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Mechatronics Design of an Unmanned Hovercraft System

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ABSTRACT

Recently, an efficient transportation system is required due to the reducing energy sources. One of the alternative solutions is the use of hovercraft for transportation system. The hovercraft is an efficient system since it is almost a frictionless system. In addition it also can hover on a variety of terrains such as on land, river and sea. However the frictionless condition of the hovercraft causes the difficulty of controlling its trajectory motion. To overcome this problem, this paper describes the mechatronics design approach in the design and development of an automatic hovercraft system. The mechatronics design approach is primarily based on the synergistic integration of mechanical and electronic elements coordinated by control architecture. A prototype of a hovercraft is design and developed. Moreover, for controlling the motion of the hovercraft, an automatic control system is designed and developed. The automatic hovercraft is tested experimentally to follow a certain trajectory. The experimental result shows that the motion of the hovercraft successfully follows the desired path motion.

Keywords: *Automatic, design, hovercraft, mechatronics, unmanned*

Introduction

Due to the limitation of the energy sources, efficient transportation systems are highly demanding. One of the alternative solutions is the use of hovercraft for transportation system. A hovercraft, or an air cushion vehicle, is a vehicle which is suspended upon a cushion of air. The air cushion is provided by a fan that pushes air downward within a flexible 'skirt' attached to the perimeter of the vehicle. The skirt maintains the cushion by restraining the air. Thus the craft floats above this cushion, due to a phenomenon known as the ground effect (Fitzgerald & Wilson, 1995). The hovercraft is then propelled by a propeller or by control of the air exhaust through small openings around the skirt.

The hovercraft travel close to, but above ground or water, therefore it is virtually frictionless. The hovercraft is an efficient transportation system since it can attain higher speeds than can either ships or most land vehicles and use much less power than helicopters of the same weight (Fitzgerald & Wilson, 1995). In addition it also can hover on a variety of terrains such as on land, river and sea. Most of the hovercraft which exists today for use travel on water. Hovercrafts ride much smoother than boats because they travel over the surface of the water, not through it – and also since the skirt also acts as a suspension. It travels over water with no concern for depth or hidden obstacles and go against the current of a river with no speed reduction. The hovercrafts also work well in rapids and white water, making it an excellent rescue vehicle, see http:// hovercraft.com/index.html. However, the hovercraft is an underactuated system, which is a system with a smaller number of control inputs than the number of controlled outputs.

Due to the fact that the hovercraft is an underactuated and also frictionless system, it is difficult to control the motion of the hovercraft. To overcome this problem, this paper describes the mechatronics design approach in the design and development of an automatic hovercraft system. The mechatronics design approach is primarily based on the synergistic integration of mechanical and electronic elements coordinated by control architecture. A prototype of a hovercraft was designed and developed. Moreover, for controlling the motion of the hovercraft, an automatic control system is designed and developed. The automatic hovercraft is tested experimentally to follow a certain trajectory. The experimental result shows that the motion of the hovercraft successfully followed the desired path motion.

Mechatronics Design Approach

The goal of a mechatronic approach is to take advantage from an integrated design combining mechanical, electronic and computer elements which is coordinated by a control algorithm. The concurrent design for mechatronic system consists of three phases namely modeling, prototyping/ testing and deployment (Shetty & Kolk, 1997). Figure 1 shows the detail of the three phases of mechatronic design process. These three phases of mechatronic design process can be repeated until the results are satisfactory.

