Capturing the Spied Image-Video Data Using a Flexi-Controlled Spy-Robot

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***Abstract*— Wireless operated spy-robots can be immensely useful if they can be controlled remotely over a larger operating ranges. Availability of multiple modalities for their wireless control operation can further enhance their capabilities and the range of applications. In this paper we develop a prototype spy-robot that can be controlled remotely, using multiple modalities. The spy-robot can be controlled using a smart phone based DTMF, remote control application, voice commands and tilt-gesture control application. DTMF uses the alpha-numeric keypad of the mobile phone. The remote control application is developed for the Android platform based smart phone. The voice commands use online conversion from speech to text form. The tilt-gestures controls use accelerometer of the smart phone. The control commands to the robot can be transmitted in three ways, using Bluetooth network, over Wi-Fi or using DTMF based telephone calls. The spy-robot can perform forward/backward and turning left/right movements. An on-board spy camera can also be tilted up/down or left/right, in the steps of 30°in each direction. The images or videos captured by the camera are streamed back live over the Wi-Fi network. Performance evaluation is carried to measure various operational limits, with encouraging results. The proposed flexi-controlled spy-robot can be used for range of applications including surveillance, monitoring, tracking and control.**

Index-terms: Spy-robot; flexi-controls; multiple modalities; DTMF; WI-Fi; Bluetooth; smart phone controlled spy-robot

I. Introduction

In the current age, the robots and electronic gadgets are getting more sophisticated, reliable and miniaturized. That makes these systems increasingly suitable for spying and law enforcement purposes [1]. Spy-robots can be used for a wide range of applications, from collecting sensitive intelligence data to completing covert missions [2]. With suitable sensors and cameras to perform different tasks, the spy-robots can be operated remotely for reconnaissance or patrolling tasks [3], where these can relay the videos and images captured back to the operator, through wireless communication. The need for flexi-controlled smart robot, equipped with appropriate sensors for movement, is increasing day by day due to growing risks and the concern for human safety.

Several research studies are carried out on mobile robot's controls for various applications [4]. There have been efforts to develop robots for the diverse purposes such as traffic patrolling, or search and rescue operations, monitoring structures (such as roads or urban areas), and many other applications [5]. In all such scenarios, availability of multiple modalities for remote control operation of the spy-robots can further enhance their capabilities and applications [6].

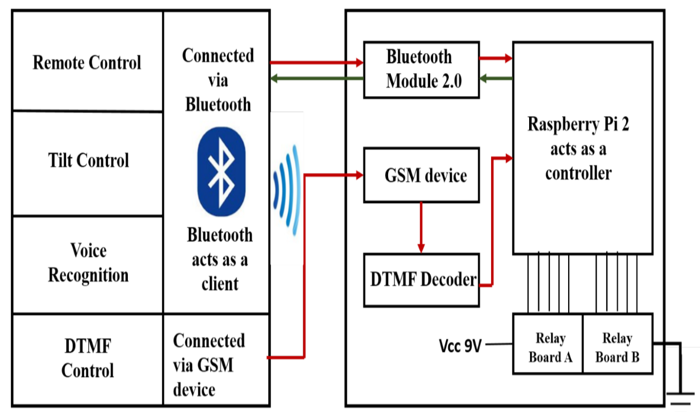


Fig. 1. System Framework of the prototype spy-robot

Using high-level behaviors consisting of gestures, speech, touch etc, the user can also demonstrate to robot 'what it should do'[7,8]. In earlier several studies, mobile robots using different network technologies have been proposed. Apart from DTMF, the Wi-Fi and Bluetooth have been used for communication between and operators, for diverse applications such as surveillance, spying, patrolling, and effective policing [9-12].

