MIMI '89 Zurich

ISMM

Proceedings of the Thirty-Ninth ISMM International Symposium

MINI AND MICROCOMPUTERS AND THEIR APPLICATIONS

Zurich, Switzerland
June 26-29, 1989

EDITOR: M.H. Hamza

A Publication of
The International Society for
Mini and Microcomputers - ISMM

ISBN 0-88986-123-4

ACTA PRESS
ANAHEIM * CALGARY * ZURICH

MODERN SENSORS IN INSTRUMENTATION: A BOARD COMPUTER FOR A GLIDER

Jean-Pierre AMANN, Waleed HAMZA

Institut de Microtechnique, Université de Neuchâtel, Rue A.-L. Breguet 2, CH-2000 NEUCHATEL, Switzerland

Abstract

A board computer for a glider, indicating speed, altitude, energy balance and some more features has been realized using a single chip microcontroller and modern silicon pressure and temperature sensors. The concept of this instrument is such that its basic functions can be used for any glider type without adaptation. For additional features where the aerodynamical behaviour of the glider is involved (e.g. speed optimization during translation), a simple mechanism allows to specify the type of aircraft.

Keywords

instrumentation, avionics, silicon pressure sensor, silicon temperature sensor, single chip microprocessor

1. Introduction

During the last years microprocessor systems have known an important evolution, in particular in the compact form of single chip microprocessors: while the performances have been rapidly increased, the size of the build-up, the power consumption and finally the price have been decreased. This allowed us to planify and to realize a small board computer for a glider. The basic ideas are the following: First, the static and the dynamic pressure as well as the temperature are measured using modern silicon sensors. Second, the non-idealities of the sensors are compensated by software. In a third step, the results are used in relatively complex formulas to evaluate the interesting parameters like altitude, speed, energy and so on. Optionally, the results can be used for other tasks (travel speed optimalization, statistics,...)[4].

In this paper, we present first the theoretical bases (§2), then the measuring principles (§3) and in paragraph 4 a review on the instruments used in traditional approaches. The next paragraph treats our proposition for a microprocessor based solution using modern silicon sensors. The paper terminates with a result section and a view on future extension which can be realized with minor modifications to the initial proposition.

2. Context, definition of the application

By definition, a glider is an aircraft without engine. Due to friction, air resistance and the creation of turbulences, the glider is loosing energy during its flight. In steady air, this loss of energy is clearly shown by the fact that the aircraft is gliding down with a vertical speed v_g, thereby loosing potential energy: $v_g = - dE_{pot}/dt \cdot 1/mg$.

The only way to lengthen a flight is to find raising air streams (thermals, waves, ...) with a vertical speed of $v_a \geq v_g$ so that the energy balance of the aircraft becomes positive or at least equilibrated (fig 1). Therefore, an instrument indicating to the pilot the energy flow, with respect to the aircraft, is of upmost importance for the choice of an optimum glider flight.

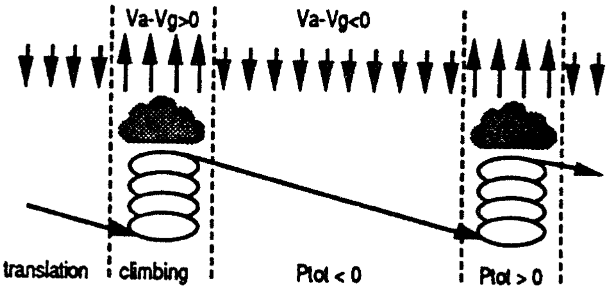

fig 1: energy balance and trajectory of a glider: translation and climbing phases

3. Measurement principles

There is no direct way to measure speed, height or energy. Therefore, in a preliminary step, physical values such as pressure and temperature have to be measured and then to be converted and eventually combined into the desired form.

terms, expressions

p_{tot} = total pressure on a surface perpendicular to the air flow [hPa]
p_{stat} = ambient air pressure [hPa]
$p_{stat}(a_0)$ = ambient pressure at altitude a_0 [hPa]
p_{diff} = $p_{tot} - p_{stat}$ [hPa]
T = ambient temperature [°C]
T_{mean} = mean ambient temperature [°C]
ρ_0, p_0, T_0 = air density [kg/m^3], ambient pressure [hPa] and standard temperature [°C]
m = mass of the glider [kg]
g = acceleration due to gravity [m/s^2]

speed, kinetic energy

The speed v and the kinetic energy E_{kin} can be determined using a formula including temperature, air density, ambient pressure and the total pressure p_{tot} measured perpendicular to the flight direction of the aircraft.