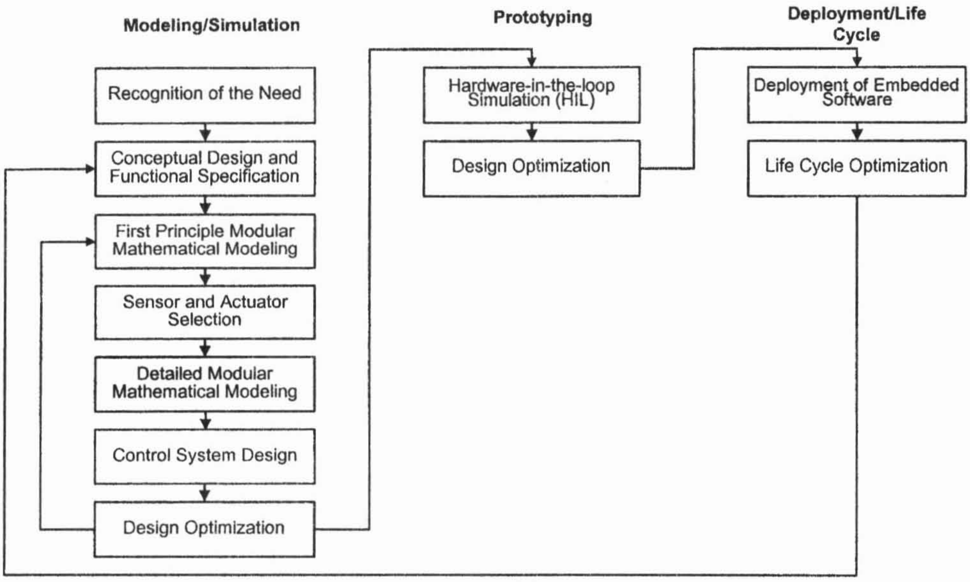

Figure 1: Mechatronics Design Process

Modeling, which is the first phase in the mechatronic design approach, is to analyze the goal of the project and the technical environment in which system is integrated. Normally a block diagram is used to create intuitively understandable behavior models of the system. In this phase, a mathematical model of each component is derived and then used to analyze and predict the system performances. Software such as ACSL, SIMPACK, MATLAB/Simulink, VISIM and MATRIX-X is useful and valuable for allowing the designer to study the interaction of components and the variation of design parameters before manufacturing.

Unfortunately it is usually very difficult to build an exact mathematical model for complex mechatronics systems including sensors and actuators. However, there is no single model which can ever flawlessly reproduce reality. There will always occur unmodeled errors between behavior of a product model and the actual product (Shetty & Kolk, 1997). These unmodeled errors are the reason why so many model-based designs fail when deployed to the product.

In order to take into account the unmodeled errors in the design process, the mechatronic design approach includes prototyping phase. In this phase, actual hardware is used to replace part of the model of each subsystem. On-board diagnoses of the signal processing, controlling and translating subsystem should be made in this phase. Each subsystem can be built and tested individually by adopting the concept of HILS. Basically HILS refers to a computer simulation in which some of the components of the simulation have been replaced with actual hardware. The actual hardware used in the HILS depends on the purpose of prototyping as shown in Table 1. This approach increases the realism of the simulation with a lower cost compared with a fully built prototype. In addition, with a functional prototyping using HILS approach it will able to emulate the mechatronics system in real time, change and test quickly new algorithm and detect errors and bottlenecks in the system specification at an early design state.

Table 1. Different Configuration of HILS

Actual Hardware	Mathematical Model	Purpose
Sensors Actuators Plant	Control algorithm	Modify control system design subject to unmodeled errors and machinery errors.
Sensors Actuators Controllers	Plant	Evaluate validity of plant model

Finally, the last phase of the mechatronics design approach is deployment in which the control code used on the embedded processor of the final product is coded and subsystems are connected to complete the full integrated mechatronic system.

Mechanical Components Design

Basically a hovercraft consists of a hull, one or more actuators to generate lifting cushion, and one or more actuators to provide forward thrust. In addition, there are a skirt around the hull perimeter to maintain the air cushion and steering mechanism to control the movement direction.

Hull and Skirt Design

A rectangular hull with the ratio of length to width of 2:1 is selected as the basic structure of the hovercraft. The hull has to be designed such that it provides the structural strength to carry its own weight and the payload. It also needs to be strong enough, yet lightweight, in case of impact. Figure 2 shows the isometric view of the designed lab-scale hull including its important dimensions.

Moreover, the type of skirt used is also important for hovercraft design. The bag/loop skirt is chosen due to the ease of making and installing it. A simple diagram showing this skirt diagram is shown in Figure 3. The skirt needs to be flexible and should contain the air under the hovercraft. The skirt material chosen was simple plastic. This is because plastic is a simple and cheap material. Different parts of the skirt were cut and then glued together onto the hovercraft, making it a whole bag like structure.

