A Novel Laser Cooling System for MRI Scanner Using Soft Computing

Roshini T V and Dr. Kamalraj Subramaniam

Abstract—Magnetic Resonance Imaging (MRI) Scanner is a powerful tool used for visualization of soft tissues by the medical community. The most expensive and important component of MRI is the superconducting magnet. During the operation, the magnet in the MRI scanner creates a very high magnetic field and which in turn creates a huge temperature, which can create undesirable effect in the scanner. So a cooling system is used to cool the superconducting magnet. Traditionally liquid helium is acting as the cooling agent. However the cost of liquid helium is high and the handling of liquid helium is difficult. In this paper we proposed a cooling system based on the LASER technology. The Laser Cooling System (LCS) with normal controller is modeled and the data obtained from this is used to model a hybrid system based on soft computing techniques. Here the PID is combined with Fuzzy. The performance analysis suggests that the hybrid system provides better results than the normal controller with a global temperature accuracy of 95.12%. Ultimately we suggest that our overall system becomes a new way of cooling system for MRI scanner with low cost and less maintenance difficulties.

Keywords —Magnetic Resonance Scanner (MRI), Laser Cooling, superconducting magnet, ANN, Fuzzy logic, PID controller, Hybrid controller.

1 INTRODUCTION

MRI is a medical instrument used for the visualization of delicate tissues. The most expensive and important part of MRI is superconducting magnet (Steven Chu 1998),. The requirement of superconducting magnet includes increased centre field, long Helium refill period etc (F. J. Davies 2000). There is MRI with varying magnetic field strength like 0.35 tesla (T), 0.5T, 1T and 1.5T. Out of that 1.5T system is faster and has better image quality. The advantage of MRI with superconducting magnet includes better performance, higher signal to noise ratio, higher resolution and lower life cycle cost (Y. Lvovsky et al. 2005).

Light Amplification by stimulated Emission of Radiation (LASER) is a device that releases light by optical intensification utilizing the stimulated emission of electromagnetic radiation (William Thomas Silfvast 1996). LASER gives incredible applications inside fields such as scientific, military, medical and commercial (Walter Koechner 2006). In 1975 the LASER radiations have been utilized with the end goal of cooling the gasses (Theodor W. Hansch et al. 1975). The laser cooling system works on the fundamental guidelines of Doppler Effect (Thomas C Cosmus et al. 2011). During the operation of MRI scanner enormous heat is generated, which effects the performance of the system. Because of that windings of the magnet must be cooled below its critical temperature. Liquid helium is the coolant used in the MRI scanner. Lliquid helium around the magnet rapidly boils off and escapes from the vessel housing of the magnet. for that reason places using liquid helium needs special air flow centers (Olivia Solon 2013). A typical MRI scanner uses 1,700 liters of liquid helium, which needs to be topped up periodically. The majority of the world’s helium supply is created through natural radioactive decay and cannot be artificially synthesized, as the gas is a non- renewable resource. To overcome the difficulties of liquid Helium, Laser Cooling System (LCS) is employed (Prof.M. Lilly Florence et al. 2009). The basic excitations in superfluid helium have been probed with tremendous fulfillment the use of techniques which include neutron and mild scattering. However, measurements of phonon excitations have up to now been constrained to average thermodynamic houses or the pushed response a ways out of thermal equilibrium (C. Baker et al. 2016).

The advantages of LCS are compactness, free of vibration and high reliability. During the emission process

1. *Roshini T V is a Research Scholar, Department of ECE, Karpagam Academy of Higher Education, Coimbatore, roshini.tv@gmail.com*
2. *Dr. Kamalraj Subramaniam is Associate Professor, Department of ECE, Karpagam Academy of Higher Education, Coimbatore, kamalrajece@gmail.com.*

of laser, the thermal energy contained in the lattice vibration is taken away by the emitted photons resulting in the cooling of solids. Laser cooling of semiconductor is more interesting due to its more efficient absorption, much lower achievable cooling temperature and direct inerrability into electronic and photonic devices (Dehui Li et al. 2013). Galina Nemova and Raman Kashyap described in their paper about Laser cooling of solids with anti-Stokes fluorescence in uncommon earth-doped low phonon samples (Galina Nemova et al. 2017). Even though the cooling wavelength of InF is located in the quick-wavelength ultraviolet light (UVC), a frequency quadrupled Ti: sapphire laser (189–235 nm) may be capable of producing laser transition wavelength of InF (Quan-Shun Yang et al. 2017) . The perovskite crystals showcase sturdy photoluminescence up conversion and near cohesion outside quantum efficiency for the realization of net laser cooling. Our findings suggest that solution-processed perovskite thin films may be a tremendously appropriate candidate for building incorporated optical cooler gadgets (Son-Tung Ha et al. 2015).

