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Towards a new Infra-Red based approach for indoor localization

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Abstract – The interest for ADL (Activity Daily Living) applications within smart homes, such as elderly monitoring, is increasing nowadays. Those applications are usually performed using machine learning algorithms that link actions with human activities which often depends on the human’s position. Human indoor localization is usually performed using Pyroelectric Infra-Red PIR sensors network, however, the latter presents several limitations, and to cope with these last, its results are sometimes combined with other sensing modalities to enhance location accuracy. In this paper, we present an idea to combine PIR network results with a non-intrusive Infra-red imaging sensor, relying on interval analysis IA techniques. We also show the advantages of using Ibex software to deal with IA calculations. Our future work is to characterize the error from the imaging sensor so that to encompass imaging result(s) within box(es) that could be combined, using Ibex, with PIR network box(es) so that to enhance the location accuracy.

Keywords: Activity Daily Living (ADL), Indoor localization, Interval analysis, Infra-Red sensors.

I. INTRODUCTION

ADL (Activity Daily Living) has got an increasing interest during last years since it is related to several applications such as security and abnormal activity detection, comfort and energy optimization, and monitoring of elderly people. By 2030, a quarter of the European population will be elderly [14] and the need of assistance for elderly people is on increasing demand since elders often prefer to stay home, and staff within retirement homes cannot be available all the time, however, tele-home care applications can reduce health care costs [15] while assuring a full-time elderly monitoring.

ADL applications are often performed using data provided from sensor network and relying on machine learning algorithms as in [13]. Those applications rely also on human location which can help improving daily activity recognition results [6].

In indoor environment, and where GPS cannot be used, the localization is performed using specific techniques and technologies to provide a person’s location. During the last decade, several studies have been proposed to perform human indoor localization within a sensor network. In a recent study, E.Ahvar et al [1] proposed a survey and a taxonomy covering a

large existing location methods used in smart homes. In their survey, sensor location methods were divided into two categories, DBL (Device Based Localization) methods and DFL (Device Free Localization) methods.

DBL approaches can achieve high location accuracy, the order of sub-meter accuracy, even in case of multiple persons. However, carrying a device all the time represents a major drawback, since it is not very convenient especially for elderly people. Also, forgetting to wear the device or leaving it due to some activities, such as taking a shower, is frequent in elders daily living which will affect the care function of the monitoring system. Moreover, recent advances in wireless sensor networks and fusion of different sensor modalities allowed DFL category achieving high accuracy without using wearable devices, hence making DBL category less interesting.

E.Ahvar et al [1] presented some DFL methods w.r.t technical and technological features, advantages and weaknesses of those methods were also presented. From their study, we can see that cheap, low complexity and reliable DFL methods include often PIR Sensors. However, the major weakness of PIR sensors is the poor location accuracy, since PIR sensors can provide only information of presence or absence of moving targets in the FOV (Field Of View) of the PIR sensor. Even if binary PIR sensor network have severe limitations in target location-tracking, they present several advantages such as reduction of data throughput and communication overhead, energy efficiency and low-cost w.r.t to other sensors such as cameras.

As evoked in [1], the importance of location accuracy depends on the application. In fact, the degree of location accuracy for an energy optimization application, such as heating/cooling, is not very critical since it requires only information about target’s presence or absence so that to control devices as it was the case in [7]. In contrary, for ADL applications such as elderly monitoring the location accuracy is more important especially when several activities could be performed in different zones of the same room or area. To increase location accuracy (*i.e* number of zones within same room) using binary PIR sensor network, one have to use a significant number of PIR sensors with over-lapping FOV.

The over-lapping PIR structure suffers from several issues such as uncertainty on the PIR’s FOV, since in practice the real shape of the PIR’s FOV cannot be exactly determined which

induces uncertain measurements leading to inaccurate location results. Also, the PIR over-lapping structure generates false intersections in presence of multiple targets [4] due to interferences.

To cope with the uncertainty of the PIR's FOV, *Kim et al* [12] used a Bayesian classifier that exploits the analog output (the signal), instead of binary output, of each PIR sensor to estimate when a person is inside the field of view, on the boundaries and when outside the FOV. However, analog output from several PIR sensors, as in over-lapping PIR networks, can saturate the communication protocol. Hence, exploiting PIR analog output to deal with FOV's uncertainties is not suitable for our study since it relies on over-lapping PIR structure.

