstone design project - a two spherical wheel drive system prototype vehicle.

The focus of this project is to produce a cost-effective, emissions-free method for moving and transporting products, equipment, and consumers in areas with limited maneuverability that is otherwise not suited for traditional methods of transportation.

The team’s target objective was to research, design, and fabricate a remote controlled, self-balancing prototype vehicle consisting of a spherical wheel drive system capable of providing omnidirectional movement within crowded and confined areas.

All required subsystems have been completed and are working properly per our specifications. This includes but is not limited to the reliable communication between all communication peripherals, such as the remote control and tilt sensor, and the systems microcontroller unit.

A few minor concerns were identified during the testing phase of the prototype where the team believes some improvements can be made. This would include the rigid movement of the prototype on the spherical wheels along with refining the inequality range of the reaction angle of the tilt sensor providing for a smoother stability reaction.

Charles Rollo ([cgrollo@uh.edu](mailto:cgrollo@uh.edu))

Michael Wilkerson ([mwilkerson@uh.edu](mailto:mwilkerson@uh.edu))

Alyssa Peloso ([adpeloso@uh.edu](mailto:adpeloso@uh.edu))

Joshua Zavala ([jzavala@uh.edu](mailto:jzavala@uh.edu))

Sincerely,

**RolloCycle Team**

Team 3: RolloCycle

Electrical Engineering Students

University of Houston

Final Report

Team 3

Alyssa Peloso

Charles Rollo

Michael Wilkerson

Joshua Zavala

December 5, 2016

Team Sponsored

Project Manager: Dr. Jose Contreras-Vidal

# Abstract

In areas with limited maneuverability that is otherwise not suited for traditional methods of transportation, one must design a vehicle capable of navigation in these confined areas for moving and transporting products, equipment and consumers. The concept of omnidirectional motion and a spherical wheel drive system inspired our team to design a dynamically stable vehicle capable of self-balancing and move on two spherical wheels. These wheels will provide the prototype vehicle, the RolloCycle, a 360˚ range of motion in the X Y plane and it will use a radio frequency remote control for user input to navigate areas with limited maneuverability

To attain self-balancing, the prototype vehicle will need to be able to determine its orientation. To accomplish this, data will be sent to our microcontroller from a TrueTilt dual axis  electrolytic Tilt Sensor (TS). This TS will communicate with the C2000 Delfino microcontroller (MCU) manufactured by Texas Instruments. The C2000 Delfino is a high performance real time MCU comprised of two independent 32-bit floating-point processors (CPU). The omnidirectional drive system incorporates two identical drive systems each driving an eight-inch spherical wheel through contact friction. Each drive system consists of three NEMA-17 bipolar stepper motors driving a 70[mm] aluminum omniwheel. Controlling each stepper motor will be a DRV8711 gate driver with on-chip 1/256 micro-stepping indexer driving an external Dual N-Channel NexFETTM Power MOSFET H-bridge capable of handling 8[V] – 52[V] input, and providing up to 4.5[A] of continuous current per H-bridge. Navigation will be accomplished by sending remote commands to the prototype vehicle using a Futaba 2.4GHz fourteen-channel RC controller. The power system requirements will be handled by a 44.4[V] 10[AH] Li-ion battery pack with a sophisticated Texas Instruments BQ7690EVM power management subsystem capable of providing critical system status such as faults and remaining capacity to the MCU.

Upon completion of all subsystems, the team overall is sufficiently pleased with the drive system in response to the given the remote control and/or sensor input. However, the rigid contact between the omniwheels and spherical wheels’ results in inadequate movement. The team suggests that the overall design and motor placement should be re-evaluated and/ or adjusted to provide a more precise and fluid movement. Some recommendations include design re-evaluation, fully autonomous, and a full-scale model for human transportation.

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# Introduction

The focus of this project is to produce a cost-effective, emissions-free method for moving and transporting products, equipment, and consumers in areas with limited maneuverability that is otherwise not suited for traditional methods of transportation.

The team’s target objective was to research, design, and fabricate a remote controlled, self-balancing prototype vehicle consisting of a spherical wheel drive system capable of providing omnidirectional movement within crowded and confined areas. All required subsystems have been completed and are working properly per our specifications. This includes but is not limited to the reliable communication between all communication peripherals, such as the remote control and tilt sensor, and the systems microcontroller unit. A few minor concerns were identified during the testing phase of the prototype where the team believes some improvements can be made. This would include the rigid movement of the prototype on the spherical wheels along with refining the inequality range of the reaction angle of the tilt sensor providing for a smoother stability reaction.

# Background

Our team plans to create a dynamically stable vehicle that will be able to self-balance and move on two spherical wheels. These wheels will provide the prototype vehicle, the RolloCycle, a 360˚ range of motion in the X Y plane and it will use a radio frequency remote control for user input to navigate through very tight spaces with its spherical wheels.

