NEURAL NETWORKS BASED TYRE IDENTIFICATION FOR A TYRE INFLATOR OPERATIONS

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by

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DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

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Kahandawa K. A. G. C.

26.03.2008

We/I endorse the declaration by the candidate.

UOM Verified Signature

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Dr. Lanka Udawatta

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Finally I thank to my family members for helping and encouraging me throughout the fieldwork of the research and being patient with me. I may not be able to accomplish this task without their support.

Abstract

Tire industry has become one of the huge industries at present since the number of vehicles are rapidly increasing. Since the tire directly related to the vehicle safety, durability, running cost and comfort level of the passengers tire selection and maintenance addressed widely. Maintaining a tire is a duty of the vehicle user and he may has to check the tire rapidly for wear, cuts and other irregularities. The most important activity of tire maintenance is to maintain the pressure of the tire.

The tire pressure is an important issue since it directly relates to the safety of the vehicle, durability, running cost and comfort level of the passengers as mentioned above. A rapid check for tire pressure is essential since tire pressure may reduce

normally with the time apart from losing pressure when the tire drives over a pothole or hump. Checking the tire is done using a machine called tire inflator. This machine must be accurate and user friendly since the operator has to trust on it. Tire inflators are available mostly in tire shops and in gas stations. Tire inflators are mainly two types, Analog tire inflators and Digital tire inflators. Digital tire inflators arrived the market recently and analog tire inflators are getting replaced with digital tire inflators as the convenience of operation.

Digital tire inflators read the pressure with a pressure sensor and with this sensor the dynamic pressure readings are not possible. Hence to get the static pressure the inflation process has to be stopped. In other words, while in the inflation, the tire inflator has no idea about the tire pressure until the inflation stops. In this case, to have an idea about the rise of pressure, there must be a method to identify the type of the tire.

The tire identification mechanism must be fast, accurate and reliable. The other requirement is that the tire has to be identified online and this process must not delay the inflation process.

The main tusk of this exercise is to develop an artificial neural network based tire identification method. A developed tire inflator model was used to collect information and to test the tire identification process.

To develop the network, three inputs were considered. By expanding the number of layers in the network experiment was carried out. The results were successful and that the network with two hidden layers zero percent error achieved.

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CHAPTER 1

1 Introduction to working environment

1.1 Background

With the increase of vehicles in the world motor accidents also increase tremendously. Considerable amount of the accidents is due to vehicle failures. Among main failures the tire failures lie in the top. Studies of tire safety shows that maintaining proper tire pressure, observing tire and vehicle load limits and inspecting tires for cuts, slashes and other irregularities are the most important things to avoid tire failures [1]. Common tire failures are tread separation, blowout and flat tires. From drivers consideration maintaining proper tire pressure is the main thing possible to avoid above failures and also the accidents. In this case drivers have to completely depend upon the tire inflators available in gas stations and in tire shops.

With the above mentioned steps along with other care and mountainous activities, improve vehicle handling and helps to protect against breakdowns too [2]. The tire pressure directly affects the fuel efficiency of the vehicle since it directly related to frictional force offered by tires. In the other hand the life time of the tire itself is affected by the tire pressure.

Achieving the exact tire pressure and maintaining it is very important. Drivers have no control upon achieving the exact tire pressure. Driver can set the inflation pressure and tire inflator takes over the job. When the operation completed the machine indicate that and the driver has to trust it. There is no other method to double check the pressure and hence tire inflator has to be reasonably accurate and reliable. As shown in the Figure 1.1, by naked eye the under inflated tires can not be identified easily [3].