$$v = \sqrt{2 \cdot (p_{tot} - p_{stat}) \cdot p_0/p_{stat} \cdot 1/\rho_0 \cdot T/T_0}$$

$$E_{kin} = 0.5 \cdot m \cdot v^2$$

$$= p_{diff}/p_{stat} \cdot T \cdot m \cdot 1/\rho_0 \cdot (p_0/T_0)$$

altitude, potential energy

The altitude a and potential energy E_{pot} can be determined approximately using the ambient pressure and mean air temperature between the reference altitude a_0 and a.

$$a \approx C_1 \cdot (1+T_{mean}/273) \cdot \log_{10}(p(a_0)/p_{stat})$$

$$C_1 = 1.84 \cdot 10^4 \quad [m]$$

$$E_{pot} = m \cdot g \cdot (a+a_0)$$
$$\approx m \cdot g \cdot (a_0 + C_1 \cdot (1+T_{mean}/273) \cdot \log(p(a_0)/p_{stat}))$$

total energy, power

The total energy E_{tot} and its variation, the power P, are computed using the above formulas for kinetic and potential energy.

$$E_{tot} = E_{pot} + E_{kin}$$

$$P = dE_{tot}/dt = dE_{pot}/dt + dE_{kin}/dt$$

virtual climb rate

For historical reasons, the energy flow or power P is shown to the pilot in terms of a virtual climb rate cr_{virt}: variations of both potential and kinetic energy are shown both as variations of potential energy or altitude.

$$cr_{virt} = 1/mg \cdot (dE_{pot}/dt + dE_{kin}/dt)$$

It is easy to see that the final formula of the virtual climb rate cr_{virt} expressed in function of the measured physical values will be relatively complex [2].

4. Traditional solutions

speed, altitude, climb and sink rate

Usually, speed and altitude are measured by very precise mechanical instruments where the deformation of thin metallic surfaces under the influence of the air pressure is measured and displayed. The differentiation of ambient pressure, used for climb/sink rate indication, is performed by a pneumatic equivalent of an RC-filter (fig 2). The sign of the climb rate indication depends on the direction of the air flow through the capillary, the amplitude on the importance of the variation of the ambient pressure. A similar device can be used for the measure of speed variation [4].

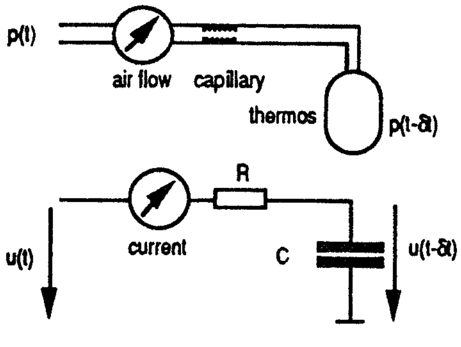

fig 2: differentiation of pressure (top) and its electrical equivalent (bottom)

total energy, power

Usually, a modified version of the above climb/sink rate instrument is used. Instead of measuring the static (ambient) pressure which allows to determine, after differentiation, the change in potential energy, a specially shaped pressure opening is used (Pitot tube, "antennas"). While the "antenna" works at zero-speed like a normal ambient pressure opening, during translation a speed dependent under pressure component will be superposed to the static pressure (fig 3).

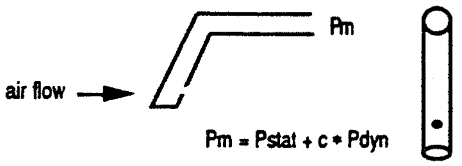

fig 3: "antenna" of the NICK's type [4]: side view (left) and front view (right)

If either speed variations or altitude variations occur, the measured pressure p_m will vary and an energy change will be indicated.

$$p_m = p_{stat} + c \cdot p_{dyn}$$

$$dp_m/dt = dp_{stat}/dt + c \cdot dp_{dyn}/dt$$

It can be shown that c must have an exact value of (-1) to insure a correct power measurement for both speed- and altitude vatiations [4], a critical value to reach in practice.

discussion of the traditional approaches

Some disadvantages are common to all these traditional solutions. By their construction, the instruments do not consider all the necessary aspects for precise measurements. They are relatively cumbersome and the partial results cannot be reused for further applications (fig 4).

