Design of Human Tracking Robot Utilizing Pyroelectric Sensor and Analogue Circuitry

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Abstract— **A tracked crawler robot using body heat detection and a purpose built analogue tracking circuit is designed in this work. The infrared detection module consists of a single dual element pyroelectric infra-red sensor. The drive and steering control system is designed using a single chip 74HCXX Quad 2-input NAND gate as the logic controller and providing constant forward propulsion whilst in real time adjusting to the subject's direction. Automatic tracking of animal or human subjects is the sole purpose of the design. The range has been limited to two meters, with a maximum range of five meters. Modification of the pyroelectric sensor enables detection of both left and right movement. The robots ability to follow human and animal motion has been achieved. Visually observed results show the robot is able to drive, turn and detect human and animal motion and can work reliably. The design is able to be utilized using a microprocessor or as a highly responsive analogue unit making it both adaptive and flexible.**

Index Terms - Robot, PIR, Analogue, Motion Detection, tracking, Sensors

I. INTRODUCTION

The main contribution of the paper revolves around the need for fast and reliable human detection in closed environments. Obstacle avoidance addresses those static and non-static objects within a dynamic environment, however the human following and detection arena encompasses more, those matters of safety, primarily where mobile robotics platforms are becoming increasingly larger with associated weight and mass. Attempts have been made to address these issues from both a human follower and surveillance perspective [14] [15], and this paper attempts to simplify one aspect of the methodology with a view to obtaining a non-processor reliant yet robust system. In any closed or limited area environment, both human and animal movement tracking and following remain the focus of much research in the areas of computer vision, robot mobility and robot obstacle avoidance. Many advanced technologies exist in the various fields which include but are not limited to automaton control, pattern recognition, artificial vision and obstacle mapping. Intelligent electronic monitoring may require any of these or fall to some other model based methods. Alongside computational technology developments, the design of communications electronics are also developing rapidly with higher importance toward the value of human motion detection, animal (pet) avoidance and obstacle detection. The principles behind following and tracking are increasing in the areas of smart weapons systems, virtual reality and the robotics arena. [1][2]. With regard to the model-based methods, interesting work is presented by Freund et al. [3], which deals with model and conditions for safety path planning. Shiller et al. present another excellent work [4], in which a mathematical model of free places is developed.

The most common areas of research are based on the various computer based vision methods for human tracking to detect the possible shape of body, filter the noise, get the features of the face and compare against a database to identify the object. However there are many disadvantages for computer vision based human tracking methods being the problem of mass image data storage, heavy computational loads, cost of required cameras and the need for verbose and complicated algorithms to reduce the noise, extract relevant features and to follow or track the subject. [5][6][7].

Electronic human motion detection is susceptible to a variety of noise which includes, excessive lighting, changing backgrounds, insufficient lighting and non-static obstacles making it very difficult to obtain suitable results in detecting or tracking a subject. The objective was to design an effective system for detecting human or animal motion with subsequent tracking of that subject in line with current research topics in the field of computer vision. The system must be robust, demonstrate real time tracking capabilities and be versatile.

The resultant system incorporates a single modified pyroelectric sensor [8], amplifier, comparator and logic driver. The system demonstrates the ability to detect and follow a subject effectively utilizing only passive analogue circuitry, yet has the ability to be easily connected to a microprocessor for more advanced function.

Almost all indoor environments represent overly cluttered closed spaced and are classed as non static. In developing this system it was paramount to forego the requirement for recognition of objects and items, instead focusing on the objective to track successfully a human or animal subject. The use of analogue circuitry is also in response to this objective. The form factor is minimal, passive element response time is negligible and costs are low. The robot is a wheeled vehicle and therefore restricted to relatively flat surfaces and as such if multiple floors were to be patrolled, multiple robots would be required. Keeping costs to a minimum also serves the criteria. Hybrid structured robotics for the purposes of home security abound with many able to convert from wheeled to walking to tracked vehicles, robot of walking and vehicle

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types is presented in [9] for the performance of home security tasks and can transform between the legged walking and the wheeled driving modes. The objective in this paper however, is not to create a better mobile platform but to ease the microprocessor requirements of existing robots.