This paper proposes to combine binary PIR results with another non-intrusive sensor modality using Interval Analysis techniques to deal with both FOV's uncertainties of PIR sensors, and false intersections caused by the presence of multiple persons within an over-lapping PIR network.

II. INFRA-RED BASED INDOOR LOCALIZATION APPROACH WITHIN A BOUNDED ERROR FRAMEWORK

PIR's FOV can be modulated using Fresnel lenses [10] to get more adequate sensing areas in case of wall mounted installation. In fact, in recent indoor localization studies [2] [3], Fresnel lenses were used to obtain approximately a box shape for the PIR's FOV. Such a shape simplifies the sub-region task of a covered area and the intersection of several box shaped FOVs will lead automatically to a box shape. Consequently, instead of getting several shapes if using the real PIR's FOV, Fresnel lenses allows getting homogenous measurement shape whatever the number of the intersected FOV is. Hence, this allows using a same set membership framework which is interval analysis framework [16].

Set membership approaches are more suitable, for indoor human localization, than other approaches (such as Kalman filter [11]) which assume that noises have a Gaussian distribution, and such assumptions do not always hold in practice. Set-membership approaches consider only that errors on measurement process are bounded with known bounds.

Within a set-membership context, *Amri et al* [2] used, in addition to PIR sensors network, three simulated distance measurement sensors to enhance the PIR's network results. They have also characterized the errors on those distance measurements by considering inner and outer disks.

In this paper, we investigate the use of a non-intrusive imaging sensor (Irllynx sensor¹) instead of distance measurements. Irllynx is a matrix of infrared sensors that provides an image only when a person is moving on its field of view. The image obtained from Irllynx sensor is non-intrusive since the shape is obtained from the heat generated by the moving target as shown in Figure 1.

1

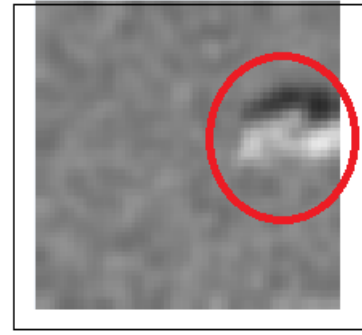


Figure 1. Shape of a moving person provided by Irllynx sensor

The challenge now is how to characterize the error on the provided shape(s) and encompass it within a box(es) using paving process of interval analysis. Once the box(es) from Irllynx is (are) obtained, we combine then this box(es) with boxes provided from over-lapping PIR network to deal with both PIR's FOV uncertainty and also ambiguous intersections caused by interference within the overlap PIR network.

One can say that we can use Irllynx sensor alone since it has better performances than PIR's over-lap sensor network. Unfortunately, Irllynx has border limitations, *i.e* if the person moves near the border and then no shape is provided, we cannot conclude if the person has stopped at the border or exited the Irllynx FOV. An approach consists on using several Irllynx sensors with over-lapping FOV, however, such approach is costly since Irllynx sensors are too expensive comparing to PIR sensors, also, Irllynx sensors consume more energy. Moreover, Irllynx sensors do not provide images for motions that have very low speed.

Consequently, the use of both over-lap PIR network with an Irllynx sensor seems to be the best compromise. Shape(s) from Irllynx will be encompassed into box(es), then combined with the other box(es) obtained from the PIR network.

To get the intersected box(es), the problem can be formulated as a Constraint Satisfaction Problem (CSP) and solved using constraint propagation techniques such as forward-backward contractor [16]. Constraint programming tools could be used to solve the constraint propagation problem, however, a more efficient tool (Ibex²) has been developed to deal better with CSP problem within the interval analysis framework.

Ibex (for Interval Based explorer) is a C++ numerical library based on interval arithmetic and constraint programming. This tool can be used to solve a variety of problems that can roughly be formulated as: Find a reliable characterization with boxes (Cartesian product of intervals) of sets implicitly defined by constraints. Ibex can be divided into three layers: An extended interval calculator, contractor programming library, and a system solver / global optimizer. Each usage corresponds to a different layer and each layer is built on top of the previous one. For instance, Ibex gives the ability to build high-level

¹ <http://www.irlynx.com/>

² G. Chabert, IBEX, an Interval-Based EXplorer, <http://www.ibex-lib.org>

interval-based algorithms declaratively through the contractor programming paradigm [5].

