Development of a new instrument for the measurement of the milk constituents based on the embedded system

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Abstract. This paper presents a new way for measuring milk constituents. The new technology utilizes the scattered light to transmitted light ratio of laser light to determine the amount of protein and fat in milk. Fundamental theories of this new technology are discussed in detail and the design blueprint of an embedded system built based on this technology is outlined. Furthermore, the protein concentrations measured by the newly developed instrument are fit well with the authentic results from Dairy Quality Supervision and Inspection Center of the Country, indicating the instrument is feasible and has great potential for the application in dairy industry.

1. Introduction
Continuously raising the people’s standard of living, particular in developing countries, has not only dramatically increased the consumption of milk and but also demanded high quality milk. As a result, accurate measurement of the constituents of milk is getting more and more attention because it will not only enable consumers to choose milk they like, but also enable farmers to match the fodder for their cows based on the measurement results. Currently, two types of approaches, the chemical one and the physical one, have been applied in the milk measurement field. Although the chemical method is more accurate, it has irreparable shortcomings, such as inconvenient, long measurement period, and etc, that could be overcome by a physical approach. However, the development of a physical instrument is complicated and requires various aspects of expertises. Therefore, so far, the problems such as the low measurement accuracy and poor repetition have not been solved. Currently, two methods are explored in the physical instrument design, one of which is using ultrasound wave and the other one is using infrared spectrum. Both methods have advantages as well as disadvantages. In this paper, a new method from a different angle is proposed, in which the ratio of scattered light to transmitted light of laser light is used to determine the constituents of milk. Light scattering technology involves several different physical and engineering fields and has been widely applied in research and industry. We have successfully applied this technology to measure the constituents of milk and demonstrated that it is a feasible and effective application. The application of this technology has created a new field in dairy product measurement.

2. Theory
The scattered light to transmitted light ratio of the laser light is the ratio that $I_t$ to $I_s$, where $I_t$ is the transmission light intensity and $I_s$ is scattered light intensity that is perpendicular to the
transmission light on the same plane. The ratio is one of the token optics parameters of milk constituents. The measurement method is based on the following three theories.

1. The Condition of Light Scattering: It is well known that light spreads along the refraction route and does not scatter in a uniformity medium. Scattering occurs when light travels through the medium containing asymmetry structure, existing in milk. As far as the milk is concerned, the scattered light intensity is much stronger than the transmitted light intensity; while the contrary is true with respect to distilled water. As a result, milk satisfies the scattering condition.

2. Mie’s theory: According to the Mie’s theory, milk is a kind of inspissations dispersoid, in which the sizes of fat globules and casein micelles are relative big and play a key role in light scattering, while low concentrations of lactoglobulin and somatoplasm cells are relative smaller and their effects on light scattering can be ignored. Therefore the protein and fat content in milk may be determined through the scattered light. In practical, it is not easy to control the incidence light intensity consistent due to various reasons such as the voltage mutative and the laser source aging, etc. Therefore, to achieve high accurate measurement (<0.1%), the ratio of scattered and transmitted light is measured in order to reduce or eliminate the various influences from a light source.

3. Beer’s law: When a thread of homochromy light with fixed wavelength travels through well-proportioned liquid, in which the concentration is fixed and the light is absorbed. The reduction of light intensity is proportional to the concentration of the liquid and the intensity of the light.

\[ \ln \left( \frac{I}{I_0} \right) = \alpha \cdot C \]  

Where \( \alpha \) is absorbing quotient. Milk can be considered as watery liquid, hence the interference on the light scattering between milk fat and protein is small, according to Beer’s law:

\[ I_{t1} = I_0 e^{-\mu_1 \xi_1 d} \]  
\[ I_{t2} = I_0 e^{-\mu_2 \xi_2 d} \]

where \( I_0 \) is the incidence light intensity; \( I_{t1} \) is the transmitted light intensity through fat; \( I_{t2} \) is the transmitted light intensity through protein; \( \mu_1, \mu_2 \) are the macroscopically scattering quotient of fat and protein; \( \xi_1, \xi_2 \) are the concentrations of fat and protein; and \( d \) is the length of the sample camber. Then the following relation is gotten:

\[ I_{t2} = I_0 e^{-\left( \mu_1 \xi_1 + \mu_2 \xi_2 \right) d} \]  

From equation (4) we know that if \( I_0 \) is fixed and if the \( I_{t2} \) and \( \xi_1 \) are known, \( \xi_2 \) can be calculated. Since \( I_{t1} \) could be obtained from equation (2) when laser light beamed through the liquid only containing fat. After measuring the intensity of milk containing both fat and proteins, and the intensity of protein dissolved fat liquid, \( \xi_2 \) can be obtained based on the theoretical models between \( \xi_1 \) and \( \xi_2 \). In this study, EDTA was used to dissolve the protein micelles. Then the scattered light is only from fat globules in the protein-dissolved milk. Therefore, the relation between the ratio and the content of fat can be measured and then the content of protein could be calculated. In order to further confirm the feasibility of this method, a series of diluted milk were used to examine whether ratio of the scattered laser light to transmitted laser light can determine the concentrations of various ingredients in milk. Six milk dilutions were measured the ratio of the scattered laser light to transmitted laser light. The relation between the concentrations and ratio is showed in Figure 1. As we expected, a well correlation between the milk concentration and the ratio was observed.