The motivation for this project came from a combination of spherical wheel devices or “Ballbots”. A Ballbot, shown in Figure 1; moves on a single ball, not on wheels. A Ballbot can move spontaneously in any direction and does so in a manner as smooth and elegant as a figure skater on ice. [3] The theory which the Ballbot is modeled after is called the inverted pendulum, which aims to keep an inherently unstable system from falling into its stable state by having almost instantaneous response to outside disturbances. [1]

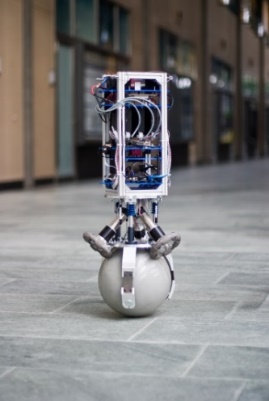


Figure 1: Rezero, The Ball Bot

Although we are not designing a single pivot Ballbot, the theory behind our design is very similar. We are basing our project off of a team of engineering students at San Jose State University (SJSU) who are designing an omnidirectional self-balancing motorcycle. Figure 2 shows a prototype of their project. As of 2012 their project is approximately 85% complete in hardware and 20% complete in software & electrical. [2] The spherical drive system idea is unlike any other robot that can be seen in use today. [1] Figure 3 shows a spherically driven vehicle in futuristic movies such as IRobot.

|  |  |
| --- | --- |
| Figure 2: Self-balancing motorcycle | Figure 3: “I Robot” Robot transport vehicle |

# Target Objective and Goal Analysis

To achieve the target objective, the team has provided a goal analysis outlining the required milestones that need to be completed. Figure 4 below illustrates the breakdown of goals to achieve to produce a prototype vehicle capable of omnidirectional movement in confined/crowded areas.

Goals represented in red boxes were scheduled for completion during the spring 2016 semester and the remaining milestones in white boxes are scheduled for completion during the fall 2016 semester.

The motor controllers synchronize omniwheels milestone was moved from the spring to fall semester and a new goal was added to the spring semester; Individual Motor Control. This change was due to the complexity of programing the new Texas Instruments C2000 Delfino MCU and hardware failures. The scope of our new goal, Individual Motor Control, was modified from our old goal to test each motor controller independently to verify communication and response. After testing, all six motor controllers successfully passed and our goal was completed. Our team then went on to complete the motor controllers synchronize omniwheels, which we felt was the teams’ biggest challenge since it involved system stabilization. Another goal added to the fall 2016 semester was the chassis construction. The chassis design grew to be a much bigger task than we first thought. Therefore, we felt this goal needed to be included in our analysis and since forth has been completed.

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| Figure 4: Goal Analysis for RolloCycle Team 3 |

# Engineering Specifications and Constraints

## Specifications

Our team has outlined the specifications for this prototype vehicle. The vehicle must be able to navigate within a crowded/confined area with omnidirectional motion, and must do so without losing stability. To accomplish this goal the following subsystems must meet several specifications.

1. The power system must be able to provide the required load current within a tolerance of 5%. SMBus communication must be established between the power system and the microprocessor to provide power system status 100% of the time.
2. The drive systems must have enough torque to maintain stability when in motion or at rest.
3. The spherical wheels must have enough grip to maintain the necessary friction between the spherical wheel and the Omni drive wheels to prevent slippage.
4. The self-parking system must be able to detect when the mechanical kickstand has reached its target within a 2% error.
5. Positioning and orientation sensors must be able to detect position and orientation within ±2 degrees, allowing for some margin of error, yet still providing enough feedback for acceptable motor control.

Table 1 provides a complete list of specifications.

Table 1: Specifications

|  |  |
| --- | --- |
| **General** | |
| Size: | 26 x 10 x 10[in] |
| Weight: | 24[lbs.] |
| Runtime: | 30 Minutes |
| Range of Motion | Omni-directional |
| Turning Radius: | 360° ± 1° Drift |
| Payload Capacity: | 4[lbs.] |
| Stability Error: | ± 2° |
| Wireless Operation Range: | 30[m] “98[ft.]” |
| Fail-safe Enabled | |
| **Drive System** | |
| Holding Torque: | 6.5 [kg·cm/motor] |
| Spherical Wheel: | 8 [in. dia.] |
| Voltage: | 24 [VDC] |
| Current: | 3 [A] ~ 8[A] /drive system |
| **Self-Parking System** | |
| Holding Torque: | 0.60 [kg·cm] |
| Voltage: | 24 [VDC] |
| Current: | 0.67[A/Phase] |
| Position Accuracy: | ± 5% |
| **Power System** | |
| SMBus Host Communication |  |
| 12S4P Li-Ion Battery Pack: | 44.4[VDC] ~ 10[Ah] |
| Discharge Current: | 20[A] max |
| Charging Method: | Cell Balancing |
| **Hardware Protection Features** | |
| Overvoltage (OV) | Under Voltage (UV) |
| Overcurrent in discharge (OCD) | Short circuit in discharge (SCD) |
| Secondary protector fault detection | Compensated End-of Discharge Voltage (CEDV) |

## Constraints

The primary constraint for this project is size due to the complexity of the drive system and the lack of resources needed to build a full-size chassis. The following bulleted list identifies the remaining constraints for this project.

