# A Hall Effect sensor based syringe injection rate detector

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# A Hall Effect Sensor based Syringe Injection Rate Detector

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***Abstract*—Rate of injection of anesthesia affects various physiological and pathological changes in a patient such as perception of pain and time taken for onset of akinesia. A training system based on a suitably modified syringe equipped with a simple measurement system where a trainee can observe the rate of injection, prior to practicing on live patients, can be of immense value towards reducing the risks involved. In this paper, we propose a low-cost Hall Effect sensor based measurement scheme for detection of rate of injection from a syringe. The Hall Effect sensor along with a permanent magnet senses the position of the syringe piston relative to the syringe body. A new design of a suitable piston has been discussed that minimizes anesthesia wastage by providing the illusion of anesthesia flow through the needle. A prototype system has been built and tested that validated the new scheme. The rate of injection was measured and displayed in real time. It was within acceptable error limits demonstrating the usefulness of the system for practical training purposes.**

## I. Introduction

Administration of anesthesia by injections is a standard clinical practice. The rate of injection of anesthetic fluid has been shown to affect the quality of the anesthetic procedure [1]-[3]. Several pathological and physiological changes such as perception of pain, onset of akinesia and spread of anesthetic agent have been positively correlated to the rate of injection in all major fields of anesthesiology [1]-[8]. Therefore, it is necessary for the anesthetist to have an idea of the rate at which the anesthetic agent is being injected. Training on human subjects is risky and cadavers do not emulate the pathological changes required to assess the quality of an anesthetic procedure. Thus, a training system wherein the trainee is given real-time indication of the rate of injection can be of immense value in practicing a safe and painless rate of injection in real-life procedures. Image or video based methods of calculation of rate of injection require direct line of sight between the image capture device and the syringe [8]. This impairs free movement for the anesthetist who does not perceive an accurate training scenario. A magnetostrictive displacement transducer based method proposed in [9] and the magnetic encoder system used in [10] are both large and bulky which make it difficult to maneuver and hold and therefore not well suited for training purposes. In this work, we present a low-cost single element Hall Effect sensor and ring magnet based design for measurement of rate of injection. The needle is blocked to prevent discharge of any anesthetic fluid during training thus obviating the need for cleaning and minimizing wastage. To give the trainee a realistic training experience, a specially designed piston structure that conceals the anesthetic fluid when the piston is pressed providing the illusion of actual liquid flow through the needle is employed. Additionally, the piston also houses the Hall sensor, hiding it from the view of the trainee, thus providing a maneuverable and compact syringe to practice safe rate of injection.

## II. Hall-Effect Based Injection Rate Detector

The modified syringe has a specially designed piston as shown in Fig. 1. The needle is blocked permanently to prevent passage of any fluid. Ring magnets are attached to the transparent syringe body. The magnets are concealed by a magnet holder developed. The needle shown in Fig. 1 is a standard 23G needle and the syringe body is a standard commercially available 5ml syringe. The design of the piston is discussed in the following section.

### A. Modified Piston of the Syringe

The modified piston consists of a translucent hollow cylindrical chamber (**C**) connected to the atmosphere through a ball valve (**V**) on one end as shown in Fig. 2(a). The other end of the piston has a rubber seal as usual but with a hole (**H**)

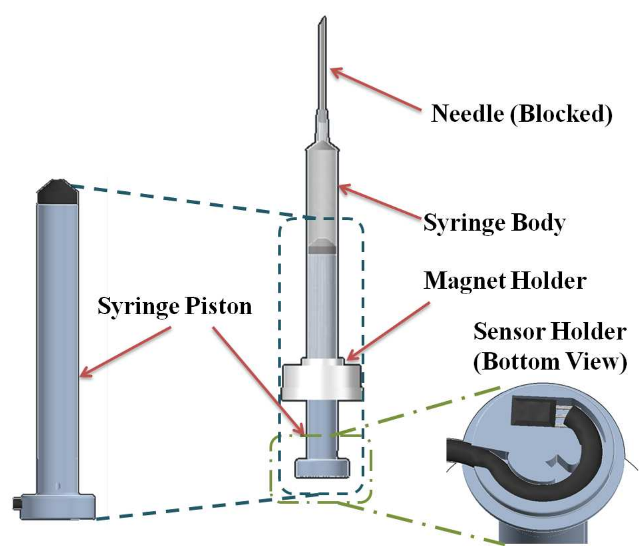


Fig. 1. Various parts of the syringe: new piston, Hall Effect Sensor Holder, Ring Magnet Holder and the Syringe body. The blocked needle is also visible.

