AIR MASS MOTION REMOTE CONTROL SYSTEM

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ABSTRACT:

An ecologically pure system is under development that is designed for prompt control any region of space. The control is based on generation of air mass velocity diagram. The system physical ground is Doppler analysis of CO_2 laser signal reflected from scattering centers of real atmosphere in a specified region. In the course of analysis a radial velocity of a scattering center is measured. To restore the complete vector of air mass velocity the interframe processing methods are applied to the obtained arrays that allow to evaluate a tangential component of velocity vector as a quotient of an interframe displacement by a procedure period. The possible applications of the system under development are atmospheric emission motion remote control and air traffic management.

INTRODUCTION

An ecologically pure system is under development that is designed for prompt control any region of space. The control is based on generation and analysis of three-dimensional air mass velocity diagram.

The system physical ground is Doppler analysis of CO_2 laser signal reflected from scattering centers of real atmosphere in a specified region. Dust, aerosol or other inhomogeneous inclusions into the atmosphere exemplify such scattering centers. Literature sources (for example, Harney) and the results of full-scale tests conducted by the authors in mid-European conditions and in the ranges in Kazakhstan and the Barents sea allow to conclude that CO_2 laser systems can be applied for given problem solution in most weather conditions. In the course of analysis a radial velocity of a scattering center is measured. The individual measurements are combined into a three-dimensional array which presents a field of radial velocities of a controllable region in some time interval Δ_t. The procedure is repeated with $T > \Delta_t$ period. To restore the complete vector of air mass velocity the interframe processing methods are applied to the obtained arrays that allow to evaluate a tangential component of velocity vector as a quotient of an interframe displacement by a procedure period.

KALMAN FILTER VELOCITY ESTIMATION

In the general case an interframe displacement can be evaluated in different ways. In our opinion the most promising is a three-dimensional Kalman filter method similar to the two-dimensional case studied by J. Stuller and G. Krishnamurthy (Stuller, 1983).

The evaluation theoretical grounds are simple enough. It is supposed that over the period $T = t_i - t_{i-1}$ a radial velocity $V_R(\overline{A}_k, t_{i-1})$ array element corresponding to a scattering center with spherical coordinates $\overline{A}_k = (\psi, \vartheta, R)'$ has negligibly changed in magnitude but has shifted by amount equal to $T\left|\overline{V}_R(\overline{A}_k, t_{i-1}) + \overline{V}_{tg}(\overline{A}_k, t_{i-1})\right|$. Here $\overline{V}_{tg}(\overline{A}_k, t_{i-1})$ is a tangential velocity vector.

Then using Taylor expansion in neighborhood of the point $\overline{A}_k$ and confining to the first member of the expansion one can show that

$$\begin{aligned} &V_R(\overline{A}_k, t_i) - V_R(\overline{A}_k, t_{i-1}) = \\ &= -T\, gr\overline{a}d\{V_R(\overline{A}_k, t_{i-1})\}\, M(\,\overline{V}_{tg}(\overline{A}_k, t_{i-1}), V_R(\overline{A}_k, t_{i-1}))' + \\ &+ r\{\overline{V}_{tg}(\overline{A}_k, t_{i-1}), V_R(\overline{A}_k, t_{i-1})\} \end{aligned}$$

Here $M = \begin{pmatrix} M_\psi & 0 & 0 \\ 0 & M_\vartheta & 0 \\ 0 & 0 & M_R \end{pmatrix}$ is a scale matrix.

Upon obvious rearrangement we obtain

$$\begin{aligned} Z(\overline{A}_k, t_i) &= V_R(\overline{A}_k, t_i) - \left[1 - TM_R \frac{\partial V_R}{\partial R}(\overline{A}_k, t_{i-1})\right] V_R(\overline{A}_k, t_{i-1}) = \\ &= H\overline{V}_{tg}(\overline{A}_k, t_{i-1}) + r\{\overline{V}_{tg}(\overline{A}_k, t_{i-1}), V_R(\overline{A}_k, t_{i-1})\} \end{aligned}$$

Here

$$H=-T\begin{pmatrix} M_{\psi}\dfrac{\partial V_R}{\partial\psi}(\overline{A}_k,t_{i-1}) \\ M_{\vartheta}\dfrac{\partial V_R}{\partial\vartheta}(\overline{A}_k,t_{i-1}) \end{pmatrix}$$