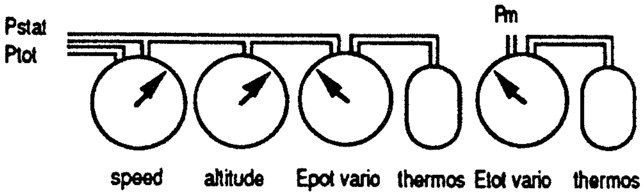

fig 4: conventional pneumatic system

Additionally, concerning the power measurement, an important calibration problem occurs for the so called "antennas", the pressure openings. Depending on their place on the fuselage and on the type of aircraft, their shapes have to be adapted mechanically, requiring a difficult, lengthy, and expensive work since test flights will be necessary. Of course, similar problems could also exist for the openings for both static pressure p_{stat} and total pressure p_{tot}. But there is an important difference: since the measurements directly concerned with these openings are vital (speed, altitude), the constructors are bound by law to obtain good results. A possible solution for ambient pressure measurements is the combination of several openings in order to obtain correct results independently of the fuselage direction with respect to the airflow.

5. Realization

basic concept

Based on the results of the theory and the experiences made with conventional instruments, we propose the following concept (fig 5):

- use of modern space saving silicon-based pressure and temperature sensors
- use of a modern single chip microprocessor for data acquisition and correction
- use of the same microprocessor for the user interface (display, keys, audio output) and for the evaluation of precise results, including all available information.
- elimination of the special pressure opening for the "total energy" measurement.

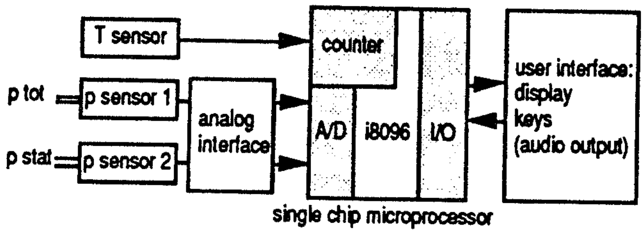

fig 5: basic concept of the board computer using Intel's i8096

The analog outputs of both pressure sensors are directed, after preprocessing, to the multiplexed 10 bit analog input of Intel's i8096 microcontroller [3]. The temperature sensor is a quartz the frequency of which depends on the temperature [1] (fig 6). Integrated into the same package, a preprocessing stage which allows a noise insensitive transmission of the frequency-modulated output signal using the two power supply wires. These features are interesting since i) the distance from a point exposed to external temperature (nose of the aircraft, ventilation channel) can be rather long and prone to noise sources, and ii) the board radio generates important HF-noise while emitting.

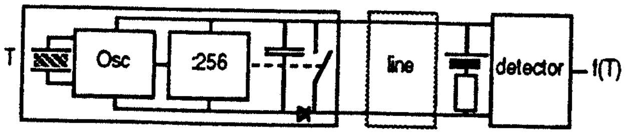

fig 6: temperature sensor

practical aspects

Prior to realization, the performances of the involved elements had been checked. This lead to some minor modifications:

- in order to achieve a better resolution, the derivative of the p_{stat} signal is evaluated electronically using simple analog hardware
- the differential pressure p_{diff} is evaluated directly using a differential pressure sensor.

final solution

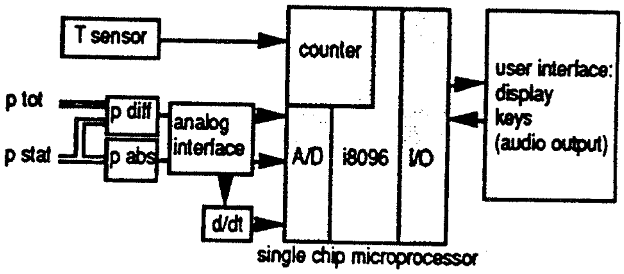

fig 7: final concept of the board computer

Finally, a prototype has been realized using Intel's i8096 microcontroller (fig 7) The pressure sensors are out of the program of SENSYM, the temperature sensor TP-50 is from ETA Microcrystals [1].

