Wheeled Blimp : Hybrid Structured Airship with Passive Wheel Mechanism for Tele-guidance Applications

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This paper presents a novel design of indoor airship having a passive wheeled mechanism and its stationary position control. This wheeled blimp can work both on the ground using wheeled vehicle part and in the air using the floating capability of the blimp part. The wheeled blimp stands on the floor keeping its balance using a caster-like passive wheel mechanism. In tele-guidance application, stationary position control is required to make the wheeled blimp naturally communicate with people in standing phase since the stationary blimp system responds sensitively to air flow even in indoor environments. To control the desired stationary position, a computed torque control method is adopted. By performing a controller design through dynamic analysis, the control characteristics of the wheeled blimp system have been found and finally the stable control system has been successfully developed. The effectiveness of the controller is verified by experiment for the real wheeled blimp system.

Key Words : Blimp, Wheeled Vehicle, Tele-Presence, Stationary Position Control, Computed Torque Control Method

1. Introduction

In the field of intelligent mobile robotics, design of various wheel mechanisms, sensing and intelligence have been actively developed in the past decades. Most current wheeled mobile vehicles, however, have limitation in the capability of traveling on uneven ground surface such as stairways. Some specially designed wheeled vehicles are able to climb up uneven surface, and yet their mobile capability still have limitations in performance such as climbing-up angle, speed and so on. In order to overcome the limitation of wheeled mobile robot in the uneven floor, therefore, balloon type blimps with several thrust motors have been developed and are commercially available.

Interest on UAV (unmanned aerial vehicles) has grown in the past few years in terms of increasing their use on surveillance, exploration, monitoring, advertisement, telecommunication and transportation tasks. Especially there is a growing interest in dormant LTA (lighter-than-air) vehicle according to the advantages of LTA

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vehicle. Advantages of LTA vehicle are the following : low speed flight, small supply of power, vertical take-off and landing, harmony of environment, human friendliness and so on. In earlier times of 1900s, structure of a blimp was nearly established. Various researches on flight character of a blimp and manufacture of an autonomous blimp have been performed during the past few years.(Gordon and Ivan, 1997 ; Gabriel and David, 1999 ; Ely et al., 1998 ; Sjoerd et al., 2000 ; Lee, 2001) Among the various kinds of UAVs, a small indoor blimp filled with gas lighter than air can float and rove in space by using some thrust with motor-driven propeller. However, it is quite difficult to control the blimp to keep a stationary position in space since the blimp is largely affected by change of airflow, temperature and humidity.(Eric and John, 1998) To solve this problem in blimp, design of a new blimp is attempted in this work.

The conventional tele-operation technology recently tends to evolve to tele-presence which extensively utilizes multimedia communication as well as the information of motion and haptics. (Goldberg et al., 2002) From the rapid technological progress in internet, wireless communication, data compression and microprocessors, the tele-presence technology using a robotic embodiment rather than using only audio/visual information is evolving nowadays. For instance, the video conferencing exchanging only audio/visual information is not enough to fully communicate with each other. If a physically embodied robot can play a role of intermediate for communication between the remote users through gazing, indication and expressing gestures, it is possible for the users to exchange their intention more completely. This is an important aspect of the tele-presence technology. However, the excellent design of the agent robot for the tele-presence is not presented yet. Therefore the need for the design of agent robot suitable for tele-presence is being emerged which breaks through the limitation in conventional wheeled vehicle.

In summary, this research focuses on design and control of a wheeled blimp for tele-presence which is free from the limitation of obstacles on the floor. By taking advantage of the hybrid structure with a blimp and a wheeled vehicle, the problem in keeping a stationary position on the floor becomes easier. As well, by attaching various multimedia devices for audio/visual communication, the wheeled blimp can be used as a low-cost and lightweight agent robot for telepresence applications.