* Control System – Synchronizing 6 motors for stability and movement.
* Spherical Wheels – Availability of six-inch spheres with adequate friction coefficient.
* Cost of Motors and Drive System – This is a cost vs efficiency/torque constraint.
* Rechargeable Batteries – Adequate power with limited footprint battery pack.

# Design

The team’s target objective is to design and build a fully functional, remote-controlled and self-balancing prototype vehicle capable of omnidirectional movement within crowded and confined areas. 5 below illustrates the required systems that are designed to achieve this objective.

To attain self-balancing, the prototype vehicle will need to be able to determine its orientation. To accomplish this, data will be sent to our microcontroller from a TrueTilt dual axis  electrolytic Tilt Sensor (TS). This TS will communicate with the C2000 Delfino 32-bit microcontroller manufactured by Texas Instruments. The Delfino provides the necessary processing power we need to handle all the motor control and Real-Time response given the data from our sensors.

The omnidirectional drive system incorporates two identical drive systems with each driving an eight-inch spherical wheel through contact friction. Each drive system consists of three NEMA-17 bipolar stepper motors driving a 70mm aluminum omniwheel. Controlling each stepper motor will be a DRV8711 gate driver with on-chip 1/256 micro-stepping indexer driving an external Dual N-Channel NexFETTM Power MOSFET H-bridge capable of handling 8[V] – 52[V] input, and providing up to 4.5[A] of continuous current per H-bridge.

Navigation will be accomplished by sending remote commands to the prototype vehicle using a Futaba 2.4GHz fourteen-channel RC controller. This controller has unique S-BUS capabilities. The S-BUS allows us to transmit and receive all fourteen channels simultaneously as opposed to transmitting each channel individually. This allows us to reduce the CPU overhead caused by servicing multiply interrupts and in turn, allows for more efficient coding and quicker response times for motor control.

The power system requirements will be handled by a 44.4[V] 10[AH] Li-ion battery pack with a sophisticated Texas Instruments BQ7690EVM power management subsystem capable of providing critical system status such as faults and remaining capacity to the C2000 Delfino MCU.

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| Figure 5: Overview Diagram. Omnidirectional prototype vehicle. |

# Methodology

* Stability System
  + Maintain balance while still and moving
* Low Center of Gravity Chassis
  + Designated space for payload, kickstand and components
* Sufficient Grip between Spheres and Omni wheels
  + Firm position on spherical wheels for optimal movement
* Adequate Power System
  + Cell balanced charging and high current discharge
* Remote Control System
  + Operated via remote control for movement, non-autonomous

# Results

## Prototype Structure Complete

Chassis

The aluminum frame of the prototype is complete and sturdy. The chassis seen in Figures 6 and the motor mounting system seen in Figure 7 underwent a rigorous testing procedure involving repeated drops from a height of four inches to replicate the effects of falling over from stability loss.

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| Figure 6: Chassis Solid Works Design and Main Frame Completion |

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| Figure 7: Motor Mount Assembly Construction |

Components

All necessary components for operation have been assembled: power unit, microprocessor, stability unit, motor drive system and RC system. Figures 8 below shows a 3D rendering of the completed RolloCycle consisting of a top payload area for carrying different items during demo and a lower area for all the required electronics.

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| Figure 8: Model of Complete RolloCycle |

## Remote Control System

System Communication

The system takes commands from the Futaba remote-control system and responds accordingly. The microcontroller receives the motion commands and in turn initiate the required motor control algorithms for the drive systems to synchronize all six motors to rotate both spherical wheels.

## Motor Drive System

System Movement

All six motors accurately responded to the input commands from the Futaba remote controller and rotated with the proper direction and speed.

## Power System

Power Operation

The system operates as necessary, it supplies sufficient power to the prototype, detects faults within the battery cells and shuts down upon detection of critical faults. As well as regulates power so the battery cells do not drain too quickly.

## Stability System

Stability Detection

The tilt sensor adequately detects the orientation of the prototype and collects and transmits this data so that the motors can respond accordingly.

Stability Execution

The drive system adequately responds to the detection of instability while the prototype is still.

# Conclusion

Upon completion of all subsystems, the team is sufficiently please with the remote control and sensor communication with our motors. However, the rigid contact between the omniwheels and spherical wheels’ results in inadequate movement. The team suggests that the overall design and motor placement should be re-evaluated and/ or adjusted to provide a more precise and fluid movement.

# Recommendations

* Design Re-Evaluation
* Full scale model built for human transportation
* Maintain complete stability without the need for training wheels
* Refined algorithms for movement control
* Fully autonomous prototype

# Financial Summary

The total labor costs for the project was $62,400.00 and materials cost for the project was $2,607.96 for a total of $65,007.96. Our targeted labor cost was $57,900.00 and estimated materials cost was $2,200.00 for a total of $60,100.00. As shown in Table 2, our team exceeded both labor and materials cost. These exceeding labor and materials cost were justified by the complexity of the overall project and unforeseen obstacles.

Table 2: RolloCycle Financial Summary



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