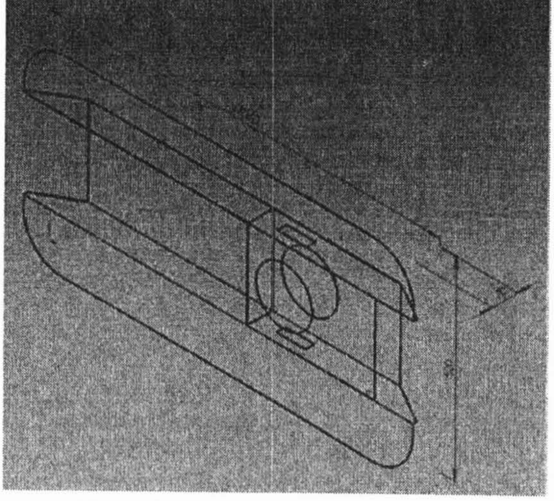

Figure 2: Isometric View of the Hull

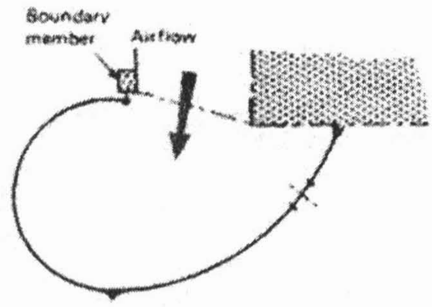

Figure 3: Loop / BagsSkirt

Steering Mechanism Design

There are two main types of turning mechanism that are used frequently; namely the simple rudder mechanism and the differential thrust mechanism. Here differential mechanism driven by two motors as shown in Figure 4 is used to control the motion direction of the hovercraft. The differential mechanism uses two thrust units instead of just one as in the earlier case. The difference in the two thrusts causes the turning as illustrated in Figure 4.

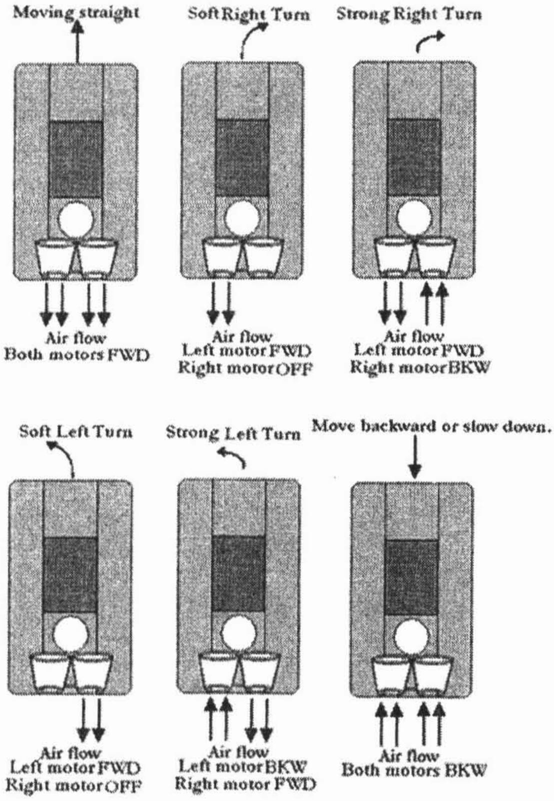

Figure 4: Differential Turning Mechanisms.

Actuator and Sensor Selections

Steering Mechanism Design

Hovercrafts are supported by a fluid air, which allows the hovering with little or no friction. The amount of air pressure that is needed is directly related to the weight of the craft. Therefore, the less the weight is for a hovercraft, the less the air pressure required, which in turn results in energy savings. The following equation is used to calculate the required cushion pressure

$$P_c = \frac{W_h}{A}$$

where P_c, W_h and A are cushion pressure, hovercraft weight and surface area respectively. This cushion pressure is supplied by fan driven by a DC motor. Furthermore, by considering the perimeter of the designed hovercraft equal to 3,16 and its weight of 5 kg, DC Motor of MABUCHI Sport RS540 is used since it satisfies the equation. The same DC motors are also used for generating thrust force as well as turning mechanism.