This paper is organized as follows. Section 2 describes a design concept of the wheeled blimp. Section 3 describes its dynamic modeling in standing phase and controller design for keeping the stationary position. In section 4, experimental setup of the wheeled blimp control and its results are described. Some design variations for teleguidance applications based on the design concept of the wheeled blimp are additionally presented and discussed in Section 5. Finally concluding remarks and discussion are contained in Section 6.

2. Design of Wheeled Blimp

The blimp is usually denoted as a small indoor helium gas airship actuated by electric motors. It can be regarded as a flying robots having aerostatic lift by the density difference between air and helium gas filled in the envelope. Helium is the most commonly used lifting gas. At sea level in the International Standard Atmosphere, a pure helium gas generates a unit lift of 10.539 (N/m^3).

In this work, the wheeled blimp (WB) is newly designed as a hybrid structure composed of an envelope filled with helium gas and a wheeled vehicle part. The design concept is depicted in Fig. 1.

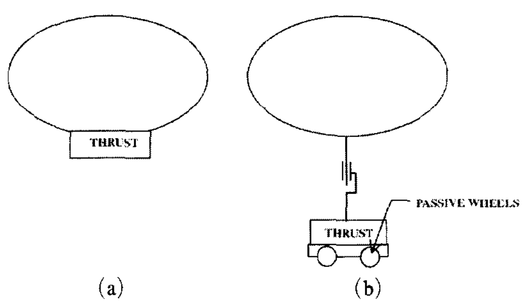


Fig. 1 Normal blimp (a) and Wheeled blimp (b)

The WB can work both on the ground using the passive wheeled vehicle part and in the air using the floating capability of the blimp part. The passive wheeled mechanism in the vehicle part assists the stable taking off, landing on the floor keeping a stationary position on the floor. Because the wheeled vehicle part has omni-directional wheels, the WB is able to move any directions. When the WB with wheels stands on the floor, some of degrees of freedom of the WB can be reduced. Thus the degrees of freedom of the WB are less than those of a normal blimp. That makes a stationary position control easier and there is a possibility to decrease the number of actuators for the control.

The weight of the WB is tuned to be slightly heavier than the buoyancy of the blimp at rest. Normally the WB stands on the floor keeping its balance. Namely, the floating force of the WB is achieved by the lift generated by propeller of the wheeled vehicle.

Using a large surface area of a blimp's envelope, the WB can be used as an agent robot with a large video display. The design variation of this big display will be addressed in section 5. Using multimedia devices such as cameras, speakers, LCD and microphone mounted on the blimp surface, additionally, this system can give information and communicate with people from a distance.

3. Stationary Position Control of WB

To play a role of a tele-guidance robot, most of communications and interactions between people and the robotic WB take place in standing phase. Therefore, it is important to control for the WB to maintain the desired standing position on the floor especially in the tele-presence application. Owing to having a large volume, however, the blimp responds sensitively to atmospherically derived forces. In order to keep the stationary position against the disturbed motion by an uncertain airflow, a position controller for the WB is needed.

3.1 Dynamic modeling of WB

An experimental WB is designed and its dynamic equations are derived. Based on dynamic modeling of a general airship (Sergio and Josue, 1998), nonlinear dynamic equations describing the WB's motion in the standing phase are derived. It is assumed that the whole of WB in a standing phase is a rigid body and its motion is so small that the aerodynamic forces are negligible. The dynamic model can be obtained by Newton-Euler equations of motion like a normal blimp. In place of considering virtual mass, Coriolis and centrifugal terms and aerodynamic terms, friction forces and normal reaction forces between the floor and wheels are considered.

For a stationary position control on the floor in the standing phase, the computed torque method is adopted to compensate the nonlinear terms such as Coulomb friction forces. In this work, only 3 DOF motion, namely translations in the direction of x and y axis and a rotation about z axis (yaw) is considered. To verify the proposed controller, simulations and experiments are performed with the experimental WB. A free body diagram of the experimental WB is shown in Fig. 2.

