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INITIAL RESULT ON MEASUREMENT OF GAS VOLUMETRIC FLOW RATE IN GAS/LIQUID MIXTURES USING LINEAR CCD SENSORS

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Abstract. The aim of the project is to investigate the feasibility of using linear CCD sensors to detect, measure and produce tomographic images of the oil droplets. In the first instance, the instrument will measure gas bubbles in a water tank and estimate their size distribution and velocity.

Keywords: Optical tomography, CCD sensor, oil droplets

Abstrak. Objektif utama penyelidikan ini adalah untuk melihat keberkesanan penderia CCD untuk mengesan, mengukur serta menghasilkan gambaran profil tomografi titisan minyak. Pada keseluruhannya instrumen yang akan dihasilkan berupaya mengukur kelajuan buih gas di dalam tangki.

Kata kunci: Tomografi optik, penderia CCD, titisan minyak

1.0 INTRODUCTION

Optical systems and image processing have been used extensively in a vast number of different applications such as medical diagnostics, geological surveying, chemical engineering, machine vision, information technology, flow measurement and military guidance [1]. In two-phase flow, optical tomography combined with image processing is becoming a powerful technique to study flow phenomena and in particular to measure volumetric bubble flowrates [1, 2].

Present day experimental tomography systems for the measurement of gas/liquid mixtures use capacitance [3], electrical impedance [4] and gamma radiation [5]. Capacitance and electrical impedance have relatively poor spatial resolution i.e. 10% accuracy [6, 7]. Gamma systems are slow because of present day hardware limitations. Optical systems have the potential to be fast and have high resolution, better than 1% [8]. Existing optical tomography systems use either optical fibres or video cameras and relatively complex signal processing and data capture systems. Usually, researchers and engineers deal with expensive commercial products that are supported

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with complex interfaces or grabber cards. They are capable of extremely high data rates but have memory requirements, and require complex control of the CCD arrays. As an alternative, the proposed system uses linear CCD devices which provide integrated optical to electrical transduction with built-in data capture and transfer.

The use of the different projections will provide differing estimates of bubble size and shape and be the basis for tomographic imaging. The combination of volume and velocity measurement will provide gas volume flowrates.

Data collected from the linear CCD sensors will also be used to develop a model of small bubble development and flow in order to be able to more fully describe the behavior of gas/liquid mixtures containing small bubbles. The result from this modeling work will in turn be used in the development of the gas (volume) flow rate measurement system.

There are many possible applications for tomographic measurement of flow in process industries, wherever two or multi component flow occurs. The major advantage of tomography over other measurement methods is it enables concentration [9] and velocity profiles [10] to be measured at specific cross-sections in the flow. The major disadvantages are cost and complexity. The present system of 8×8 sensors samples only 20% of the measurement volume. With all 38 sensors (four arrays) 47.5% of area is interrogated. Abdul Rahim used a 16×16 array of sensors providing 50% sampling. Optical methods mainly measure gas content i.e. bubble flow, but can measure oil droplets in a water carrier; they will not measure water in oil unless infra red light is used because oil in optically too opaque for visible radiation. Several applications are now outlined.

The oil industry has supported research in Norway [11] and the United Kingdom to design on-line, non-intrusive devices to measure oil-water fractions in production pipes. A further requirement is to measure flushing water from oil tankers. Most research was developed to measure the distribution of oil, water and gas in a cross-section of the pipe. Tomographic flow imaging can also be used in flow characterization for process optimization in the oil industry. There is a current requirement to detect and quantify the presence of gas bubbles in oil exploration. For this reason a method has been developed to measure simultaneously the velocity, size and refractive index of large optically transparent bubbles and droplets in the laboratory [12]. Recently, this investigation described a measurement technique used to determine both velocity and diameter of transparent spherical objects, mainly droplets and gas bubbles. A prototype optical tomography system for detection and measurement of shapes of the gas bubbles moving in a liquid has been developed using an adjustable optical system which easy repositioning of the detectors [13]. Measurement of gas bubbles in a vertical water column has been investigated using optical tomography; concentration and velocity of the bubbles was measured using layergram back projection to determine cross-sectional concentrations and cross correlation of images for velocity distributions [10].