It is rather useful to show the result of an algorithm with a visual example, which can be helpful for analyzing the algorithm results and to easily communicate with others. Several GUI (Graphical user interface) tools exist in practice, and some of them are developed for specific fields. For example, the Rviz tool was developed for robotic field and especially for ROS [9] (Robotic Operating System). For the interval analysis framework, graphical tool VIBes (Visualizer for Intervals and Boxes) was developed to be easily and quickly used to draw simple graphics via C++ API or MATLAB API. VIBes architecture and some examples are presented in [8].

Example using Ibex and Vibes:

The appendix at the end of this paper shows a simple code using Ibex to estimate the position of a target moving as follows: at time t_0 the target was in position (1,1) after one second it moved to (2,2) and finally at (3,3) after another second. Three simulated distance measurement antennas are used and placed on the (0,0), (0,10) and (10,10) coordinates. The code of the main algorithm is presented in the annex, and an initialization file containing the position of the three antennas is in the header file "data3.h", and this latter was included at the beginning of the code of the main presented in the annex. Vibes was used for visualization and a screen shot of the final is presented in Figure 2.

From the annex we can see that location boxes can be easily obtained using few codes which shows that Ibex is a very suitable tool for approaches using interval analysis localization algorithm, comparing to other software.

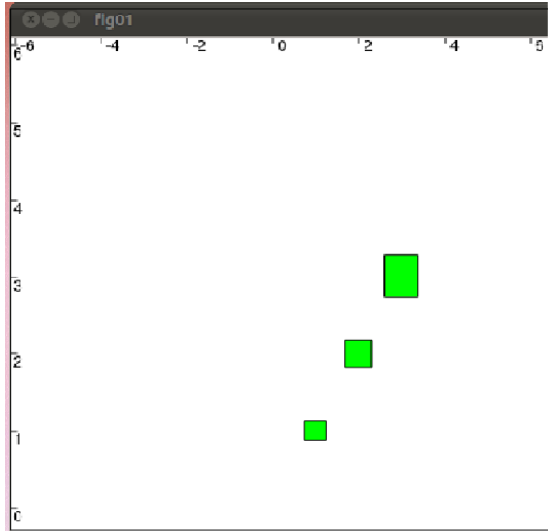


Figure 2. Ibex results visualization using Vibes.

III. CONCLUSION AND PERSPECTIVES

Indoor localization is essential for ADL applications such as elderly monitoring since locations could be linked to activities. Localization for elderly monitoring is often performed using over-lapping PIR sensor networks, however, such networks presents several limitations such as, inaccurate location results due to uncertainties on the PIR's field of view, and inconsistent intersections caused by the presence of several persons. In our study, we plan to deal with these issues by combining PIR network results with a non-intrusive infrared based imaging sensor. The challenge now is how to characterize the errors from imaging sensor to encompass its measurements within boxes which could be merged with boxes provided by the overlap PIR network.

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APPENDIX (Ibex code)

```
#include "ibex.h"
#include "data3.h"
#include "vibes.cpp"
using namespace std;
using namespace ibex;

int main() {
    vibes::beginDrawing ();
    vibes::newFigure("fig01");
    Variable a(2);
    Variable b(2);
    Function dist(a,b,sqrt(sqr(a[0]-b[0])+sqr(a[1]-b[1])));
    init_data();
    Variable x(2);
    IntervalVector box(2,Interval(0,20));
    IntervalVector box_mob(2,Interval(0,20));
    for (int t=0; t<T; t++)
    {
        vector<Ctc*> ctc;
        for (int b=0; b<3; b++) {

            NumConstraint* c=new
            NumConstraint(x,dist(x,beacons[b])=d[t][b]);
            ctc.push_back(new CtcFwdBwd(*c));
        }
        CtcCompo compo(ctc);
        CtcFixPoint fix(compo,1e-03);
        fix.contract(box);
        vibes::drawBox(box,"[green]");
        cout << " box at t =" << t << endl << box << endl;
        box+= IntervalVector(2,Interval(-2,2));
    }
    vibes::endDrawing();
}
```

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