International Journal of Advanced Computer Technology (IJACT)

ISSN:2319-7900

HUMAN WIRELESS CONTROLLING FIRE FIGHTING ROBOT (FFR) WITH 3-AXIS HOSE

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Abstract

This paper gives an overview of FFR, an open source fire fight robot software and hardware. This paper discus's design and implementation of the fire fight robot, from raw materials and equipping it with IR sensing Aid, the FFR is controlled by wireless frequency broadcasted from remote computer. This FFR has the advantage of the very low cost that comes from using recycled parts and materials and modified electronic devices such as the wireless camera that modified to work as thermal imaging capture (TIC) that didn't cost more than 40 $ instead of 140,000 for a TIC which might be more expensive than the robot price, also a modified wireless remote control to provide wireless control channels. This FFR is different than other types of FFRs that almost have same size and design, it has an arm have three degrees of freedom, one Cartesian and two Rotations, that provides approximately a full coverage for the water hose in all directions. Also the images from the modified camera are easy to be entered to personal computers to be processed using image processing programs, while the thermal camera images cannot be displayed on other devices more than the built in screen. The efficiency of the FFR discussed in last paragraph that shows an accuracy of (95%) as average for overall actions in both operating modes the automated mode and the manual mode. Also during the tests it was clear that even with the simple control program, the automated mode is better than manual mode during operation as will be explained in below paragraphs.

Key word: firefighting robot, 3 axis fire hose, modifying camera to a TIC, heat detection matlab program, preview video in matlab.

Introduction

In general, a robot is a mechanical or virtual intelligent agent or any operated machine that can perform tasks automatically or with guidance and replaces human effort, typically. In practice a robot is usually an electromechanical machine that is guided by computer and electronic programming. Robots can be autonomous, semiautonomous or remotely controlled. The word robot first appeared in a play by the Czech writer Karel Capek in 1920. Robots may or may not resemble and perform functions like human beings. But they are often designed to perform tasks repeatedly and in an efficient manner [1]. Nowadays, robots do a lot of different tasks in many fields and the number of jobs entrusted to robots is growing steadily [2].

Recently, it has sometimes been impossible for firefighting personnel to access the site of a fire, even as the fire causes tremendous property damage and loss of human life, due to high temperatures or the presence of explosive materials or the fire smoke hazard in tunnel fires. In such environments, fire-fighting robots can be useful for extinguishing a fire. Firefighting robots are special robots, which as special firefighting equipment can replace firefighters near the scene to fight fire and rescue effectively and carry out reconnaissance missions of the fire.[3] This paper studies and implements the method to build a mobile robot with human remote control system in order to help a remote operator who is located far away from the firefighting robot. The mobile robot sends information of fire scene to remote terminal wirelessly in real time; remote terminal receives fire information which will be processed by the mangers computer using image processing programs to compiling the incoming data to useful information to decide the proper strategy to fight the fire and controlling the mobile robot.

Design Goals

It is unnecessary for firefighters to expose themselves under the dangerous Condition. The motivation of this research is to improve the situation of fire location for the firemen. Therefore the objective of this research illustrated in points below

- Building a mobile robot with 3 degree of freedom hose arm one Cartesian and two rotational for the spray hose that is controlled from remote by fire specialist.
- This FFR should be able to access the various areas and step on some obstacles which require specific design for the mechanism of moving including climbing stairs, among many designs for such robots mechanism the proper decision was to going on the tank chain design since it's more suitable with our requirements.

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- As the requirements of fire station, the FFR should have a detecting system that helps in drawing a map for the separation of the fire for the firemen, the infra red waves of the objects in scene could be captured through a wireless IR camera which will broadcasting alive images to a remote computer to be calculated mathematically to thermal images.
- A multifunction radio transmitter and receiver are needed to allow the fireman specialist to control the various actions that is required to react properly to the fire using the hose to extinguish it.
- The remote communication system is connected to a remote computer to control the robot and processing the incoming data.
- An automated control system embedded in the GUI control program in the remote computer is required to assist the firemen to detect and locate the hottest spots of the fire depending on image processing techniques.