In two-phase flow, optical tomography combined with image processing is becoming a powerful technique to study flow phenomena and in particular to measure volumetric bubble flowrates [1, 2]. An important on going aspect of tomography is to use a computer tomography reconstruction algorithm to produce high quality images at high speed and with the minimum complexity. A fast generalized back projection algorithm was investigated, adapted and tested using different measurement techniques including capacitance, using real measurement data.

Bui Dinh (1999) and Choi [1] has introduced a new method for automatic bubble identification of two-phase bubbly (gas bubbles disposed through the liquid) and slug (gas concentrated mainly in a large single bubble with diameter approximately that of the conveyor) flow in a small vertical pipe using a CCD camera. Polonsky *et al*. [14, 15] has studied the motion and velocity of elongated [15] bubbles in air/water vertical flow by processing a consecutive series of digitized video images. Unfortunately producing images using these devices have problems, especially in terms of lighting, speed and interlacing which can cause distortion.

Another possible application is the measurement of oil content in water being used to flush oil tankers after delivery of the oil. There is an industrial requirement to measure the volume of oil per cubic meter of sea water, to ensure this specification is being met. The required oil concentration is low (100 ppm) and at present it appears that only optical techniques are feasible. The flushing water is pumped from the tankers via pipes which move the mixture in a vertical direction, then a horizontal direction and finally downward into the sea.

In this research a method for measuring the volumetric flowrates of gas bubbles is proposed using an optical tomography measurement system with a linear back projection algorithm (LBP) to generate images of the measurement cross-section. During the initial stages of the project, three optical devices have been tested. These are; a digital camera, a video camera and CCD devices. These experiments use a gas bubble flow in a vertical pipe in the laboratory as a model. The reason gas bubbles are used in the flow pipe is to have two different phases. The importance of this experiment, is that the bubbles approximately describe the characteristic or behavior of oil droplets. In flushing water from tankers, oil droplets are small and have very high optical attenuation. Because of the high optical attenuation it behaves like a solid particle for the attenuation of light. Ibrahim [10] shows that small gas bubbles, less than 1 mm in diameter, allow only a small proportion of the incident beam to be transmitted. This behavior is similar to an equally sized oil droplet in its attenuation of the transmitted beam. In order to produce tomographic images of the droplets a minimum of two optical arrays placed around the flow pipe need to be used. The use of the different projections will enable more accurate estimates of bubble size and shape. The combination of volume and velocity measurement will provide gas volume flowrates [10].

2.0 DIGITAL CAMERA

A digital camera was used to capture sequential images as shown in Figure 1. This camera can store four or six images once triggered. Electronic shutter speeds as fast as 0.001 s may be selected. In these experiments, the shutter speed was set at 0.002 s, which proved to be capable of capturing images clearly. To obtain the best results, a diffused light source was installed to produce back lighting to the pipe. The minimum time interval between two consecutive images was 0.25 s.

