Special Vehicle for Transporting Unstable Chemicals
Project Proposal

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1 Introduction

1.1 Motivation

Our team would like to implement a special vehicle (robot) for transporting unstable chemicals. As engineering students who are required to take chemistry courses and perform experiments, we clearly know that safety always has top priority when dealing with chemicals. Besides, proper transportation of volatile substance is also essential for experiments to yield correct results. However, although people treat chemicals with all the care, hazard still exists, maybe in moving a flask from one desk to another in a crowded lab room, or maybe in bringing a freezer from Chemistry Annex to Noyes Lab through the underground tunnel. As a result, we would like to create a transportation tool that fits both compact environment (e.g. lab room) and road transportation. In addition, the project can be extended to other uses such as lunar rover, wheel chair, etc. We are looking forward to see this special vehicle shuttles between Noyes Lab and Chemistry Annex in the future.

1.2 Objective

The major goal for the project is to keep the chassis of the vehicle stable. To reach that, the mechanical system adopts a novel movement scheme that is able to keep the vibration of chassis in a tolerable range with the help of a control system. In order to facilitate the calibrating process during the development stage as well as the performance evaluation afterwards, the system also equips a real-time data acquisition system that transmits sensor readings to a computer for further analysis. So far, the system intends to provide the following features:

1. a four-wheel omni-direction movement scheme
2. a symmetric design that allows any of the four sides of the vehicle to dynamically take over as the forward direction
3. an active suspension system on each wheel
4. a control system that stables the chassis based on the feedback from MEMS sensors
5. a wireless link used for transmitting real-time sensor data to a computer for performance analysis

The project also offers the following benefits:

1. enhancing safety level in road transportation for chemicals
2. easing people's tension when moving dangerous chemicals in the lab

2 Design

2.1 Block Diagram

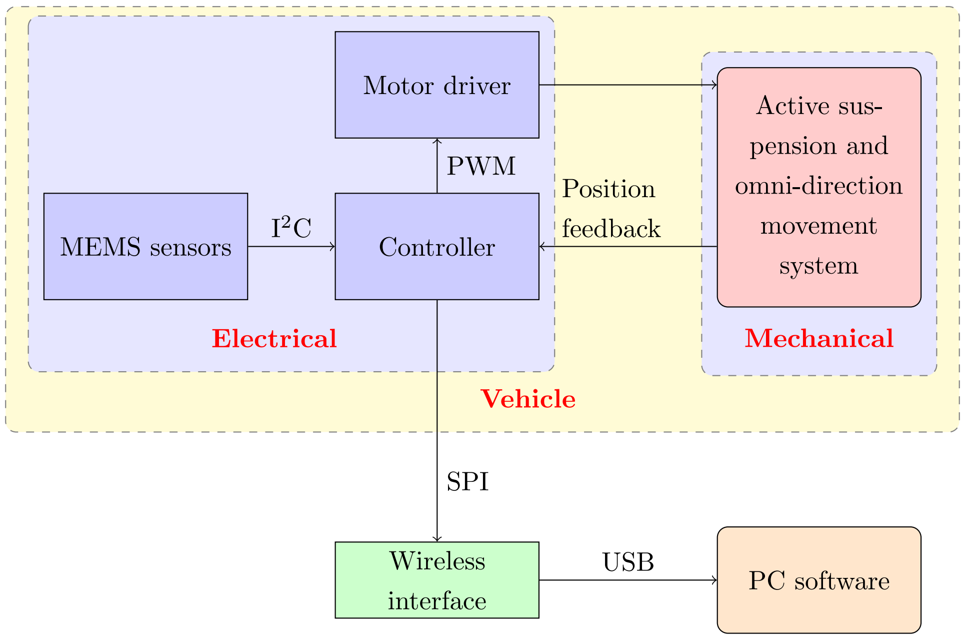

Figure 1: Block diagram

2.2 Block Descriptions

Since the vehicle is the major part of our project, we discuss its components first. The electrical portion on the vehicle consists of three modules:

1. **Controller:** This module includes a microcontroller and components that support its operation, such as power management circuitry. The microcontroller performs the following tasks:

   (a) gathering data from the MEMS sensors and using Kalman filter to reduce noise

   (b) operating the active suspension system according to the sensor readings

   (c) adjusting four wheels to actualize omni-directional movement

   (d) sending real-time sensor data to a PC via wireless

   In order to execute the above tasks simultaneously, we decide to build the program upon a RTOS (real-time operating system).

2. **MEMS sensors:** We will use both accelerometer and gyroscope to measure the state of the chassis. The controller acquires data from them via I^2C protocol.

3. **Motor driver:** We will apply multiple H-bridge motor drivers in the system for driving both the active suspensions and the wheels. In order to achieve optimal efficiency and driving capability, we will not use integrated H-bridges; instead, we decide to implement the circuits using discrete components. The motor controllers adopt PWM (pulse width modulation) signals along with direction signal from the controller.

The main mechanical challenges in the project are the active suspension system and the omni-directional movement system.

1. **Active suspension:** Although hydraulic actuators are preferable for the final product, the reduced-size model system that will be designed this semester uses worm motors to operate the suspension. In order to monitor the current position of each suspension, a potentiometer will be attached to the motor and gives analog feedback that can be read by the controller's ADC (analog to digital converter). The worm motors are driven by the H-bridges described above.