II. TEST ROBOT DESIGN PARAMETERS

To present the reader with an idea of the small scale of the device included here is a short overview of the design parameters. The mobile platform is constructed from heavy compound impact resistant plastic. It is a tracked platform with tracks of 80% rubber, ensuring longevity. The speed and direction of each track is freely controllable, having independent drive trains with a gear ratio of 80:1. It is driven by a pair of noise suppressed 280, 6V motors capable of handling from 6 to12v DC. One of the gears in each drive train has a hole that can be used for tracking motor rotation with a resolution of 4 counts per output shaft revolution, which corresponds to a linear distance of about 37mm. Battery compartment is in the base keeping battery weight in a low centre of gravity. Nominal current drain is from 160 – 180mA dependent on chosen motor voltage and load. Driving Gradient is >30^{o} dependant of friction only. Dimensions: 173×125.5×55(mm). Nominal Load: 7.5kg.

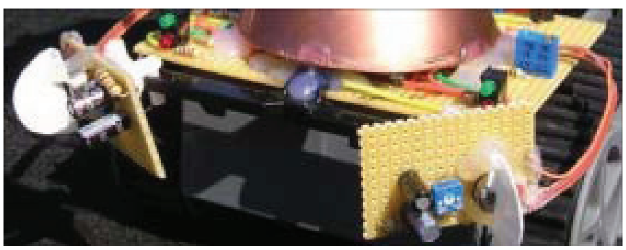

Fig. 1. Prototype mounted with two modified PIR sensors

III. PYROELECTRIC SENSOR

The output voltage, being a function of the amount of infrared radiation sensed at the input is the basis for the Passive Infrared Sensor (PIR). Therefore we are interested in the responsivity of the detectors. Electrical response depends on two factors: thermal response of the detector due to incident radiation and the response of the pyroelectric material due to temperature changes. A typical pyroelectric detector system consists of four basic elements. These are the sensor, amplifier, window comparator and coupler. In this paper we look specifically at current response R_I, and voltage response R_V [10]. Where:

c': volume specific heat (J/cm3K);
c : specific heat of material (J/gmK);
ρ : density (gm/cm3);
b : sensor thickness (μm);
GR : irradiative conductance (W/cmK);
A : detector area (cm2);
η : emissivity of the crystal;
σ : Stefan-Boltzmann constant (5.67x10-12 W/cm2K4);
T : temperature (K).

Current responsivity of various photovoltaic materials: RI is the ratio of the output current flow ΔI to the input radiation power incident to detector surface Pi. The current responsivity can be calculated as [10] [11]:

$$R_I = \frac{\Delta_I}{P_I} \qquad (2)$$

Pyroelectric charge ΔQ is given by:

$$\Delta Q = \Delta I = pA\Delta T = AP_s \qquad (3)$$

Where p is the pyroelectric coefficient of material and P_S is the polarization. Suppose that radiation power is a sinusoidal function, therefore, temperature changes of whatever detector due to irradiation flux is given by the steady-state equation [11]:

$$\Delta T = \frac{\eta P_i}{c'bA}\frac{\tau}{\left(1+\omega^2\tau^2\right)^{1/2}} \qquad (4)$$

Substituting (3) and (4) into (2), the final expression for this current responsivity becomes (5):

$$R_I = \frac{p\eta\tau}{c'b\left(1+\omega^2\tau^2\right)^{1/2}} \qquad (5)$$

Voltage responsivity of various photovoltaic materials: R_V is determined as a ratio of the voltage generated in the detector ΔV and radiation power incident to detector surface Pi. From this definition, we have [11] [12] [13]:

$$R_V = \frac{\Delta_V}{P_i} \qquad (6)$$

The generated detector voltage is given by:

$$\Delta V = \frac{\Delta Q}{C_d} \qquad (7)$$

Where ΔQ = pAΔT is electric charge and Cd = εrε0A/b is detector capacitance. When substituting (3), (4) and (6) into (7), we get the final expression for the voltage responsivity (8):

$$R_V = \frac{p\eta\tau}{c'\varepsilon_r\varepsilon_0 A\left(1+\omega^2\tau^2\right)^{1/2}} \qquad (8)$$

The above parameters become especially relevant during the responsivity measurement of the unmodified pyroelectric sensor in Fig. 2 and the modified pyroelectric sensor in Fig. 3. With the addition of varying band pass filters, a segregation of the dual ceramic substrates and the addition of the mirrored partition, the above referred parameters are essential in the conversion process to ascertain the amplification gain necessary to ensure that the overall initial sensor responsiveness remains equal to or better than the unmodified sensor .

