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Cost Effective Spy Ball Robot for Surveillance, Rescue and Exploration

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Abstract – Surveillance and inspection cameras play an important role in security and monitoring applications. Various cameras are designed for such purpose including Biometric surveillance cameras, Aerial surveillance cameras and payload surveillance cameras. As an extension to the domain of surveillance cameras, in our work we have designed a new prototype spy ball that is capable of transmitting wireless video and audio signals. The spy ball also contains a radio controlled navigation system which can assist in moving the ball in different directions. The ball can be used as a surveillance device and hence it is made shock proof. This ball also supports its personal video streaming application that contains different options for video capturing and recording facility. Upon testing this ball on various platforms, excellent video capturing with stability is achieved.

Keywords: spy camera, wireless, surveillance, rescue, controller

I. INTRODUCTION

Security and surveillance have been a major topic for the last decade. With the rapid increase of population and terrorist activities throughout the world, and with the advent of sophisticated technologies which is usually used by unwanted elements, a need of powerful security and monitoring systems was inevitable. Hence various techniques, algorithms, methods and implementations have been proposed in these areas of research by researchers, ranging from a simple proposed algorithm for object detection to a complex fully intelligent multi-purpose and specialized robot capable of either monitoring the surrounding or making decisions on behalf of human being. An effort was made to introduce equipments and cameras either standalone or mounted on robots capable of providing security, surveillance, detection and tracking [1]. Hence camera selection remains one of the most important factors in surveillance applications. For instance night vision security cameras which are ideal for any low-light areas, not just for the night time. Similarly decentralized IP-based Closed-circuit television (CCTV) camera is a type of digital video camera commonly employed for surveillance capable of sending and receiving data via a computer network and the Internet unlike analog CCTV cameras [2]. While most of the cameras have wired connection, some have wireless capabilities. Such cameras offer more flexibility in set up. They are easy to install, can be moved easily, are often small, have no tell-tale wires, and are very discreet [3]. One type of wireless cameras is concerned with exploring difficult areas where human approach is not possible due to environment, weather, size or even when presence of human being is not allowed (spy or hidden). The latter requires cameras that are not easy to detect, small, flexible and wireless (most of the time). Such cameras are known as the spy cameras. Spy cameras come in different shapes and sizes depending on the application. Some of them are fixed and some are movable through a wireless connection. Some spy cameras are shown in Fig. 1. We can categorize these spy cameras into two groups, integrated and non-integrated. Integrated cameras mean that they are merged with some common daily used devices or objects without being detected or noticed by the user. For example, a small spy camera hidden in the top of the phone. While walking around and pretending to text message or even setting the phone down on a table or counter and record everything that happens without anyone having even the slightest idea [4]. Similarly, a common integration of hidden cameras occurs in pen or even fitted on a ring equipped with recording capabilities like a camcorder. On the other hand non-integrated cameras are those which are stand alone spy cameras commonly operated wirelessly. For instance, Micro eyes color DVR ball camera which is approximately a Golf ball sized and has the capability of self recording to micro SD card and having a rechargeable battery shown in Fig. 1 (d).

Beside spying and surveillance purposes of spy cameras, they can be used for search and rescue purposes especially in difficult terrain or narrow areas

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(e.g. tunnel, gas pipe, chimney, etc …) [5, 6]. These kinds of cameras can be mounted on special robots known as Tele-Presence robot which can be controlled manually or full autonomous like in Unmanned Arial Vehicles (UAVs) [7]. In most of the tele-presence applications both the remote station and the controlled station (e.g. robot) have cameras, monitors, speakers and microphones to allow for two-way video/audio communication. The controlled entity's camera provides video images to a screen at the remote station so that the user can view the robot's surroundings and move the robot accordingly. In addition most of the communication between the two entities takes place through a wireless communication infrastructure. Mediums of communication can vary according to application and distance Satellite, microwave, sonar and many more channels can be used for remote control and communication. In addition it would be desirable to modify such systems to have two way communication or to transfer robot control from one robot station to another.