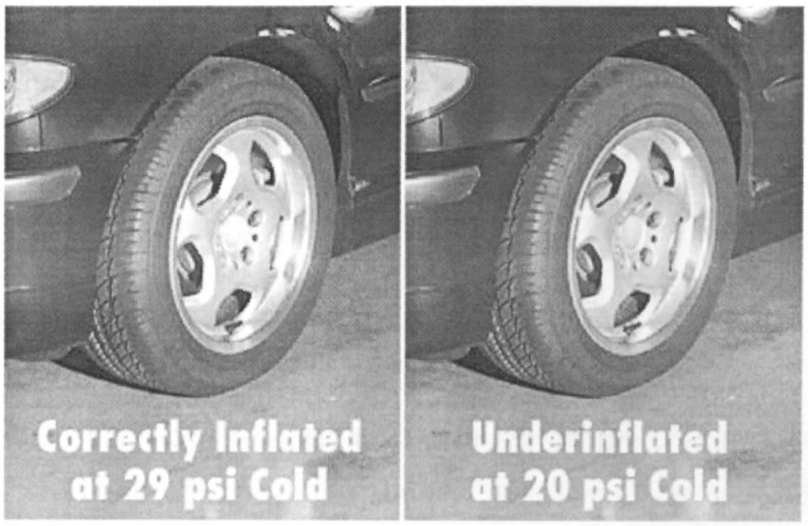


Figure 1.1: Correctly Inflated and Underinflated Tire.

The tire inflator is an essential machine for gas stations today. Apart from that all the tire shops must have a tire inflator. Normally there is only one tire inflator available in one place and it is used to inflate all types of tires. That is, from bicycle tire with smaller volume to truck tires with larger volume. The tire inflator must be treating all these tires similarly. That is small tires and also large tires should reach the set pressure accurately and as quickly as possible. To have quick inflation, for large tires flow rate of air should be increased and for small tires the flow rate must be small to avoid over inflation since for small tires, due small volume, pressure can be dangerously high if more air enters the tire.

Hence accurate tire identification is essential for tire inflators for efficient operation. The identification method must be very accurate that is if accidently a small tire identified as a larger tire may end up with blowout of the tire. Tire inflators are a commercial product and goes with customer satisfaction. Hence one accident may end the carrier of a particular brand name. In this situation all the tire inflators in the market comes with a simple on off controller and it is slow in operation. To be competitive in the market the inflator must be reliable, fast and at the same time it should be cheaper.

To make the tire inflator cheap it is difficult to use real time flow controllers. In this case manufacturers prefer to keep the flow rate constant and vary the inflation time, which is the valve opened time interval so that the air can inflate to tire. To make the operation faster normally flow rate has to fix at a high value. In this situation for small tires the pressure rise is high for even small inflation time intervals. In this case there is a risk of tire blowout. Hence normally tire inflator comes with small inflation cycles and these machines are slower in operation. With this situation accurate tire identification is essential in tire inflators to have better operation.

1.2 Pressure inside Tire

The tire connector is used to connect tire inflator to the tire (Figure 1.2). When the connector is connected to the tire, the tire and the inflator (connector, hose, up to pressure sensor) are act as a single system. In other words, pressure inside the tire and pressure inside the pressure sensor synchronize. What ever the pressure variation occurs inside tire is sensed by the pressure sensor.

Figure 1.2: Tire Connector

When the valve is opened the inflation of air begins. The pressure inside tire starts to rise and soon after inflation stopped, then pressure inside tire starts to decay and settle in a pressure which is higher than the starting pressure as shown in Figure 1.3.