At 229 nm for the utility of laser cooling of Cd atoms turned into generated via the fourth harmonic the use of two successive 2d-harmonic generation stages (Yushi Kaneda et al.2016). A magneto-optical lure overlapped with the lattice laser beam is used to put together laser-cooled atoms. The atoms are then similarly cooled the use of optical mo-lasses to a temperature of 40μK. (Andreas Jockel et al. 2014). The new physical mechanism has created to cool down atoms based on physical effects like optical pumping etc and Doppler Effect has considered as the fundamental working principle of Laser Cooling System (C. Cohen- Tannoudji et al. 1990) .

In the most recent decades, laser cooling have been at the heart of exceptional research in atomic physics (C.J Foot (2005). The laser cooling of molecules has permitted remarkable access to ultra-cold temperatures. The power of laser cooling generally derives from the ability of specific particles to ceaselessly dissipate photons from a laser. In particular, Doppler laser cooling depends on redundant energy kicks coming out because of the assimilation of red-detuned photons spreading counter to the movement of a particle. Jun Zhang et al have obtained 10 Kelvin for semiconductor device cooling at the wavelength of 514nm and 15 Kelvin at the wavelength of 532nm (Jun Zhang et al. 2013)].

2 PROPOSED LASER COOLING SYSTEM (LCS)

In the proposed work we are developing a LCS for the MRI scanner to cool the superconducting magnet. The critical temperature of the superconducting magnet is 10Kelvin, hence while running the superconducting magnet must be maintain near to its critical temperature. In this proposed system, we are intended to develop a cooling system for the MRI scanner which comes for long time in low cost. So our aim is to model an optimal LCS which can maintain 10 Kelvin cooling. From the literature review, it was found that the temperature reduction is completely depending on the wavelength of the laser beam. In the proposed method, the wavelength of the laser beam is controlled based on the requirement.

The architecture of the proposed system is shown in figure 1.

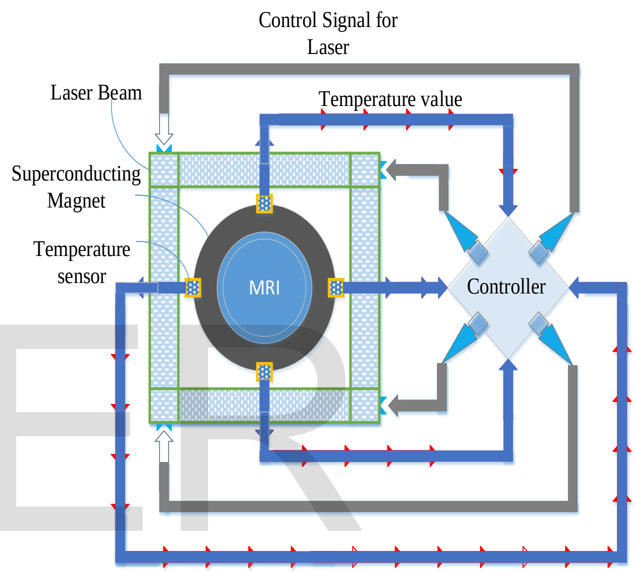

Figure 1: Architecture of LCS in MRI

In this system, four temperature sensors were fixed on the four sides of the superconducting magnet. It can predict the temperature level at the super conducting magnet, and transmit to the controller. So the controller has to be designed for making the cooling effective.

2.1 HYBRID PID AND FUZZY CONTROLLER:

The Classical PID and fuzzy controllers were combined to form a hybrid controller. Basically, blending mechanism depends on the actuating error. The PID controllers are used for linear system. Fuzzy logic is well suited for nonlinear application. The main objective of the proposed system is to improve the performance by reducing the actuating error. Fuzzy PID controllers are categorized into three parts as Direct action type, Fuzzy gain scheduling type and hybrid type fuzzy controllers. The direct type is classified into three parts single, double, triple input.

The output transfer function of a standard PID controller is defined as

$$GPID(S) = (K(\frac{1}{Ti}) + TdS)$$

Where K is the proportional gain, Ti is the Integral time constant and Td is the Differential time constant.

The proportional term is providing an overall control action. Steady state errors were reduced by integral gain. The derivative gain raises the transient response by compensating the high frequency using differentiator. The fuzzy controller has one input and one fuzzy rule base. The inputs are classical error and rate of change of error. Triangular membership function used here as input variables.