2. **Omni-directional movement:** Since the typical omni-wheels (http://en.wikipedia.org/wiki/Omni_wheel) that are available for purchase vibrates when rolling, we consider to use a servo to adjust the z-axis angle of regular wheels instead. The controller can change the positions of the servos by sending them PPM (pulse position modulation) signals. By designing the whole vehicle symmetric respecting to both x-axis and y-axis, the vehicle can adopt a new forward direction and shifts when it turns. Applying this scheme means that a separate motor is required to drive each wheel, which introduces an issue that different motors may output varied speed. To solve that, the controller can adjust the absolute speed of each motor by reading the encoders mounted on the wheels.

In order to analyze the system performance, the vehicle constantly send the sensor readings wirelessly to a computer. We choose a 2.4GHz RF solution to fulfill the task. The on-vehicle controller can send commands and packages to the RF chip via SPI (serial peripheral interface). On the other hand, another microcontroller handles the computer side RF chip in the same way, and reconstructs the received data into USB (universal serial bus) packages before sending to the computer. A computer software will also be built to visualize the data and to calculate the statistics for further analysis.

2.3 Performance Requirement

Some modules have specific performance requirements.

1. **Controller:** The controller has to perform all the tasks described in the previous section at the same time. Among them, the Kalman filter requires intense calculation. As a result, the RTOS based program has to balance the computing power for different tasks so that all of them can run smoothly without interfering each other.

2. **MEMS sensors:** After applying the Kalman filter, the resulting data have to eliminate most of the noises in the unprocessed ones.

3. **Omni-directional movement:** With the help of the encoder, the four-wheels should rotate at the same speed when moving straight forward, and modify their speed respectively when encountering uneven surface.

4. **Active suspension:** The suspension has to respond to uneven surfaces within 0.3S. The maximum dynamic tilt angle between the chassis and the horizontal surface has to be constrained in 5 degree.

3 Verification

3.1 Testing Procedures

The functionality of the suspension is tested by the following procedure:

1. Prepare several ramps with different slopes.

2. Run on the ground without ramps and collect sensor data, comparing with the data after Kalman filtering.

3. Test the stability when run one wheel over the ramp.

4. Use the same ramp and run two, three and four wheels over it.

5. Change the slope of ramp and do the above step again.

6. Run over the ramp when the car is turning.

7. Add on different weight and do the above step again.

3.2 Tolerance Analysis

Slope of the surface, change of the slope in a certain area, and the velocity of the vehicle are the factors that will affect the performance of the vehicle. If the slope of the surface is in great magnitude, as the vehicle raising its wheel to adapt to the slope, eventually the wheel may be raised to its maximum there is no room for adaption, thus the chassis will have contact with the slope. This is a rare case, but we decide to make the maximum slope of operation to be 50±10 degrees. In addition, if there is very dramatic change of slope on an uneven surface, there may be malfunction. Currently we are unable to define this limit. Velocity also has big effect on the performance. When operating on a high velocity, it is more difficult to achieve stability, especially for this small vehicle. The active suspension system requires time to adjust itself. In our design and testing, the maximum velocity used is around 15cm/s.

4 Cost and Schedule

4.1 Cost

1. **Labor:**

   Zhangxiaowen Gong: \$35/hr × 12hr/week × 10 weeks = \$4200

   Wenjia Zhou: \$35/hr × 12hr/week × 10 weeks = \$4200

   Jun Ma: \$35/hr × 12hr/week × 10 weeks = \$4200

   Total: \$4200 × 3 = \$12600

2. **Parts:**

Part name	Unit cost	Number required	Subtotal
AVR32 microcontroller	\$10	1	10
AVR8 microcontroller	\$5	5	\$25
Worm motor	\$10	4	\$40
Servo	\$10	4	\$40
DC motor	\$10	4	\$40
Encoder	\$2	4	\$8
RF module	\$10	2	\$20
Accelerometer	\$10	1	\$10
Gyroscope	\$10	1	\$10
PCB	\$20	4	\$80
Misc. components	N/A	N/A	\$20
Total			\$303

Table 1: Itemized budget

   Note: machine shop cost is not covered.

The total expense is \$12600 + \$303 = \$12903

4.2 Schedule

Time	Task	People in duty
2.5-2.11	Write proposal	Jun, Wenjia Andy
2.12-2.18	Build the chassis and mechanical part of the car	Machine Shop
	order components	Andy
2.19-2.25	Derive the dynamics of the electric machine active suspension system;	Jun, Wenjia
2.26-3.3	PCB design	Andy
	Design the feedback control algorithm for the active suspension system;Implement Kalman filter	Jun,Wenjia
3.4-3.10	Simulate the design using MATLAB	Wenjia
3.11-3.17	Solder and test PCBs Tune PID parameter to reach the desired performance	Andy Jun
	Implement device drivers	Andy
3.18-3.24	Implement the PID control in C	Wenjia
	Implement the wireless communication and RTOS based embedded programs	Andy
3.25-3.31	Verify the design on the car	Jun, Wenjia ,Andy
4.1-4.7	Test the design under different scenario	Jun, Wenjia, Andy
4.8-4.14	Tune PID parameter again if needed	Jun

Table 2: Schedule