

A New Method of Ink Level Detection For Inkjet Printers by Pressure Conditions

Chin-Tai Chen
Optics-Electronics System Labs
Industrial Technology Research Institute
Chutung, Hsinchu/Taiwan R.O.C

Abstract

Method for the ink level detection of thermal bubble ink-jet printer was studied in the paper. Some past and current methods of ink level detection for thermal bubble inkjet printers were reviewed first in the paper. Disadvantages of them could be found. Therefore, the fundamental physical principles (fluid dynamics) have been discussed to understand what physical properties would be changed as the ink being consumed in the ink reservoir. It's found that the natural and close relationship between the pressure and ink level could be applied to predict continuously the ink volume contained in the reservoir. Following the relationship, one new method, including three different schemes herein, have be presented explicitly for doing such an implementation by a pressure transducer which is available at the present day. A simple procedure was also described to show how the data process and transformation should be manipulated. The new presented method here will own many advantages, including no waste of ink, early warning of ink out, and so on.

Introduction

Methods for ink level (volume) detection of the ink reservoir have been much explored and studied since 1983 when the ink-jet printer was invented and getting more and more popular in many offices and families. Some of them detect the remaining ink volume of the reservoir by observing the changes of dielectric medium therein, but the features of dielectric medium often change for different compositions of ink.[1,2,3,4] Some of them detect the ink level by observing the change of specified object's position in the ink bag or the change of brightness of light window in the container.[5,6] In last year, other interesting methods for the same goal of ink level detection were disclosed one by one, including measuring temperature of ink,[7] weighting the ink of container,[8] and ultrasonic method.[9] It's obvious that most of them have at least one disadvantage, including waste of ink, lack of early warning of ink out, and so forth.

It's noted that there was one detection method of ink level disclosed by Young et al in 1987 which the remaining ink level of the container can be calculated by a pressure differential gage.[10] The basic principle applied in the method was fluid statics. It mentions in one sense that the fluid height (level) between two points of our interest can be evaluated by taking the pressure differential of them However, one important idea should be carefully pointed out herein that the shape of ink reservoir might be changeable as the ink being consumed if a ink bag was used to contain the ink. Hence, the ink height can not really tell the ink volume contained in the reservoir in this case. In addition, taking the pressures on the top and bottom of ink reservoir will need a tube with enough length for the connection that could not be very desirable in many ink reservoirs.

Detection Method by Pressure

Fundamental Principles

In a typical thermal bubble inkjet printer, the ink cartridge always holds a significant property of fluid mechanics: an operational pressure range. This pressure range should, in general, have a maximum pressure at the initial use and a minimum pressure near the use-out time. For completely closed ink reservoir, the vacuum (air) pressure on the top of reservoir should follow the perfect gas equation (1) that clearly gives the vacuum pressure in terms of volume and temperature for a defined gas number of closed region.

$$PV=nRT \tag{1}$$

Supposed that the ink consumption is reasonably slow and stable enough, it will give an isentropic and isothermal process. Meanwhile, it's noted that the vacuum volume is increasing when the ink is decreasing in the operation. Consequently, the vacuum pressure is going down and forming the operating pressure range out. Thus, the previous gas equation (1) could be further simplified into following equation (2). It makes sense in our ink reservoir.

$$PV=constant \tag{2}$$

Generally speaking, the initial conditions are room temperature (295K) and pressure (1.0127×10^5Pa); at the mean time, the pressure range of our interest could be from zero to negative fifty centimeter water column (-50 cm W.C.). Hence, the pressure can be expressed in Taylor series (3) with first order accuracy.

$$\because P\Big|_{v_0+\Delta v} = P\Big|_{v_0} + \Delta v \frac{dP}{dh}\Big|_{v_0} + \cdots$$
$$\therefore P\Big|_{v_0+\Delta v} - P\Big|_{v_0} = \Delta v \frac{dP}{dh}\Big|_{v_0} = -\frac{\Delta v}{v_0} P\Big|_{v_0} \equiv \Delta P \quad (3)$$

One example for an ink reservoir with equal cross-section area is shown in *Figure 1*. It's obvious that the change of vacuum volume is very small and hardly to work in our operational range. Hence, at least one pressure regulation is necessary to be applied thereof to slow down the decreasing rate of pressure.