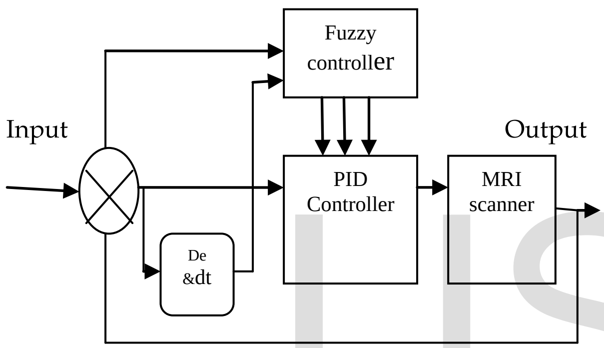

Figure 2: Block diagram of combined PID and FUZZY controller

The figure 2 depicts the block diagram of Combined PID and Fuzzy controller. This combination makes a model to reach a desired set point in the minimum time with shortest overshoot during external disturbance. Fuzzy controller has two inputs and three outputs. Deviation and deviation rate are given as the input to the model. After receiving the input data, fuzzy transforms that into fuzzy forms and fuzzy is worked according to its IF THEN rules. In order to provide single output, fuzzy evaluates the table of fuzzy control rules. Then defuzzification is done to produce accurate values such as kp, kd and ki. These coefficients are passed through PID controller. Mamdani's interference method is adopted.

Fuzzification is the process of converting a input data into crisp quantity fuzzy. It is the first step of the fuzzy logic controller. These crisp inputs are measured from the temperature sensors and its passed through the control system. Each crisp input has its own membership function which exists within a universe of discourse. The fuzzy variable and its range is shown in table 1.

Table 1: Fuzzy variable & its range

S.no	Crisp input range(temp in K)	Fuzzy variable name
1	1 to 5	Low
2	5 to 10	Medium
3	10 to 15	High
4	15 to 20	Ver High

The figure 3 shows that fuzzification process in MATLAB and its Membership function values for the crisp input

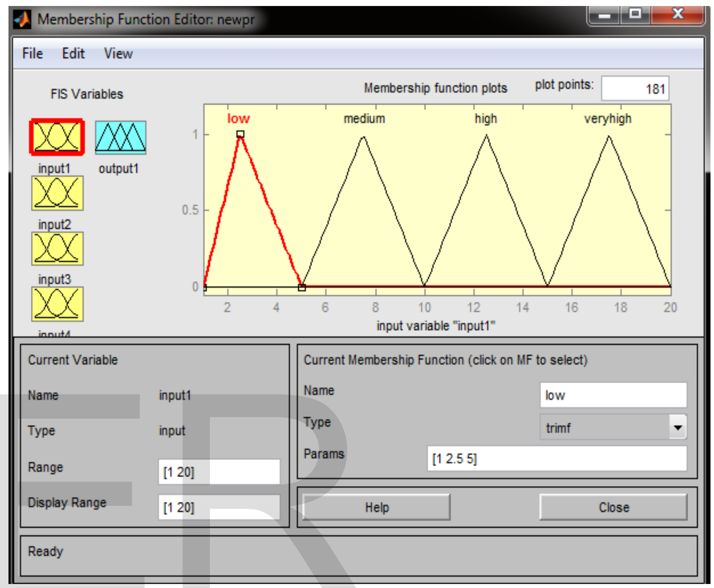

Figure 3: Fuzification process

Fuzzy rules are formed based on condintions which is simple if else. It was developed by Zadeh. A decision structure are needed to determine the rules . The interference of operator in this developed system is shown in table 2.

Table 2: Fuzzy Logic Rule

S.no	Condition	Output
1	If temperature is Low	Low
2	If temperature is Medium	Medium
3	If temperature is High	High
4	If temperature is Very High	Very High

We have created 256 rules based on the above using MATLAB.

2.1.1 FUZZY INTEFERENCE SYSTEM:

It converts the fuzzy input to the fuzzy output using IF then type fuzzy rules.

There are two types of inteference methods are avialable

- Mamdani inteference

- Sugeno Inteference

In the proposed method we prefered mamdani interference.

Defuzzification is the process of converting fuzzy sets and corresponding membership functions into crisp quantifiable logic output. Variety of methods were used to achive this defuzzification.Averaging method was adopted which was otherwise called as Center of gravity method

3 RESULTS & DISCUSSIONS:

The proposed FUZZY PID controller were designed and simulated in MATLAB R2013a and is shown in figure 4.