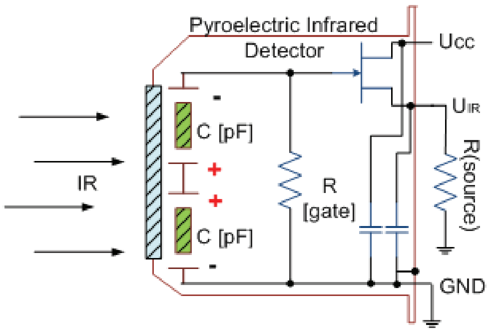

Fig. 2. Unmodified Pyroelectric sensor

IV. MODIFIED PYROELECTRIC SENSOR

One dual pyroelectric sensor has been modified to produce the left and right signal necessary for directional detection of the subject. Fig. 3 shows the schematic of the sensor. In effect, what has been done is to divide the transmission window in order to detect directional movement as opposed to simple motion detection.

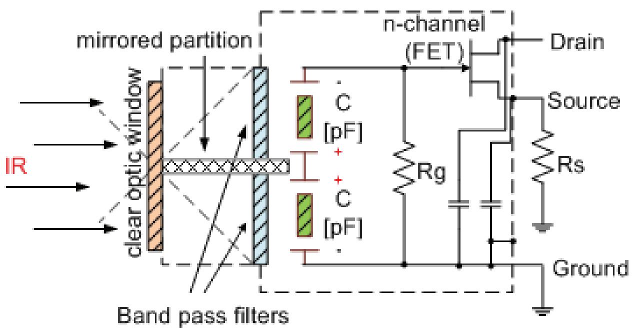

Fig. 3. Modified PIR sensor

The two sensing elements are connected such that one subtracts from the other, therefore when our robot or mobile platform is stationary, all sensors are cancelled out by ambient radiation and our unit is effectively converted to a motion detector able to distinguish subject IR which may pass its sensors. Upon mobilization our robot effectively reverses its role in that hereto before stationary objects become moving objects. Without any radiation source amplification (Fresnel lens), the range of the sensors is limited to a few metres.

Through the physical division of substrate pairs on any single sensor with the mirrored partition, success has been had in determining left to right and right to left motion. Additionally, with quad substrate configuration, up, down and diagonal movement joins that list and can be controlled largely through manipulation of the thermal imaging frequencies of each substrate, however that remains the subject of further research.

In the dual element configuration a body passing across the sensor activates first one and then the other element whilst vibration and other background signals, affecting both elements simultaneously are cancelled. The layout of the two elements allows for maximum sensitivity along a single axis. The sensing elements are connected such that one subtracts from the other. This arrangement causes any signal common to both elements to be effectively cancelled out. A body passing in front of the sensor activates first one and then the second element whilst vibration and other background signals, affecting both elements simultaneously are cancelled. A dual sensor PIR will operate most efficiently with an external radiant, IR Source, progressing across its breadth as in Fig. 4.

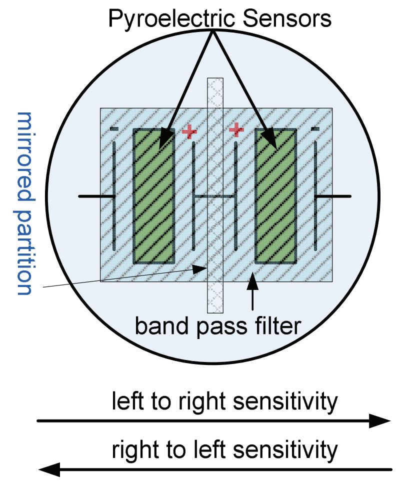

Fig. 4. Sensitivity of the modified quad sensor along the x, y axis.