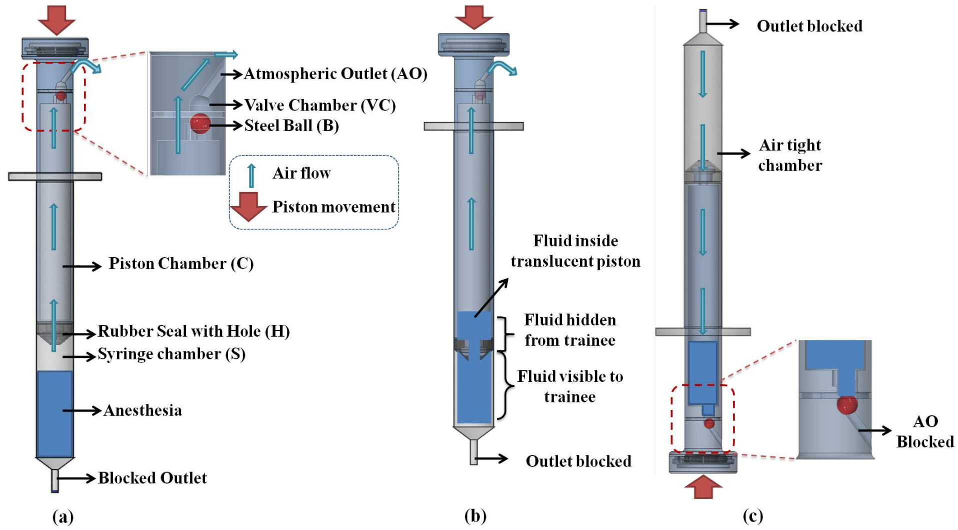


Fig. 2. (a) Needle facing downwards. Flow of air through AO to atmosphere enabled as ball valve moves down. (b) Fluid entry into piston chamber creating the illusion of liquid ejection from needle. (c) Needle facing upwards. Formation of air tight chamber inside piston and syringe body due to ball valve action is visible.

that connects the cylindrical chamber (**C**) to the syringe body chamber (**S**). The ball valve consists of a steel ball (**B**) sliding in a cylindrical valve chamber (**VC**) leading to the atmospheric outlet (**AO**) as indicated in Fig. 2. The outlet of the syringe is blocked with a cyanoacrylate based water resistant adhesive, preventing passage of fluid through the needle outside the syringe body.

Anesthetic fluid is initially filled in the syringe chamber **S** and the syringe piston is inserted into it with the needle tip facing downwards. In this condition, steel ball **S** slides through **VC** towards **C** due to gravity. This will open up **AO** to atmosphere. When the syringe piston is pushed inside syringe chamber **S**, the air entrapped inside chamber **C** of piston, escapes to the atmosphere through **AO** and the fluid inside **S** enters **C** as shown in Fig. 2(b). Since the piston is made of a translucent material, the fluid remains concealed from the view of the trainee and he feels as if the fluid has been ejected through the needle, whereas it is actually stored inside chamber **C** of the piston as illustrated in Fig. 2(c). Similarly, when the piston is pulled back, while performing aspiration, the fluid reenters syringe chamber **S** from **C**.

However, when the syringe is held with the needle facing upwards, steel ball **B** slides through **VC** towards **AO** due to gravity, closing **AO** as shown in Fig. 2(b). Now, the chambers consisting of **S** and **C**, form a completely air tight chamber, since all the outlets are blocked. Therefore, in this position, the piston cannot be pushed inside the syringe body. This prevents leakage of anesthetic fluid from the system, while giving a realistic training environment to the trainee. As shown in Fig. 1, the new piston also houses a Hall Effect sensor SS49E from Honeywell. The detection axis of the Hall sensor