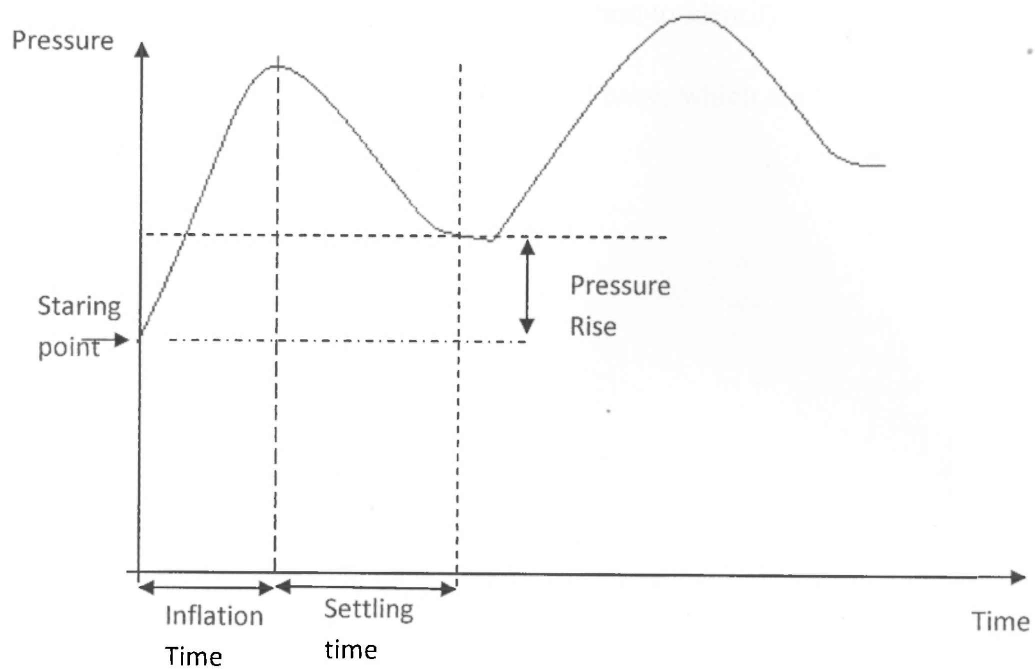


Figure 1.3: Dynamic Pressure Rise inside a Tire with Time.

According to the results obtained it is not possible to rely on the real time pressure. A relationship with the real time pressure and the actual pressure can be obtained if the system remains unchanged. But the out put pressure of the compressor available in gas stations is not constant. It varies normally between two threshold values (7 psi to 10 psi). Even if compressor fixed at a constant value the system consists of the tire also. The tire connects to the machine varies in a large range and also new tire types comes to the market unpredictably. The actual pressure that is required is the final pressure where the finally pressure settled. To get that pressure first of all the inflation valve has to be closed and secondly have to wait until the pressure settles. In this case the controller of the tire inflator should have an idea where the pressure will settle for a particular tire. The controller should now have a prediction capability apart for the tire identification capability for efficient operation. Before predicting the tire identification is critical and it must be fast and reliable.

1.3 Goal

The goal is to develop a neural network based method to identify the tires correctly.

There are some properties that the system should have, which are being identified as important.

- The model should be automatic
- It should be able to adapt for new tires
- Fast operation is required
- It must be accurate and reliable.

CHAPTER 2

2 Problem Identification

2.1 Properties of the Tire

All the tires comes with the all the details of the tire. As shown in the Figure 2.1 and the user can read the details himself. The parameter that is important in this research is the tire volume. It can be calculated using the rim diameter, width of tire and the aspect ratio.