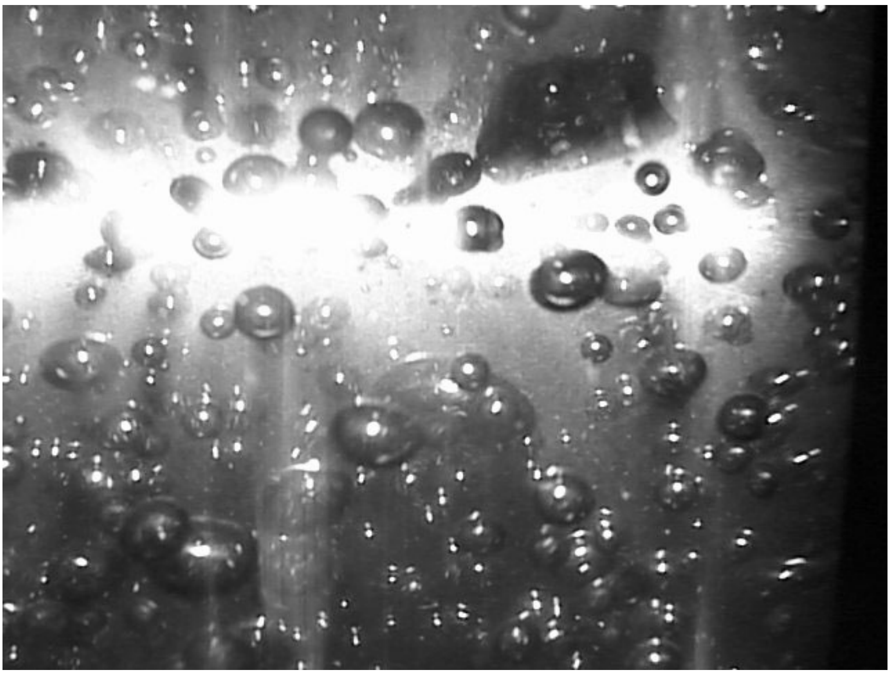

Figure 1 Bubbles flow using digital camera

However this time interval is too long to analyze the motion of bubbles, because only one image of any specific bubble was obtained. At the same time, current work using optical tomography, by Ibrahim [10] has shown that the bubbles have an approximate velocity of 0.25 ms^{-1}. This means that a minimum frame/picture repeat rate of 20 per second is required. The higher speed digital camera is expensive which is not practical for this project.

3.0 VIDEO CAMERA

A home video camera, was used for this project as second approach to capture sequential images. This approach needed both specialized software and hardware to convert the analogue signal images into digital signal images. For tomographic

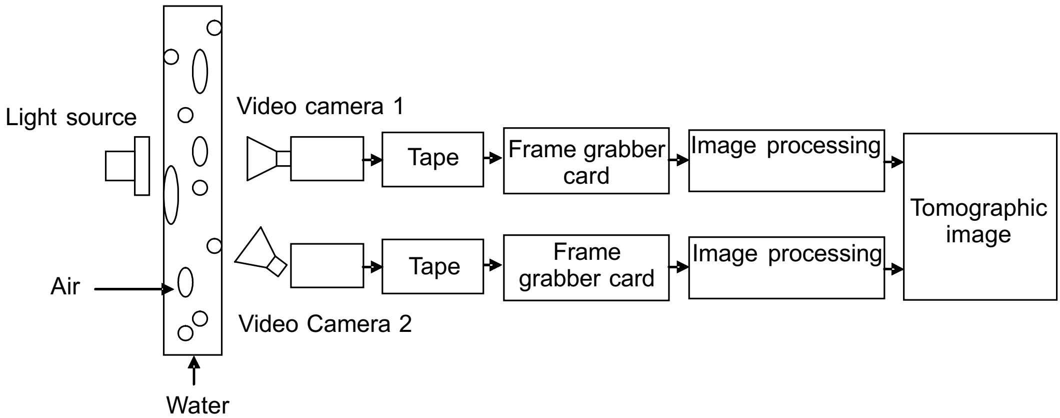

Figure 2 Schematic diagram of flow visualization instrumentation

measurement a minimum of two video camera is required as shown in Figure 2, however, as a feasibility study only one video camera was used.

The bubbles were recorded by the analogue video camera on a small video tape. Then the information on the small video tape was converted into normal tape format using facilities in the Adsetts Centre SHU Library. Then, software was needed to convert the tape into digital images. Other software was needed such as "*snaglt studio*" to separate the images frame by frame with speed 25 frames/second into