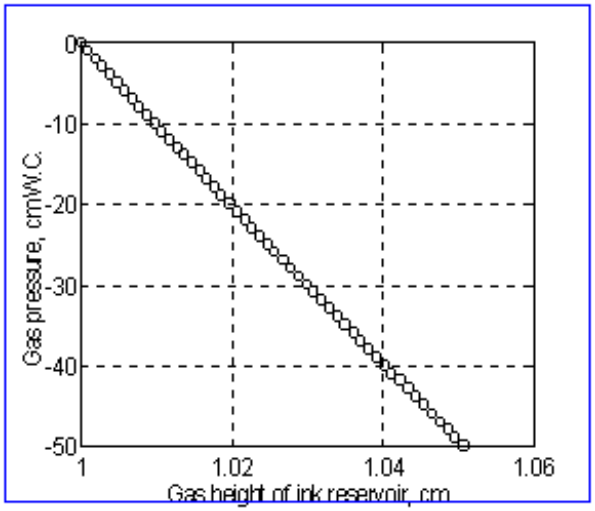

Figure 1.Pressure vs. Height in the reservoir

There are two ways to set up the mechanism of pressure regulation: (1) put one pressure regulator into the ink reservoir (2) put one remote ink container, separated from the ink reservoir, to continuously supply ink (so-called ink supply system). In fact, Most of desktop printers follow the first way and most of wide-format printers follow the second one on the present days. It's significantly noted that the vacuum pressure and ink height can be approximately related in the equation (4).

$$\Delta(P+h)_{\text{printhead reservoir}} = \Delta(P+h)_{\text{ink container}}$$
$$\because \Delta(h)_{\text{printhead reservoir}} \cong 0, \Delta(P)_{\text{ink container}} \cong 0 \quad (4)$$
$$\therefore \Delta(P)_{\text{printhead reservoir}} \cong \Delta(h)_{\text{ink container}}$$

Three Implementation Schemes

By applying the fundamental principles of pressure, there could be three main scheme to implement the ink level detection, shown in Figure 2.a~2.c. Note that one small pressure transducer (sensor) will be used to take the measurement of vacuum pressure of printhead reservoir or ink container for all schemes. In addition, the working range of such pressure transducer should cover the operational range of our interest. In fact, these transducers (e.g. Si-based pressure sensor) are available and inexpensive nowadays.

