# Position Estimation on a Grid, Based on Infrared Pattern Reception Features

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**Abstract.** The location of the position of a moving target on a grid plane is studied in this paper. The estimation method is based on encountering the number of infrared patterns that arrive to the target as expected, unexpected or out of order. Since the position of the target is not determined by an analog signal intensity, no high precision sensors and measurements are required and the coordinate estimation can be carried out by a pair of transmitters and a pair of sensors on the moving target. The speed of the estimation is adjustable according to the desired accuracy. An error of less than 5% can be reached in most of the covered area. The presented system can be used in a number of automation, robotics, virtual reality and ubiquitous applications.

## 1 Introduction

Several approaches have been recently proposed in order to estimate the position of a moving target in an indoor area. The target may be a vehicle, a robot or even a human in virtual reality applications.

The Global Positioning System [1] is the dominant solution for outdoor navigation while cellular phone infrastructure can also provide indication of the position of a mobile user [2]. Concerning indoor navigation all of the approaches presented so far are based on measuring ultrasonic, RF, laser, magnetic or infrared light signal strengths [3-9]. Triangulation methods are often applied to combine the indication provided by multiple transmitter signals into a single coordinate. Another popular technique is measuring the time of the flight of a signal in order to estimate distance. In this case, the signal transmitter and receiver can both be mounted on the target. Some techniques are also used in order to identify both the distance and the surface of the target [7]. The indoor distance that can be estimated ranges from some centimeters (for accurate machine tool handling) to several meters.

The position estimation system presented in this paper is not based on measuring directly the strength of a signal. The signal strength is expressed as the ratio (*success rate*) of the received digital infrared patterns to the expected ones in a specific time interval. Different patterns are transmitted from 2 or more devices (called IRTX) mounted on constant positions around the area we are interested in. Two sensors (IRRX) are placed on the moving target facing opposite directions. The fact that the infrared transmitters and receivers are not both placed on the moving vehicle results

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in larger area coverage since the signal does not have to travel a return path. Processing digitally the success rate values can be performed by low cost microprocessors. No high precision transmitters and receivers are needed as required in the approaches based on analog signal intensity. Moreover, utilizing the success rate of digital infrared patterns makes our positioning system feasible for a number of domestic applications that already use infrared remote controls. For example, TV or Hi Fi sets could recognize the position of a person and adapt appropriately their orientation of the speakers and the screen, the sound volume etc.

In our previous work [10], the position of a moving target was estimated in an area of $5m^2$ using two transmitters with overlapping ranges. A calibration stage precedes normal operation in order to specify the success rate behavior at specific points in the covered area. If the two IRTX devices do not transmit concurrently, an exponential model can be used in order to approximate the success rate behavior anywhere in the plane. The success rate value measured at a specific position is identical for a number of locations if a single pattern type is used. Hence, multiple infrared pattern types are employed in order to assign an individual success rate vector in each position.

In the present work we extend the success rate vector considering the scrambled patterns and the number of patterns received out of order. These additional dimensions provide better estimation accuracy. In order to increase the speed and minimize error, we focus in the case of two IRTX devices covering a confined area and transmitting concurrently infrared patterns. In this case an approximation model cannot be easily selected due to high scrambling and non-uniform behavior. Consequently, a different approach is followed: a grid is drawn on the area that is covered by the two IRTX devices. During the calibration phase the target visits the grid nodes and learns the values for the various success rate dimensions.

At real time, the nearest node to the target is selected according to the least deviation of the current success rate values from the calibration ones. Then, a fast refinement procedure is carried out in the selected node's neighborhood. This refinement procedure is based on a two-dimensional interpolation search.

An estimation error mapping is presented for a grid plane of 20cm squares examined as a case study, indicating the areas where accurate position estimations can be achieved. The average relative error in these areas is less than 5% in each direction. The error estimation can be further reduced if more samples are encountered both during the calibration and the position estimation phase.