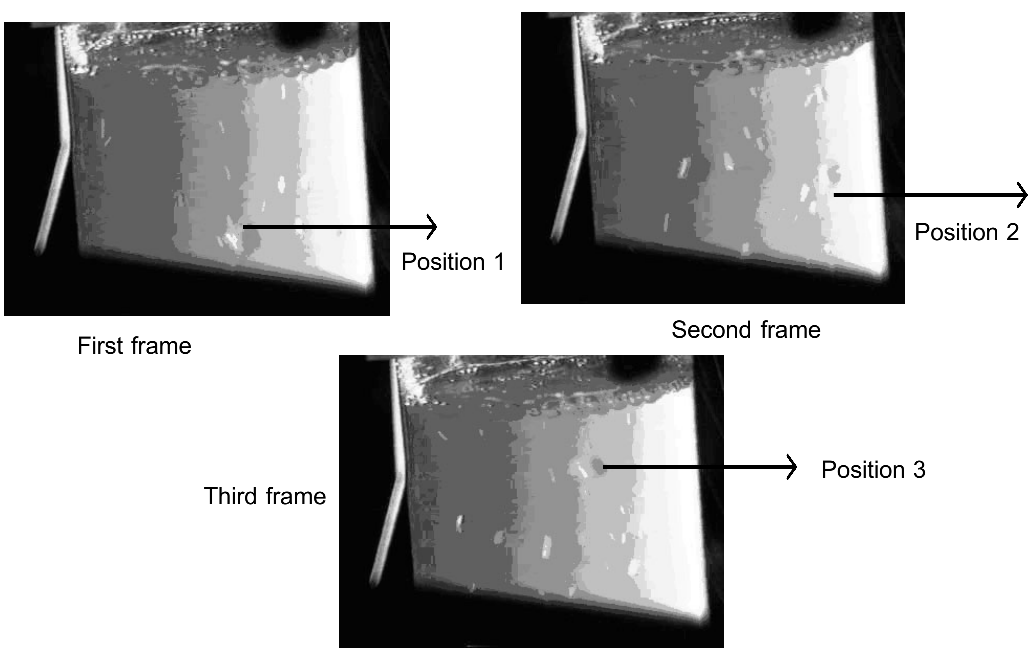

Figure 3 Sequential bubbles flow recorded using video camera

individual frames before using the image processing tool. For this project, it was thought that too many processes were needed and the cost was higher than this project could support.

Some results are shown in three consecutive frames, where a specific bubble is tracked.

From the sequential images in Figure 3 the velocity of bubbles can be measured. The time interval between frames is 0.04 s. The positions of a chosen bubble is measured and used to calculate the velocity. This velocity is approximately the same as measured using the optical fibre sensors [10].

The position of the top of the specific bubble to a reference point on the frame is measured and scaled to give a distance in millimeters.

Top of bubble for the first picture,

$$x_1 = \frac{13}{57} \times 80 = 18.25 \text{ mm}$$

Top of bubble for the second picture,

$$x_2 = \frac{20}{57} \times 80 = 28.07 \text{ mm}$$

The velocity of the bubble in moving from frame 1 to frame 2 is:

$$\nu = \frac{x_2 - x_1}{t}$$

$$\nu = \frac{(28.07 - 18.25) \times 10^{-3}}{0.04}$$

$$\nu = 0.245 \text{ ms}^{-1}$$

Top of bubble for the third picture

$$x_3 = \frac{27}{57} \times 80 = 37.89 \text{ mm}$$

and the velocity of the bubble in moving from frame 2 to frame 3 is:

$$\nu = \frac{x_2 - x_1}{t}$$

$$\nu = \frac{(37.89 - 18.25) \times 10^{-3}}{0.08}$$

$$\nu = 0.2455 \text{ ms}^{-1}$$

which is in good agreement with 0.25 ms^{-1}[10]

4.0 CCD LINEAR SENSORS

The ILX503A is a CCD linear sensor containing 2048 sensors (effective pixels) where the pixel size is 14 μm × 14 μm and the maximum clock frequency is 5 MHz. The CCD and parallel light would provide high resolution of droplets or particles (*i.e.* 14 μm) and interrogate all the volume infront of the sensing device. The resolution of this window is 14 μm, so that very small bubbles could be detected and at very low bubble concentrations. Figure 4 shows the arrangement of CCD linear sensors.