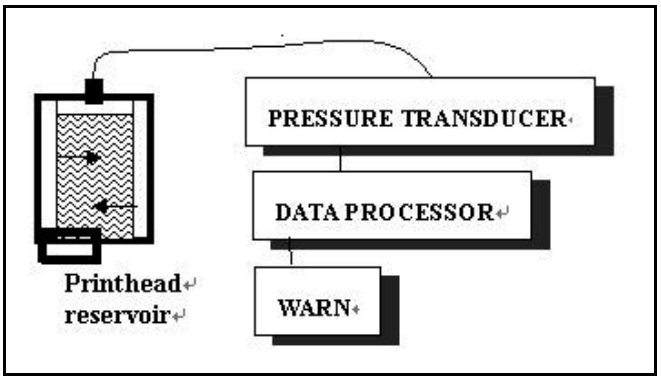

Figure 2a. First detecting scheme

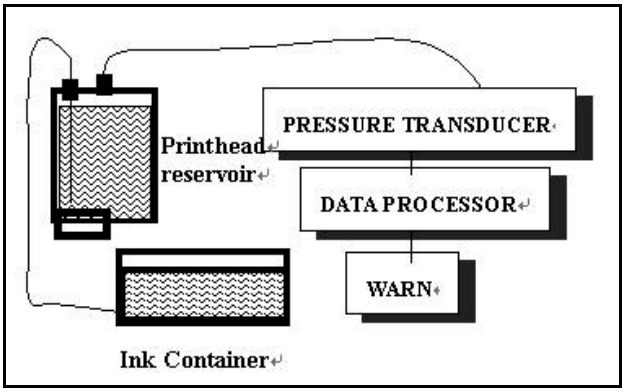

Figure 2b. Second detecting scheme

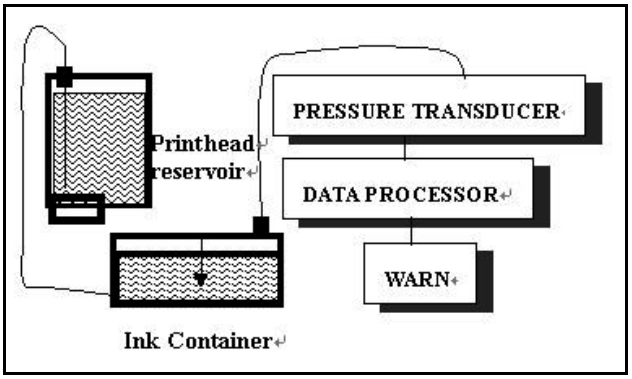

Figure 2c. Third detecting scheme

In the first detecting scheme (see *Figure 2a*), the pressure transducer is mounted on the top of ink printhead reservoir to take the vacuum pressure thereof. In the second detecting scheme (see *Figure 2b*), the pressure transducer is also mounted on the top of ink printhead reservoir as well, but it is equipped with one external ink supply system. In the third scheme (see *Figure 2c*), the pressure transducer is rather mounted on the top of ink container of ink supply system which is closed and not able to allow the environmental air enter into the container.

Data Processing Procedure

No matter what scheme of the three is implemented, the pressure data taken by the transducer should be passed to a process unit (processor) for data transformation which one one-to-one mapping function for the pressure and ink level will be applied thereof. Thus, one warn unit will early warn the user when the ink level is lower than some predetermined value. One preferred flow chart for such a data processing procedure is shown in the following *Figure 3*.

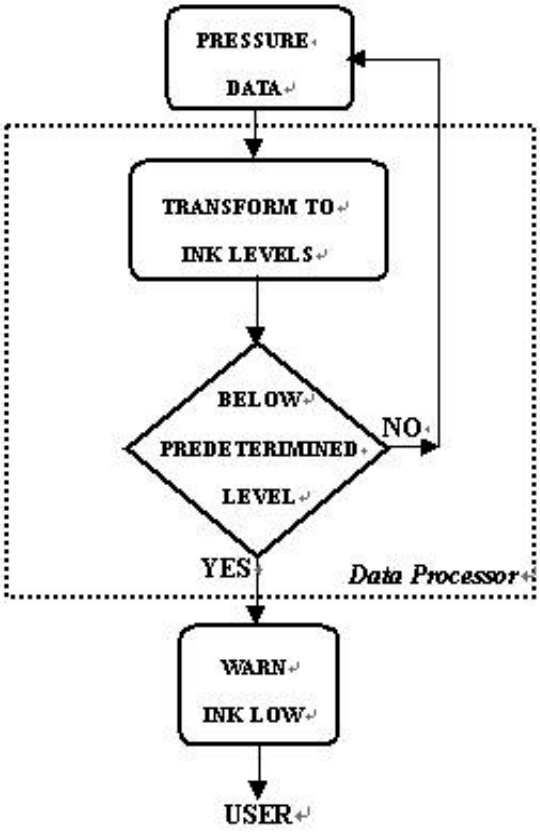

Figure 3.Data processing procedure

One Example: HP51645A Cartridge

The present method can be applied onto the current well-known cartridge HP51645A, manufactured by Hewlett-Packard Company. This cartridge has a completely closed and flexible ink bag (an ink reservoir), and contains a leaf spring inside used as pressure regulation. Its effective maximum volume of ink could be around 40 ml. Hence, the first detecting scheme could be implemented to detect the remaining ink level in the cartridge. At the mean time, the mapping transformation for pressure and ink level of cartridge can be done by the following nonlinear relationship of *Figure 4*(yielded by experiment).