Now in order to develop a tele-presence or a spy robot, and looking at the present demands of robots especially in developing countries, appropriate development of robots in a cost effective manner is required. This development helps many industries, workplaces, rescue teams and research development centers to utilize robots in place of humans. In our work we have designed and developed a spy robot/camera in a ball shape which has the ability to move in any direction especially in narrow areas such as tunnels and pipes. It can be used both for spying or inspection and rescue. The spy ball is operated through a wireless connection and can transmit video through a cam mounted in the middle of the spy ball. The transmission through this ball is very stable even with continuous movement of the ball in all direction. Rest of the paper is organized as follows: in section 2 major hard ware components of the spy ball and their connectivity are discussed. The software support along with Direct Show which is an integrated part of the spy ball is discussed in section 3. The mechanical description and the overall functionality of the spy ball are presented in section 4. Finally conclusions and future enhancements are proposed in section 5.

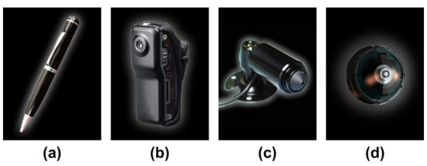

Fig. 1. Different Spy Cameras

II. HARDWARE COMPONENTS AND THEIR CONNECTIVITY

The overall block diagram of our system is shown in Fig. 2 and work as follows: there are actually three main components in the developed system. The first component is the spy ball which consists of mechanical parts, camera, transmitter and receiver. The ball is controlled by the second component which is the control unit with a joystick that provides movement instructions to the ball. The control unit consists of mechanical parts mainly in the form of joystick, transmitter circuitry and antenna. Finally the third component is the computer terminal which has software supporting both video and audio feed and a wireless receiver for audio/video reception from the spy ball camera.

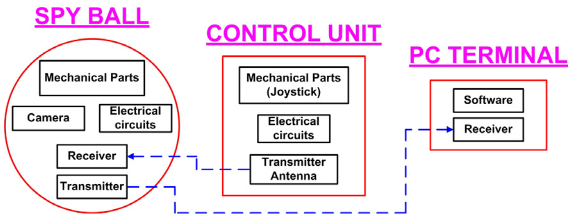

Fig. 2. Block diagram of the proposed system

The hardware circuitry components which are used to constitute the overall electrical base of the spy ball are chosen in such a manner to provide precision as well as cost effectiveness. The following components are used with brief overview of each component and their functionality.

Airwave 655 RF Transmitter: It is a 2.4 GHz Audio/Video wireless RF Transmitter. Airwave RF module is compliance with the criteria of FCC and R&TTE which can transmit a wide band audio and video signals up to 100 meters in an open area. In addition, there is no need for external audio circuit as both Audio/Video input and output is integrated onto one module base-band PCB. Furthermore, this transmitter is compact in size and has low power consumption. There are four channels in this transmitter where channel 4 being the default one. In a similar manner, Airwave 655 RF receivers are used as video receptors.

Camera: It is mounted inside the inner layer of the ball. A very stable camera is used with high performance to stabilize the video quality while ball movement. The video captured by the camera is transmitted through the transmitter module and received at the user end through receiver module. The application at the user end enables the user to view and record the video.

Wi-Fi Antenna: Wi-Fi antenna is used to transmit the signals from the transmitter and receiver modules respectively. The Wi-Fi antenna broadcasts the signals from transmitter with a frequency of 2.4 GHz. An RJ174 Coaxial cable with electrical resistance of about 50 ohms is used to join with Wi-Fi antenna.

Microphone: An external mike is used to perceive the audio signals and transmits those signals from the transmitter to the receiver module. The mike is dedicated for detection of sound ranging up to 10 meters.

Power Supply: Nokia 1100 (Model BL_4C) mobile battery has been used to provide power to the ball. This battery provides 3.7 volts output voltage. Four consecutive batteries are connected in series to obtain the output voltage around 12-14 volts. These batteries are the main power reserve for the whole circuit along with the accessories connected with it. These batteries are mounted on the package installed inside the ball. When fully charged it provides life of about 30 minutes to the ball circuitry. Different components require different electrical power supplies. Camera requires 9 volts to operate. ICs require 5.5 volts as input that is provided through batteries. The batteries provide them 14.8 input voltages that are reduced to desired input voltage using L7805 voltage regulator. Capacitors including 470uF/16V, 1000uF/10V, 33uF/10V, 470uF/10volts are used in the circuit to obtain functionality of the circuit.