The system was designed to use eight sensors, two arrays of four for concentration. Then cross-correlation of concentration profiles could be used to obtain velocity. However, only one sensor was tested to obtain real data from the flow rig. The CCD linear sensor used in this project was ILX503A (Sony).

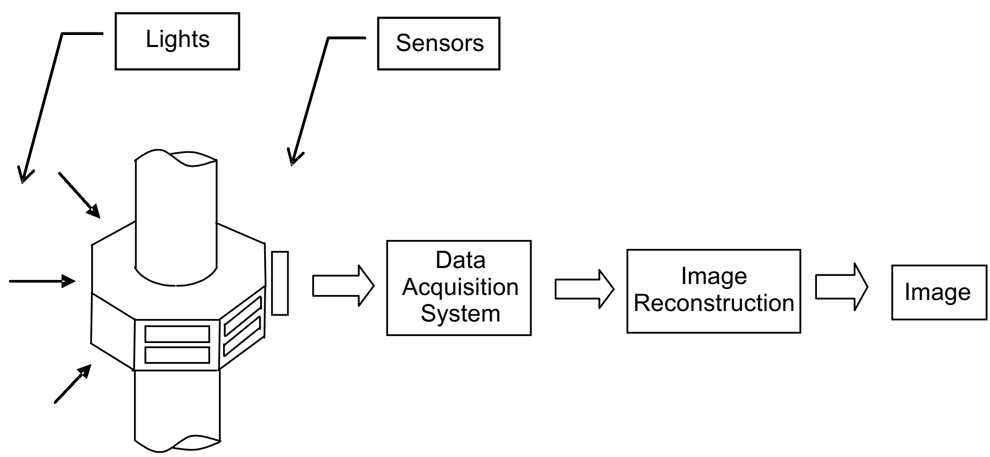

Figure 4 The arrangement of CCD linear sensors

5.0 THE ACQUISITION ARCHITECTURE

Most of the linear CCD sensors such as ILX503A, ILX511 (Sony), TCD132D, TCD1252AP (Toshiba) and TH7804A (Thomson-CSF) can be operated using only two signals. The sample line signal for line sampling and a clock signal for charge shifting.

The circuit shown in Figure 1 is proposed. It is composed of a CCD sensor (ILX503A) and timing generator built using 3 inverting Schmitt triggers CMOS (74HC14). One Schmitt trigger is used to buffer an external clock, which runs at approximately 1 MHz. This signal is used to clock the sampled data from the sensor. An oscillator termed the line scan oscillator, whose period can be adjusted by the potentiometer, provides a signal with period T. This is built using two inverting CMOS Schmitt triggers (74HC14) and operates as shown in Figure 5.

