Trials of Discrete Values Control by a Tracked Model for Wing Sale Eco-ship

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***Abstract*- This paper presents the discrete values control induced by the variation method when the manipulated variable is not included in the evaluation function. This new control method is different but similar to previous bang-bang control methods. A single wing sail model was loaded on a cart with four wheel casters and straight line test runs were performed on a track to determine the effectiveness of discrete switching control.**

***Keywords*- Discrete Control; Wing Sale; Tracked Vehicle; Bang-Bang Control**

I. INTRODUCTION

Needs such as the reductions in the fuel consumption rise because the nuclear accident such as Fukushima nuclear power plants in recent years influences the needs due to an East Japan Great Earthquake. Then, the eco-ship has been re-evaluated again in the field of the ship transportation. E-ship1 which has 4 rotors goes into service in Germany since 2011, and it succeeds in the fuel reduction in 30% [1]. On the other hand, attention has been paid to the wing sail ship because USA17 [4, 5] that is the yacht with a hard monster wing which has been imaged from bird's wing through aircraft wing as shown in Fig. 1 had won the championship in an American cup, doing the high speed operation. It is thought that two supplementary boats of Fig. 1(d) prevent the overthrow by the strong wind.

(a) Japanese crane [2] (b) Airplane [3] (c) USA17 (2010 American's CUP)[4] (d)Front photograph of USA17 (supplementary boat)[5]

Fig. 1 Image expansion of wing from birds, airplanes to sales

There is a basic research on two or more wings by Shinkai [6] in Japan, then the challenger project [7-9] by the University of Tokyo, Class NK, and the Mitsui O.S.K Lines (MOL), etc. are advancing, which has series nine piece changeable height wings like Fig. 2.

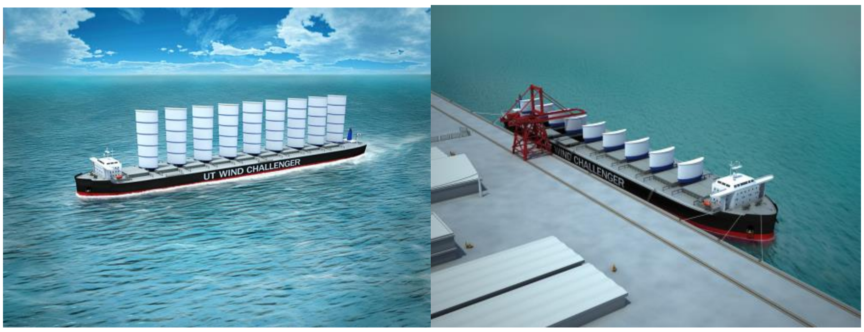

Fig. 2 Wind challenger project (HP of Tokyo University) [5]

The changeable height wings are planning to be shortened in harbors or under the strong wind. Of course, it is included in the aim of our research to use the control theory proposed here for their projects and other eco-ship development parties.

There are various types of eco-ship besides these types, and they have been researched and developed from old time [10-

13]. The wind car race has been held, which is a kind of eco-ship running in land, and various types of wind cars are uploaded to YOUTUBE etc.

Recently, we produced some wind car examination models with 4 wheel casters running on a track, which are imitating the rotor ship, and began the research of dynamics and microcomputer controls on the models [14, 15].

On the other hand, the Bang-Bang control has been researched from old time as the optimum control to some class of nonlinear systems using the Pontriyagin's optimality principle. Recently, the Bang-Bang control based on the Theory of Dissipative System is researched [16]. The Bang-Bang control is a kind of discrete values control in a discrete event system. Recently, more advancing time optimal control is proposed [17].

The land examination machine of the single wing sail suitable for the discrete values control solution induced from variation method as well as linear optimal feedback control solution when the manipulated variable is not included in the evaluation function in the next chapter of this text. Afterwards, the model is produced and examined to obtain the characteristics. Then, it is confirmed to reach the target point at the short time by discrete value control experimentally.

II. DISCRETE CONTROL

A. Basic Optimal Theory for Discrete Control

This paper presents the necessary conditions for optimal control in the case of constrained manipulated input with Bang-Bang control for a class of nonlinear systems by variation methods.

We assume that the controlled object is described by the following nonlinear equation with input constraints:

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{f}(\mathbf{u}(t)), \qquad \mathbf{x}(0) = \mathbf{x}_0 \tag{1}$$

When the manipulated variable is not included in the evaluation function for error state variables, we obtain

$$\mathbf{R} \to \mathbf{0}, \mathbf{e}(t) = \mathbf{x}(t) - \mathbf{x}_d(t) \tag{2}$$

$$J = \mathbf{e}^T(t_f)\mathbf{P}(t_f)\mathbf{e}(t_f) + \int_{t_0}^{t_f} \mathbf{e}^T(t)\mathbf{Q}\mathbf{e}(t)dt \tag{3}$$

Let's assume that a discrete-valued operation is performed though it is different from conventional linear feedback solution.