TV Device: The device is used inside the system in order to interface the receiver circuit to the computer terminal. The device serves as the source for the Spy ball application. Radio Corporation of America (RCA) cable is used to connect device and the receiver module. The device is further connected to personal computer using USB port.

Control Circuit: Radio control (often abbreviated to R/C or simply RC) is the use of radio signals to remotely control a device. The term is used frequently to refer to the control of model vehicles from a hand-held radio transmitter. Industrial, military, and scientific research organizations make use of radio-controlled vehicles as well. For our spy ball, separate movement control unit based on RC is developed as shown in Fig. 3. This control unit is similar to a joystick with one stick controlling the horizontal movement and the second one controlling the vertical movement of the spy ball. The circuit used for providing control feature is TX-2B. This is a pair of CMOS LSIs designed for remote controlled car applications. The TX-2B has five control keys for controlling the motions (i.e. forward, backward, rightward, leftward and the turbo function) of the remote controlled car. For controlling the ball we have used the rightward as forward and leftward as backward. This board has wide operating voltage range from VCC = 1.5 to 5.0 Volts. In addition it exhibits low stand-by current and it has auto-power-off feature. Note that an antenna and circuit board inside the ball receives signals from the transmitter and activates motors inside the ball as commanded by this transmitter. Infact a similar receiving circuit board used at the receiving end (i.e. spy ball). Both the block diagram of the transmitter circuit and the actual receiver circuit is shown in Fig. 4.

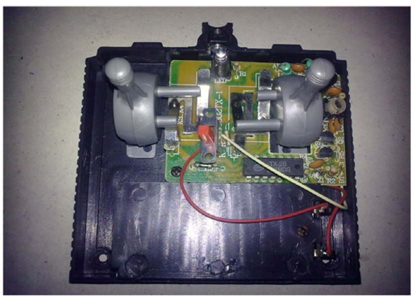

Fig. 3. Control unit for the spy ball

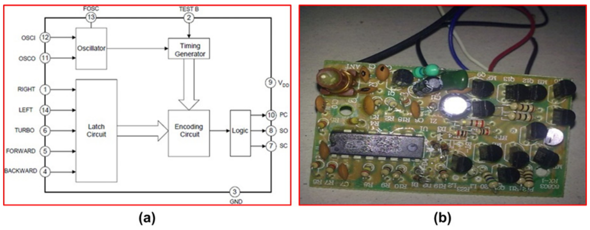

Fig. 4. (a) Block diagram of the trasmitter (b) Receiver circuitry

The components of the circuit including microphone and camera output pins are connected to transmitter's input pin 4, 5 and 6 respectively. The Transmitter generates output signals in radio frequency mode through WI-FI antenna (2.4GHz) that are received by the Receiver as data signals. The transmitter then directs the encoded data signals to the personal computer through RCA cable that is connected to TV device. The device decodes the signals into required form and then forwards it to the computer via USB port. The output video (800-640) is generated on the screen using video application software. The application supports video saving and playback along with snapshots at runtime that helps the end user to analyze the output (i.e. audio/video signals). In the next section, a detailed description of the software used at the PC terminal is given.

III. SOFTWARE SUPPORT AND DIRECT SHOW

The main purposes of the application on the PC terminal is to stream live video, record the video and take still images from the video. For this purpose DirectShow API is used. DirectShow (sometimes abbreviated as DS or DShow), codename Quartz, is a multimedia framework and API produced by Microsoft for software developers to perform various operations with media files or streams [8]. It is the replacement for Microsoft's earlier Video for Windows technology. Based on the Microsoft Windows Component Object Model (COM) framework, DirectShow provides a common interface for media across various programming languages, and is an extensible, filter-based framework that can render or record media files on demand at the request of the user or developer. The DirectShow development tools and documentation were originally distributed as part of the DirectX SDK. Currently, they are distributed as part of the Windows SDK (formerly known as the Platform SDK).