With the help of such robot the fire men work will be easier and effective regardless the main reason which will make it more safety for them keeping them outside the zone of dangerous ring.

The Main Design and Plans

When building a mobile robot, selecting the drive motors is one of the most important decisions you will make. It is a perfect example of an ideal world meeting the real one. Before selecting motors, it is necessary to know what characteristics the robot will have. How large will it be? How much will it weigh? How fast will it move? What terrain will it operate on? [4].

The main frame of the FFR is consist of a steel chassis so it can support the load of the consisting parts including the main heavy parts such as the battery, the manipulator parts, driving motors and the track chains that formed by using bicycle driving chain and driving gears as drive sprocket after it have been modified. The modification process include forming hard thermal plastic pads which usually used as brake pads into tracker pads to be fastened to bicycle chain with bolts and nuts. The sprockets gear that supports the tracker is bicycle driving gear that needs to be modified too, the gear teeth was modified in such way to neglect one tooth next to the one left. The bicycle gear is mounted on the DC motor by using aluminum shafts that is turned to have threaded surface as the same threads of the bicycle driving sprocket gear.

Four car windshield wiper DC motors used as driving sprockets instead two motors. This decision came with some advantages and disadvantages which are:

The advantages are:

- Increasing the torque power
- Flexibility in choosing parts due to the increasing the torque power
- Solving the ball bearing issue
- Increase reliability of the FFR in case of failure one of the motors

While the disadvantage comes with:

- More weight
- Consuming more amp/hr so minimizes the life time of battery
- Rotation speed Synchronizing of each pair of the motors is required

The fire fight robot depends on a 60 amp/hr car battery as a power source to provide a 12 DC volte to the dc motors and the control circuit boards plus the wireless receivers'. The battery ampere and size was chosen carefully after calculating the fire fight robot needs of power to be less weight and as more as amp/hr.

Manipulater Design and Mechanism

Time to accomplish any mission for any robot depends on the robot capability and its degrees of freedom, many FFRs had no manipulators to guide the extinguisher hose to the direction of fire, they are depending on relocate the direction of the robot itself towards the fire, where the extinguishing hose is fixed in front of the FFR.

To avoid this obstacle decision made to give the robot some degrees of freedom by adding an extinguisher manipulator to control the space around the FFR instead of relocate the FFR each time. And since tries made to minimize the robot load which cannot be done unless the consisting parts minimized, and that’s mean minimizing the degrees of freedom. After discussing the demands of Kirkuk city fire department clear idea get to mind, that the manipulator should consist of 3 degrees of freedom, two rotational and one Cartesian motion as shown in figure (1)

International Journal of Advanced Computer Technology (IJACT)

ISSN:2319-7900

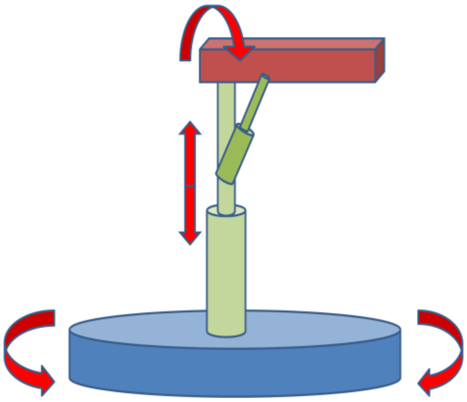

Figure (1) Three axis freedom extinguishing hose manipulater

Using the robot arm calculations and The Denavit-Hartenberg Matrix the transformation matrix for the hose manipulater obtained.[5]

$$T_{i-1}^{i} = \begin{bmatrix} \cos\theta_i & -\operatorname{sen}\theta_i \cos\alpha_i & \operatorname{sen}\theta_i \operatorname{sen}\alpha_i & a_i \cos\theta_i \\ \operatorname{sen}\theta_i & \cos\theta_i \cos\alpha_i & -\cos\theta_i \operatorname{sen}\alpha_i & a_i \operatorname{sen}\theta_i \\ 0 & \operatorname{sen}\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Three degree of freedom and the D-H parameter table will be filled according to the arm joint analysis as shown in figure (2)