V. SINGLE PYROELECTRIC SENSOR MODEL

The model in Fig. 5, was designed to be simplistic, functional, robust and of a small form factor. Signals from the modified PIR sensor feed to an amplification circuit which utilizes two transimpedance operational amplifiers to attain a gain of 10,000 in line with the formula described in section III and a chained pair of comparators in order to successfully detect left and right movement across the sensor substrates. Although the test unit has been designed as a stand-alone human tracker we have additionally configured the circuit to enable microprocessor control of the unit. This is pre-emptive of future research into area mapping, database adaption and higher level computer vision work. The robot is also designed to accommodate dual cameras.

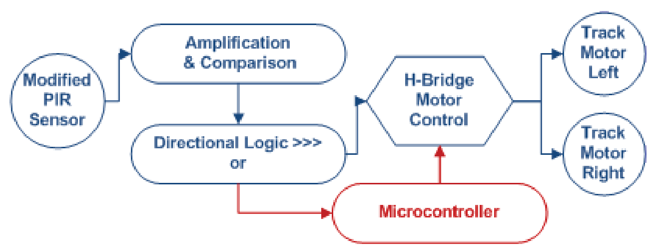

Fig. 5. Simplified schema model

The amplification and comparator circuit in Fig. 6, with only two possible outputs is fed to the logic circuit in Fig. 7 below. The circuit has adjustable transimpedance amplification capable of gain at around 10,000 which is necessary for amplification of the low signal from the pyroelectric sensor.

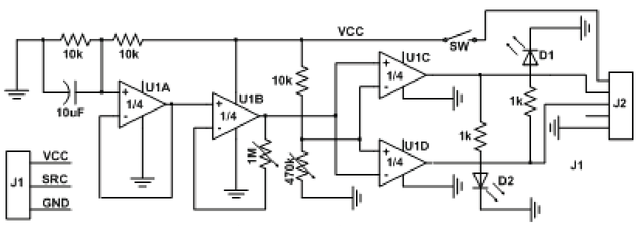

Fig. 6. Amplification and comparator circuit

The logic circuit in Fig. 7, is connected directly to an H-Bridge motor driver capable of forward and reverse motoring of the tracks, making the test unit impressively agile. It is configured so that when both substrates of the pyroelectric sensor are balanced (e.g. no radiant energy is detected), the robot will continue to move on the last logical path detected until the subject is again detected. In this manner we can re-locate the subject when it may temporarily go out of range or pass behind an obstacle.

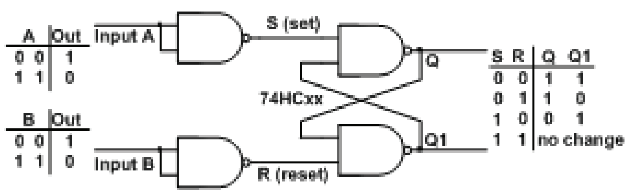

Fig. 7. Directional logic configuration

VI. RESULT

Testing of the device by its nature required visual observation within a real time environment utilizing live animal and human subjects. Video recording of the observed responses indicates a more than acceptable degree of success with high responsivity and negligible time delays upon detection of a subject and subsequent following maneuvers. Slight problems were indicated in the situation where a subjects' path crossed that of a static object however the resultant temporary pause of the mobile robot is indicative of further investigation and analysis of the video footage. In the case where the mobile robot "looses" the subject, the configuration of the logic circuit ensures the robot will perform a circular maneuver ensuring a secondary path cross of the subject enabling continued pursuit. This particular scenario occurred only once during testing and was successful.

VII. CONCLUSION

To date all expectations have been met with respect to the use of a single pyroelectric sensor for human tracking or following for robots. Due to the nature of the device, real time visual testing was required, as the only criteria to be assessed was whether the robot, utilizing only one modified pyroelectric sensor, amplification/comparator unit and a logic motor driver could successful track a subject in a closed environment. Although the results prove very successful, stage two of the project shall require that the modified sensor be manufactured more precisely as opposed to hand constructed. The pyroelectric sensor was able to detect both moving and stationary objects where those objects were of approximate human temperature however the larger signal of the subjects left right motion was easily detectable as the band pass filter window of the pyroelectric sensor is specifically designed for the human wavelength.