The building block of DirectShow is a software component called a *filter*. A filter is a software component that performs some operation on a multimedia stream. For example, DirectShow filters can read files, get video from a video capture device, decode various stream formats such as MPEG-1 video and pass data to the graphics or sound card. In addition the basic objective of a filter is to receive input and produce output. For instance, if a filter decodes MPEG-1 video, then input is the MPEG-encoded stream and the output is a series of uncompressed video frames. Furthermore, in

DirectShow an application performs any task by connecting chains of filters together so that the output from one filter becomes the input for another. A set of connected filters is called a *filter graph*. Fig. 5 for instance shows a filter graph for playing an AVI file and Fig. 6 shows the three tasks performed by DirectShow. These tasks are listed as below:

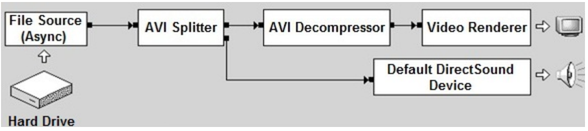

Fig. 5. A Direct Show filter graph for playing an AVI file

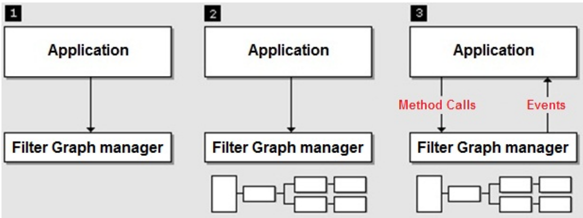

Fig. 6. Essential tasks performed by Direct Show

1. The application creates an instance of the Filter Graph Manager.
2. Afterwards the application uses the Filter Graph Manager to build a filter graph. The exact set of filters in the graph will depend on the application.
3. Finally, the application uses the Filter Graph Manager to control the filter graph and stream data through the filters. Throughout this process, the application will also respond to events from the Filter Graph Manager.

The basic filters for application making are:

1. **DirectShow Video Capture filter:** This filter is used to capture video from any device. There is an option for device selection from which the required device can be selected. This filter has an output, an enable and an audio output pins as shown in Fig. 7 (a).
2. **DirectShow Video Logger filter:** This filter is used for recording audio and video data. This filter has an input pin, an audio input pin, an enable pin and a file name pin at which the path of the file where a video is to be saved is defined as shown in Fig. 7 (b).
3. **DirectShow Image Display filter:** This filter is used to display the data from a device using the DS Capture filter or from he disk using the DS Video Player filter. This filter has an input and an enable pin as shown in Fig. 7 (c).
4. **Generic filter:** This filter is used to convert the data received on input pin into binary form and required functions to be performed on this data. This filter has an input pin, an output pin, and an enable pin as shown in Fig. 7 (d). For snapshot purpose, the generic filter is used to take snap shots from the stream. The generic filter converts the video into binary form. It is then converted to a bit map. The bit map is saved onto the disk at the specified path.

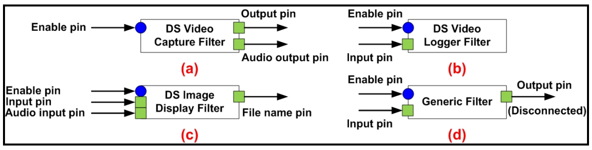

Fig. 7. Direct show filters: (a) DS Video Capture Filter (b) DS Video Logger Filter (c) DS Image Display Filter (d) Generic Filter

A complete data flow diagram and connections between the above mentioned filters are shown in Fig. 8 and works as follows:

1. The DS Video Capture filter recognizes a device attached to a PC and captures the data.
2. The data captured by the DS Video Capture filter is transmitted through its output pin and the audio data is transmitted through the audio output pin.
3. Input pin of Video Logger filter is connected to the output pin of Video Capture filter.
4. The audio input pin of the DS Video Logger filter is connected to the audio output pin of the DS Video Capture filter.
5. Saving path and file name is defined at the filename pin of the Video Logger filter.
6. The input pin of DS Image Display filter is connected to the output pin of DS Video Capture filter.
7. The input pin of the Generic filter is connected to the output pin of the DS Video Capture Filter.
8. The data received in the Generic Filter is converted into bitmap and saved on the disk.