Moreover, motor drivers are also designed to drive the motor speed and direction through a command from the controller. The motor drivers were developed using the combination of power relays and MOSFETs as shown in Figure 5. This unique combination allows very high current to flow and also fits all the requirements for the design specifications.

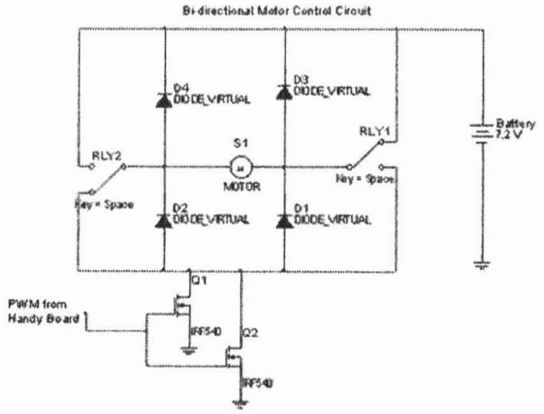

Figure 5: Bi-directional Motor Control Circuit

Sensor Selection

Sensors are needed to realize an automatic hovercraft. Here line detecting sensors are required to detect the line, which is used to guide the hovercraft motion. A low LDR-based line detecting sensors were designed as shown in Figure 6. The design of the sensor proved to be extremely useful since it can also be used in brighter surrounding with a little change of LED and LDR arrangement. This type of sensor can be used in any line detecting robots since it can provide very good results with variable lighting conditions as well variable distance from the line. The hovercraft was thus designed to have four sensors in which two sensors are placed in the front and the other two sensors at the back. The sensor arrangement is as shown Figure 7.

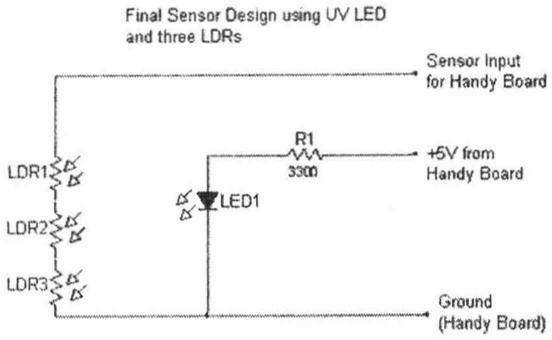

Figure 6: LDR-based Line Detecting Sensor.

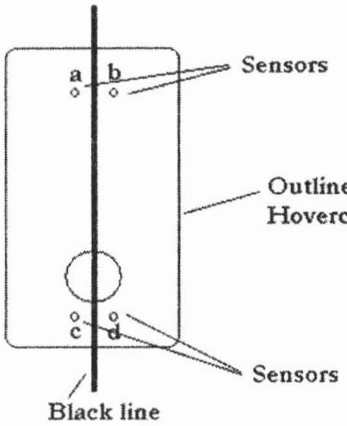

Figure 7: Sensor Arrangements in the Hovercraft.

Controller Design

The controller used for this project is the Handy Board controller. The Handy Board is a hand-held, battery-powered microcontroller board. Based on the Motorola 68HC11 microprocessor, the Handy Board includes 32K of battery-backed static RAM, outputs for four DC motors, inputs for a variety of sensors, and a 16_2 character LCD screen. The Handy Board runs Interactive C, a cross-platform, multi-tasking version of the C programming language. The Handy Board is distributed under MIT's free licensing policy, in which the design may be licensed for personal, educational, or commercial use with no charge. A schematic diagram showing the basic parts of the Handy Board is as shown in Figure 8. The basic inputs for controlling the hovercraft motion are deviations from white line and the deviations is used to control the magnitude and direction of the motor speed of the differential thrust mechanism.