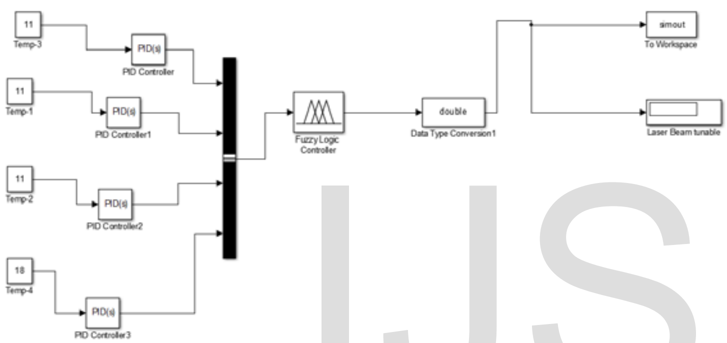

Figure 4: Hybrid PID-Fuzzy:

The different output parameters like accuracy, sensitivity, specificity, TPR, TNR etc. are calculated using MATLAB R2013a.

Temperature Comparison:

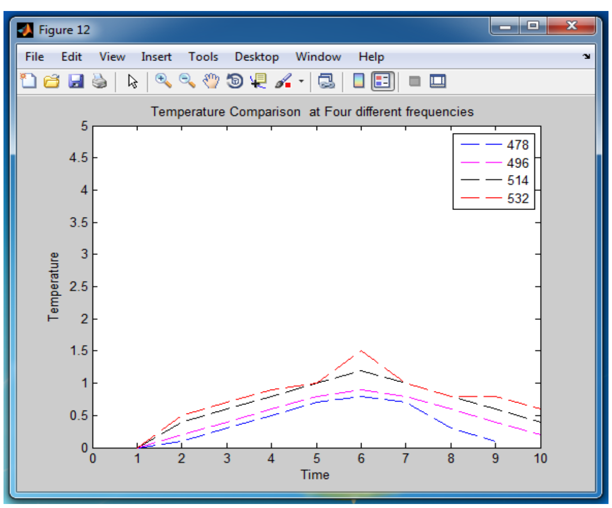

Figure 5: Temperature reduction at different frequencies

The temperature comparison for four different frequencies is shown in figure 5. From the figure it is clear that as the wavelength of the laser increases the temperature reduction also increases i.e., as the wavelength increases from 478nm to 532nm the amount of reduction in temperature also increase. So depending on the temperature of the superconducting magnet, the semiconductor ring laser produces the laser beam with required wavelength. This process continues to keep the temperature of superconducting magnet at its critical temperature and maintain the same.

3.1 OUTPUT PARAMETERS:

TPR, TNR, PPV, NPV and FDR were calculated and tabulated in the table 3.

Table 3: Output parameters.

Method	TPR	TNR	PPV	NPV	FDR
Normal	75	80	75	65	15
ANN	80	87	80	75	5
Fuzzy	87	100	91	86	1
Hybride	90	100	95	90	0.5

3.1.1 TRUE POSITIVE RATE:

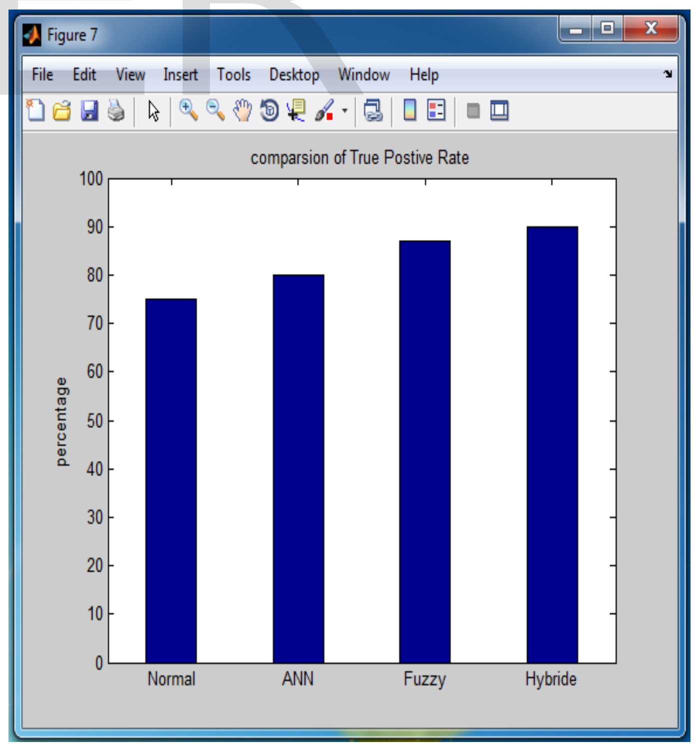

Figure 6: True positive rate of different controller

The figure 6 shows the comparison of true positive rates of different controllers. True positive

ISSN 2229-5518

indicates that if the temperature is in the specified range, the proposed method cools the system. The true positive rate of the hybrid controller is better when compared with the othe controllers.