The followings are six force and moment equations of the free body diagram shown in Fig. 2(a) and (b).

$$m\ddot{x} = (T_{dp} + T_{ds})^{*}\cos\mu - (F_H + F_{BR} + F_{BL})^{*}\cos\psi^{*}sign(\dot{x}) \quad (1)$$

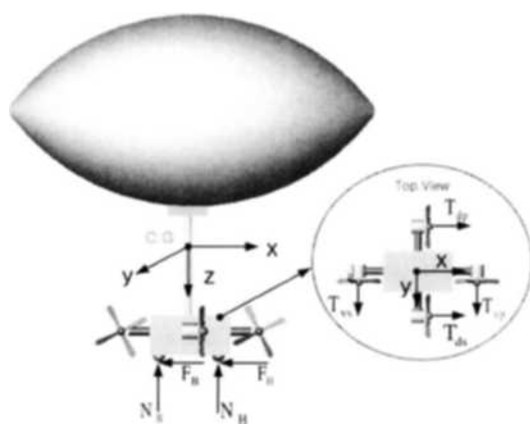


Fig. 2 Free body diagram of the wheeled blimp

$$m\ddot{y}=(T_{yp}+T_{ys}) - (F_H+F_{BR}+F_{BL})*\sin\psi*sign(\dot{y}) \quad (2)$$

$$m\ddot{z}=W-B-(T_{dp}+T_{ds})*\sin\mu - (N_H+N_{BR}+N_{BL}) \quad (3)$$

$$I_{xx}\ddot{\phi}=-(T_{yp}+T_{ys})*dzr+(T_{ds}-T_{dp})*\sin\mu*dym +\{(F_H)*\sin\psi*dzc+(F_{BR}+F_{BL})*\sin\psi*dzw\} *sign(\dot{y})-(N_{BR}-N_{BL})*dyw \quad (4)$$

$$I_{yy}\ddot{\theta}=(T_{ds}+T_{dp})*\cos\mu*dzm-(N_H)*dxc +(N_{BR}+N_{BH})*dxw +\{(F_{BR}+F_{BL})*\cos\psi*dzw+F_H*\cos\psi*dzc\}*sign(\dot{x}) \quad (5)$$

$$I_{zz}\ddot{\psi}=(T_{ds}-T_{dp})*\cos\mu*dym+(T_{ys}-T_{yp})*dxr -(F_{BR}-F_{BL})*\cos\psi*dyw*sign(\dot{x}) -\{(F_H)*\sin\psi*dxc+(F_{BR}+F_{BL})*\sin\psi*dxw\}*sign(\dot{y}) \quad (6)$$

where

m : total mass of a WB

I_{xx}, I_{yy}, I_{zz} : moments of inertia about x, y and z axis, respectively

x, y, z : the linear displacement with respect to body fixed frame xyz

ϕ, θ, ψ : the angular displacement with respect to body fixed frame xyz

T_{ds}, T_{dp}, T_{ys}, T_{yp} : thrust of starboard side, port side and right and left side direction, respectively

μ : the tilting angle

dxm, dym, dzm : distance from center of mass to main propeller along the body fixed axis

dxr, dyr, dzr : distance from center of mass to rudder propeller along the body fixed axis

dxc, dyc, dzc : distance from center of mass to caster along the body fixed axis

dxw, dyw, dzw : distance from center of mass to omni wheel along the body fixed axis

F_H, F_{BR}, F_{BL} : friction force of a front, rear right and rear left caster, respectively

N_H, N_{BR}, N_{BL} : normal reaction force of a front rear right and rear left caster, respectively