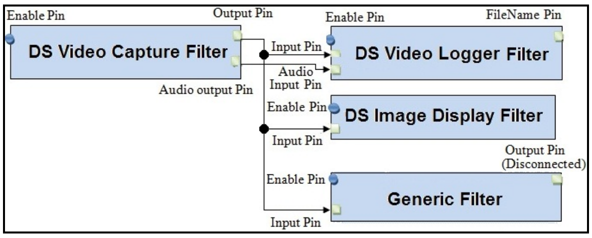

Fig. 8. Data flow diagram and connections between filters

Note that when processing is completed, the application releases the Filter Graph Manager and all the filters. As it is evident, the Filter Graph Manager builds and controls filter graphs. This object is the central component in DirectShow. Applications use it to build and control filter graphs. The Filter Graph Manager also handles synchronization, event notification, and other aspects of the controlling the filter graph. Now whenever a media file or stream is played, recorded, captured, broadcast, or processed in any way, it is done by means of connecting one or more filters together in a construct called a filter graph. The graph-building process can be done manually by an application or automatically by the Graph Builder or Filter Graph Manager. In either case the process usually begins with the source filter and is always based on two main factors: the number of streams and their media types that a filter expects as input, and the number of streams and their media types that it outputs. For example, consider a simple filter graph for playing back an AVI file with compressed video. A source filter, such as the File Source (Async) Filter, would read the bytes from the file and pass them on to the AVI Splitter Filter video compression scheme, parse the data into time-stamped media samples, and pass the video samples downstream to the AVI De-compressor Filter. For video, each sample contains one frame of video. The AVI De-compressor would then find the correct codec to decompress the samples and pass the decompressed video frames to the video renderer filter, which will display the video on the computer screen. A snapshot of our developed software is shown in Fig. 9.

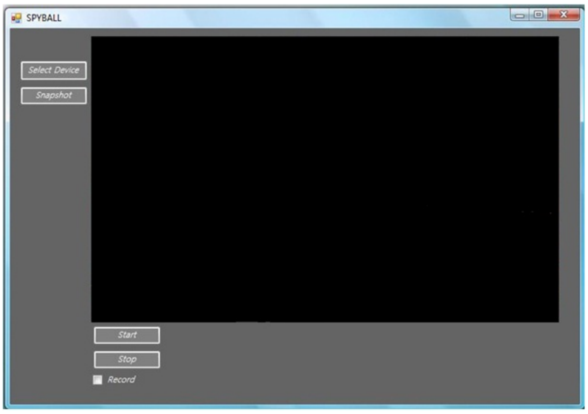

Fig. 9. Snapshot of the software at the PC end

IV. DESCRIPTION OF THE MECHANICAL COMPONENTS

The spy ball structure consists of two hemispheres connected together by a shaft. On that shaft each and everything hangs freely in the sense that the movement of the hanging package will not affect the movement of the hemispheres and vice versa as shown in Fig. 10. The ball is designed in such a manner to be shock proof and flexible and hence the material which is used to provide this flexibility is polymer. The polymer is molded in a way to give a shape of a ball. The part of the hemisphere that is connected to the shaft is rigid, strong and light. For this to achieve, aluminum is infused with the plastic material at the point of contact for both male and female parts of the mold. Aluminum molds are easy to develop and cheaper than steel [9]. Fig. 11 shows the molded part of the hemisphere.

The actual polymer material which is used for the construction of the ball is Elastomer. Some polymers which are Elastomers include Polyisoprene or natural rubber, Polybutadiene, Polyisobutylene and Polyurethanes. What makes Elastomers special is the fact that they can be stretched to many times their original length and can bounce back into their original shape without permanent deformation.

Furthermore, gears similar to the one shown in Fig. 12 are used for connectivity. Gears are important parts in the mechanical structure of a robot. Gear reduction in motorized equipment is necessary as in a small motor spinning quickly; it can provide enough power for a device but not enough torque. For instance, an electric screwdriver has a very large gear reduction because it needs lots of torque to turn screws, but the motor only produces a small amount of torque at a high speed. With a gear reduction, the output speed can be reduced while the torque is increased [10]. Also gears adjust the direction of rotation. For instance, in the differential between the rear wheels of a car, the power is transmitted by a shaft that runs down the center of the car and the differential has to turn that power 90 degrees to apply it to the wheels. On any gear, the ratio is determined by the distances from the center of the gear to the point of contact. In the spy ball we use modern gears that have tooth profile called an *involute*. This profile has the very important property of maintaining a constant speed ratio between any two gears. The contact point moves; but the shape of the involutes gear tooth compensates for this movement.