In this paper, a flexi-controlled mobile smart robot is developed that can be controlled remotely, and can relay back live image-video data. A prototype working model of the proposed robot is developed. The prototype spy-robot can be controlled using four modes, namely, DTMF, remote control, voice commands and tilt-gesture control of a smart phone. These control commands can be communicated to the spy-robot using three types of connection protocols, namely, Bluetooth, Wi-Fi and DTMF. Bluetooth is economically cheaper and not easily affected by noise, but it has limited range of operation. Hence, to compensate for that, DTMF as a substitute control mechanism is proposed. Further, Wi-Fi network based remote control of the prototype spy-robot is proposed, in order to significantly enhance the range of operation and bandwidth for transmission of the captured video data. Experiments are conducted to measure the operational

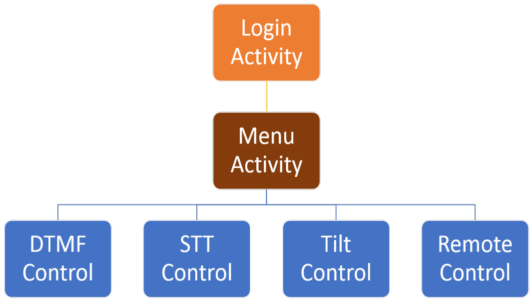


Fig. 2. Activity Flow diagram for the prototype spy-robot

ranges, stream quality and limitations of the prototype robot. Functional testing and results are also discussed briefly.

This paper is organized as follows. In Section 2, design details with the system overview of the prototype spy-robot are discussed. In Section 3, the communication protocols used for transmitting commands to the spy-robot, and image or video data transferred back to the operator, are discussed briefly. Design details of an Android application are discussed along with controls, in Section 4. Details of different working modes of the prototype spy-robot are discussed in Section 5. Experiments conducted to measure different parameters and compute the operational limitations are discussed in Section 6. Lastly, a summary is given in Section 7, along with scope of further work.

II. Design details

The prototype spy-robot consists of a mobile robotic platform with multiple control mechanisms. A noticeable feature of the robot is that it has a spy-camera mounted on-board, to make it capable of spying and surveillance activities, with remote-controlled operation. The camera has two degrees of freedom. The camera motion can be controlled through different control mechanisms integrated in the application. The camera can turn by 30°angle in the direction desired by the user. The captured video or image data is transmitted back to the controller of the robot. System framework of the prototype robot is shown schematically in Figure 1. The system consists of:

(a) Hardware Components:

- Raspberry Pi 2 Model B
- DTMF Decoder Module
- Android Smart Phone with minimum API level-19

(b) Software Components:

- Android Applications :
  - 'RoboControl' (developed by us)
  - IP Webcam
- Algorithm

Various components are discussed below:

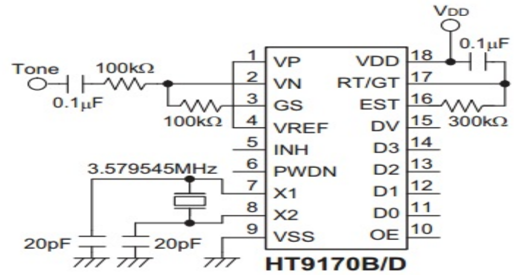


Fig. 3. Circuit Diagram of DTMF decoder module

A. Hardware description

(a) *Raspberry Pi-2 Model-B:* Raspberry Pi-2 Model-B micro controller board is used in the prototype spy-robot. Its main function is to process the data, based on the input control command it gets using either of the four modalities. Raspberry Pi was preferred due to various reasons. Firstly, it has a powerful processor which decreases response-time of the robot. Secondly, the prototype involves a large Python script which requires a higher amount of memory, that can be easily stored on Raspberry Pi, due to the provision of expanding its memory. Thirdly, the access to Ethernet and Wi-Fi on Raspberry Pi makes it easier to organize and operate over a secured (SSN) network.

(b) *DTMF Decoder:* It decodes the DTMF signals to corresponding binary outputs. It receives the DTMF signals from a GSM (phone) device through 3.5mm Audio cable. It is based on the IC HT9170B/D chip, which takes DTMF audio signals as input and returns the binary code of the corresponding number as output. Figure 3 shows the circuit diagram of the DTMF decoder module used in this prototype.

