DETECTION, TRACKING AND COMMUNICATION BETWEEN TWO ROBOTS

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Abstract

Mobile robot Detection and tracking is an important and challenging problem in the area of computer vision. In this context fits our project which presents a target-tracking system for mobile robots realized with two robots, one robot acts as a moving target and the other plays the role of a tracker. The proposed algorithm includes two main steps: robot detection and robot tracking. Robot detection is based on the Gabor filter for robot feature extraction and the Support Vector Machine (SVM) classifier. The concept of tracking robot is realized once the robot detection is accomplished using the Kalman filter. The ZigBee technology is, also, used for the communication between the two robots .

Keywords

Detection, Tracking, Communication, Robots, ZigBee, Kalman Filter, Gabor Filter, SVM training

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I. INTRODUCTION

Mobile robots are the center of attention of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research. As well and under the robotic research, the *REsearch Group on Intelligent Machines* (REGIM) proposed the project *"Detection, Tracking and Communication between two robots"*.

The detection and tracking of robots have an increasing importance in multirobot systems. In addition, individual robots will need to interact and collaborate with other robots while performing different tasks in a common environment. Cooperation and interaction will be required even when these different robots have not met before or in the case that they don't share a common protocol of data communication. One of the basic skills that robots will require is robust visual interaction with the environment which includes the detection of other robots [12].

The aim of this project is first to detect an autonomous mobile robot based on the Support Vector Machine (SVM) classifier and the Gabor filter for robot feature extraction, then to track it using the Kalman filter and finally to enable it to communicate with another robot and controlling them by the ZigBee communication.

II. PROJECT OVERVIEW

For realization of the project scheme, two mobile robots, the *IRobot Create* robot and the *Bioloid Biped* robot, have been configured as the target and the tracker respectively. (See Fig 1 (a) and (b)).

(a)

(b)

Figure 1. Mobile robots: (a) The Target Robot "The IRobot Create Robot"

(b) The Tracker Robot "The Bioloid Biped Robot"

The *IRobot Create* and the *Robotis Bioloid* robots are designed for entertainment, educational and research use. They are robust programmable mobile robots that provide an out-of-the-box opportunity for educators, students and developers to program behaviors, sounds, movements and add additional electronics.

We have already programmed the two mobile robots to navigate properly, easily and securely in the indoor environment. The *IRobot Create* robot is planned to follow a trajectory and to avoid obstacles using light intensity actuators and infrared sensors respectively [18].

III. COMMUNICATION BETWEEN ROBOTS USING ZIGBEE TECHNOLOGY

ZigBee is a rather new wireless technology that looks to have applications in a variety of fields. ZigBee is a technological standard based on the IEEE 802.15.4 specification for low data rates in the industrial, scientific, and medical radio bands. The technology allows for devices to communicate with one another with very low power consumption, and enables them to run on simple batteries for several years.

Figure 2 shows a comparison of the various 802 technologies for data rate and range.

Table 1 gives a more detailed comparison and contrast for a few of the technologies.