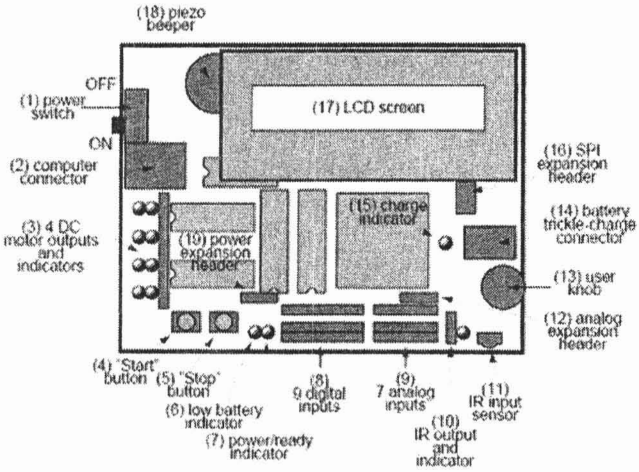

Figure 8: Handyboard.

The movement of the hovercraft is controlled based on the information of the line detecting sensors. The possible different inputs of the line detecting sensors are as shown on Figure 9. For example, Figure 9 shows that sensor 'a' is sensing the line only and the other sensors have not yet sensed a line. In this condition, thus, the output will turn Soft Left Turn.

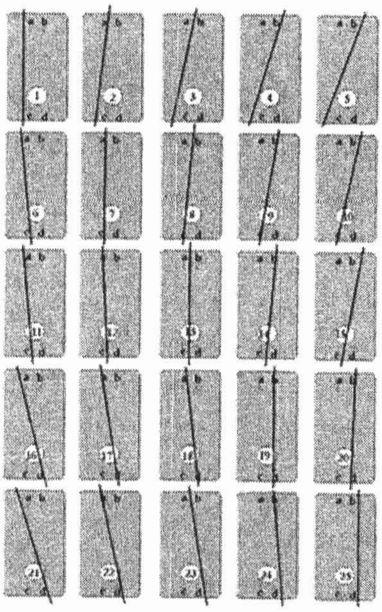

Figure 9: Different Possible Inputs

Testing and Discussion

Following the mechatronics design approach as discussed previously, the prototype of the automatic hovercraft finally is developed and built as shown in Figure 10. In summary, the hovercraft is driven by DC motors for both hover and forward movement. Moreover, Handy Board is used to controller hovercraft movement based on the information from the line detecting sensors.

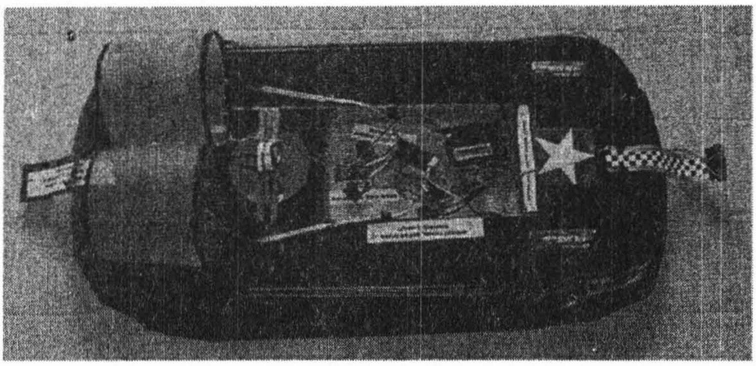

Figure 10: Prototype of Unmanned Hovercraft

The performance of the automatic gantry crane is tested in the laboratory to follow a track as shown in Figure 11. The black line covers the floor in a predetermined fashion, consisting of straight lines and turns to observe the automatic turning of the hovercraft. Initial testing shows that the automatic hovercraft works properly. The hovercraft can hover as well as move forward. However, by using current controller, the hover craft only successfully follows the desired motion when the hovercraft moves with a low speed. In the case of the maximum speed, it fails to follow the track especially during cornering. Further improvement in the controller part has to be done.

Figure 11: Desired Hovercraft Motion Trajectory

Conclusion

The mechatronic design approach has been used for designing the automatic hovercraft. The designed system is a fully integrated mechatronic system since it is a synergic combination of the mechatronic and electronic components coordinated by control algorithm. A lab-scaled automatic hovercraft was developed and tested. The initial testing shows the automatic hovercraft work well. Further improvement is needed so that it can work at a higher speed.

References

Fitzgerald, C. & Wilson, R. (1995). *Light hovercraft design (3rd ed.)*. Hoverclub of America.

Shetty, D. & Kolk, R.A. (1997). *Mechatronics system design*. PWS Publishing.

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