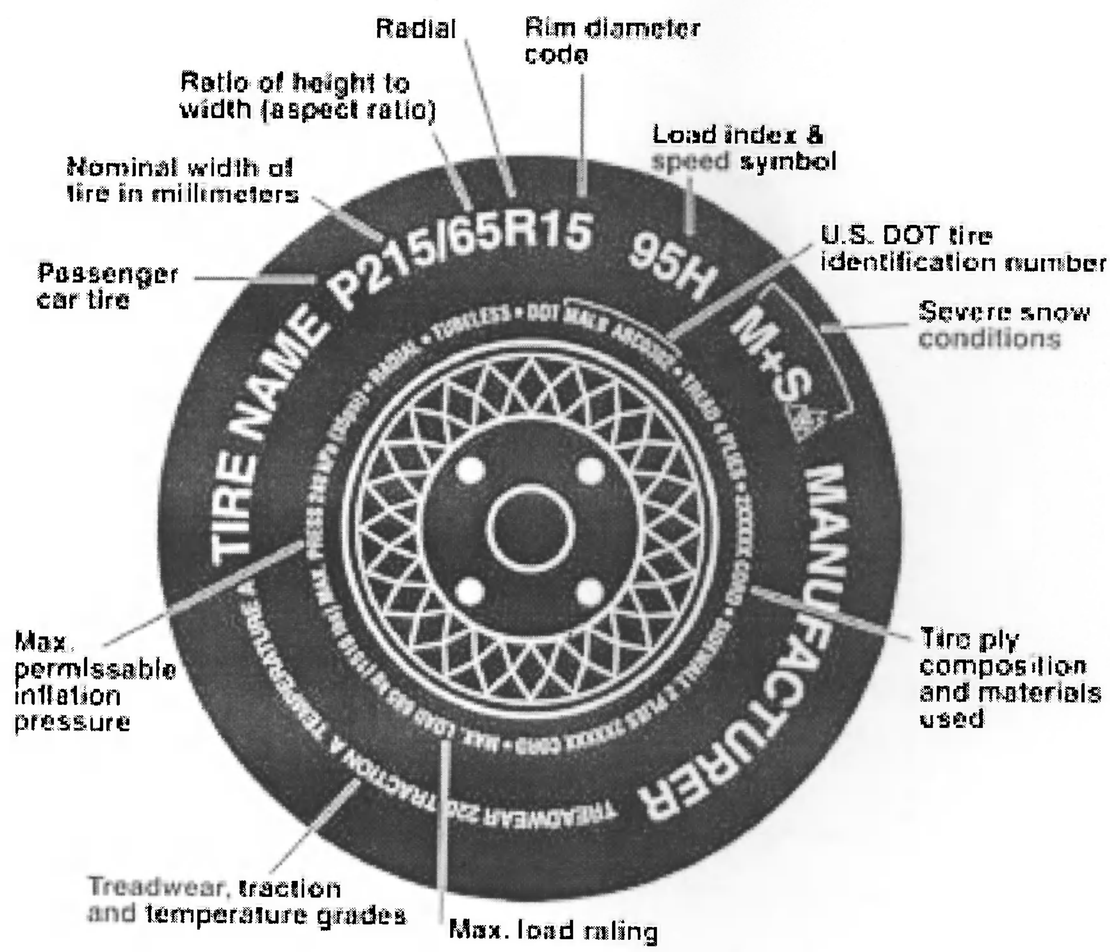


Figure 2.1: Tire Details Available in the Tire Side Wall

Most important information available on the side wall of a tire are,

- Manufacturing Date
- Speed Symbol
- Max. Load Capacity /tire
- Tread wear
- Traction
- Temperature Resistance

2.1.1 Temperature Resistance

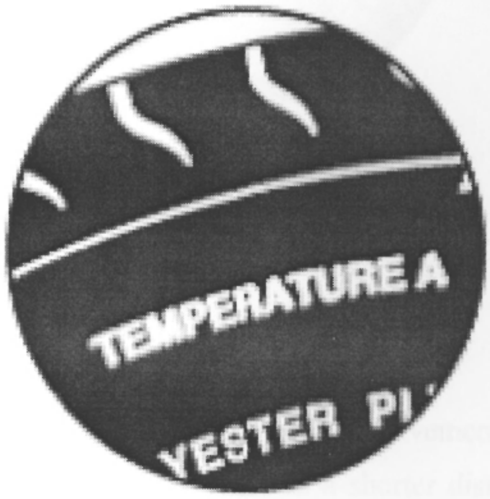


Figure 2.2: Temperature Resistance Mentioned in Tire.

These letters indicates a tire's resistance to heat. From highest to lowest, a tire's resistance to heat is graded as "A", "B", or "C" as shown in Table 2.1.

Symbol	Area
A	Hot area
B	Normal weather area
C	Cold area

Table 2.1: Temperature Resistance of a Tire

2.1.2 Tread Wear Number

This number indicates the tire's wear rate. The higher the tread wear number is, the longer it should take for the tread to wear down. For example, a tire graded 400 should last twice as long as a tire graded 200.