Subjects were detected at up to two meters distant. Further distance could be attained with the addition of a Freznel amplifying lens with the sacrifice of an associated loss in accuracy. Distance can be reduced somewhat and would be a matter of fine tuning in reference to section III regarding responsivity. Another minor problem relates to the need for a separate system purely for obstacle avoidance. The crawler robot, dependant only of passive analogue configuration, exhibits abilities to avoid objects (continue tracking subject), turn, reverse and the ability to detect not only human and animal motion but also some stationary objects. Future work will focus on improving the self-control mechanism of the tracking robot. We plan to add more sensors for standard obstacle avoidance and to provide more analytical passive response times.

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REFERENCES

[1] M. Kanbara, N. Yokoya, and H. Takemura, "A stereo vision-based augmented reality system with marker and natural feature tracking," IEEE Press, pp. 455-462, 2001[Proceedings of IEEE the 7th International Conference Virtual System and Multimedia VSMM'01, Washington. DC, USA].

[2] S. You, U. Neumann, and R. Azuma, "Hybrid inertial and vision tracking for augmented reality registration," Proceedings of IEEE Virtual Reality, pp. 260-267, 1999

[3] E. Freund, M. Schlusse and J. Rossmann. Dynamic collision avoidance for redundant multi-robot systems. InProceedings of the 2001 IEEE/RSJ Int. Conference on Intelligent Robots and System, v. 3, pages 1201-1206,

[4] Z. Shiller, F. Large and S. Sekhavat. "Motion planning in dynamic environments: obstacles moving along arbitrary trajectories." In Proceedings of the 2001 IEEE/RSJ Int. Conference on Intelligent Robots and System, v. 4, pages 3716-3721, 2001.

[5] Ren C. Luo, Yi-Huei and Jhu, Ogst Chen . "Robotics Human Tracking System Through Wireless Pyroelectric Sensor System." IEEE International Conference on Advanced Robotics and its Social Impacts. Taipei, Taiwan, Aug. 23-25, 2008

[6] I.S. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.

[7] R. Aggarwal, A. Dosis, F. Bello and A. Darzi , "Motion tracking systems for assessment of surgical skill," Surgical Endoscopy, Volume 21, Number 2, 2007

[8] Naval Weapons Engineering 'ELECTRO-OPTICS' Introduction to Electro-Optics (pp286-303, supp/probs 10.4-6,9,11)

[9] C.H. Kuo, C.C. Chen, W.C. Wang, Y.C. Hung, E.C. Lin, K.M. Lee and Y.M. Lin, "Remote Control Based Hybrid-Structure Robot Design for Home Security Applications," Proceedings of the IEEE/RSJ Int. Conf. on Intell. Rob. Syst., Beijing, China, Oct. 9-15, 2006, pp. 4484-4489.

[10] Analysis of MWIR Infrared Pyroelectric Detectors Parameters G. Hyseni, N. Caka2, K. Hyseni, Faculty of Electrical and Computer Engineering, Department of Electronics, Department of Automation, University of Prishtina, Republic of KOSOVA,PDF www.wseas.us/e-library/conferences/2010/Cambridge/NAICIP/NAICIP-24.pdf.

[11] P.H. Beerman, The Pyroelectric Detector of Infrared Radiation, IEEE Transaction on Electron Devices, Vol. Ed-16, No. 6. (1969).

[12] S.T. Liu, D. Long, "Pyroelectric Detectors and Materials", Proceedings of the IEEE, Vol. 66, No. 1, (1978).

[13] R. Ciupa, A. Rogalski, Performance Limitations of Photon and Thermal Infrared Detectors, Opto-Electrics. Rev.,5, no. 4, (1997).

[14] Xiaohu Lv and Yongxin Liu, Design of Human Motion Detection and Tracking Robot Based on Pyroelectric Infrared Sensor, Proceedings of the 8th World Congress on Intelligent Control and Automation July 6-9 2010, Jinan, China

[15] Jun Zhang, Guangming Song, Guifang Qiao, Tianhua Meng, and Hongtao Sun, An Indoor Security System with a Jumping Robot as the Surveillance Terminal, IEEE Transactions on Consumer Electronics, Vol. 57, No. 4, November 2011

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