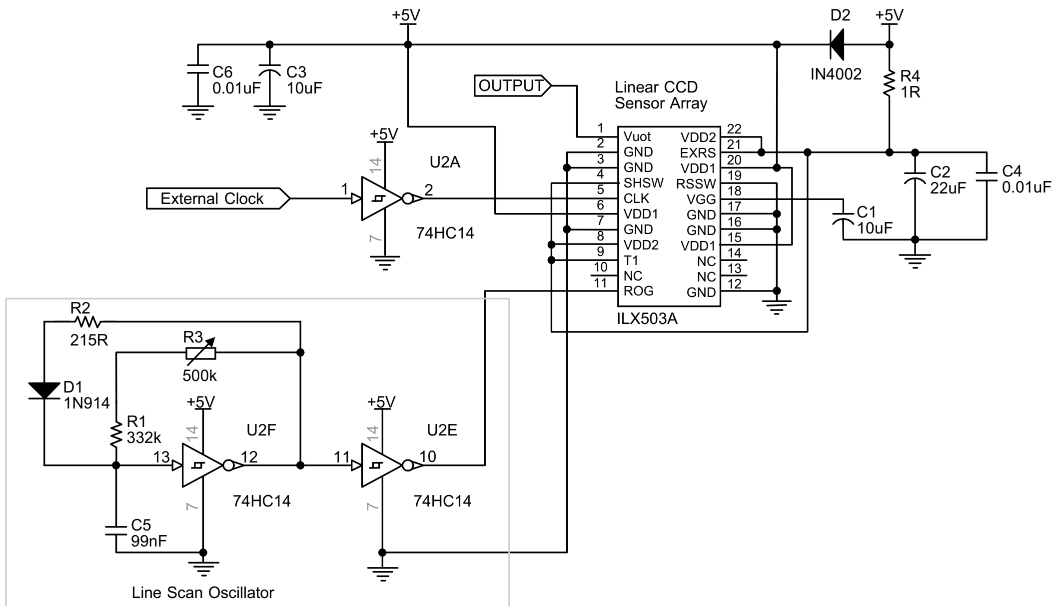

Figure 5 A linear CCD sensor circuit

If pin 12 is high (5V), then pin 13 is low (0V). As a result C_5 is charged up through R_1 and R_3 and C_5 is also charge up (diode on) through R_2. On the other hand, if pin 12 is low (0V), then pin 13 is high (5V) and C5 discharge through R1 and R3 whereas the R_2 circuit is open (diode off).

The typical voltage at pins 13 & 12 is shown in Figure 6 for the scan raster.

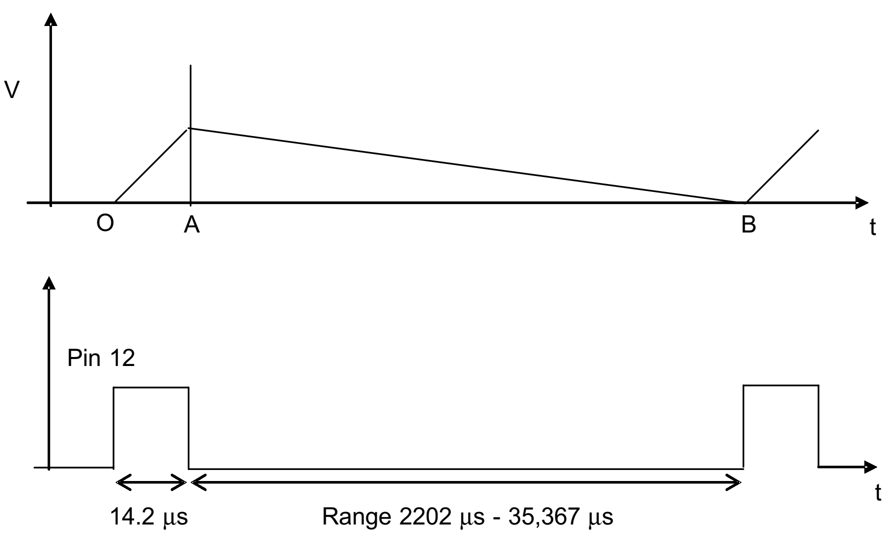

Figure 6 The timing diagram of scan raster

The charge OA is

$$\begin{aligned}\tau &= RC \\ &= 213.6\times 99\times 10-9\times 0.67 \\ &= 14.2\ \mu\text{s}\end{aligned}$$

The discharge AB when the potentiometer is 0 W

$$\begin{aligned}\tau &= RC \\ &= 33.2\times 10^{3}\times 99\times 10^{-9}\times 0.67 \\ &= 2202\ \mu\text{s}\end{aligned}$$

The discharge AB when the potentiometer is 500K

$$\begin{aligned}\tau &= RC \\ &= (500k+33.2k)\times 99\times 10^{-9}\times 0.67 \\ &= 35367\ \mu\text{s}\end{aligned}$$

The analogue level *V*out for one pixel k in the CCD line is

$$V_{out}(k) = PI_kT_i$$

where P is the proportionality constant and I_k is the equivalent light intensity at the point k of the CCD array.