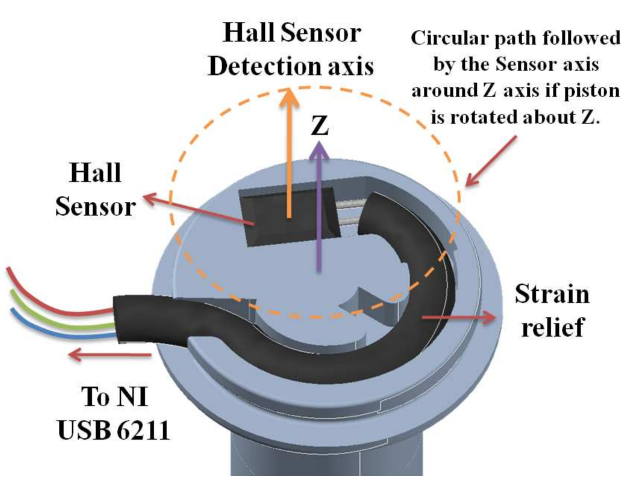


Fig. 3. The Hall Effect sensor with strain relief for cables. Hall detection axis is parallel to the cylindrical axis of piston.

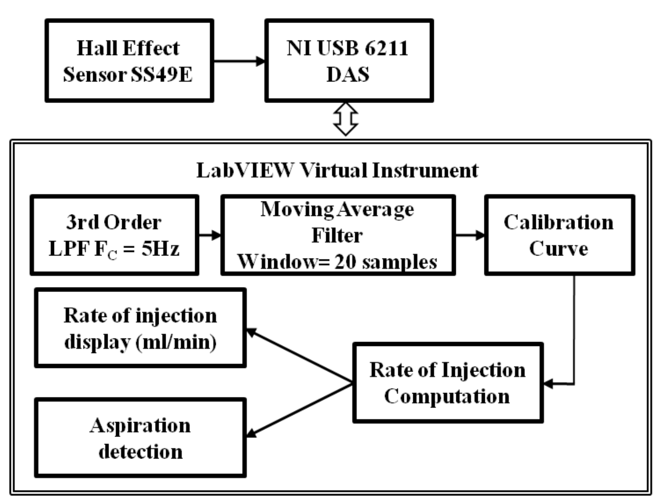


Fig. 4. Block Diagram of the measurement setup.

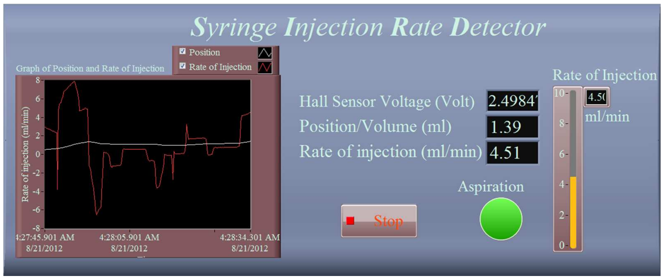


Fig. 5. LabVIEW based Virtual Instrument front panel showing the rate of injection, piston position and Aspiration indicators in real-time.

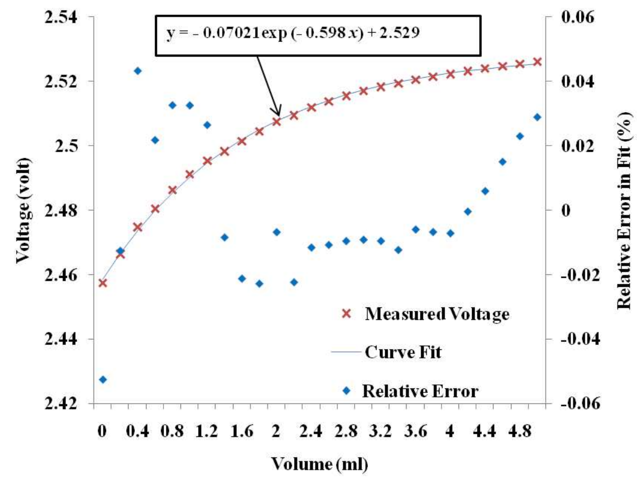


Fig. 6. Exponential curve fit of (1) with percentage relative error in fit.

is aligned to the direction of movement of the piston. The wires connected to the sensor are provided with a strain relief and taken out from the piston body as shown in Fig. 3 to the measurement system.

### B. Magnet Holder

A magnet holder has been fabricated that houses a set of three Nd-Fe-B ring magnets of outer diameter $25.4mm$, inner diameter of $19.05mm$ and thickness of $2.38mm$ each. This holder is fitted on the syringe body as shown in Fig. 1. The surface magnetic flux density of each magnet is $2635Gauss$. The magnets are axially magnetized with poles on the flat face. The three magnets are stacked on top of each other with their magnetic axis parallel to the axis of the Hall sensor. Since, the piston of the syringe body is free to rotate about the central axis (Z) as shown in Fig. 3; the Hall sensor detection axis can transcribe a circle of fixed radii around Z-axis, while always remaining parallel to the central axis. The magnetic field produced by the ring magnet is uniform over this circle. Hence, the rotation of the piston or the syringe body about the central axis does not produce any change in Hall sensor output signal. Therefore, the trainee can freely rotate the piston (as in a typical syringe) or the syringe body as may be required for adjusting the bevel direction of the needle.