Figure 2.3: Tread Wear Number

2.1.3 Traction of a Tire

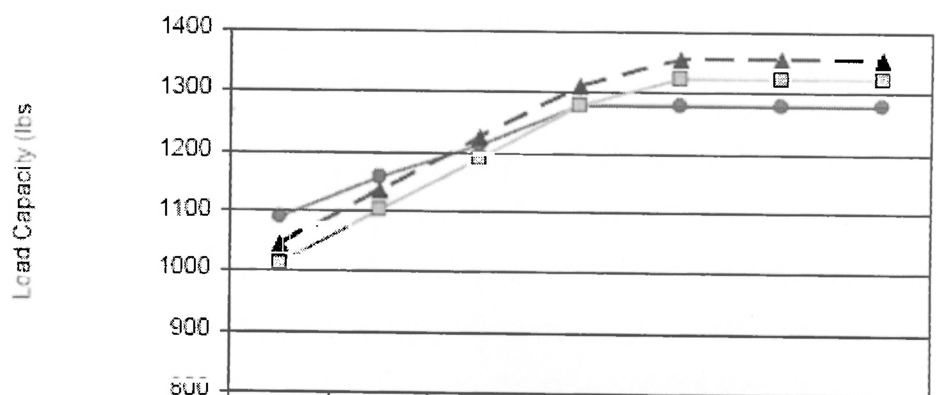
This letter indicates a tire's ability to stop on wet pavement. A higher graded tire should allow stopping the car on wet roads in a shorter distance than a tire with a lower grade. Traction is graded from highest to lowest as "AA","A", "B", and "C"

Figure 2.4: Traction of a Tire

2.1.4 Maximum Load Capacity and Tire Speed

Fig. 2.5: Load Index and Speed Symbol of the Tire

This number indicates the maximum load that can be carried by the tire. Symbol indicates the maximum speed at which a tire is designed to be driven for extended periods of time. Tires with the same load index, regardless of tire size, may carry the same load, but not always, and they may require substantially different inflation pressures.



	26	29	32	35	38	41	44
P205/55R16 89 (SL)	1091	1157	1213	1279	1279	1279	1279
205/55R16 90 (SL)	1014	1102	1190	1279	1323	1323	1323
*205/55R16 91 (SL)	1047	1135	1224	1312	1356	1356	1356

Inflation Pressure (psi)

Figure 2.6: Load Capacity Vs Inflation Pressure for Three Different Tires

Table 2.2: Maximum Load Caring Capacity of a Tire with Load Index

Load Index	Load / kg
71	345
72	355
73	365
74	375
75	387
76	400
77	412
78	425
79	437
80	450
81	462
82	475
83	487
84	500
85	515
86	530
87	545
88	560
89	580
90	600
91	615
92	630
93	650
94	670
95	690
96	710
97	730
98	750
99	775
100	800
101	825
102	850
103	875
104	900
105	925
106	950
107	975
108	1000
109	1030
110	1060
111	1095
112	1129
113	1164
114	1200
115	1237
116	1275
117	1315
118	1355
119	1397
120	1440
121	1485
122	1531
123	1578
124	1625
125	1677

Table 2.3: Maximum Speed Limit of a Tire

Speed Symbol	Maximum Speed / (km/h)	Maximum Speed / (m/h)
Q	160	100
R	170	106
S	180	112
T	190	118
U	200	124
H	210	130
V*	Above 210	Above 130
V	240	149
W	270	168
Y	300	186
Z	Above 300	Above 186