B. Software description

(a) *Android Application:*

- *RoboControl:* It is an Android Operating System (OS) based application for smart mobile phones, developed by the authors. It encapsulates various controls of the prototype spy-robot into a single platform to allow interoperability. It has features like - *secure login access* to the robot and *Bluetooth chat* to transmit control commands from the Android device to the Surveillance Robot. Figure 2 illustrates the activity flow in the basic framework of the Android application developed.
- *IP Web-cam:* It is a free downloadable application available in the Google Play Store [13]. This application is used to achieve a real-time visual data transmission over Wi-Fi network, between two devices connected to the same access point, i.e., the smart phone mounted on the *robot* and any other LAN connected device using IPv4 network protocol.

(b) *Algorithm:* To implement multiple connection protocols to work simultaneously, a closed loop algorithm (with feedback loop to check for presence of DTMF connection) was

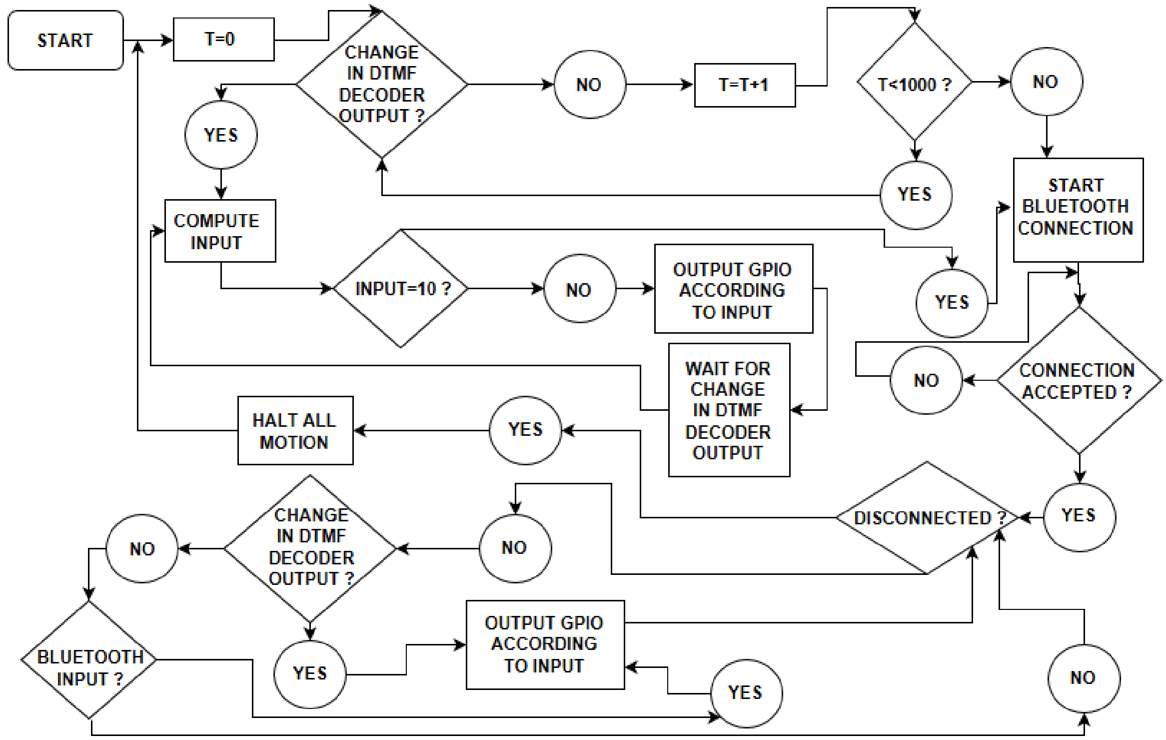


Fig. 4. Flowchart describing the algorithm used in the robot

required. In Figure 4, a flowchart of the prototype spy-robot developed, is shown. As can be observed in Figure 4, the algorithm developed for the prototype spy-robot continuously checks for the incoming DTMF and Bluetooth connections. If any control command data is received from either of the two connection protocols, then Raspberry Pi sends control signals to the prototype spy-robot accordingly.