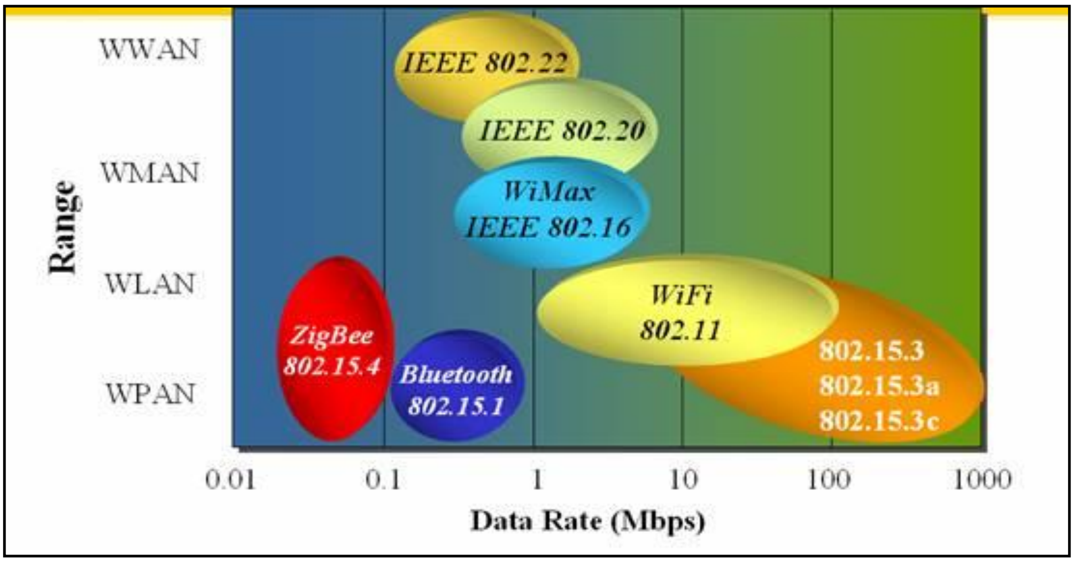


Figure 2. The 802 Wireless Technologies

Table 1. Comparison of ZigBee with other wireless standards

Market Name **Standard**	**ZigBee ™** **802.15.4**	**GPRS/GSM** **1XRTT/CDMA**	**WI-Fi ™** **802.11b**	**Bluetooth ™** **802.15.1**
Application Focus	Monitoring & Control	Wide Area Voice & Data	Web, Email, Video	Cable Replacement
System Resources	4KB-32KB	16MB+	AMB+	250KB+
Battery Life (days)	100-1,000+	1-7	.5-5	1-7
Network Size	Unlimited(2^{64})	1	32	7
Bandwidth (KB/s)	20-250	64-128+	11,000+	720
Transmission Range (meters)	1-100+	1,000	1-100	1-10+
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

J. Magne Tjensvold,"Comparison of the IEEE 802.11, 802.15.1, 802.15.4 and 802.15.6 wireless standards", September 18, 2007.

The tracker robot *"Bioloid Biped robot"* uses the ZigBee for wireless data communication. As such, a ZIG-100 wireless communication module (See Fig 3 (a)) and ZIG2Serial (See Fig 3(b)) for PC interface are provided. ZIG-100 is embedded in the CM-5, allowing communication between robots (Remote control communication) and for controlling robots via PC when the ZIG-100 is connected to the ZIG2Serial [17].

(a)

(b)

Figure 3. ZigBee Modules of the Bioloid Bipeb Robot: (a) ZIG-100 (b) ZIG2Serial

The tracker employs an embedded wireless set camera to capture the images of the moving target robot in his surroundings. The wireless camera set is composed of a wireless image transmitter (wireless camera) and a receiver (see Fig 4).

Figure 4. Wireless Camera Set

By receiving an image from the transmitter that is embedded in Bioloid robot (see Fig5), the receiver connected to the PC via USB port can process the image (see Fig 6). An intelligent supervised learning technique is then invoked for the detection and recognition of the target image processing.