## 2 System Description

The architecture of the IRTX devices is presented in Fig. 1. A processing unit generates the digital codes of the various pattern types. Each code consists of a number of identical pulses. The codes are transmitted over a carrier in order to avoid interference from other infrared light sources. The carrier frequency used in our setup is 38KHz in order to utilize commercial low cost infrared receivers. A higher frequency can be used in order to achieve faster position estimation. The carrier and the pattern signals are mixed and amplified prior to the infrared emitting diode driving. A number of commercially available diodes can be used according to the area that has to be covered. A single diode of moderate beam angle ($40\ ^o$) dissipating

50mW has been used at each IRTX device for our case study. Diodes with wider beam angle and higher power dissipation can increase the area covered by a single IRTX device.

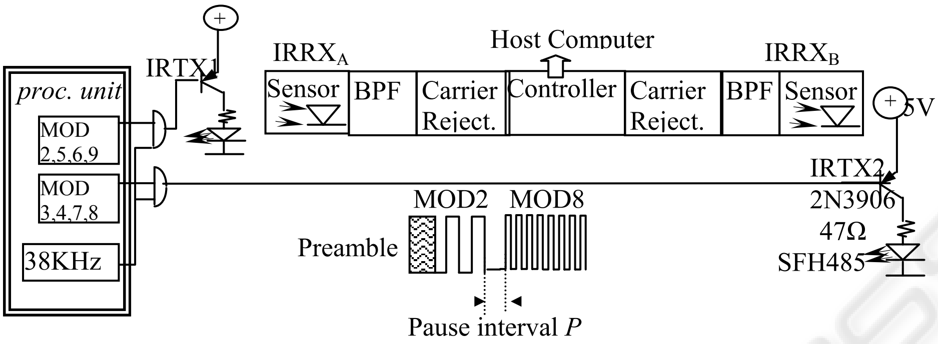



**Fig. 1.** The architecture of the IRTX and the IRRX device. A sample pattern sequence: A Preamble followed by one MOD2 and one MOD8 pattern.

The IRTX device transmits initially a preamble indicating that a new round starts (Fig. 1). The preamble can be a long pause period or a special pulse code not matching any of the pattern codes that follow. As a next step, $M$ identical codes are transmitted, each one consisting of $i$ long pulses. All of these codes belong to the same pattern type called MOD$i$. These $M$ codes are separated by pause intervals of a specific duration, $P$. The value of $P$ is longer than the pulse period of any pattern code. Then, another set of $M$ identical codes of different type is transmitted. These codes consist of $j$ pulses shorter than the MOD$i$ ones. Hence, using this sequence, all of the pattern type codes are transmitted and a new preamble is sent again indicating that a new round starts.

Four pattern types are transmitted in our setup by each one of the two IRTX devices used. In particular, IRTX1 transmits MOD2, MOD5, MOD6 and MOD9 while IRTX2 transmits MOD3, MOD4, MOD7 and MOD8. The specific combination was used in order to compare the behavior of similar pattern types like MOD3 with MOD4 or MOD5 with MOD6. In the general case, MOD$i$ can cover longer distances than MOD$j$ if $i<j$. Nevertheless, no position estimation can be carried out by long period patterns in short distances. If the two IRTX devices transmit codes simultaneously the aforementioned behavior of MOD$i$ compared to MOD$j$ is not always valid, due to intense scrambling.

The receiver consists of 2 sensors ($IRRX_A$ and $IRRX_B$) facing opposite directions and a microcontroller (Fig. 1). Each IRRX sensor consists of an infrared detector followed by a carrier filter. The output of the carrier filter is connected to the processing unit. This unit is responsible for the recognition of a code as a valid pattern or not. Both valid and invalid codes are encountered and the average values of the samples retrieved are used for the position estimation. In our experimental setup, a host computer or a laptop is needed to process the average values and present the resulting coordinates.

In our experimental setup, the processing unit controlling the IRRX devices estimates the success rates during a single round (between two preambles) based on the state diagram presented in Fig. 2. The 2nd and 4th character of the state names indicate three potential stages of a single round reception on $IRRX_A$ and $IRRX_B$ respectively: *U* for Unknown, *P* denotes that a preamble has been recognized on the specific sensor and *n* denotes that any arriving pattern is encountered.

In AnBn both receivers accept and record patterns although some of them may not arrive in the order expected or by the corresponding IRRX device. The number of patterns that arrived in order on $IRRX_A$ are stored in vector *A*, while the out of order patterns are stored in *A'*. Vectors *B* and *B'* are used in the same way on $IRRX_B$. The state End denotes that a new preamble has been detected.