3.2 Controller design

For a stationary position control on the floor in the standing phase, the computed torque method is adopted to compensate the nonlinear terms such as Coulomb friction forces exerting between the casters and the floor. The computed torque method is a special application of feedback linearization of nonlinear systems. In this paper, only 3 DOF motion, namely translations in the direction of longitudinal and lateral and a rotation about normal axis is considered. Thus, the control input is thrust from each propeller (T_{dp}, T_{yp} and T_{ys}) and the control output is the position of the WB (x, y and ψ). Note that the thrust of starboard side (T_{ds}) is same as the thrust of port side (T_{dp}). And the vectorization angle μ sets zero, so that a normal directional motion does not exist. Also it is assumed that the normal reaction forces of the rear wheels are same. The selected 3 DOF dynamic equations are rewritten as

$$\begin{bmatrix}\ddot{x}\\ \ddot{y}\\ \ddot{\psi}\end{bmatrix}=Eu+a \quad (9)$$

where

$$u=\begin{bmatrix}T_{dp}+T_{ds}(=2T_{ds})\\ T_{yp}\\ T_{ys}\end{bmatrix}$$

$$E=\begin{bmatrix}\frac{1}{m} & 0 & 0\\ 0 & \frac{1}{m} & \frac{1}{m}\\ 0 & -\frac{dxr}{I_{zz}} & \frac{dxr}{I_{zz}}\end{bmatrix}$$

$$a=\begin{bmatrix}-\frac{1}{m}(F_H+F_{BR}+F_{BL})*\cos\psi*sign(\dot{x})\\ -\frac{1}{m}(F_H+F_{BR}+F_{BL})*\cos\psi*sign(\dot{y})\\ \frac{1}{I_{zz}}\{(F_H)*\sin\psi*dxc+(F_{BR}+F_{BL})*\sin\psi*dxw\}*sign(\dot{y})\end{bmatrix}$$

The control equation from the PD-based computed torque method is

$$u=E^{-1}(v-a) \quad (10)$$

where v is a new input. The closed loop system is described as

$$\begin{bmatrix}\ddot{x}\\ \ddot{y}\\ \ddot{\psi}\end{bmatrix}=v=\begin{bmatrix}\ddot{x}_d+k_v\dot{e}_1+k_pe_1\\ \ddot{y}_d+k_v\dot{e}_2+k_pe_2\\ \ddot{\psi}_d+k_v\dot{e}_3+k_pe_3\end{bmatrix}$$

Finally, the error dynamic is derived as

$$\ddot{e}_i+k_v\dot{e}_i+k_pe_i=0 \quad (11)$$

where $i=1$, 2 and 3

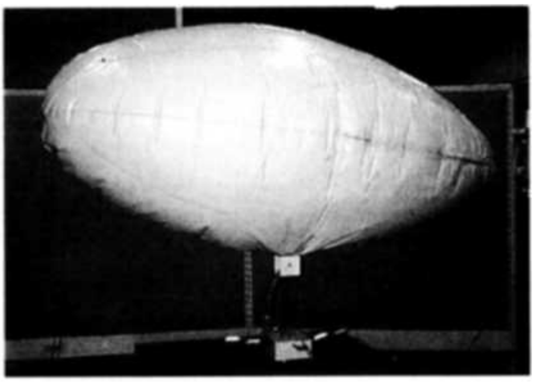


Fig. 3 The wheeled blimp for experiments

$$e_1 = x_d - x,\ e_2 = y_d - y,\ e_3 = \psi_d - \psi$$

Since this controller is based on PD control for robustness in uncertainties, the desired performance in each component of the error may be achieved by properly tuning PD gains.

4. Experiments

In this section, the hardware setup for the computed torque control for the stationary position control of WB is presented. Also the result shows that the controller has been successfully verified in the experimental WB system.

4.1 Hardware setup

A small and light WB is designed and manufactured for experiments to evaluate the capability of a position controller. The experimental WB is composed of the blimp and the wheeled vehicle as shown Fig. 3. The blimp filled with helium gas is made of metalized nylon and a streamline shape. The body of the wheeled vehicle and the gondola is made of cherry and balsa. The gondola and wheeled vehicle are attached on the middle and lower surface of the blimp. The vehicle is placed in parallel with the gondola, and is connected to gondola by four carbon pipes which are 0.24 m in length. The passive wheel mechanism uses three ball casters in order to move any directions on the floor.