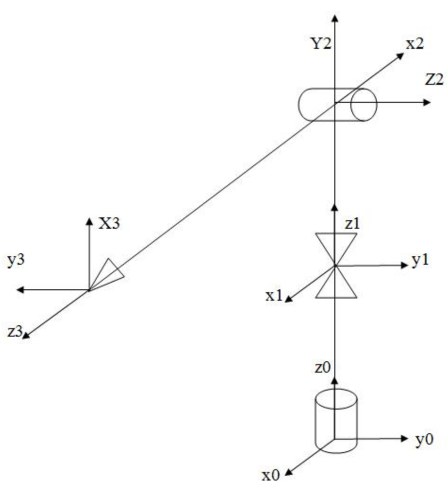

Figure (2) fire fight robot Denavit-Hartenberg joints parameters

$$\begin{pmatrix} C1 & -S1 & 0 & 0 \\ S1 & C1 & 0 & 0 \\ 0 & 0 & 1 & 60 \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & E \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} C3 & S3 & 0 & 0 \\ S3 & -C3 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T=

$$T_0^3 = \begin{pmatrix} C1S3-S1S3 & C1S3+S1C3 & 0 & 0 \\ S1C3+C1S3 & S1S3-C1C3 & 0 & 0 \\ 0 & 0 & -1 & 60+E \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Electrical Component Design

Using a combination of both relays and transistors a description of the control circuit for the four DC motors could be found, that each two of them are synchronized to same direction, and has capability of controlling these motors to maneuver the fire fight robot in the four directions. As shown in figure (3)

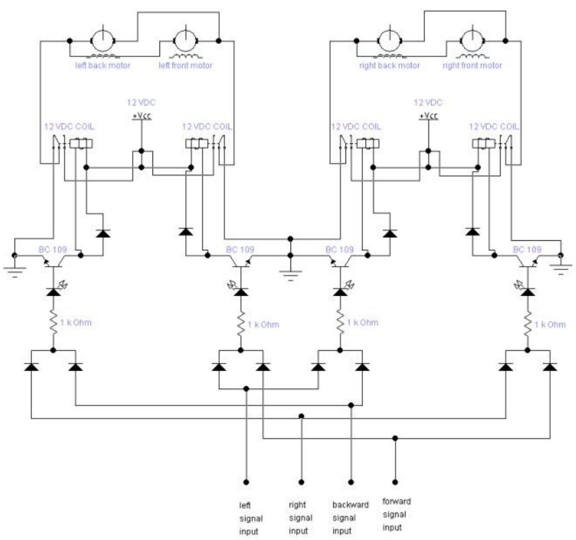

Figure (3) control board of the driving DC motors of FFR

Commercially available Remote Control (R/C) units use small microcontrollers in the transmitter and receiver to send, receive and interpret data sent via radio frequency (RF). The receiver box has a PCB (printed circuit board) which comprises the receiving unit and a small servo motor controller.

From the present-day internet to the old-fashioned radio and black & white television, communication systems form the backbone of many commonly used applications. The requirements of a communications system vary based on their application. Some constraints that can factor into the design of a communication system include:

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- Cost
- Power requirements
- Reliability
- Range of communication needed
- Speed / Data Rate
- Conformance with Standards

These and other factors mean that the elements of a communication system can differ greatly from one system to another. For instance, a garage door opener or remote keyless entry on an automobile will need transfer speeds that are barely a fraction of what is required by optical fibers that support the internet infrastructure. Communication systems can be broadly classified as analog or digital based on the nature of the message being transmitted. Again, depending on the application, either an analog or digital system might be the preferred way to communicate. Even within digital communication systems, for example, the implementation of the transmitter and receiver can vary tremendously. [6]