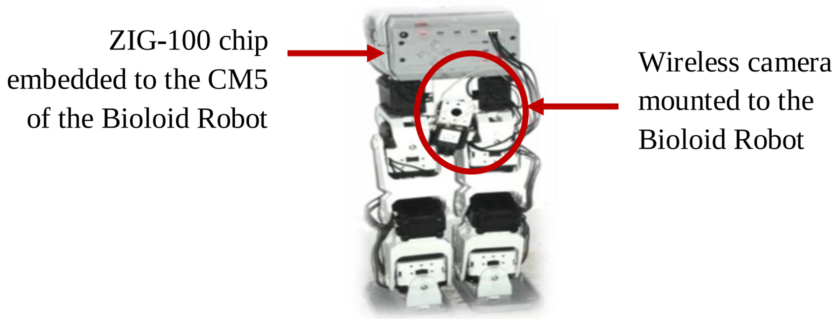


Figure 5. ZigBee Module and Wireless Camera added to Bioloid Biped Robot

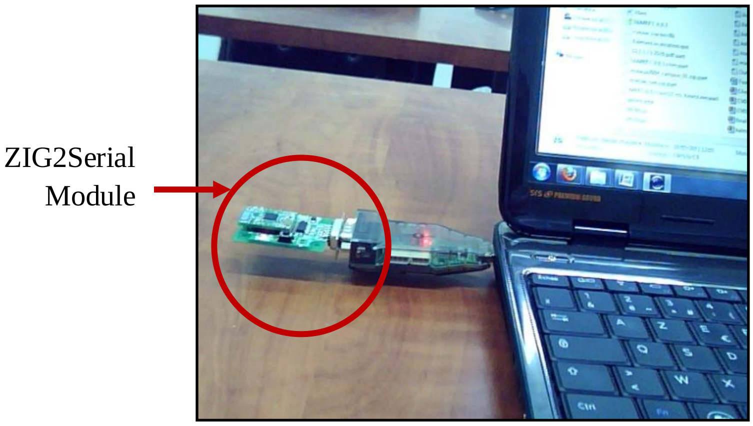


Figure 6. ZigBee modules connected to PC

We choose ZigBee for controlling robots in our project that it makes simple to develop and deploy the solution. In addition, ZigBee is the only standards-based wireless technology designed to address the unique needs of low-cost, low-power, long battery life capability, robust security and high data reliability for wireless sensor and control networks. ZigBee also connects the widest variety of devices into easy-to-use networks, giving unprecedented control of the used devices.

IV. ROBOT DETECTION

Object detection from video sequence is the process of detecting the moving objects in frame sequence using digital image processing techniques. Object detection methods have been classified as point detectors, segmentation, background subtraction, and supervised classifiers. The research for object detection and recognition is focused on:

- First, the representation: How to represent an object,
- Second, the learning: Machine Learning algorithms to learn the common property of a class of objects
- And finally, the recognition: Identify the object in an image using learned models.

In our case, we choose the Gabor filter for the target robot features representation and the supervised learning method the support vector machine (SVM) that used for classification and recognition of the target robot.

The development of such method is a complex task because of the loss of information caused by the representation 3D world on a 2D image, the noise in images, and the complex object shapes. Therefore the problem addressed in this paper is restricted to 2-D only for simplicity of realization with mobile robots.

4.1. Gabor Filter

In image processing, a Gabor filter, named after Dennis Gabor, is a linear filter used for object detection. In the spatial domain, a 2D Gabor filter is a Gaussian kernel function modulated by a sinusoidal plane wave. The Gabor filters are self-similar: all filters can be generated from one mother wavelet by dilation and rotation (see Fig 7). A set of Gabor filters with different frequencies and orientations may be helpful for extracting useful features from an image [14].

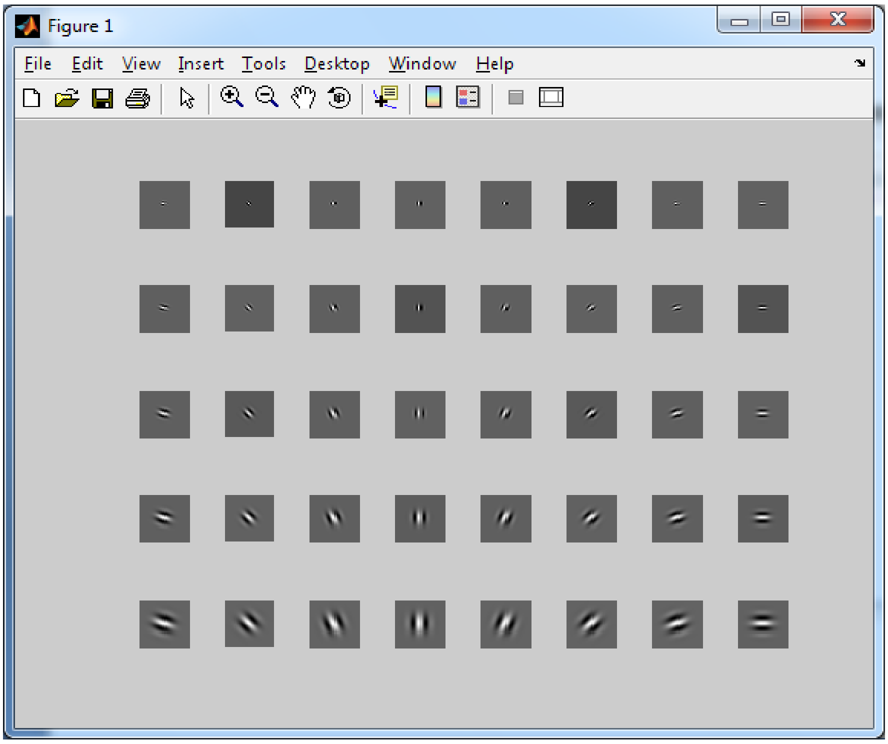


Figure 7. Example of a two-dimensional Gabor filter

A method for the automatic classification of images of the robot is proposed. The method uses a 2D Gabor wavelet representation and a linear classification scheme. The algorithm is tested on two distinct databases one contains the target robot images and the other contains the non-robot images. The algorithm is implemented with matlab language based on the Gabor filter functions defined as follow:

$$G(x, y; \theta, f) = \exp\left\{-\frac{1}{2}\left[\frac{{x_\theta}^2}{{\sigma_x}^2} + \frac{{y_\theta}^2}{{\sigma_y}^2}\right]\right\}\cos(2\pi f x_\theta) \quad (1)$$