$$\mathbf{f} = \text{constant} \tag{4}$$

$$\mathbf{u}(t) = \boldsymbol{\gamma}_1 \tag{5}$$

The variation equations then become:

$$\frac{\partial H}{\partial \mathbf{u}^T(t)} = \mathbf{R}\mathbf{u}(t) + \frac{\partial f(\mathbf{u}(t))}{\partial \mathbf{u}^T(t)}\boldsymbol{\lambda}(t) = 0 \qquad \mathbf{u}(t) = -\{\mathbf{u}_{\max}, \mathbf{0}, \mathbf{u}_{\min}\} \tag{6}$$

$$\frac{\partial J^*}{\partial \mathbf{e}^T(t)} = \mathbf{Q}\mathbf{e}(t) + \mathbf{A}^{\mathbf{T}}\boldsymbol{\lambda}(t) + \dot{\boldsymbol{\lambda}}(t) = 0 \qquad \dot{\boldsymbol{\lambda}}(t) = -\mathbf{Q}\mathbf{e}(t) - \mathbf{A}^{\mathbf{T}}\boldsymbol{\lambda}(t) \tag{7}$$

$$\frac{\partial J^*}{\partial \mathbf{e}^T(t_f)} = \mathbf{P}(t_f)\mathbf{e}(t_f) - \boldsymbol{\lambda}(t_f) = 0, \qquad \boldsymbol{\lambda}(t_f) = \mathbf{P}(t_f)\mathbf{e}(t_f) \tag{8}$$

$$\boldsymbol{\lambda}(t) = \mathbf{P}(t)\mathbf{e}(t) \tag{9}$$

The following equation, which is similar to the Riccati equation, is obtained:

$$\dot{\mathbf{P}}(t)\mathbf{e}(t) = -\mathbf{P}(t)(\mathbf{A}\mathbf{e}(t) + \mathbf{f}(\mathbf{u}(t)) - \mathbf{Q}\mathbf{e}(t) - \mathbf{A}^{\mathbf{T}}\mathbf{P}(t)\mathbf{e}(t) \tag{10}$$

When f=0 , the following Riccati equation is obtained.

$$\dot{\mathbf{P}}_1(t) = -(\mathbf{P}_1(t)\mathbf{A} + \mathbf{A}^{\mathbf{T}}\mathbf{P}_1(t) + \mathbf{Q}) \tag{11}$$

The boundary conditions at the terminal points of all sections are assumed to be as follows.

$$\mathbf{P}_1(t_f) = \mathbf{Q}_f \tag{12}$$

Because **f** = constant, a possible solution for the optimal manipulated vector is as follows.

$$\mathbf{u}(t) = \boldsymbol{\gamma}_1 \tag{13}$$

The closed-loop equation has the following simple form using this manipulated variable.

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t), \qquad \mathbf{x}(0) = \mathbf{x}_0 \tag{14}$$

The results of this theoretical derivation can be applied to a straight tracked vehicle model with a manipulated angle of attack $\pm\alpha°$ of the wing for the wind direction.

III. TRACKED WING SALE MODEL

A. Research on Wing Sale

The static characteristics of the lift and drag forces for the symmetrical wing of NACA18 when the angle of attack was varied were theoretically investigated based on data for a wing sail given in Ref. [6].

We simulate the static characteristics (aspect ratio = 1) of the lift and drag forces of a wing sail vehicle on a track based on data given in Ref. [6].

The results of the simulation were shown as Fig. 3. Here, the horizontal axis is attack angle, the vertical axis is force. The lines describe Coefficient of Lift force, Lift Force, Draft Force, Advance Force on Track, Slipping Force on Track, Slipping Force without Track and the Direction of Advance Force without Track.

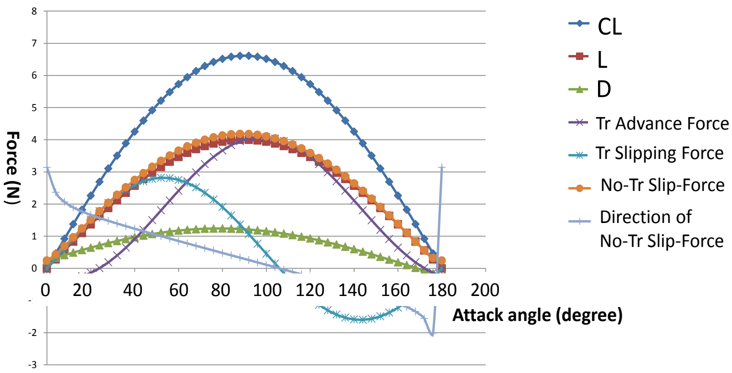

Fig. 3 Static property (aspect ratio = 1)

The parameters used in the basic static simulation are listed below:

$$\rho = 1.21[kg/m^3], k/d = 0.0526$$
$$C_L = 6.2832(1+\mathrm{k/d})\sin(\alpha/180{*}3.1416)$$
$$\mathrm{L}{=}0.5\rho C_L v_{wind}^2 S$$
$$C_d = 2.01 \quad for \quad 2D(low \quad aspect(=1) \quad parts)$$
$$C_d = 1.18 \quad for \quad 3D$$
$$C_d = \{2.01 + 1.18{*}(aspect - 1)\}/aspect$$
$$a/b = 0.2 \quad for \quad Naca18$$
$$D = 0.5\rho C_d v_{wind}^2 S\{\sin(\alpha/180{*}3.1416)+(\mathrm{a/b}){*}\cos(\alpha/180{*}3.1416)\}$$

We produced a taller model as results obtained based on the theoretical coefficients of the lift force (CL) suggest that it could run on a track based without the wing falling off. We did not consider the mechanical loss due to the rolling loss and friction loss of the small niron four casters.