First kind of RF controller's choose had a good transmittance range but later found to be not fit with the FFR DC motors due to the EMI emitted by the motors that lead to malfunction in the controllers since it depends on 300 MHz as a working frequency. The highest ratio of EMI for the motors is at the frequency around 300 MHz according to the figure (4) [7]

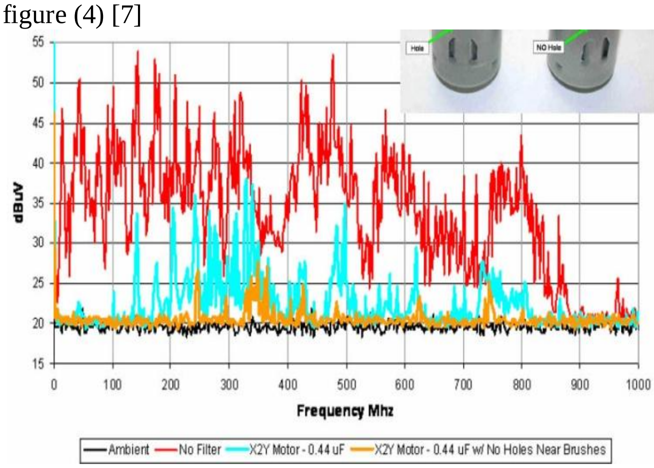

Figure (4) EMI noise generated from DC motors corresponding to the frequencies

Graphical User Interface (GUI)

A graphical user interface (GUI) is a graphical display in one or more windows containing controls, called components, which enable a user to perform interactive tasks. The user of the GUI does not have to create a script or type commands at the command line to accomplish the tasks. Unlike coding programs to accomplish tasks, the user of a GUI need not understand the details of how the tasks are performed. GUI components can include menus, toolbars, push buttons, radio buttons, list boxes, and sliders—just to name a few. GUIs created using MATLAB tools can also perform any type of computation, read and write data files, communicate with other GUIs, and display data as tables or as plots.[8]

Starting from the concept of making as simple as possible GUI frame and in same time including the necessary tools to help the firemen, decision made to merge the incoming video signal from the fire fight robot in the matlab GUI and also to process it in same time.

The first design of the GUI was very. It include just the buttons nothing else to operate the fire fight robot manually, but later the text labels added to notify about the actions that are be done. And finally the video panel was added to shows the processed videos.

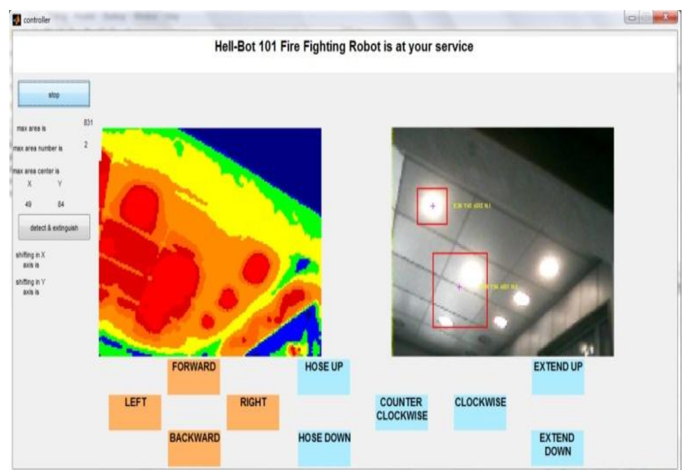

Figure (5) GUI in operation

The program has advantage of processing the gray scale incoming video to images and processing them digitally, later finally show them in sequence to generate alive video. The fire fight robot GUI program main idea to operate is illustrated in figure (6) in as simplified flow chart to show the general steps of the program.