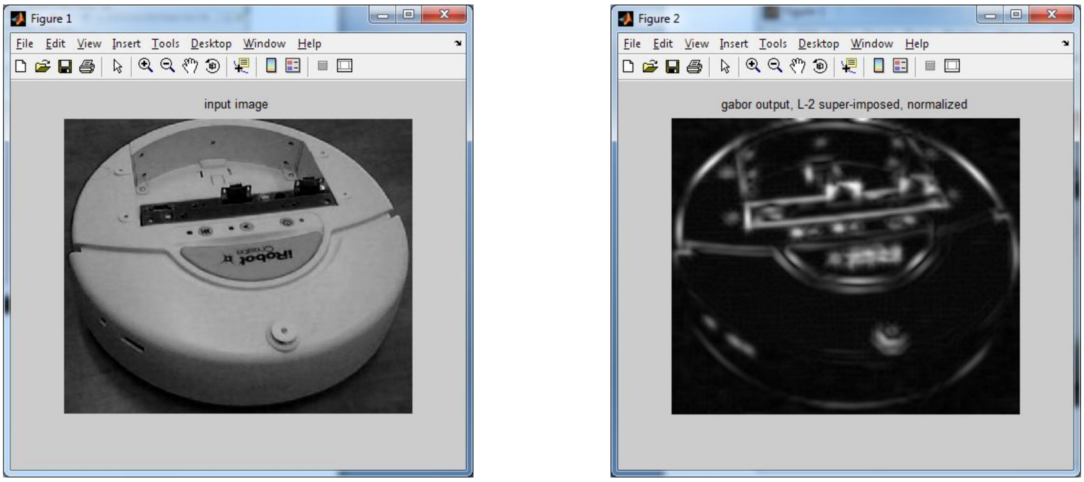
$$x_\theta = x\cos\theta + x\sin\theta \quad (2)$$

$$y_\theta = -x\cos\theta + x\sin\theta \quad (3)$$

Where

- θ is the orientation of the Gabor filter,
- f is the frequency of the cosine wave,
- σ_x and σ_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively,
- x_θ and y_θ define the x and y axes of the filter coordinate frame, respectively.

Gabor filters have been successfully applied to the segmentation of textured images for the robot recognition (see Fig 8 (a) and (b)).



(a) (b)

Figure 8. Gabor Filter features extraction: (a) Input image of the target robot (b) Robot features

These robot features are classified using support vector machines (SVMs). When applied to classification, SVMs seek the optimal separating hyperplan between two classes, typically in a higher dimensional space than the original features.

4.2. Support Vector Machine

A support vector machine (SVM) is a concept in computer science for a set of related supervised learning methods that analyze data and recognize patterns, used for classification and regression analysis [15].

The standard SVM takes a set of input data and predicts, for each given input, which of two possible classes. The input is a member of, which makes the SVM a non-probabilistic binary linear classifier.

Given a set of training examples, each marked as belonging to one of two categories, an SVM training algorithm builds a model that assigns new examples into one category or the other. An SVM model is a representation of the examples as points in space, mapped so that the examples of the separate categories are divided by a clear gap that is as wide as possible. New examples are then mapped and predicted to belong to a category [16].

Based on the SVM classifier demarche, we implemented a matlab program having as training examples the vectors of features extracted of the databases of the IRobot Create robot images and the non- robot images. After that, SVM model is created (See Fig 9).

