LifeNet: an Ad-hoc Sensor Network and Wearable System to Provide Firefighters with Navigation Support

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Abstract. This paper describes a concept called LifeNet for using an ad-hoc sensor network providing relative positioning and a wearable system to support firefighters at indoor-navigation under impaired visibility. We describe the concept and a first implementation.

Keywords: sensor networks, localization, navigation, wearable computing.

1 Introduction: The LifeNet Concept

When moving through a building structure under impaired visibility, firefighters use ropes to mark the path they have taken. This helps them in finding their way back out and helps other teams to take the same path. These ropes are called lifelines.

While this technique works reliably in many situations, there are also a number of shortcomings that can become critical and in fact have let to fatalities in the past. In particular, the lifeline can get stuck or be cut under doors or other objects, it can become entangled with furniture, railings etc. and it generally limits the operational range. Moreover, a lifeline always only offers one retreat path and communicates no or very little information on the firefighters to the outside.

The understanding of these difficulties was obtained through empirical research with the Paris Fire Brigade, including interviews, observations and participation in different trainings [1]. Based on this understanding we defined a concept called LifeNet to address the difficulties. The concept proposes that

- firefighters automatically deploy sensor nodes along their paths effectively establishing an ad-hoc infrastructure for positioning, sensing and communication.

- firefighters interact with this sensor network by way of wearable computing equipment and receive navigational information on e.g. a head-mounted display or over a headset.

While the LifeNet concept has some commonalities with the Siren sensor network system proposed in [2], the main distinguishing feature is the proposed navigation support under impaired visibility based on relative localisation.

What we consider as very interesting about the LifeNet concept is that the concerned practice of indoor navigation by firefighters is a learned, skilful and collaborative activity in an extended, only partially known, changing and dangerous space and that the technology we are proposing interacts with this practice intimately and on different levels. As such the concept affords a particularly interesting opportunity to explore and investigate the usage conditions of an ad-hoc ubiquitous computing infrastructure.

In the next sections we describe a first implementation of the LifeNet. The system consists of the sensor nodes that provide relative positioning and a wearable system that retrieves and processes the information from the sensor network and provides the support to the firefighters.

2 The Sensing Subsystem of LifeNet

The sensor system is based on nodes we refer to as RELATE Bricks (Fig 1, left), a variant of a RELATE sensor node as first introduced by Hazas et al. [3]. In contrast to Hazas' device, which was realized as a USB dongle for attachment to mobile computers, the Brick is designed to function stand-alone. Core processing and communication for the Bricks is handled by a Particle Computer [4] sensor node with an 8bit PIC18 micro controller and 868 MHz TR1001 radio front-end. Communication and time synchronization primitives are provided by the AwareCon network stack [5]. The sensor board consists of four 40 kHz narrow-band ultrasound transducers, a temperature sensor and power supply using AAAA batteries. We use the transducers to act both as receivers and transmitters, for bi-directional ultrasonic sensing such that devices can measure their relative positions peer-to-peer. The RELATE Brick also hosts an I^2C expansion slot for adding further sensors, for instance an accelerometer. A USB port is used as a command bridge to connect at any point in the network to other devices like a portable or wearable computer.

Additionally, we fitted two of the nodes onto a pair of heavy duty boots similar to the ones worn by firefighters (see Fig. 1, right). The transducers are attached to flying leads and threaded through the lining of the boots. The body of the sensor node is attached to the top of the boot and the transducers were placed on the toe, on the heel and in the middle of both sides of the boot. Their placement is low to the ground, to be in approximately the same plane as sensor nodes deployed on the floor. This is because the sensor system performs best in terms of accuracy when all nodes are located in the same plane.