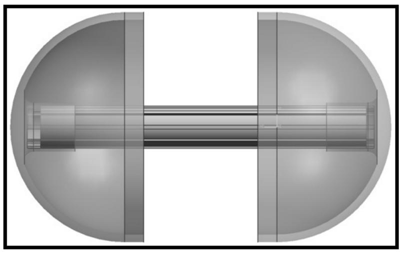

Fig. 10. Spy ball structure based on two hemispheres and a shaft

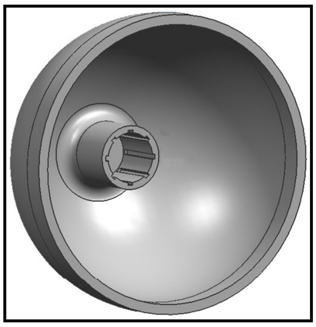

Fig. 11. Molded part of the hemisphere

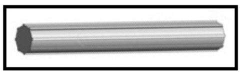

Fig. 12. A Type of a gear used in the mechanical structure of the spy ball

Now for the circuits, they are placed in the empty space in the center of the package and the batteries used to supply power are at the lowest point in the package so that the torque required to turn the package is reduced considerably. Camera is placed at the front of the circuit facing upwards so that it is easier to recognize. A 3-D model of the integrated mechanical parts in the spy ball is shown in Fig. 13. As it is evident that a slight opening exists between the two balls which allows the camera to take video of the surrounding. Also it is worth mentioning that as the ball moves around, the internal mechanical parts keeps the camera in a stable position for undisrupted video feed. This is very important in spy and rescue situations. Fig. 14 shows the final version of our developed spy ball and the images acquired by it of the surroundings. The stability of the designed ball is good as well as the recovery time from a sudden displacement or movement like hitting a wall or rotating quickly. There is going to be disturbance in the transmission during such impulsive movement but it will die out quit quickly to a proper function and stable video transmission.

Finally Table I shows the approximate cost of individual hardware components in most of the under developed countries and the total cost for creating the spy ball which is less than 200 US dollar and which is very cost effective as well as being an effective spy ball that can be used in many applications such as rescue, spy, inspection and surveillance.

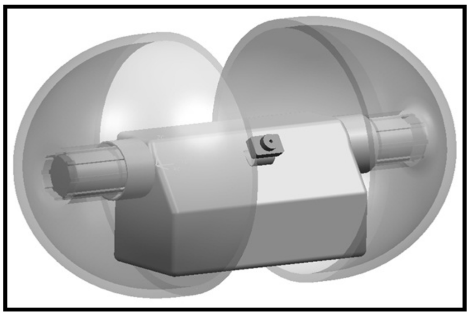

Fig. 13. A 3D model of the spy ball

Fig. 14. Snapshots of the spy ball while moving in speed, rotating, while still and when taking an image from the camera along with video feed display by the software

V. CONCLUSIONS

In this paper, a spy ball robot with a camera is developed which can be used for surveillance or rescue purposes. It has a flexible shape and can move easily in narrow areas where human reach is difficult. Furthermore, the developed spy ball is capable of transmitting video in a very good quality and with minimal disruption due to movement. The ball can be controlled through a wireless device in any direction. In addition to its mechanical structure, cost effective and quality hardware components are used. The total cost of the hardware is below 200 US Dollars which is very cheap especially for under developed countries. In addition as future enhancement, night vision capability can be added. Further automation can be increased by adding some intelligent decision features to the spy ball (e.g. path finding, image and scene analysis, object detection and classification, etc…).

Table 1: Cost of hardware components used in spy ball construction

Accessories	Cost
Transmitter	US $38
Receiver	US $42
Camera	US $10 (vary)
Microphone	US $10 (vary)
Batteries	US $6 (vary)
TV Device	US $12 (vary)
WI-FI antenna	US $11
Remote Control Circuit	US $11
Mold	US $55
Motors	US $3
Total	***US $198***

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