RAMP System for Proactive Pipeline Monitoring

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***Abstract*—In this poster, we demonstrate a novel cost effective, scalable, and customizable RFID-based autonomous pipeline monitoring system, called RAMP system, which combines sensing technologies with robot agent based technologies for efficiently inspecting health related events and RFID technologies for the storage of event related information and location support. RAMP system integrates a new concept of Multiple-channeled Redundant Array of Independent RFID Tags (called McRAIT) to increase the capacity of RFIDs needed to store information, to authorize higher communication bandwidth, to provide efficient localization of events, and to improve the fault tolerance. Further, we present some simulation experiments and prototypes to demonstrate the feasibility and scalability of RAMP system.**

I. Introduction

Most of the existing pipeline monitoring systems are primarily based on two major factors: reliability of the communication network and efficient localization of the events and incidents. The reliability of the communication network mainly rely on the network connectivity, the power supply continuity, and the network maintainability, which make it difficult to achieve due to cost. The localization methods, they use to locate events and support the sensors/agents motion, including signal triangulation, beacons interpolation, number of wheel rotations, and blueprint of the pipeline exhibit several shortcomings that are essentially related to efficiency and cost-effectiveness, in addition to other various limitations of these pipeline monitoring systems[1], [2].

To overcome these limitations, we aim at developing a RFID-based pipeline monitoring system, called RAMP system, which combines sensor technologies with robot agent based technologies for proactive and corrective monitoring, in addition to the efficient technique for event and incident localization. Our system would allow frequent inspection, early detection of problems, controllable-error localization, and planned recovery measures. The key innovations of RAMP system are 3-fold: (a) it can apply to a large variety of pipeline systems; (b) it is cost effective since it uses low cost powerless McRAITs; and (c) the robot is autonomous and the localization technique allows controllable errors. Simulation experiments and prototype demonstrate the feasibility of our system.

II. RAMP System Description

Our solution builds on a novel concept denoted by McRAIT and two other main components: the High Performance Mobile Sensors (called HPMS) and the Fully Autonomous topology-aware Mobile Pipeline Exploration Robots (called FAMPER). Figure 1 depicts an application of RAMP system.

The installation of McRAIT can be made initially (at the construction of the pipeline) or when needed by the pipeline operation. At the starting of the inspection, the mobile sensors are deployed at strategic locations from nearby upstream station and the fluid transported by the pipeline provides sensor mobility. They examine the pipeline using different sensing functions in their course of operation and report the objects and incidents identified to the McRAIT system close to the incidents. After the inspection completion, the mobile sensors are collected at the exit point and the central controlling system (CCS) starts post-processing for detailed examination. The robot agent performs actions as soon as CCS instructs.

A McRAIT is used to overcome the detectability and storage capacity limitations of individual RFID tags in different inspection requirements of pipelines. Figure 2 depicts the architecture of McRAIT. Three major components integrated in McRAIT are: (a) the array of tags to integrate a reasonably large number of tags depending on the frequency band it is using; (b) the low radio range multi-channel transponder for the physical communication with the array of tags; and (c) the McRAIT controller to provide multiplexing/demultiplexing and communication with tags and sender/receiver main program; the fault tolerance capability by allowing to read/write data to/from the array concurrently with various read/write strategies maintaining redundant data. Each tag in the array is allocated different channel properly so that all tags in the array can communicate simultaneously. This system provides a mechanism to handle concurrently data on multi-tags, where the data is saved in fragments in a similar way to the storage of data in a system using Redundant Array of Independent Disks (RAID).

HPMS (as depicted in Figure 3a) is in charge of processing complex tasks within short periods of time and providing flexible interface with other sensors and storage systems. It is improved then the previous version of MICA1 [1] and consists of: a main board, a McRAIT controller, different sensors, and a container. Our HPMS design provides high performance processing power, large memory, and interface with sensors in addition to other necessary functions. FAMPER (as depicted in Figure 3b) is a robot built on a previous version [3], [4] by adding improvements to the mobility techniques used in the original FAMPER and achieving reduced scales and higher performance of the embedded devices. Our new design of caterpillars which are tilted 5 degrees from the robot body allow FAMPER to move with spiral motion and provide self-adjust positioning of the robot to overcome *motion singularity problem* [4], [5].