2.1.5 Manufacturing Date

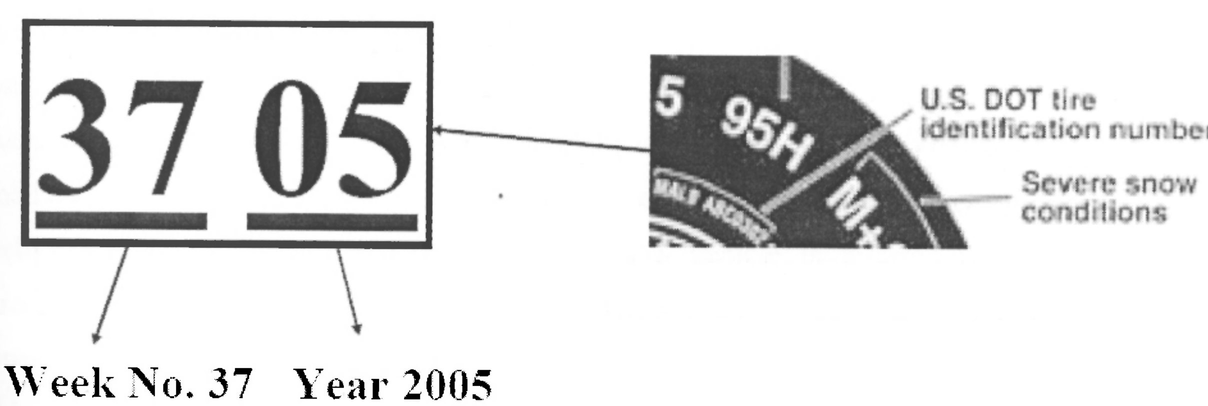


Figure 2.7: Tire Manufactured Year

Manufactured week and year of a tire are mentioned in the tire by a number. In the example in Figure 2.7 the tire is manufactured in the 37th week of the year 2005.

Vehicle tires have a 4-year validity period from their Date of Manufacture (DOM). Thereafter, the tire expires and may burst whilst in use. All the tires have to be checked for safety purposes. Using expired tires may end up with serious accidents. They are likely to burst (especially when running in hot weather) because the rubber component may have hardened and cracked.

2.1.6 Tire Pressure

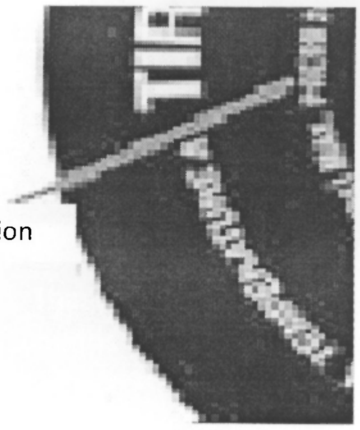


Figure 2.8: Maximum Permissible Pressure that Tire Could Withstand

The maximum permissible pressure that a tire could with stand is indicated in the tire as shown in the Figure 2.8. Reaching pressures above this value may end up with tire blowout. Best tire pressure for a vehicle is lower than this value. The most suitable pressure for a tire varies with the vehicle load and the speed of tire. Manufacturers of passenger vehicles and light trucks determine this value based on the vehicle's design load limit, that is, the greatest amount of weight a vehicle can safely carry and the vehicle's tire size. The proper tire pressure for a vehicle is referred to as the "recommended cold inflation pressure." It is difficult to obtain the recommended tire pressure if the tires are not cold. Generally this value mentioned in the vehicle near driver's door.

The recommended tire inflation pressure that vehicle manufacturers provide reflects the proper psi when a tire is cold. The term cold does not relate to the outside temperature. Rather, a cold tire is one that has not been driven on for at least three hours. During drive, the tires get warmer, causing the air pressure within them to increase. Therefore, to get an accurate tire pressure reading, must measure tire pressure when the tires are cold or compensate for the extra pressure in warm tires.

If the vehicle carries an extra load, the tire pressure has to be increased to withstand the extra load.