The propulsion is provided by crossed four DC motor with propellers enabling the WB to translate in the direction of longitudinal and lateral

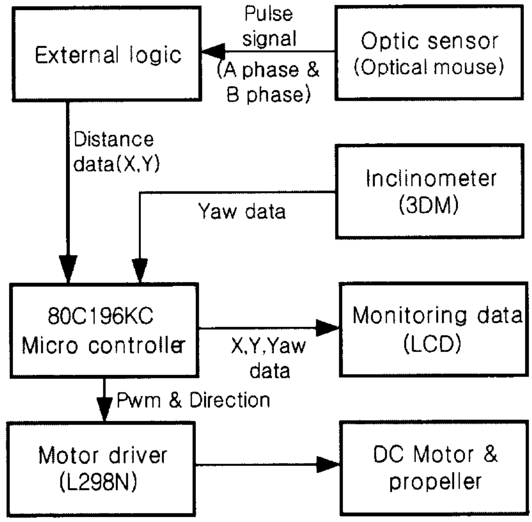
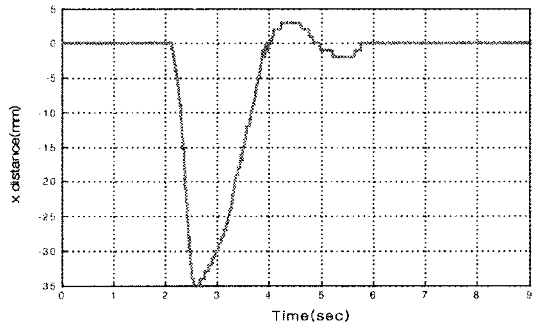


Fig. 4 Block diagram of hardware

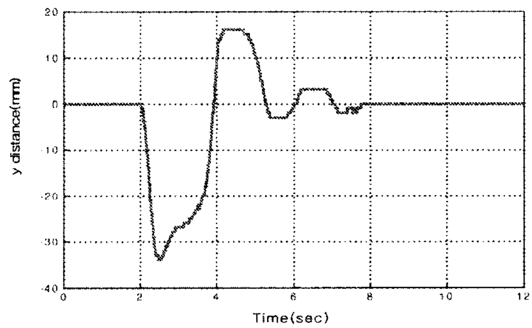
direction and to rotate on normal axis. The inclinometer measuring yaw angle is attached at the back of the blimp. The optic sensor customized by a commercial optic mouse measuring linear displacement is placed the base side of the vehicle. As a multimedia device, one camera is attached in the front of the blimp. As on-board controller, an Intel 80C196KC microprocessor is used. Because of a restriction of weight, the controller and battery pack are not mounted on this system, but tethered to an external part. The control structure and its hardware components are shown in Fig. 4.

4.2 Experimental results

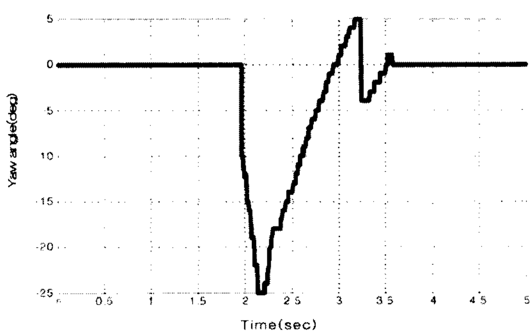
The control performance of 3 dof motion, namely translations in the direction of x and y axis and a rotation about z axis was experimented. An MIMO (multi-input and multi-output) control for stationary position experiment is performed. When an external impulse force of each direction is exerted to the stationary WB, the data of position response expresses that the WB returns to initial position even though there are unexpected disturbance. Figures 5(a), (b) and (c) show the experimental results on X, Y and yaw control respectively that the WB returns to the initial position after it was artificially disturbed by an external force (or moment). Thus it has been verified that the stationary position