3.1.2 TRUE NEGATIVE RATE:

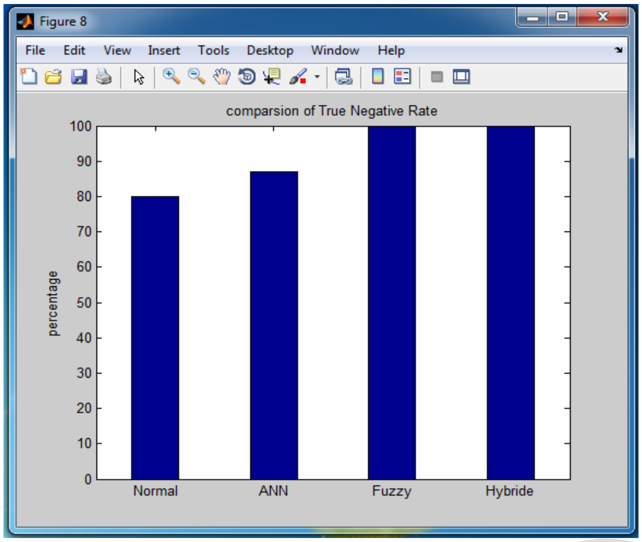

Figure 7: True negative rate of different controller

The figure 7 shows the comparison of true negative rates of different controllers. True negative rate indicates that if the temperature is in the specified range, the proposed method cools the system. The true negative rate of the hybrid controller is better when compared with the othe controllers.

3.1.3 POSITIVE PREDICTIVE RATE:

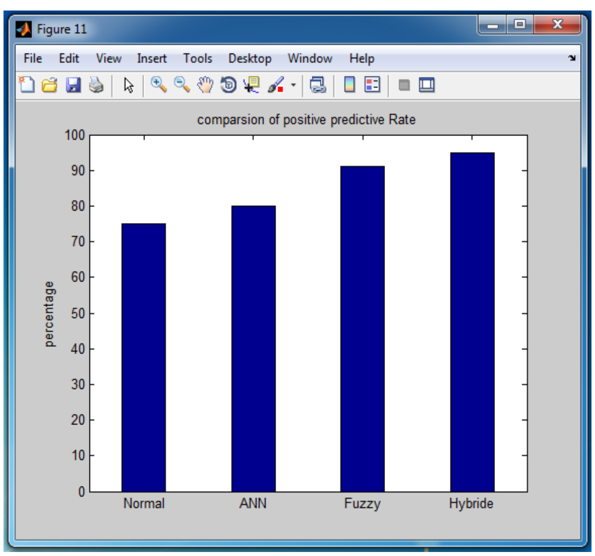

Figure 8: Positive predictive rate of different controller

The figure 8 shows the comparison of positive predictive rates of different controllers. It is the ratio of true positives to the total number of positives. There are two types of positives, true positives and false positive. True positive indicates that if the temperature is in the specified range, the proposed method cools the system. Whereas in false positive , the proposed method cools the system if it is not in the perticular range. The proposed hybrid controller along with the normal, ANN and fuzzy controller were analysed based on this and it is being observed that the hybrid controller has the better performance