7.0 DETERMINATION SCAN RATE VERSUS BUBBLE VELOCITY

An important parameter in this measurement system is the relationship between bubble velocity and the maximum CCD scan rate. Consider a 42 μm diameter bubble (Figure 7). To fully scan the 42 μm diameter bubble with a 14 × 14 μm sensor requires three scans (3 × 14 μm = 42 μm). So the time for bubble to travel 42 μm at velocity v m/s is

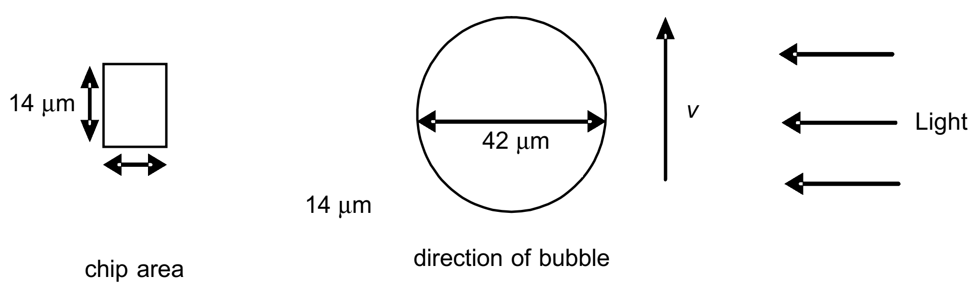

Figure 7 Bubble diameter and chip area

$$V = \frac{s}{t}$$

$$t = \frac{s}{v} = \frac{42 \times 10^{-6}}{v}$$

The relationship between scan rate and velocity is shown in Figure 8. For 100% sampling the vertical resolution with a maximum scan rate of 1.1 ms (Clock frequency = 2 MHz) the velocity of coverage material must not exceed 0.004 m/s. For a real industrial process velocities are probably 0.5 – 4 m/s. So for an industrial instrument to obtain 100% coverage of a bubble traveling at 4 m/s requires a scan rate of 0.0105 ms (10.5 µs/scan). Alternative devices by Sony offer 5 & 15 MHz clock rate. With the 15 MHz device compared with the above calculations (1100 ms/2 MHz) the scan duration is reduced by a factor of 7.5 to 147 µs. From the graph this corresponds to 0.3 m/s. To obtain full coverage at 4 m/s the scan rate must be 10.5 µs, which equates to a clock speed 104.8 times faster than 2 MHz. For this example the clock is 209 MHz.

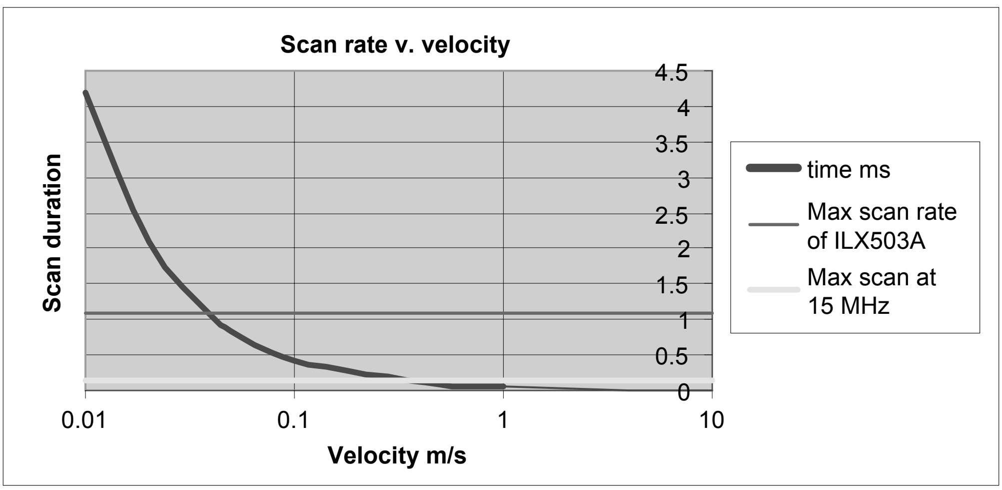

Figure 8 Scan rate and velocity

8.0 CONCLUSIONS

Using the ILX503A limits the bubble velocity to 0.04m/s when sampling at 1 MHz. However the feasibility of this form of detection can be investigated practically by ensuring very slow movements.

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