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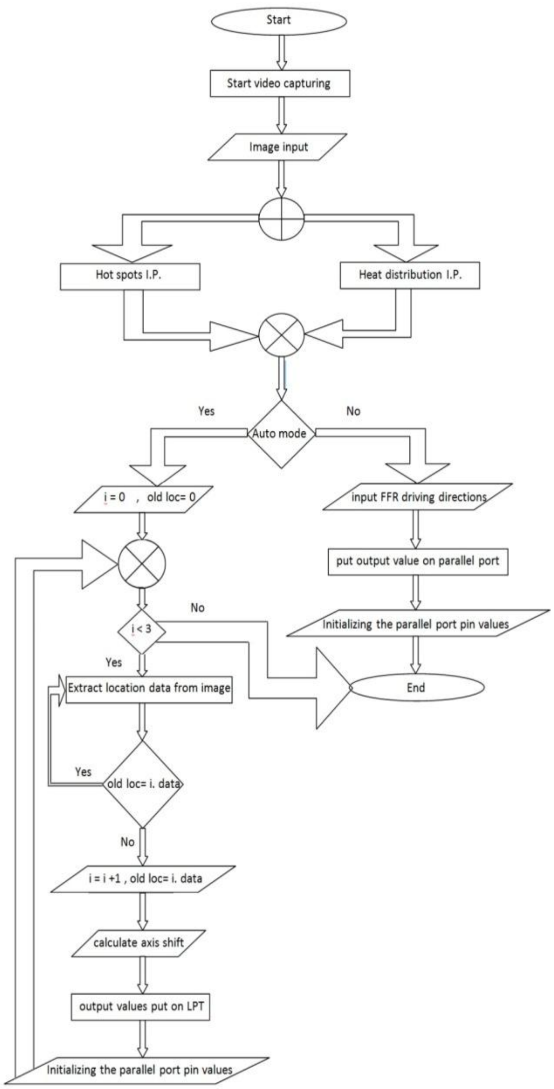

Figure (6) flow chart of the FFR GUI program

The output of this program is a RGB image giving an idea for the heat distribution over the scene by coloring the gray scale image to RGB depending on a previously calibration test for a piece of steel been heated and both the temperature and IR intensity been measured for different cases, figure (7).

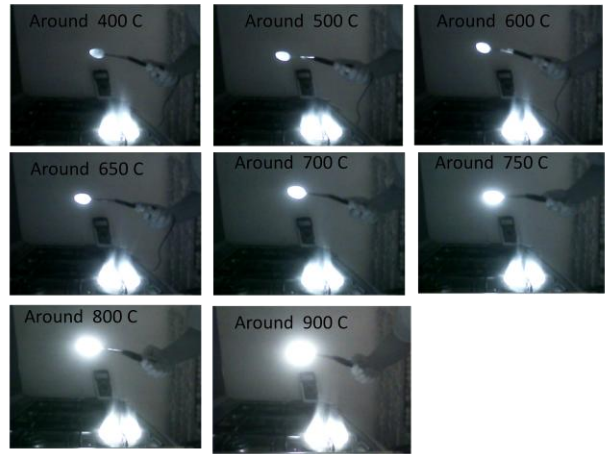

Figure (7) Heating steel piece in steps to obtain temperature – intensity relation

The images above taken by modified camera to capture only the IR radiation and later was mounted on the fire fight robot in order to work in similar way to a thermal camera. In fire fight robot case the quantity that been measured is the displacement between two points which are the water spray direction and the center of heat. The measuring process that is done by image process has an output of X and Y coordinates in terms of pixels that will be the initial C variable of the closed control diagram where the values of (320) in X axis and (240) in Y axis represents the R variable in control diagram the E will be the difference between both, the process in the closed loop include calculating the time delay depending on the difference in the pixels.

The accuracy of the arm is not exactly 100 % because the value of delay time for transfer from point to point is affected by some factors like:

- Delay in response of the wireless communication.
- Delay in response of the controlling computer.
- Variation in rotation of the DC motor due to number of use of that motor, the applied voltage.

Therefore a closed loop is required to control the motion of the arm, the feedback will be the next image taken and processed again to be calculated for correction. During the tests for the fire fight robot if was found that to reach a point using the automated mode it require about 4-5 tries, therefore designing the closed loop to correct the output vales by doing 4 loops otherwise the process will lost in an infinite loop in trying to reach the zero value for (E) while this is impossible because of the center of heat is variable by small value due to motion of the flame, the control operation diagram for the fire fight robot is shown (8).