The Logic of the LifeNet sensor subsystem is implemented on the sensor nodes as software modules using the RELATE Black Board architecture [6]. All modules are loosely coupled via a common blackboard interface that acts as a distributed shared

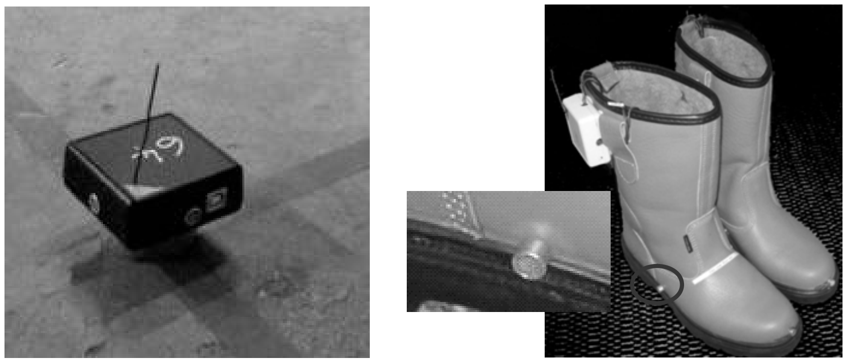

Fig. 1. RELATE Brick sensor node with ultrasonic transducers on its four sides (left). Boots augmented with RELATE sensor nodes, with transducers placed around the base (right).

memory system. Essential to the application scenario is the collaborative sensing module, using ultrasonic measurements synchronized over RF. It is used to perform spatial discovery (of nodes within a defined range) and to measure the distance and the angle-of-arrival with respect to discovered nodes. The measurement range in the present implementation is about 2.5m, with distance estimates between neighbouring nodes accurate to about 10cm, and angle-of-arrival accuracy of around 30º. On top of the sensor measurements, a LifeNet module establishes virtual lifelines of sensor nodes when these become deployed (i.e. dropped along the path of a firefighter).

In a setup phase after the deployment of a node, its LifeNet module tries to join a lifeline of already deployed sensors. Lifelines are started by a dedicated node at the entrance of the building and then extended as nodes get dropped to the floor. Each node denotes its position in the lifeline and the distance towards the exit. If nodes are already on the path (i.e. when a firefighter crosses an already deployed sensor trail), no new nodes get dropped but already deployed nodes join the lifeline (i.e. the same node can be part of multiple lifelines). Once deployed, the LifeNet module periodically scans along the line to detect missing links. If a lifeline is interrupted, this information is propagated to the other participating nodes telling them that this path to the exit is no longer available.

3 The Wearable System Components

The current wearable system prototype for use with the LifeNet consists of an OQO micro PC that communicates with the sensor nodes through the USB bridge mentioned above and that displays on a Carl Zeiss look-around head-mounted display integrated with the breathing mask (Fig. 2). The PC runs an application that queries the LifeNet sensing subsystem to provide navigation support to the firefighters. Currently, the support consists in directional indications available alternatively as an arrow on the HMD, or as audio commands on the headset. Following these indications, the firefighter is guided from one sensor node to the next on a trail leading out of the building. In case there are multiple retreat paths, the firefighter may be rerouted if a shorter path becomes available or the currently taken path becomes unavailable. The questions that we explore with this system is how the LifeNet needs to be deployed, what functionality the individual nodes need to have and how the processed information needs to be presented to the user for safe operation under the physically and cognitively difficult circumstances of an intervention. Because of the size and casing of the sensor nodes, they are currently still deployed by hand. But a device for automatic deployment and smaller ruggedized sensor nodes are under development.

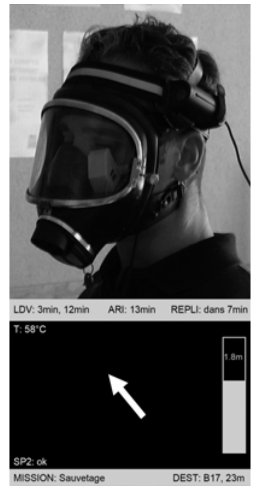

Fig. 2. HMD in breathing mask and HMD interface

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