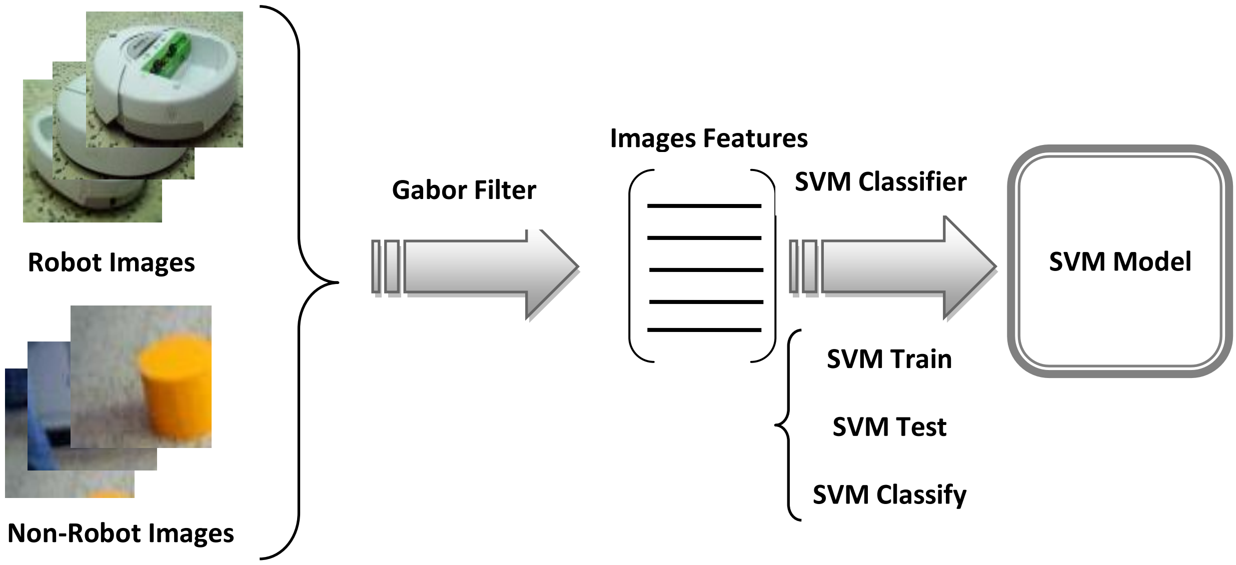


Figure 9. Application of the SVM Classifier

Now we can test an input image of the environment, in order to detect the robot presence or not. First, we apply the Gabor filter extraction to the image, and then the obtained feature vector is tested using the learned model. Finally we obtain the robot position coordinates and the robot will be surrounded by a green square (See Fig 10).

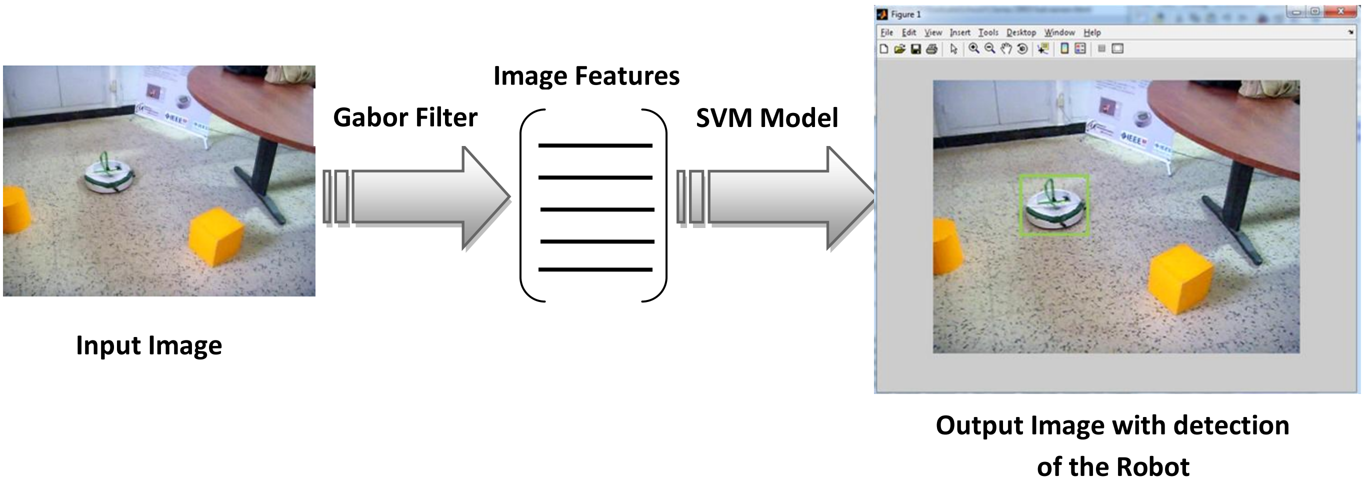


Figure 10. Robot Detection

V. ROBOT TRACKING

The Kalman Filter (KF), developed by Rudolf E. Kalman in 1960, is a set of mathematical equations that provides an efficient computational recursive means to estimate the state of a process, in a way that minimizes the mean square error [11].