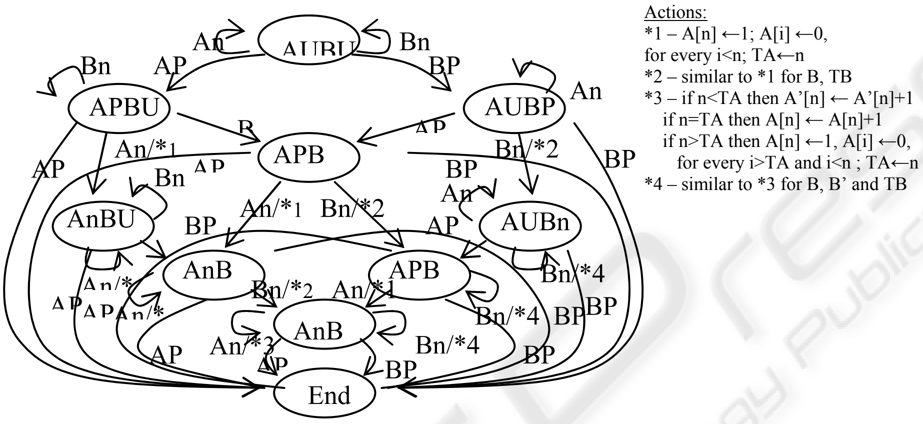



**Fig. 2.** FSM for the recognition of the patterns received on $IRRX_A$ and $IRRX_B$.

## 3 Position Estimation Method

The success rate is defined as a ratio of the number $n_i$ of the received successive identical MOD*i* patterns, to the number *M* of the expected ones. *M* is common for all MOD*i*. Hence,

$$SuccessRate_{MODi}=n_i/M \tag{1}$$

A number of samples are retrieved and the average value of the sample success rates is used for the position estimation or as a reference value defined during the calibration phase. In order to minimize the effect of instant noise, some samples that deviate mostly from the others may be excluded from the averaging process.

The two IRRX devices (named $IRRX_A$ and $IRRX_B$) provide independent success rate measurements but it is more convenient to have $IRRX_A$ facing at IRTX1 and $IRRX_B$ facing at IRTX2. Considering the restricted beam angle of the receiving devices it would be expected that every IRRX device receive patterns from the transmitter in front of it. Despite the fact that inside too large indoor areas with no surrounding objects this might be true, this is not the case for smaller rooms where reflections are significant. Instead of viewing the reflections as a drawback we exploit their effect by encountering the scrambled patterns as a different factor during the position estimation phase. More specifically, we define two vectors for storing the success rates measured from an IRRX device as derived by Fig. 2. $IRRX_A$ determines the vectors *A* and *A'* that store the success rates of the in and out of order samples respectively. These vectors refer to all of the MOD*i* pattern types even if some of them were expected from the $IRRX_B$ instead of the $IRRX_A$ device. In the same way *B* and *B'* are set by $IRRX_B$ device. Hence, vector *A* contains the following 10 values:

$$A=[a_1,a_2,\ldots,a_{10}] \quad (2)$$

For example, $a_2$ in equation (2) denotes the success rate measured by $IRRX_A$ for MOD2 using patterns that arrived in order while $a_2'$ in *A'* includes the MOD2 patterns that arrived out of order. If IRTX1 transmits MOD2, MOD5, MOD6 and MOD9, the parameters $a_3$, $a_4$, $a_7$, $a_8$ encounter patterns sent by IRTX2 and received by $IRRX_A$ through reflection. Parameters $a_{10}$, $a_{10}'$, $b_{10}$, $b_{10}'$ may encounter scrambled or attenuated MOD*i* patterns ($i$>9) that are not supported by any IRTX device.

The vectors $RA_j$, $RA_j'$, $RB_j$ and $RB_j'$ corresponding to *A, A', B* and *B'* are defined during calibration for every grid node *j*. All *RA, RA', RB* and *RB'* vectors are stored in the memory of the IRRX microcontroller. For example, if the area is covered by a grid of 100 nodes then 400 vectors of 10 floating point values need to be stored after calibration.

