The PipeProbe system is non-intrusive and requires no alteration to the water pipeline infrastructure.

I. INTRODUCTION

When indoor water pipes are hidden inside cement walls or under floor coverings, diagnosing them without direct inspection is difficult. Especially, when the original diagram of the pipeline layout is also missing, searching for the pipeline locations becomes guesswork and often requires brute-force methods such as knocking down cement walls or ripping up floor coverings. This creates an opportunity for the development of a mobile sensing probe, called PipeProbe, which can be dropped into the source of a water pipeline. During its traversal of the pipeline, the PipeProbe collects the sensor readings necessary for the reconstruction of the 3D spatial layout of the traversed water pipelines. In comparison to the traditional brute-force approach, the PipeProbe system is a non-intrusive method of mapping and locating indoor water pipelines that requires no alteration to the water pipeline infrastructure.

Two recent projects that apply wireless sensor network technologies for monitoring water pipes include the NAWMS project [1] and the PIPENET project [2]. The NAWMS project detects and locates pipe leaks by attaching vibration sensors to the pipe surface. Similarly, the PIPENET project monitors water flow and detects leaks by attaching acoustic and vibration sensors to large bulk-water pipelines and pressure sensors to normal pipelines. In contrast to these projects, the PipeProbe system does not assume that water pipe surfaces are exposed and accessible for sensor module attachment. In the general domain of environmental sensing, both wireless and wired sensor network technologies [3] have been used extensively, and a wide variety of inexpensive sensor nodes have been created with different sizes, sensor combinations, computational power, battery power, and radios. Our work focuses on a novel mobile sensor system for mapping indoor water pipelines.

II. THE PIPEPROBE SYSTEM

The PipeProbe capsule is built from the tiny EcoMote board [4] (shown in the Fig. 1(a)). EcoMote’s physical size is 13x11x7 mm, which is small enough to be dropped into normal-sized (>2 inch) indoor water pipelines. EcoMote comes with a built-in 3-axial accelerometer. Additionally, the tiny pressure sensor module MS5541C from Intersema [5] (6.2x6.4 mm, shown in Fig. 1(b)) has been added to the EcoMote. When submerged in water, the pressure sensor measures water pressure ranging from 0 to 14 bars at a resolution of 1.2 mbar. The whole package is fit into a teardrop shape and sealed waterproof with glue and acrylic.
During post-processing, a pipeline mapping algorithm analyzes the sensor readings and computes the 3D coordinates of the PipeProbe capsule as it moves inside the pipeline network. The capsule’s 3D movement coordinates also mark the 3D path of the pipeline network. Interpolating the discrete location samples of the PipeProbe capsule over time yields the spatial layout of the water pipelines. The pipeline mapping algorithm is described in Section III.

The algorithm can be described using the following steps. Step (1) estimates the flow velocity inside the pipe from the water pressure. To accurately measure the flow velocity, the PipeProbe capsule must be fit into a specific tear-drop shape such that the water flow velocity approximates the capsule movement. According to fluid dynamics, equation (2) can be used to estimate the flow velocity $v$ from the water pressure $p$ inside the pipe. This equation states that the pressure difference between the head $(p_h)$ and the tail $(p_t)$ of the capsule is square-root proportional to the flow velocity:

$$v = \sqrt{2(p_h - p_t)} \tag{2}$$

Step (2) traces the 3D coordinates $(x, y, h)$ of the capsule. To estimate the $z$-axis position $h$, equation (3) is derived from equation (1) by substituting $v_0=0$ (corresponding to the sensor being dropped in) and $p=1$ (water density). $h_0$ is the height of the input water source, $p_1/p_2$ are the detected pressures at the tail of the capsule and at the input water source, $v$ is the flow velocity from equation (2), and $g$ is the gravity:

$$h_1 = h_0 + \frac{(p_1-p_0)}{g} \cdot \frac{v^2}{2g} \tag{3}$$

To determine the $(x, y)$ coordinates of the capsule, the 3-axis accelerometer reading from the capsule is first analyzed to determine its movement direction $\theta$ over the $x$-$y$ plane. Integrating velocity $v$ from step (1) over time yields the relative displacement $d$. Vector calculus over the displacement $d$ and the movement direction $\theta$ produces the relative $(x, y)$ coordinate movement.

In step (3), for each mapping trip, a 3D water pipeline path is drawn beginning from the position of the water input source toward the position of the water output faucet where the PipeProbe capsule was retrieved.

IV. FUTURE WORK

We are currently implementing the PipeProbe system and look forward to evaluating its positioning accuracy.

REFERENCES