The Kalman Filter has been used in a wide range of applications. Control and prediction of dynamic systems are the main areas [4]. A KF can for example be used to control continuous manufacturing processes, aircrafts, ships, spacecrafts, and robots. The KF is the best possible, optimal, estimator for a large class of systems with uncertainty and a very effective estimator for an even larger class. It is one of the most well-known and often used tools for so called stochastic state estimation from noisy sensor measurements [10].

The Kalman filter model assumes the true state at time k is evolved from the state at (k − 1) according to following equations:

$$\boldsymbol{X_k = F_k X_{k-1} + B_k U_k + W_k} \qquad (4)$$

Where

- $\mathbf{F_k}$ is the state transition model which is applied to the previous state $\mathbf{x_{k-1}}$;
- $\mathbf{B_k}$ is the control-input model which is applied to the control vector $\mathbf{u_k}$;
- **wk** is the process noise which is assumed to be drawn from a zero mean multivariate normal distribution with covariance $\mathbf{Q_k}$.

At time k an observation (or measurement) $\mathbf{Z_k}$ of the true state $\mathbf{X_k}$ is made according to

$$Z_{\boldsymbol{k}} = H_{\boldsymbol{k}} X_{\boldsymbol{k}-1} + V_{\boldsymbol{k}} \qquad (5)$$

Where

- $\mathbf{H_k}$ is the observation model which maps the true state space into the observed space.
- $\mathbf{V_k}$ is the observation noise which is assumed to be zero mean Gaussian white noise with covariance $\mathbf{R_k}$.

The Kalman filter can be written as a single equation, however it is most often conceptualized as two distinct phases: *Predict* and *Update*. The iterative predictor-corrector nature of the Kalman filter can be helpful, because at each time instance only one constraint on the state variable need be considered. This process is repeated, considering a different constraint at every time instance. All the measured data is accumulated over time and helps in predicting the state [4] (See Fig 11).

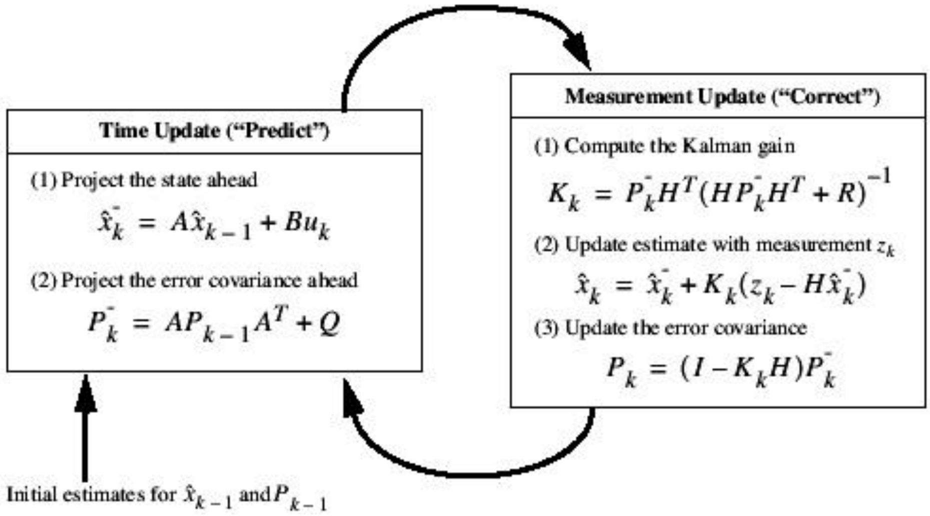


Figure 11. A complete representation of the operation of the Kalman Filter

To use Kalman filter for robot tracking, we assume that the motion of the robot is almost constant over frames. The state variables, dynamic matrix and measurement matrix are combined to form an estimate of the location of the robot.

The Kalman tracking algorithm allows the tracking of the target robot in a sequence video extracting it frame by frame.

We start by the initialization of the matrices and parameters of the Kalman filter based on the initial position detected of the robot already done in the previous section.

Then, we use initial conditions and model to make prediction and measurements. Next, we correct the prediction due to measurement.

We repeat this process predictor–corrector iteratively and all the measured data is accumulated over time until we find the measurement the closest to the real state (See Fig 12).