At real time operation, the vectors *A, A', B* and *B'* store the measured success rates at a specific position of the vehicle and are compared to all *RA, RA', RB* and *RB'* node vectors in order to locate the closer one. The comparison is based on the calculation of the relative deviation between a node success rate value and the corresponding value of the current position of the vehicle. This operation can be applied to all the values of the vectors *A, A', B* and *B'* if the reflection or scrambling effects need to be considered. The relative deviation $d_j$ between the real time measured value $v$ of a position vector and the corresponding reference value $r_j$ of a node *j* (estimated during calibration) is defined by equation (3). Parameter $v$ can be any of $a_i$, $a'_i$, $b_i$ or $b'_i$, and $r_j$ its corresponding value in the $RA_j$, $RA_j'$, $RB_j$ and $RB_j'$ vectors of the node that is currently examined. All the resulting $d_j$ parameters are added up into a single deviation value $Dj$ that indicates how close is the current position to the node *j* (equation 4).

$$d_j=(v-r_j)/v,\ if\ (v>r_j)$$

$$d_j=(r_j-v)/r_j,\ if\ (v\le r_j) and\ (r_j\neq 0) \quad (3)$$

$$\mathrm{d_j=1\ if\ v=0\ or\ r_j=0}$$

$$Dj=\sum_{r\in RAj,v\in A} dj+\sum_{r\in RAj',v\in A'} dj+\sum_{r\in RBj,v\in B} dj+\sum_{r\in RBj',v\in B'} dj \quad (4)$$

In equation (4) both the expected, unexpected and out of order samples have been considered. The closer node is selected from the minimum of the *Dj* values. Although the selection of the closer grid node is a fundamental issue, a refinement procedure should follow in order to further approximate the exact position of the target. This refinement stage is based on the assumption that in the small dimensions of a grid the success rate of a specific pattern changes linearly between successive nodes and thus, an interpolation search in two dimensions can be applied.

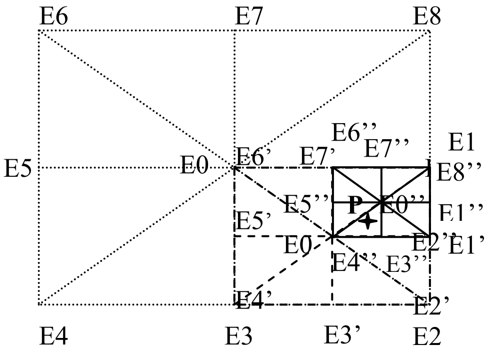


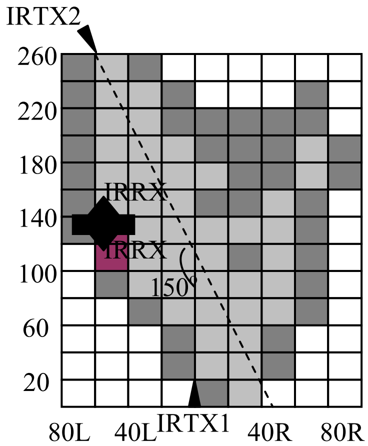

**Fig. 3.** Refinement Stage.

For instance, consider the grid of Fig 3. If *E0* is the initial node that is found to be closer to the current position *P*, the reference values between the success rate vectors of *E0* and its neighboring nodes *Ei* ($1 \leq i \leq 8$) are averaged in order to get an approximation about the reference success rates of the position in the middle of *E0* and *Ei*. These new reference success rates are used in equation (4) in order to determine the direction we should look for the target. In Fig. 3, it is shown that *P* was located in the direction of *E2* in the initial set of neighboring nodes. The point in the middle of *E0* and *E2* (denoted as *E0'*) is now assumed to be the center of a new grid with node distance set to the half of the initial. The reference success rates of the neighboring nodes of *E0'* in the new grid are once again determined by averaging the known or estimated from the previous step success rate values. Applying recursively the refinement procedure, the position *P* can be approximated at the next step by *E0''* etc. If the minimum *Dj* estimated in a new grid is not lower than the one of the previous grid the refinement procedure stops.