III. Wireless Control Operation of the Robot

The prototype spy-robot's control operation can be carried out in a completely wireless way. Various wireless connection protocols can be used in the prototype spy-robot developed. These can be selected as per user's choice and convenience. These different connection protocols are:

1) Bluetooth
2) Wi-Fi
3) DTMF

A. Bluetooth: Bluetooth is a wireless technology standard for exchanging data over short-distance, from fixed and mobile devices, and building personal area networks (PANs). The IEEE standard for Bluetooth is IEEE 802.15.1. Bluetooth network protocol is used in this work because it is economically cheaper, consumes very less power and ensures reliable connection. Moreover, there is very less effect of noise on the transmission of Bluetooth signals because of it's frequency hopping characteristic. To simulate *RFCOMM* for Bluetooth communication the Python script library *PyBluez* is used [14,15].

Bluetooth Server System Architecture : Bluetooth Server is needed to provide an abstraction for communication between the robot and the Android device [16]. This layer of abstraction receives data through Bluetooth, parses it and sends it back to the robot. For transmitting the data, two types of Bluetooth profiles can be used :-

1) *Object Push Profile (OPP)* [17]: OPP defines the roles of push server and push client. These roles are analogous to (and must inter operate with) the server and client device roles that GOEP defines.
2) *Serial Port Profile (SPP)* [18]: SPP defines how to set up virtual serial ports and connect two Bluetooth enabled devices.

In OPP, the advantage is that all the transfers are initiated by the client, so as to achieve any desired action. The client can call methods from the server. On the other hand, SPP is effective for sending streams of data between client and server, and vice-versa. SPP is used in this work, to control the robot, to communicate the serial data between the Android phone and the Raspberry Pi micro-controller module.

B. Wi-Fi: Wi-Fi is a popular wireless networking technology that uses radio waves to provide *wireless* high-speed Internet and network connections. It corresponds to the IEEE 802.11x Standard. It works with no physical wired connection between the transmitter and the receiver, by using radio frequency (RF) technology. In this work, this system of communication is used to send real-time visual data (i.e., image or video data) spied (i.e., captured) using a smart phone attached to the robot, for sending to any other device placed at a distance within the range of Wi-Fi network.

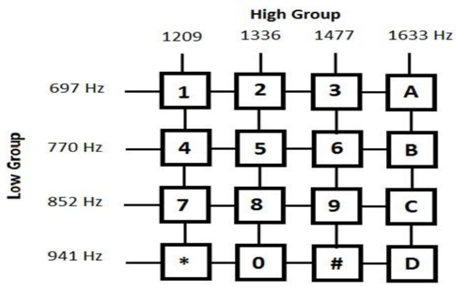


Fig. 5. Frequency Generation Table for DTMF

C. DTMF (Dual-tone multi-frequency) : DTMF is an in-band telecommunication signaling system, that uses the voice-frequency band for communication over telephone lines, other communications devices and switching centers. In DTMF, when each key is pressed, it generates two tones with specific frequencies. One tone is generated from a high-frequency group of tones and the other from a low-frequency group, as illustrated in Figure 5.

DTMF is used as a substitute control for Bluetooth, due to it's longer range as compared to Bluetooth. Other reasons include its speed, reliability and easy to decode.

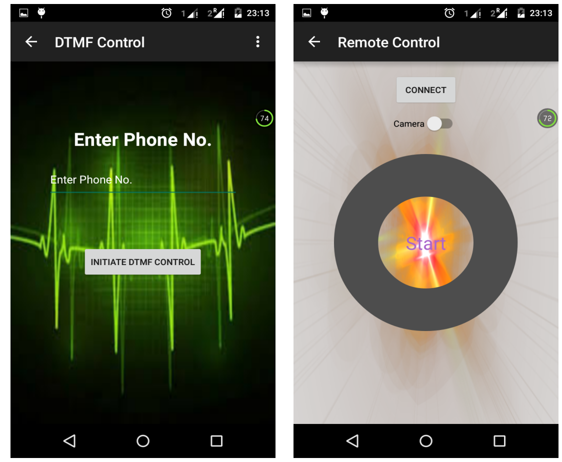
IV. Android Application based control

A. RoboControl: This work uses OS Android [19] base application 'RoboControl' developed by us. It implements four control mechanisms i.e., DTMF, Remote Control, Speech Recognition and Tilt-Control of a smart phone.