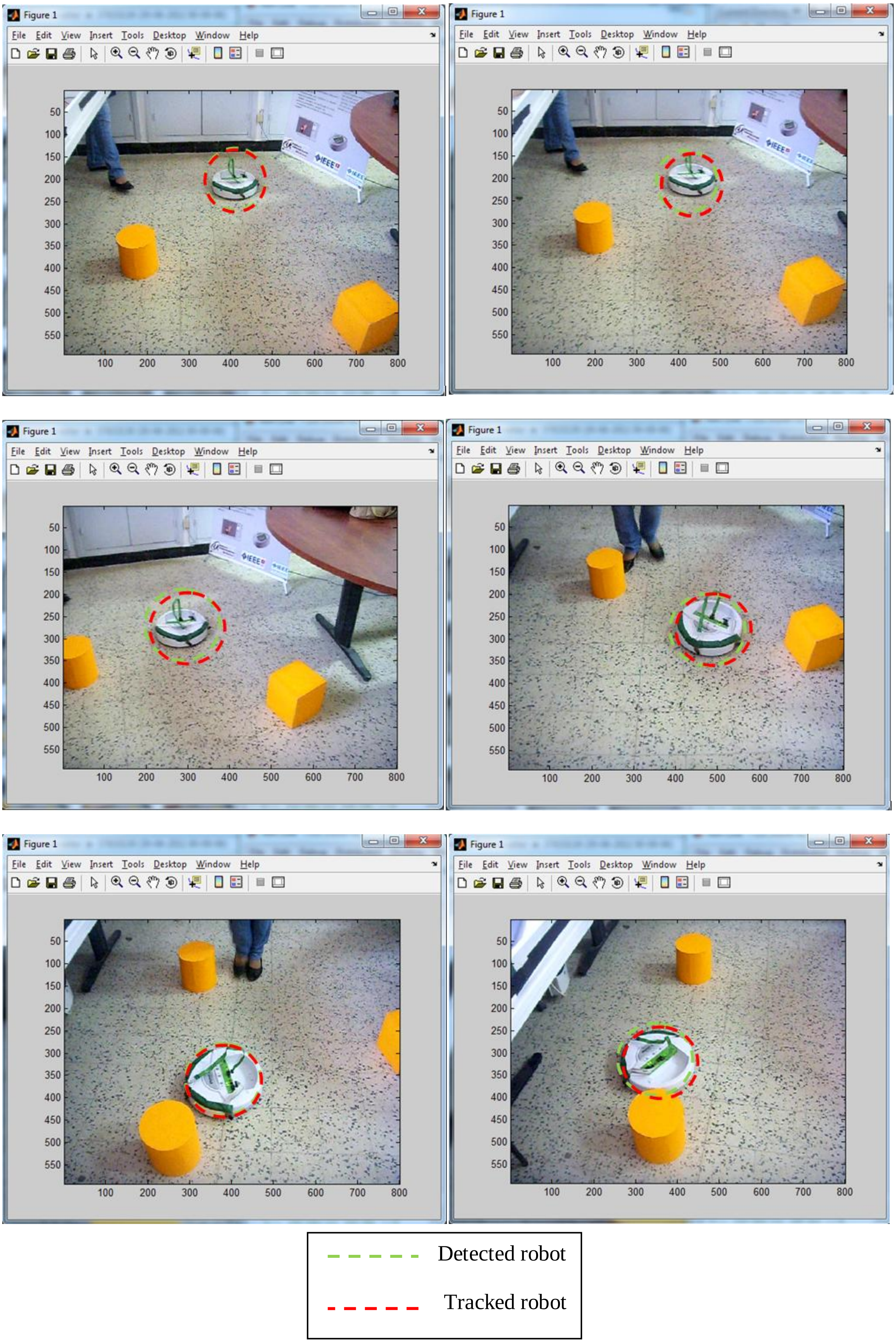


Figure 12. Tracking of the IRobot Create Robot using the Kalman Filter

VI. CONCLUSION

In this work we have thoroughly outlined the problem of Robot Detection and Tracking. To solve this problem, we proposed a system able to detect and track a moving mobile robot and estimate its position in a noisy dynamic environment. The combination of Gabor texture features and SVM classification give great results. The Kalman filter is the best optimal iterative predictor-corrector estimator for tracking. The ZigBee technology makes a low cost simple and secure control. This project combined robust and efficient techniques.

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