(a) Longitudinal displacement control (X)



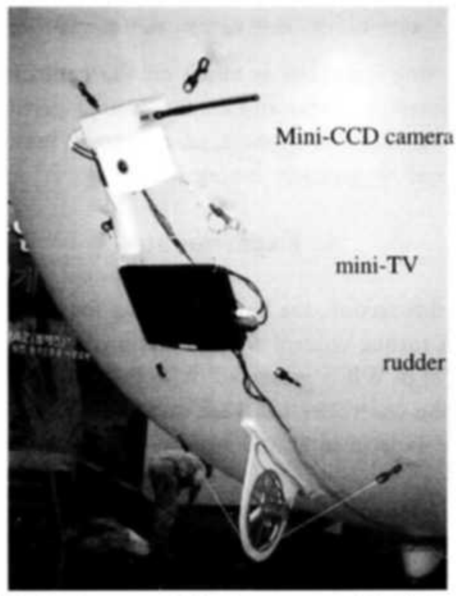
(b) Lateral displacement control (Y)



(c) Yaw control

Fig. 5 Experimental control results

(a) Flying



(b) Equipments of the front part of air Melon : micro-CCD camera, mini-TV and rudder

Fig. 6 Air melon

control is successful.

5. Design Variations of WB

It has been found in this work that the design concept of the WB can be extended to various versions depending on tele-presence applications. As a first example, a large blimp system with landing gear for a demonstration is developed. This blimp called Air Melon is shown in Fig. 6.

Like the experimental WB, the lift of Air Melon is achieved by the thrust generated by the propellers of the two main motors mounted on the gondola. The two main motors provide the up-and-down and forward-and-backward thrust of the WB, and the rudders attached to the blimp generates the right-and-left rotational thrust. Air Melon is remotely controlled via RC (Radio Control). The floating capability of Air Melon enables the WB to move freely regardless of the ground condition or obstacles.

Using multimedia devices such as a micro-CCD camera, a television, and a wireless image transmitter-receiver mounted on the blimp surface, this system can communicate with people from a remote site. The Air Melon was exhibited for public exhibition in Korea Science Festival 2001.

As another design variation, Air Guide in Fig 7. has a large displayed image on the flat surface of the blimp. The Air guide cannot fly due to its heavy active mobile base. Instead, the design focus of the Air guide is to make a low-gravity-centered mobile robot with a big screen display. By directly attaching a light-weight projector to the rear part of a blimp, we can get a light and large screen display system. The advantage of the Air Guide is that low center of gravity design is possible although it has a big screen display compared with the size and weight of lower mobile base part. Like Air Melon, multimedia devices such as pan-tilt cameras, speakers, microphone, and a wireless image transmitter-receiver mounted on the mobile robot. Self-navigation and local collision avoidance by sonar sensors of the mobile robot are possible in the assigned area, which makes an autonomous agent robot for tele-presence application. The Air Guide was exhibited to public at NEW-TECH KOREA EXHIBITION 2002.

Fig. 7 Air guide

6. Concluding Remarks

In this work, we proposed a new design of the WB and its stationary position control. The WB has hybrid structure with a blimp and a wheeled vehicle part. The WB is able to move around anywhere regardless of obstacles on the floor and additionally to maintain the standing phase on the floor during communication and interaction with human.

To control the desired position, a computed torque controller is used. Performing a controller design and computer simulation, it is found that the computed torque method is feasible to be applied to the stationary position control in standing phase. Experiments are performed on a stationary position control of the wheeled blimp using a controller designed by the computed torque method.

In the near future, the wheeled blimp can be used as a robotic agent in various service areas such as customer guidance, surveillance and advertisement via its multi-media communication capabilities that are to be developed.

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