3.1.4 NEGATIVE PREDICTIVE RATE:

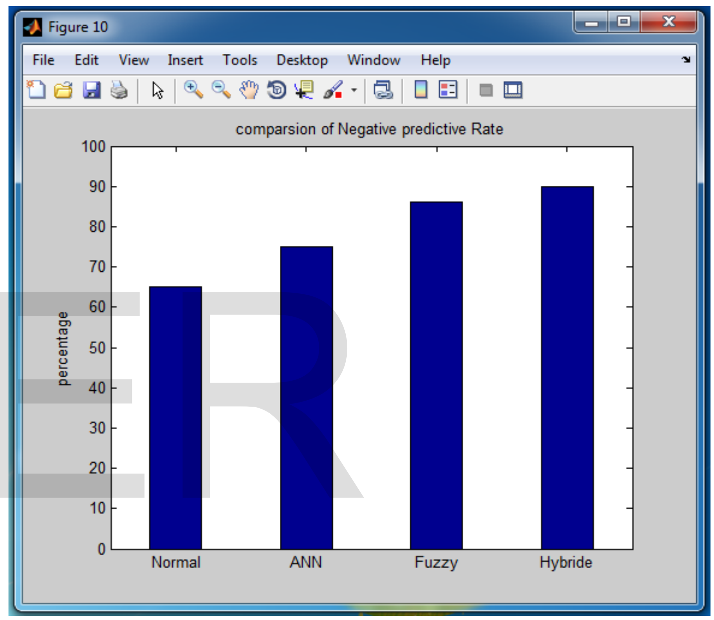

Figure 9: Negative predictive rate of different controller

Figure 9 shows the negative predictive rate of all test controllers. It is the ratio of true negatives to the total number of negatives. There are two types of negatives, true negatives and false negatives. True negative indicates that if the temperature is not in the specified range, the proposed method does not cool the system. Whereas in false negaitive, the proposed method does not cool the system if it is in the perticular range. The proposed hybrid controller along with the normal, ANN and fuzzy controller were analysed based on this and it is being observed that the hybrid controller has the better performance

3.1.5 FALSE DISCOVERY RATE:

ISSN 2229-5518

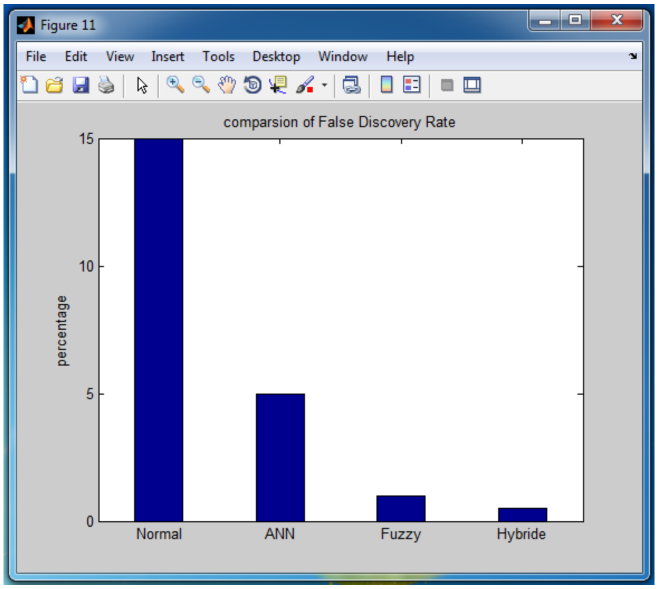

Figure 10: False Discovery rate of different controller

The figure 10 shows the comparison of False discover rates of different controllers. It is the ratio of false positives to the total number of positives. All the test controllers along with the proposed hybrid controller were analysed based on this and it is being observed that the hybrid controller performed well, ie false discovery rate hybrid controller has the least value.

The sensitivity, specificity and accuracy values are measured and tabulate.

3.1.6 SENSITIVITY :

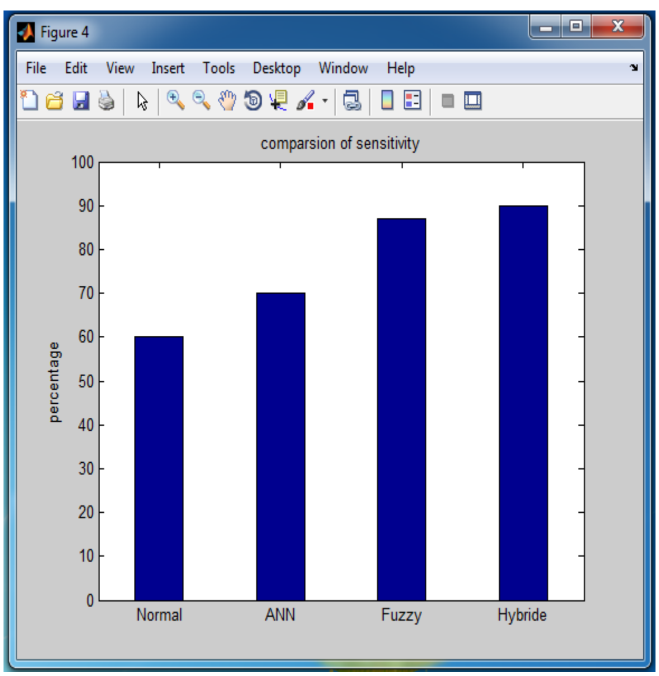

Figure 11: Sensitivity of different controllers

Sensitivity also called as true positive rate which measures the proportion of the positives that is controller cools the system when temperature is in range. The figure 11 shows that the sensitivity of the proposed method had a better performance when compared with the other test controllers.