1) *DTMF Activity:* To implement the DTMF control in the application (as shown in Fig.6(a)), appropriate combination of frequencies are required to be sent over a GSM network. To implement this 'Intent.ACTION_CALL method' Android API, is called to initiate the DTMF control. It makes a GSM call on the mobile phone attached to the spy-robot, whose number is entered in the text box in the activity.

2) *Remote Control Activity:* To implement the smart phone application based Remote Control (as shown in Fig.6(b)), a remote control is simulated in the Android Application. First a bitmap image is created containing a circular ring. Then 'setOnTouchListener' (new MyOnTouchListener()) method of imageView is used to listen to touch events on the screen. For appropriate touches different strings are sent over Bluetooth network to a Bluetooth RFCOMM server operating on the Raspberry Pi microcontroller.

3) *Speech Recognition Activity:* Speech Recognition [20,21] is implemented using Google server for processing the speech to convert it to text. This text is sent as serial data over Bluetooth to Raspberry Pi, which makes decisions based on the string input. This activity basically acts as a bridge between the Google Server and Raspberry Pi microcontroller module.



(a) DTMF Control (b) Remote Control

Fig. 6. RoboControl Application Screenshots

4) *Tilt-Gesture Control Activity:* Tilt-Gesture control is implemented using accelerometer in the smart phone. The activity sends control commands over Bluetooth netwrok, for different orientation of smart phone. When the calibrate button is pressed, it sets current acceleration in *x, y and z axes* as reference for drawing inferences from the acceleration data to send appropriate control commands.

B. IP Webcam: This application is used to achieve a real-time visual data transmission over Wi-Fi network between two devices connected to the same access point. This application also features quiet a few number of utilities for various purposes. Firstly, we can set a user ID and password so the video output from the robot can only be viewed by authorized devices in the same network. Secondly, the controller-side of the application provides features such as - view a video, listen to audio or take snapshot from the camera of the smart phone on-board the mobile robot. This application provide various ways to capture the spied image-video data (examples of which are shown in Figure 7 and 8). The stream quality for real-time video transmission can be adjusted according to the available bandwidth. It also provides a way to control the flash-light and zoom-level of camera used. This can help in the spying activities, where Wi-Fi network coverage is not good.

V. Different Modes of Control of the Robot

There are 4 different modes of controls developed for the spy-robot, each with its own command set. Following is an explanation of each control command tables of the individual controls :

A. DTMF: To initiate the control, a GSM call needs to be made to the smart mobile phone attached to the spy-robot's DTMF decoder module. Once the call is auto picked, one can press the keys on the keypad to give commands. Different numeric keys are mapped for different functions of the spy-robot.

(a) Landscape (b) Spy Activity

Fig. 7. Real-time transmission of video data using IP Webcam

TABLE I
CONTROL TABLE FOR VOICE COMMANDS

Voice Command	Response
”forward”	Robot starts moving Forward
”backward”	Robot starts moving Backward
”right”	Robot turns Right
”left”	Robot turns Left
”camera” + ”up”	Camera starts moving Upwards
”camera” + ”down”	Camera starts moving Downwards
”camera” + ”right”	Camera swipes Right
”camera” + ”left”	Camera swipes Left

TABLE II
EFFECT OF VARYING THE RANGE OF BLUETOOTH

S.No	Distance between robot and operator (in m)	Propagation Delay (in sec)	Packet Loss (in percentage)
1	5.0	1.985	01.6
2	7.5	2.193	05.3
3	10.0	2.211	08.9
4	12.5	2.232	10.2
5	15.0	2.286	11.3
6	17.5	2.122	13.2
7	20.0	2.348	19.8
8	22.5	2.442	23.7
9	25.0	2.554	30.6
10	27.5	2.563	36.1

B. Remote Control Application: The remote app is a Bluetooth based control mechanism. It consists of :
(i) a circular touch remote button to control the movement of robot and the camera mounted on-board the robot,
(ii) a button for disconnecting and connecting the Bluetooth
(iii) a toggle button for switching between the mobility-control and camera-control.