B. Experimental Apparatus for Land Tests

A tracked wing sail vehicle model with four casters and a microprocessor for controlling the high torque servo for robots was produced. The wing was produced using multi-layer alternative soft and hard materials like a seismic apparatus for seismic and lightning of the wing, and supported by the 4 poles between a ceiling board and a floor board with each micro-bearings for vibration control as shown in Fig. 4.

A counter weight or stabilizers, which may be designed to be underwater, or double floats, which are designed to be oversea as shown in Fig. 1, in the case of a ship, cannot be installed on a track on the ground. Instead, guardrails were installed on both sides of the running track.

Fig. 4 A tracked wing sale vehicle model

C. *Static Characteristic Tests*

The propelling force generated when wind flows with a suitable velocity and at angles between the parallel and perpendicular directions to the traveling direction was measured experimentally to determine the lift and drag forces. Fig. 5 shows the results obtained.

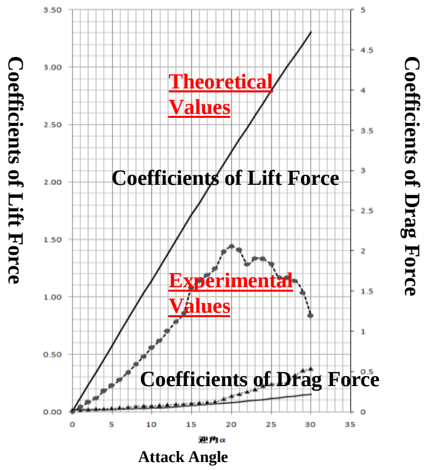

Fig. 5 Theoretical and experimental coefficients of lift CL and drag CD

The lift and drag forces of the model were measured by pulling a weight on a balance. The lift and drag coefficients were calculated. The wing might be stalled due to flaking off when the angle of attack exceeded 20°, although this result differs from those of the theoretical calculation. The angles of attack for acceleration and deceleration are respectively α and –α, while the angle of attack for stopping was determined from experimental data (Fig. 5).

IV. DISCRETE VALUES CONTROL FOR STOPPING TARGET POSITION

Method

As shown in Fig. 6, a test model vehicle was used with its wing inclined at the angle of attack for running on a straight track. The velocity of this model vehicle was measured. In addition, the deceleration required to stop at the target position was calculated.

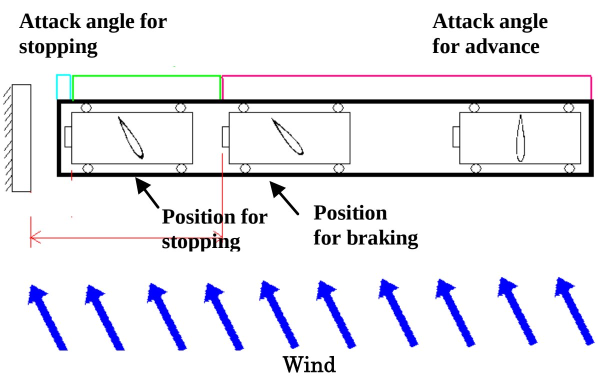

Fig. 6 Control of attack angle of wing to reach a target

The angle of attack was switched from that for acceleration to that for deceleration at the deceleration position, which was calculated from experimental data. The optimal timing for deceleration determined experimentally was much closer to the target than that obtained by simulation. This discrepancy appears to be because rolling friction was not considered in the simulation.

The angle of attack is switched to that for stopping at the stop position. This sequence of operations allows discrete valued (three values) control to be performed using a microcomputer. Moreover, a fourth angle of attack for minimum back tracking may be used against the wind when the wind angle does not permit the vehicle to stop.

V. CONCLUSIONS

Discrete valued solutions were derived as the necessary conditions for optimum control theory for a nonlinear system when the manipulated variable is not contained in the evaluation function.

It is not possible to specify the optimal switching timing using this method. This new control method is different but similar to previously proposed Bang-Bang control methods.

The following findings were made regarding this optimal method.

1) The quadratic form of the error variable (rather than the state variable) was incorporated in the evaluation function. The input was not included in the evaluation function.

2) When the manipulated function is assumed to be constant due to feedback (as assumed in past studies), discrete valued operation satisfied the necessary conditions for optimal control.

A single seismic structured wing sail model was loaded on a cart with four wheel casters and a micro computer control system was constructed. Then, straight line test runs were performed on a track to determine the effectiveness of discrete switching control.

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