3.1.7 SPECIFICITY:

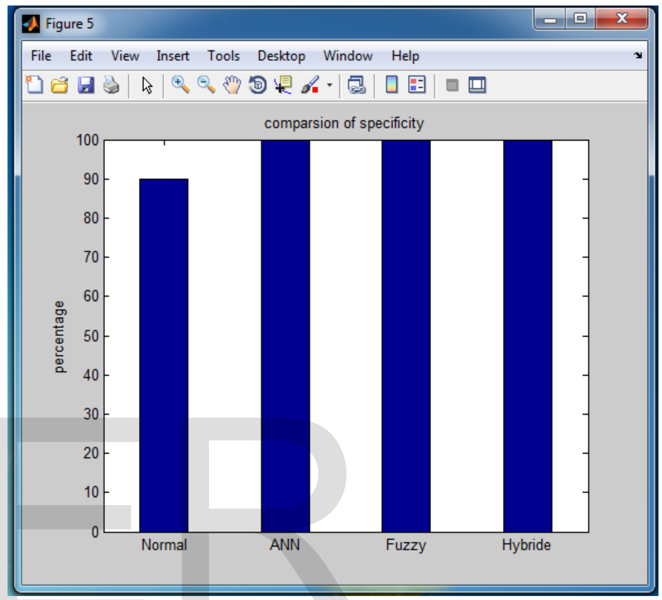

Figure 12: Specificity of different controllers

Specificity also called as true negative rate which measures the proportion of the negatives that is controller cools the system when temperature is in range. The figure 12 shows that the specificity of the proposed method had a better performance when compared with the other test controllers.

3.1.8 ACCURACY:

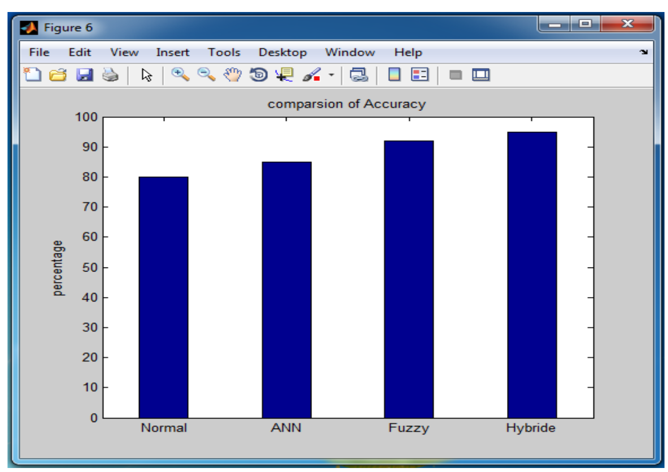

Figure 13: Accuracy of different controllers

Accuracy is the measure of how accurate system responds to our method. Accuracy= (TP+TN)/(TP+TN+FP+FN)*100. The figure 13 shows that the accuracy of the proposed method had a better performance when compared with the other test controllers.

The consolidated comparison of parameters such as sensitivity, specificity and accuracy were measured and shown in table 4 and figure 14.

Table 4: Performance parameters.

Method	Sensitivity	specificity	Accuracy
Normal	60	90	79.59
ANN	70	100	86.67
Fuzzy	87	100	92.86
Hybrid	90	100	95.12

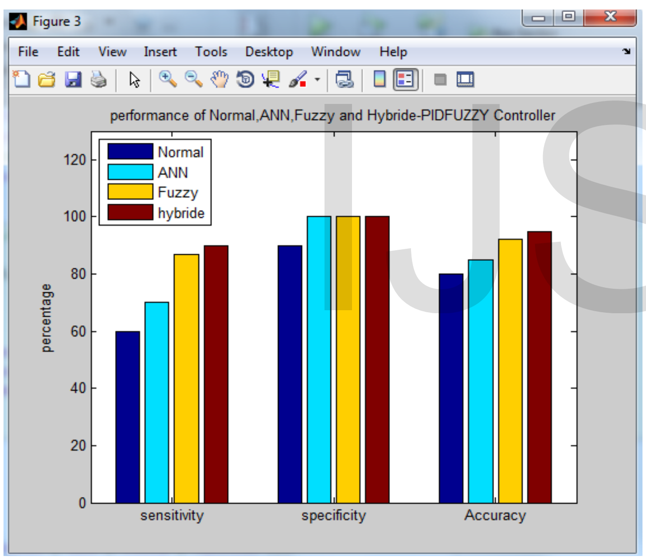

Figure 14: Performance comparison of different controllers

From the figure 14 it is clear that the performance of the controllers interms of sensitivity, specificity and accuracy is improved in the proposed method.

The accuracy of different test cnotrollers are shown in table 5, and it is clear that the hybrid controller posses maximum accuracy of 95.12%.

Table 5: Accuracy of different controllers.