## 4 Experimental Results

The experimental results presented in this section, were retrieved using the following setup: an IRTX device (IRTX1) is used as a coordinate reference. A grid of 20cm squares is drawn in front of IRTX1. The coordinates of a point are expressed in the form (*ver,hor,dir*), where *ver* and *hor* denote the vertical and horizontal distance of the point from IRTX1 and *dir* the direction (Left or Right). A second transmitting device (IRTX2) is placed at (260cm, 60cm, Left) as shown in Fig. 4. The IRTX2 is not in a vertical position related to the moving target. The specific position and orientation of IRTX2 was chosen in order to break the symmetry between the left and the right of the IRTX1 axis. Moreover, the angular displacement of the IRTX2 and the $IRRX_B$ device leads to success rates with different behavior compared to the ones achieved from the communication between IRTX1 and $IRRX_A$. The purpose of this topology is to achieve distinct *A, A', B* and *B'* vector values for each individual position on the grid in order to reduce the points that may be confused.

A mapping of the reliable and unreliable regions along with some example estimations is also presented in Fig. 4. Reliable position estimation can be carried out in more than 40 squares, covering an area of $1.6m^2$. An estimation in our set up is assumed to be reliable if the horizontal and vertical distance of the real position from the estimated one is 10cm or less. The mean error achieved in the reliable areas is approximately 5cm.




| Real Position | Estimated Position | | | | Abs. Error |
|---|---|---|---|---|---|
| | Expected Patterns | Expected+ Erroneous Patterns | Expected+ Wrong Order Patterns | Expected+ Erroneous+ Wr. Ord. | |
| **50,10L** | 20,20R | 110,30L | 30,20R | *47,19L* | 9cm |
| **70,0C** | 100,50L | 100,40L | 90,50R | *70,10R* | 10cm |
| **100,20R** | 140,40R | 140,40R | 140,40R | 140,40R | 44cm |
| **110,30R** | 95,40R | 110,30R | 110,30L | *110,30R* | 0cm |
| **110,30L** | 120,20L | 120,20L | 110,20L | *110,20L* | 10cm |
| **130,60L** | 181,52L | 150,60L | 195,77L | 190,50L | 20cm |
| **125,20L** | 180,80L | 180,80L | 190,80L | *130,20L* | 5cm |
| **160,30L** | 160,20L | *160,30L* | 163,10L | 160,10L | 0cm |
| **186,62L** | 200,80L | 200,40L | 170,60L | *194,58L* | 9cm |
| **210,50L** | 210,60L | 200,40L | 210,50L | *210,50L* | 0cm |

**Fig. 4.** Mapping of Reliable (pale shade) and Unreliable regions on the grid.

As far as the speed of the position estimation is concerned, a calculation of the time needed to get a single success rate value for a pattern is needed at first. This time interval is not equal for all the MOD*i* types. As already mentioned, the pulse period of MOD*i* is shorter for higher *i* values (ranges from 500us to 1320us in our setup) but the number of pulses is also higher.

The aforementioned pulse period times were selected in order to allow the period of the pulse to be longer than the period of the carrier (38KHz in our case). A single MOD2 pattern needs 2x1320us=2.64ms while a MOD9 pattern needs 9x500us=4.5ms. If the number of samples needed to extract a success rate is $M=10$ and the pause period between two successive codes is $P=1ms$ then the total time needed by the IRTX device to transmit a round of patterns which is the time interval between two preambles, is less than 200ms. In most cases more than one round is needed in order to get multiple success rate values and abort the samples with higher deviation.

The estimation speed achieved in our lab can be drastically enhanced if a higher carrier frequency is chosen. If infrared components with fast rise and fall times are used the carrier frequency can be increased up to 1MHz. In this case a custom carrier filter can be used at the side of the receiver.

## 5 Conclusions

The ultra low cost system presented in this paper is capable of locating the position of a target on a grid plane covering distances of more than one meter with adequate accuracy (less than 10cm error). The coordinate estimation method is based on the success rate that multiple pattern types are received at a specific position. The closer node of the grid is located first and then a 2D interpolation search estimates the exact target position. Using an appropriate topology of the pattern transmitting devices, the grid squares that allow reliable position estimation were mapped. The factors affecting the speed of the position estimation method were also discussed.

Future work will focus on studying proper topologies of more than 2 infrared transmitting devices in order to extend optimally the area covered. Moreover, it will be attempted to increase the degrees of freedom of the moving target. The history of movements of the target will also be exploited in order to predict potential future positions and increase the stability of the coordinate estimation.

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