## III. Measurement scheme

The block diagram of the measurement scheme is shown in Fig. 4. The Hall sensor inside the piston is powered by a stabilized +5V power supply and output of the Hall sensor is fed to one of the analog input channels of a National Instruments USB 6211 16-bit Data Acquisition System.

As the piston is moved, the distance between the Hall sensor and the magnets change. Thus the magnetic field strength experienced by the Hall sensor changes according to the position of the piston in relation to the syringe body. As a result the output of the Hall sensor is a function of the piston position and in turn, the volume of liquid expelled in ml. The Hall sensor output signal is sampled at the rate of $1kHz$. The signal is acquired through a LabVIEW program. It is then filtered with a 3rd order Low Pass Butterworth filter of cutoff frequency $5Hz$. The signal is then passed through a moving average smoothing filter of sample length 20 as indicated in Fig. 4. The measurement signal is then fed to a calibration curve to determine the position of the piston with respect to the syringe body. The output of Hall sensor is directly calibrated to provide the volume of liquid (**V**) in the syringe chamber body **S** in $ml$. The rate of injection (**R**) is then calculated in $ml/min$ by computing the difference in **V** (in $ml$) between successive samples and dividing it by the sampling rate. The absolute value of the rate of injection **R** is displayed to the trainee as shown in Fig. 5. Additionally, if **R** exceeds a positive preset threshold value, the system detects aspiration of the piston, which is considered as an important step in anesthesia administration.

## IV. Results

A prototype of the syringe assembly was built using a Rapid Prototyping (RP) technique and the measurement scheme was implemented in a virtual instrument developed in a LabVIEW

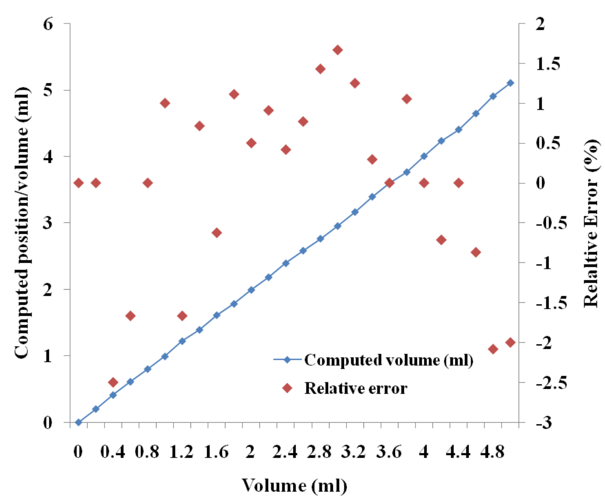


Fig. 7. Computed volume versus true volume with relative errors.

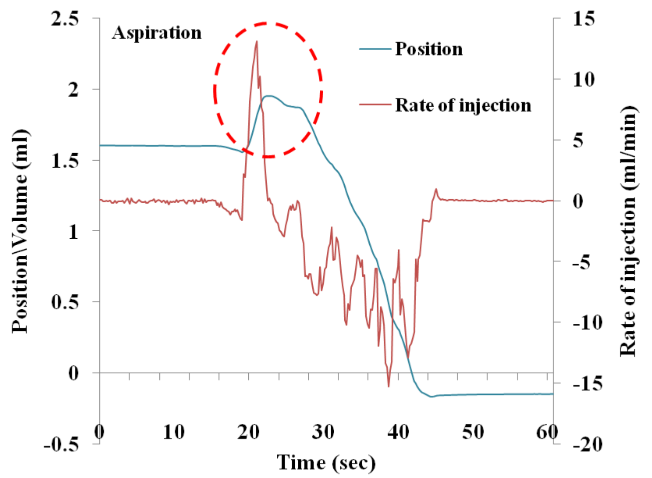


Fig. 8. Graph of computed position and rate of injection obtained from the prototype.