C. Voice Command Control: This is a control mechanism used for controlling the spy-robot through voice commands. In order to start the conversation between the two Bluetooth devices, the connection needs to be established between both the devices. Table I presents different voice control commands for different functions to be performed by the robot.

D. Tilt-Gesture Control: Tilt-gesture control is implemented using the inbuilt accelerometer in a smart mobile phone. “Calibrate” button is used to calibrate the accelerometer. Then, the “Start” button is used to control the spy-robot, which starts sending the control commands over Bluetooth to the Raspberry Pi micro-controller. To switch between mobility-control and camera-control, a toggle button is used.

VI. EXPERIMENTS AND OBSERVATIONS

The mobile spy-robot platform operates with flexible controls. Hence, for bench marking its operation range and quality of image-video transmission are important. The major communication protocols used here are Bluetooth, Wi-Fi and DTMF. The spy-robot’s operational range is actually dependent on the range of all the protocols. Since DTMF range is not limited by the user, Bluetooth was found to be a sub-optimal option for relaying commands due to its higher diversity in control mechanisms. Wi-Fi is used to relay the captured video or image data over a intranet connection. Figure 9 shows the effect of change in effective distance between the controller and the spy-robot, on the stream quality of relayed back video data over Wi-Fi. In Figure 9, it is assumed that 100% stream quality for video transmission occurs in range of 2m. The plot for stream quality vs. effective distance in Fig. 8 is valid for Wi-Fi network created using a smart phone’s Wi-Fi hotspot. The mean operation range for Bluetooth was found to be 26.4m. Table II presents the propagation delays and packet loss (in percentage) observed in transmitting the voice commands over the Bluetooth network. It clearly shows that packet loss increases, as the distance increases between the operator and the robot.

VII. SUMMARY AND CONCLUSION

In this paper, we develop a reliable mechanism of communication and control, and capture image-video data for a spy-robot. Response time-delays and driving precision are observed. For smart phone’s wireless hotspot network with the mobile, the optimum range of the Wi-Fi network is very low, i.e., about 7m with approximately 60% stream quality.

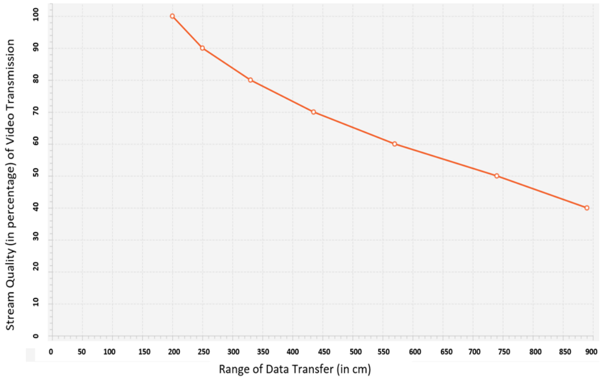


Fig. 8. Stream Quality variation to determine range variation

It is evident from Figure 9 that stream quality of video transmission decreases rapidly with increasing distance between client and server. At the maximum range, the lag-time between capturing the video data and relaying back to the operator was observed to be appreciably high. This limitation of the prototype spy-robot's response can be overcome by using more powerful modems, switches and hubs to boost up the network and increase its data transmission rate and operating range[21]. The controls that we integrated, can be used together with flexi-controls as well as individually. The stream quality (Figure 9) and packet loss data (Table II) indicate the steady increase in the range of reception of data with appreciable low lag-time, with reduction in stream quality and packet data size. The prototype robot can be used for a wide range of applications including surveillance, monitoring, tracking, spying and rescue operations.

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