ISSN:2319-7900

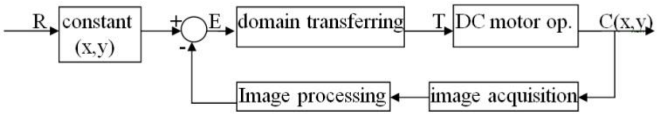

Figure (8) FFR control diagram

The fire fight robot is known to be driven manually to the location of the accident dragging all the way the water pipe into the fire or close enough to the fire and from there the operator has two choices, either operate it manual mode or in the autonomous mode. In the manual mode the fire man controls the direction of the water spray by maneuvering the manipulater in 3 axis, two rotation and one Cartesian. While in the autonomous mode the operator lets the robot choose which fire spot to be extinguished first depending on sorting the spots according to them sizes.

The complete fire fight robot after it was tested in both modes is shown in figure (9)

Figure (9) the fire fight robot after been completed and tested

Experimental Test Result

The test process include testing the robot using both modes for the same condition and later recording the time needed to extinguish the candles torch, the time needed to initialize the data been processed and later compare both records from the automated mode and the manual mode.

The test been divided to three kind first one include one torch and the second include two torches and the third one include three torches. For each case the test repeated three times and data been recorded.

The results showed that:

- It takes about (10-21) seconds to execute in automated mode. And It takes about (27-32) seconds to execute in manual mode.
- It takes about (15-35) seconds to initialize in automated mode. And It takes about (25-42) seconds to initialize in manual mode.
- It takes about (25-57) seconds as total time in automated mode. And It takes about (52-71) seconds as total time in manual mode.

Now by comparing both modes according to how fast the reach to center of the fire in figure (10) it seems that the manual mode takes the largest portion for all the three cases and the automated mode needs fewer attempts to achieve its goal in extinguishing the fire spots.

ISSN:2319-7900

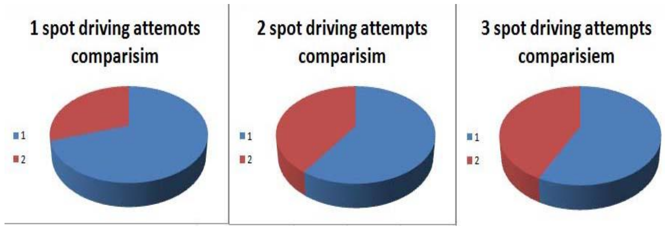

Figure (10) comparison between automated mode (Red) and manual mode (Blue)

The accuracy for the system obtained from the error that been calculated and the calculations shows that accuracy average for the automated mode is equal to (94.89 %) that can be converging to (95 %).

While accuracy average of manual mode is equal to (96.46 %) that also can be converge to (96 %).

This shows that the accuracy of the system in both modes are close enough to consider the accuracy is the same in both modes and the slight difference comes from the many factors such as the operator experience and the communications conditions and the response of the computer to the data received.

Conclusion

Fact that both the automated and manual mode is required in the fire fight robot is that the fire fight robot is the first version and the control system is not perfect, for this reason some times the operator need to make decision in some situations, in other word the human supervision is required, the difference between both modes are listed below:

The automated mode:

- Detecting the largest heat spot by image processing
- Detection process could be effected during processing
- Faster in dealing with situation
- Controlling the movement is automated

While the manual mode:

- Detecting the largest heat source depend on operator skill
- The operation under operator control
- Takes more time
- Directing the arm takes the operator attention and his time

To achieve best result for the fire fight robot both the automated mode and manual mode should be used during any extinguishing mission in order to minimize time required and losses in lives and materials.

Acknowledgments

We the authers "Dr. Wael R. Abdulmajeed", " Dr. Ali I. Mahdi " and "Karzan M. Taqi" are thankful to IJACT Journal for the support to develop this document.

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ISSN:2319-7900

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