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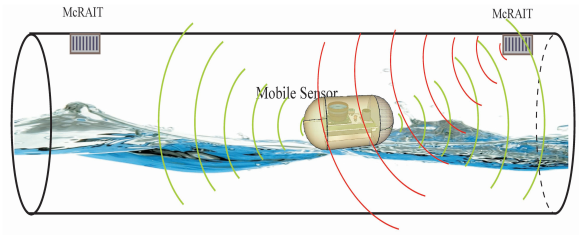


Fig. 1: RAMP system monitoring scenario

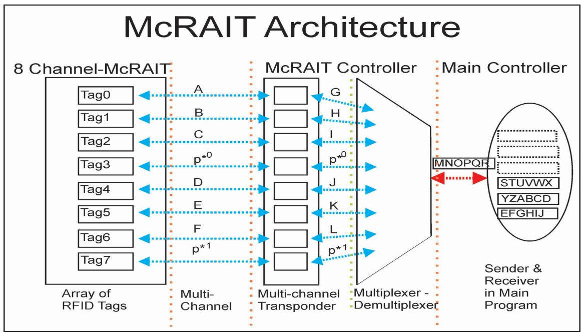
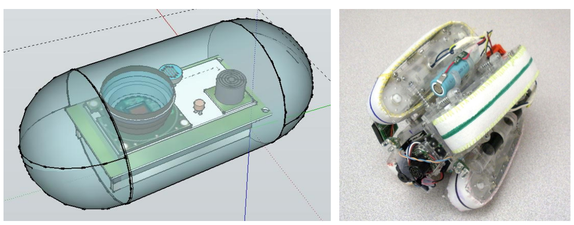
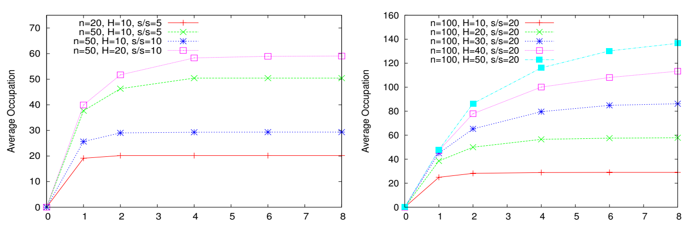


Fig. 2: McRAIT architecture



(a) Mobile sensor (HPMS) design (b) Robot agent FAMPER

Fig. 3: HPMS design and robot agent FAMPER



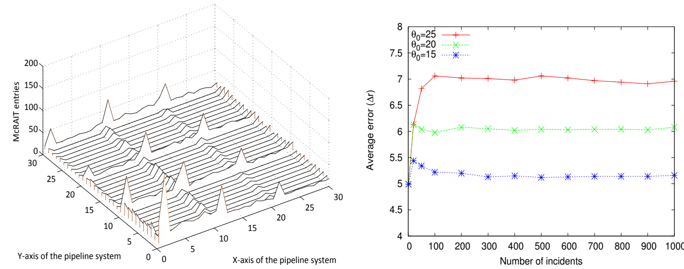
(a) Average occupation on McRAITs using different parameters and $Hop = 6$ (b) Average occupation on McRAITs in different histories and $Hop = 6$

Fig. 4: Average occupation on McRAITs in different settings

III. Experiments

To validate the performance of RAMP system, several experiments have been conducted. Figures 4a and 4b show the average occupation of messages in McRAITs with different parameter and inspection history settings. It turns out that McRAITs having more RFIDs can be able to handle more history and inspection information than having a single tag.

Figure 5a shows the 3D graph of all 4-tag-MCRAITs load for 12 randomly generated incidents when 50 mobile sensors are used assuming history $(H) = 5$, McRAITs/segment



(a) McRAIT entries concentration for 12 incidents using 4-tag-McRAITs (b) The relation between number of incidents and average error in localization

Fig. 5: RFID entries concentration and relative errors

$(s/s) = 10$, and $Hop = 6$ in the test pipeline layout given in [1]. We notice that the McRAITs located just after the incidents have higher load and that the following McRAITs have the load decreasing with the distance. Figure 5b depicts the relation between the average error (Δr) made on the reported distance and incidents count assuming the McRAITs separation in the pipeline is 1000mm, pipeline diameter L = 150mm, and mobile sensors are drifting at 50mm above from the pipeline bottom. The average error (Δr) is calculated based on the distance reported by sensors to locate itself or an incident it detects with respect to a selected McRAIT. The figure shows that when the number of incidents grows from 0 to 100 the average is increasing. This average remains constant for numbers of incidents higher than 100, despite the value of threshold angle θ_0 (details in [2]). One should notice that the error variates on the the reported distance with the variation of θ_0, which determines the threshold distance from which a mobile sensor needs to report to the next available McRAIT in its vicinity.

IV. Conclusion

In this poster, we demonstrated our work toward developing a novel cost effective, scalable, customizable, and autonomous RFID-based pipeline monitoring and maintenance system, called RAMP system. Our contributions include an efficient localization, failure tolerant information storage and localization support, and an autonomous 5 degrees tilted 4-caterpillar robot. Experiments and the prototyping show the feasibility of RAMP system, its cost effectiveness and its scalability.

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