Environment. The Hall sensor, SS49E (Honeywell) was calibrated and an inverse exponential curve of (1) was fit to it as shown in Fig. 6. Where, $y$ is the output voltage from the Hall sensor in $volt$ and $x$ is the volume of liquid in the syringe (or position of the piston multiplied by the cross-sectional area of the syringe body) in $ml$ . The worst case relative error in fit was less than $0.05\%$.

$$y = 2.529 - 0.07021e^{-0.598x} \tag{1}$$

The relative error in measurement of position (volume), V is shown in Fig. 7. Worst case relative error in measurement of position was found to be less than $2.5\%$. Therefore, the worst-case relative error in computation of difference in V between successive samples (dV) will be $5\%$. Since, the error in dt is negligible (50ppm of sampling rate), the worst-case relative error in measurement of rate of injection (dV/dt)in $ml/sec$ will not exceed $5\%$. Fig. 8 shows the graph of the computed position and the rate of injection measured in real-time from the developed prototype and the LabVIEW program.

## V. Conclusion

A Hall Sensor based system for measurement of rate or speed of injection from a syringe has been presented. This system will help to improve training of administration of anesthesia by injection. A prototype of a piston along with the syringe body has been built and the practicality has been tested. A ball valve assembly in the system prevents anesthetic fluid from being ejected from the syringe while ensuring that the visual feel of the liquid being ejected is retained, thus providing the trainee with a training experience which is close to reality. From the tests conducted on the prototype syringe, it has been noticed that the Hall sensor based measurement scheme provides position of the piston with respect to the syringe body with a worst case relative error of $2.5\%$. The rate of injection is calculated from the position information; hence the worst case error in measurement of rate of injection is $5\%$. For practical training purposes, this error is well within acceptable limits. The rate of injection rarely exceeds $15ml/s$.

## References

[1] H. Erdemir, L. Soper, and R. Sweet, “Studies of factors affecting peridural anesthesia,” *Anesth Analgesia Cr. Res*, vol. 44, pp. 400–404, 1965.

[2] K. Korttila, M. J. Matttla, and M. Linnoila, “Prolonged recovery after diazepam sedation: the influence of food, charcoal ingestion and injection rate on the effects of intravenous diazepam,” *Br J Ophthalmol*, vol. 48, pp. 330–340, 1976.

[3] J. H. Mcclure, D. T. Brown, and J. A. W. Wildsmjth, “Effect of injected volume and speed of injection on the spread of spinal anaesthesia with isobaric amethocaine,” *Br J Ophthalmol*, vol. 54, pp. 917–920, 1982.

[4] G. R. andL. Versichelen, L. Huyghe, and H. Mungroop, “Effect of speed of injection on induction of anaesthesia using propofol,” *Br J Ophthalmol*, vol. 57, pp. 743–746, 1985.

[5] T. Gillart, J. E. Bazin, M. Montetagaud, F. Bevillard, S. Amara, and P. Schoeffler, “Effect of speed of injection on induction of anaesthesia using propofol,” *Anaesthesia*, vol. 53, pp. 486–491, 1988.

[6] L. Anderson, J. Walker, C. Brydon, and M. G. Serpell, “Rate of injection through whitacre needles affects distribution of spinal anaesthesia,” *Br J Ophthalmol*, vol. 86, pp. 245–248, 2001.

[7] M. Ipp, A. Taddio, J. Sam, M. Gladbach, and P. C. Parkin, “Vaccine-related pain: randomised controlled trial of two injection techniques.” *Arch Dis Child*, vol. 92, pp. 1105–1108, 2007.

[8] K.-S. Seo, R. Derby, E. S. Date, S.-H. Lee, B.-J. Kim, and C.-H. Lee, “In vitro measurement of pressure differences using manometry at various injection speeds during discography,” *The Spine Journal*, vol. 7, pp. 68–73, 2007.

[9] D. Tran, K.-W. Hor, A. Kamani, V. Lessoway, and R. Rohling, “Instrumentation of the loss-of-resistance technique for epidural needle insertion,” *Biomedical Engineering, IEEE Transactions on*, vol. 56, no. 3, pp. 820 –827, march 2009.

[10] M. Loeffel, P. Heini, N. Bouduban, J. Burger, L.-P. Nolte, and J. Kowal, “Development of a computer-assisted high-pressure injection device for vertebroplasty,” *Biomedical Engineering, IEEE Transactions on*, vol. 54, no. 11, pp. 2051 –2056, nov. 2007.