Method	TP	TN	FP	FN	Accuracy
NORMAL	20	19	2	8	79.59
ANN	20	19	0	6	86.67
FUZZY	20	19	0	3	92.86
Hybrid	20	19	0	2	95.12

4 CONCLUSION

The objective of this work is to control the temperature of the superconducting magnet in the MRI scanner. The steady state error was well controlled in the PID controller while fast rise time and low overshoot of the dynamic response were obtained in the fuzzy controller. New control scheme of hybrid PID and fuzzy was proposed in order to increase the performance of the system. The proposed method was designed and simulated in MATLAB. The output parameters clearly emphasize the advantages of fuzzy inference systems with PID controller. From the experimental results, the hybrid fuzzy PID controller performs well in comparison with the other test controllers' interms of sensitivity, specificity and accuracy. The global accuracy of temperature control in the laser cooling system obtained by the proposed system was 95.12%.

REFERENCES AND LINKS

1. Andreas Jockel, Aline Faber, Tobias Kampschulte, Maria Korppi, Mathew T. Rakher and Philip Treuttlein (2014) " Sympathetic Cooling of a membrane oscillator in a hybrid mechanical- atomic system" arXiv:1407.6820v1 [quant- ph] 25 Jun.
2. C. Baker, D. L. McAuslan, E. Sheridan & I. Harris (2016) "Laser cooling and control of excitations in superfluid helium", Nature Physics 12, 788–793 doi:10.1038/nphys3714
3. C. Cohen- Tannoudji and William D. Phillips (1990) , "New mechanisms for laser coolong", Physics Today, Vol.43, No. 10, pp. 33-40,.
4. C.J Foot (2005) , " Atomic Physics", Oxford University Press: Oxford.
5. Dehui Li, Jun Zhang, and Qihua Xiong (2013), "Laser cooling of CdS nanobelts: Thickness matters", Optics express, Vol.21, No.16, pp. 19302-19310.
6. F. J. Davies (2000) , "MRI Magnets," in Applications of Superconductivity, NATOASI Series. : Kluwer Academic Publishers, pp. 385–414.
7. Galina Nemova and Raman Kashyap (2017), "Laser cooling of solids under the influence of surface phonon polaritons "Journal of the Optical Society of America B Vol. 34, Issue 2, pp. 483-488.

8. Jun Zhang, Dehui Li, Renjie Chen and Qihua Xiong (2013), "Laser cooling of a semiconductor by 40 Kelvin", Nature, Vol. 493, No. 7433, pp. 504-508.
9. Olivia Solon (2013), "Cooling MRI magnets without a continuous supply of scarce helium Thechnology",August,from http://www.wired.co.uk/news/archive/2013-08/12/mri-magnet-cooling
10. Prof.M. Lilly Florence and Dr. P. Balasubramanie (2009), "Multilayer Feed Backward Neural Network Model For Medical Decision support: Implimentation of Back Propagation Algorith in HIV/AIDS regimens", IJRIC.
11. Quan-Shun Yang , Tao Gao (2017) "Feasibility study of laser cooling of InF molecule" Pages 1-8 | Received 05 Sep 2016, Accepted 29 Dec 2016, Published online: 20 Jan .
12. Son-Tung Ha, Chao Shen, Jun Zhang & Quihua Xiong 2015, " Laser cooling of organic- inorganic lead halide perovskites", doi: 10.1038/nphoton.2015.243 21 December .
13. Steven Chu (1998), "The manipulation of neutral particles", Reviews of Modern Physics, Vol. 70, No.3, pp.685-706.
14. Theodor W. Hansch and Arthur L. Schawlow (1975), " Cooling of gases by laser radiation" , Optics Communications, Vol. 13, No.1, pp. 68-69.
15. Thomas C Cosmus and Michael Parizh, (2011) "Advances in Whole- Body MRI Magnets", IEEE Transactions on Applied Superconductivity, Vol.21, No.3, June.
16. Walter Koechner (2006), "Solid- State laser engineering" , Springer Book, Vol.1.
17. William Thomas Silfvast (1996), "Laser fundementals", New York: Cambridge University Press, Vol. 459.
18. Y. Lvovsky and P. Jarvis (2005), "Superconducting systems for MRI—Present solutions and new trends," IEEE Trans. Appl. Supercond., vol. 15, pp.1317–1325, June.
19. Yushi Kaneda, J. M. Yarborough, Yevgeny Merzlyak, Atsushi Yamaguchi, Keitaro Hayashida, Noriaki Ohmae, and Hidetoshi Katori , (2016), "Continuous-wave, single-frequency 229 nm laser source for laser cooling of cadmium atoms "Optics Letters, Vol. 41,Issue 4, pp. 705-708, https://doi.org/10.1364/OL.41.000705