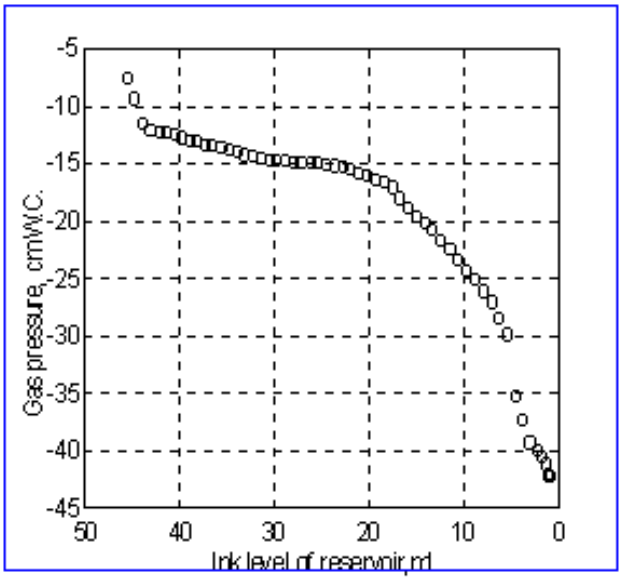

Figure 4. One example for data transformation

It's noted that the predetermined level of ink can be set as 10% full (roughly 5ml) in this case. Therefore, one ink low signal can be sent out to warn the user when the detected pressure has been lower than negative thirty-five centimeter water column (-35 cm W.C.). Then, the user might prepare to replace the cartridge with new one and continue working without abrupt pause of any printing job.

Conclusion

The paper first quickly reviewed several past and current studies related as to the method of ink level (volume) detection for inkjet printers; and some main disadvantages were pointed out subsequently. Then, based on the fundamental principle of fluid mechanism for the inkjet print head, some significant relationships between the vacuum pressure and ink level of reservoir has been explored and built up. Hence, by the relationships new method has been presented in the paper, including three detecting schemes and one data processing procedure. In short, the main result of study can be summarized as follows: (1) Applicable reservoir: should be closed (completely separated from the outside) (2) Method and schemes: need one pressure transducer to take pressure data, one data processor to transform the pressure data into ink level, and one warn unit to offer an early warning of ink level low for users (3) Data processing procedure: offer a logic flow chart to read data and determine if the ink level is low.

Acknowlegdment

This work has been supported by the program MOEA 883NB3110 for wide-format printer project from the Optics-Electronics System Labs of Industrial Technology Research Institute in Taiwan. The related application of patent has been filed as well.

References

1. Manning et al, Fluid Measuring System, *U.S. patent 4371790*, RMR Systems Inc (1983).
2. Kyogoku et al, Residual Ink Detection Mechanism, *U.S. patent 4415886*, Canon Kubushiki Inc.(1983).
3. Lichti, Apparatus and Circuit for Monitoring the Ink Supply and Ink printer Devices, *U.S. patent 4788861,* Siemens Inc.(1988).
4. Goldis, Capacitive Ink Level Detection Sensor, *U.S. patent 5635962,* Hewlett-Packard Com.(1997)
5. Cowger, Level Detection for Ink Cartridges of Ink-jet Printers, *U.S. patent 5574484,* Hewlett-Packard Com.(1996)
6. Hara, Ink Tank with an Level Detector Having a Viewing Window, *U.S. patent 5616929,* Fuji Xerox Co.(1997)
7. Benjamin et al, Cooldown Timing System Monitors Inkjet Cartridge Ink Level, *U.S. patent 5721573,* Hewlett-Packard Com.(1998)
8. Kneezel et al, Ink Level Sensing System for an Ink Jet Printer, *U.S. patent 5731824,* Xerox Co.(1998)
9. Barbehenn, Ultrasonic Method for Monitoring Inkjet Cartridge Levels, *U.S. patent 5774136,* Hewlett-Packard Com.(1998)
10. Young et al, Ink Level Detection System for Ink Jet Printing Apparatus, *U.S. patent 4639738,* Eastman Kodak Co.(1987)

Biography

Chin-Tai Chen received his B.S. degree in Engineering Science from the National Chung-Kung University at Tainan of Taiwan in 1992 and an Engineer Degree in Aeronautics&Astronautics from Stanford University at Palo Alto of USA in December,1997. Since 1998 he has worked at Optics-Electronics & System Labs of Industrial Technology Research Institute in Hsinchu, Taiwan R.O.C.. His work has primarily focused on the ink supply system of thermal inkjet printer, including ink reservoir, ink transport,ink level detection and pressure control issues.