With $r\{\overline{V}_{tg}(\overline{A}_k,t_{i-1}),V_R(\overline{A}_k,t_{i-1})\}$ considered as additive gaussian noise and $V_R(\overline{A}_k,t_{i-1})$ values as true and by assuming that

$$\overline{}_{tg}(\overline{A}_k,t_i)=\Theta\overline{V}_{tg}(\overline{A}_k,t_{i-1})+\Gamma\overline{\omega}_{i-1}$$

where $\overline{\omega}_{i-1}$ - production noise and Θ matrix is specified by

$$\begin{aligned}\Theta\overline{V}_{tg}(\overline{A}_k,t_{i-1})&=\overline{V}_{tg}(\overline{B}_k,t_{i-1})\\ \overline{A}_k&=\overline{B}_k+T\overline{V}_{tg}(\overline{B}_k,t_{i-1})\end{aligned}$$

one transforms a velocity vector determination problem into an evaluation problem corresponding to a discrete version of Kalman filter. It is well known (Lee) that the solution in this case is determined by the system of recurrent equations:

$$\begin{cases}\hat{V}_{tg}(\overline{A}_k)_k=\Theta\hat{V}_{tg}(\overline{A}_{k-1})_{k-1}+ \\ \qquad +P(\overline{A}_k)_k H'R^{-1}\left[Z(\overline{A}_k)-H\Theta\hat{V}_{tg}(\overline{A}_{k-1})_{k-1}\right] \\ P(\overline{A}_k)_{k-1}=\Theta P(\overline{A}_{k-1})_{k-1}+\Theta'+\Gamma Q\Gamma \\ P(\overline{A}_k)_k=P(\overline{A}_k)_{k-1}- \\ \qquad -P(\overline{A}_k)_{k-1}H'\left[HP(\overline{A}_k)_{k-1}H'+R\right]^{-1}HP(\overline{A}_k)_{k-1}\end{cases}$$

Here Θ and Γ are transient matrices; Q and R are correlation noise matrices. The determination of the latter in the authors' opinion will represent the main difficulty since meager statistical data is available in this field. The assumption of negligible interperiod change of radial velocity component is considered reasonable for $T < 1.5–2.0$ s. Nonetheless it should be noted that this value need refinement.

HARDWARE IN BRIEF

The system consists of a coordinate platform-mounted continuos-wave CO_2 laser integrated with a heterodyne photoelectric detector, analog-digital signal preprocessing unit, a digital computer and a display.

The coordinate platform provides the laser receiver/transmitter stabilization and azimuth elevation scanning. The elevation scanning is harmonic with pseudolinear operating zone. The azimuth scanning is highspeed circular. The range gating (vision layer selection) is by means of azimuth angle change between receive and transmit patterns.

CO_2 laser features a waveguide scheme with RF pumping and acousto-optic internal modulation. The array of four HgCdTe photodiodes with cryogenic cooling to 80–100 K are used as photoelectric detectors. The homodyning of radiation reflected from scattering center allows to simplify the design and to enhance the resistance to mechanical exposures.

The specific feature of the lidar under development is the combined coherent-interframe useful signal accumulation. The application of the combined accumulation technique allowed to simplify significantly the optical-mechanical scheme of the instrument and to provide acceptable range and velocity resolution characteristics.

The calculations showed the expediency of analog-to-digital preprocessing of RF signal fed from the photoelectric mixer. The processing is supposed to be performed by a rake of 16 analog bandpass filters. Filter output signals undergo amplitude detection and transformation into digital form with digitization rate of 1 MHz. Further processing is carried out in 16 parallel digital channels each of which contains an accumulator and an interperiod accumulation module. After comparison the channel number is written into a memory cell corresponding to current radiation pattern and used as a radial velocity array element. The resulting array is processed by a dedicated digital computer of MIMD type and presented on the display.

SYSTEM ESTIMATED SPECIFICATIONS

Range Gating, km	1-1.5
Angular Resolution, degree	not greater ±1.0
Range Resolution, m	not worse ±75
Radial Velocity Resolution, m/s	not worse 2.5
Weather Penetration, %	not worse 80
Information Change Rate, Hz	0.2-1.0
Azimuth Scanning Angular Velocity, s^{-1}	90-100
Working Air Mass Velocity Range, m/s	0-40
Weight, kg	not greater 100
Volume, dm^3	not greater 120
Power Consumption, W	not greater 600

APPLICATIONS

In authors' opinion the possible applications of the system under development are the following:

- atmospheric emission motion remote control;
- remote study of whirlwinds and similar formations;
- atmosphere state control during civil engineering and installation work with the use of aviation;
- atmosphere state control in airfield area;
- air traffic management.

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