3. The design of instrument system

3.1. Hardware design
The embedded system design based on ARM processor is used as the hardware component. The S3C44B0X chip from Samsung Corporation is chosen as the processor. The chip kernel of this
processor is ARM7TDMI with 8K Cache, and its working frequency is 66MHz. In order to improve detection accuracy, the processor’s inner ADC is not used and replaced by a 16 bit AD ADS1601 from Texas Instrument. SST39VF160 Flash ROM (2 MB, 16Bit) and HY57V641620 SDRAM (8MB, 16Bit PC100/PC133) are used as program and data memory, respectively. Due to its excellence in power consumption and cost, a 640x480 single color all reflected LCD is chosen. LCD screen refresh rate is controlled by the LCD controller in the CPU.

Figure 2 shows the system structure. It is very important to choose a proper electric eye and well-designed amplifying circuit since the photocurrent is weak from a semiconductor laser and a photocell. After several rounds of testing, the ICL7650 amplifier from MAXIM was selected for the system.

![Figure 1](image1.png)  
**Figure 1.** the relation curve between the concentration of milk and the ratio.

![Figure 2](image2.png)  
**Figure 2.** the structure of system.

3.2. Software design

The software component is mainly comprised of the system layer and the application layer. In the implementation of the system layer, firstly the embedded OS eCos (embedded configurable operating system) is ported, and then its kernel is extended to construct a simple and highly efficient OS. eCos is the key embedded operating system product of RedHat Corporation. eCos is open sourced and is very suitable for an embedded application. The OS has layered structures and reasonable interfaces. Especially its DEV and I/O packages are convenient for developers to manage the device drivers. System developers can bundle their code with eCos and easily configure new devices along with
devices already supported. Figure 3 illustrates the structure of eCos. We have ported it to our system successfully.

The application layer built on top of the OS layer is composed of the conversion between analog data and digital data, the LCD display and control mechanism for monitoring the milk coming in and out of the system. The program flow chart of A/D conversion subcomponent is shown in Figure 4.

![Figure 3. the structure of eCos system.](image)

![Figure 4. the flow chart of A/D conversion.](image)
4. Analysis of measured results
In order to determine the instrument accuracy, ten milk samples which concentrations had been determined by Dairy Quality Supervision and Inspection Center of the Country were measured by the instrument (Table 1). Comparing the results, it suggests that the instrument accuracy is above 90%. Therefore, it is appropriate to apply the method to detecting the constituents of milk.

Table 1. Standards VS Experiment Data.

| Sample number | Standard | Tested | Variants |
|---------------|----------|--------|----------|
| 1             | 3.12     | 3.12   | 0        |
| 2             | 3.08     | 2.92   | 0.16     |
| 3             | 2.79     | 2.96   | -0.17    |
| 4             | 3.10     | 3.01   | 0.09     |
| 5             | 3.06     | 2.77   | 0.29     |
| 6             | 2.84     | 2.90   | -0.06    |
| 7             | 2.96     | 3.10   | 0.14     |
| 8             | 2.68     | 2.87   | 0.09     |
| 9             | 3.12     | 3.07   | 0.05     |
| 10            | 3.59     | 3.53   | 0.06     |

5. Conclusion
A new method using the ratio of scattered light to transmitted light of the laser light to detect the concentrations of protein and fat in milk is presented in the paper. Fundamental theories including the condition to generate scattering light, Mie’s law and Beer’s law are discussed for their merits. The theory of the ratio of scattered light to transmitted light of the laser has been analyzed and the method has been applied for the instrument design. In addition we have demonstrated its feasibility through a quantitative analysis. Furthermore, the design of the instrument hardware and software are described to show how the system functions. Finally, the protein concentrations determined by the newly developed instrument are either same or very close to the authentic results from Dairy Quality Supervision and Inspection Center of the Country, indicating that the instrument is feasible and with good accuracy. Through our analysis of the theory of scattered light to transmitted light ratio of laser light and the application of the proposed method we have demonstrated that our method can be successfully applied in measuring the concentration of milk ingredients. This work breaks the ground for a new way to measure dairy product ingredients.

References
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