6. Results

characteristics of the instrument

The prototype has been tested. It showed the following characteristics for the different parameters:

temperature:
resolution 0.5° for - 5°C... 60°C
(extension possible)

altitude:
resolution < 11 m for 0..5500 m

speed:
resolution < 0.5 m/s for 45 km/h to 350 km/h

vertical speed:
resolution 0.1 m/s for -10 m/s... +10 m/s

energy balance, virtual climb rate:
corresponding to the values for the vertical speed

operating temperature:
limited by the temperature range of the microprocessor system

The tested characteristics of both temperature and pressure sensors were such that they could be lineareIy approximated. The main problem is actually the temperature range of the electronics which would force the use of "military" specified components. A second problem is the display of the user interface, usually an LCD device, which needs heating at low temperatures.

analog hardware, calibration

The silicon sensors have been calibrated manually by comparison with existing reference instruments. Their parametric model has then been written in a ROM. This approach, while reasonable for a prototype, can be replaced for batch production by an automatic test bench calibration, taking into account the multiple data exchange facilities of the microcontroller.

software, execution speed

The programs have been written in Intel's PLM96 language which includes integer division and multiplication. The log-function is implemented as a Taylor series development. The computation speed, a critical point with regard to the complex formulas, was not a problem. Since the user should be able to read the results, it is not necessary to update the display at a high frequency.

7. Future extensions

At this stage of the development, some more interesting features could be easily implemented:

- statistics (distances, time, ...)
- speed maximization for the final approach
- speed optimization during translation

While the features above (speed, altitude, power and statistics) where independent of the aerodynamic characteristics of the glider, it will be necessary to take the speed polar into account for the optimization tasks.

speed polar

The speed polar of a glider is the function which characterizes the sink rate as a function of the speed (fig 8). It can be shown that it can be approximated very well by a parabola which can be specified in turn by only three parameters [4].

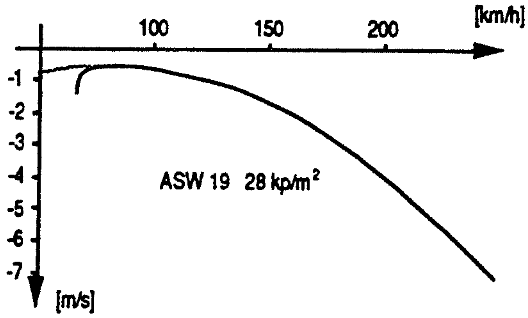

fig 8: speed polar of a glider (ASW 19) and its approximation by a parabola

Therefore it is possible to memorize a set of parameter triplets for a huge number of gliders, allowing an easy configuration of the board computer either by switch settings or by a software menu and non-volatile storage devices.

speed maximization for the final approach

Given the distance and the height available with respect to a geographic point, e.g. an airfield, the board computer can deliver two informations using the speed polar:

i) Whether the geographic point can be reached directly without any gain of energy or not.

ii) The maximum speed allowed when the first condition is fullfilled.

speed optimization during translation

Given a meteorological situation with a mean climb rate v_m in thermals, the theory of P. McCready, stated in 1949 [4], allows to compute an optimal speed during translation such that the flight time for a given distance, including both climbing and translation phases, can be minimized, this taking again into account the speed polar. Comparing the true air speed with the computed nominal value, the pilot can be informed in real time on how to adapt the speed.

8. Conclusions

A board computer for a glider, indicating speed, altitude, energy balance and some more features has been realized at a relatively low cost. It is based on modern silicon sensors and a flexible microprocessor system. The advantages of this concept are i) the suppression of mechanical parts, ii) the combination of partial results using relatively complicated mathematical formulas for more complex functions, iii) the suppression of the "antenna" openings the calibration of which was difficult and dependent on the type of aircraft, iv) the implementation on a user friendly interface, and v) the possibility to extend the instrument's features by simple changes to the software.

9. Acknowledgements

This work has been realized as a student's project at the Institute for Microtechnology, University of Neuchâtel by Waleed Hamza, supervised by J. P. Amann. We are graceful to F. Pellandini and H. Hügli who gave us the possibility to work on this project. Thanks also to J. Weber, B. Kloeck and F. Corthay for their help.

References

[1] Thermopack TP-50
ETA MICROCRYSTALS, Grenchen,Switzerland

[2] Hamza Waleed
"Application de capteurs modernes: variomètre/directeur de vol"
IMT University of Neuchâtel, Switzerland, march 1988 (internal report, in french)

[3] INTEL, i8096 µC Handbook, PLM96 User's Guide, MCS96 User's Guide, RL96 User's Guide

[4] Reichmann Helmut
"Streckensegelflug"
Motorbuchverlag, Stuttgart, Germany, 6th edition, 1985

[5] SENSYM, "1988 Pressure Sensor Handbook"

[6] Eichenberger Willy
"Meteorologie: cours pour aviateurs", Schweizer Verlagshaus AG, Zurich, Switzerland, 1973 (in french)