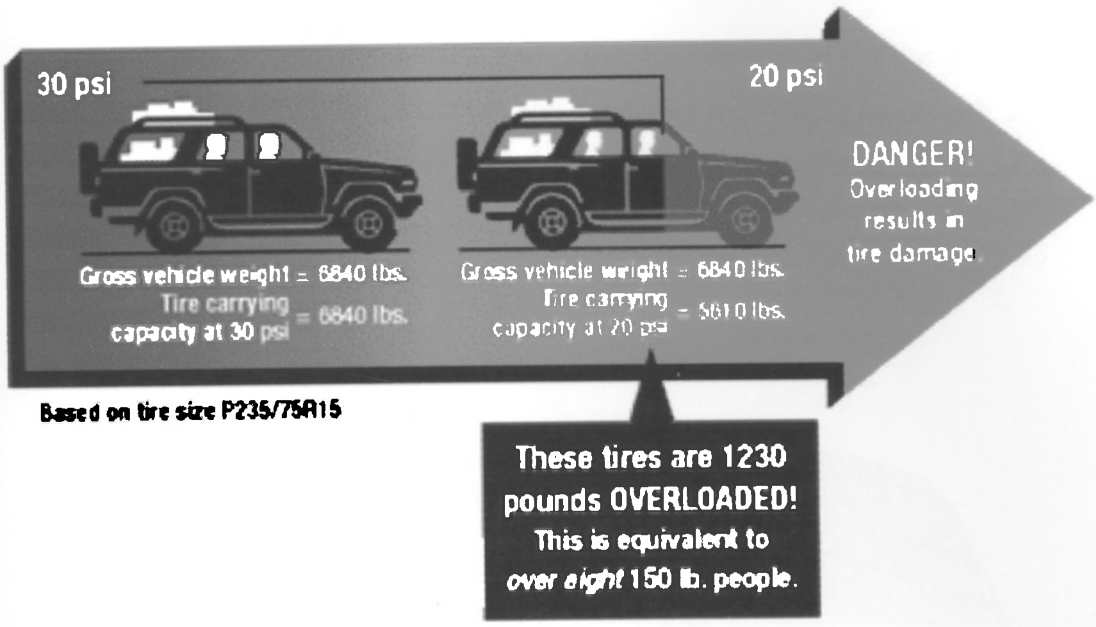


Figure 2.9: Tire Carrying Capacity with the Tire Pressure.

If the tire pressure is lesser, the load carrying capacity of the tire is also lower as shown in Figure 2.9 and that could end up resulting tire failure or even with an accident.

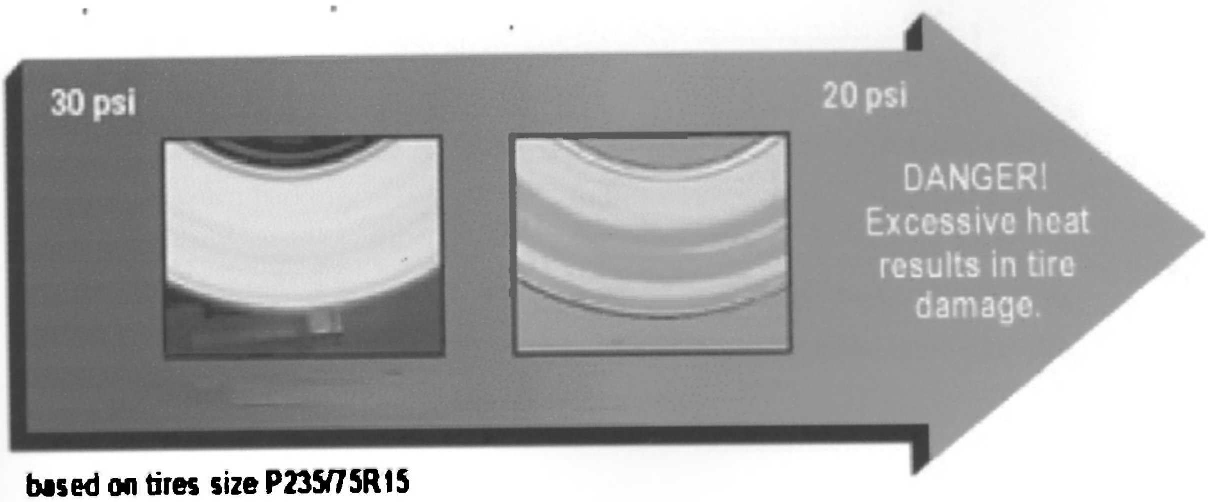


Figure 2.10: Infrared Photograph of a Tire

Lower tire pressure increases heat of the tire. The infrared photograph of a tire is shown in the Figure 2.10. It shows that the damaging heat increases as the pressure drops in the tire. It is extremely dangerous to travel in high speeds with the low tire pressure.

Over inflation is also not good and it will reduce the life time of the tire in addition to reducing the comfort of the passenger and damaging the vehicle parts such as shock absorbers, coil springs, etc. Figure 2.11 shows the effect of over inflation on a tire.

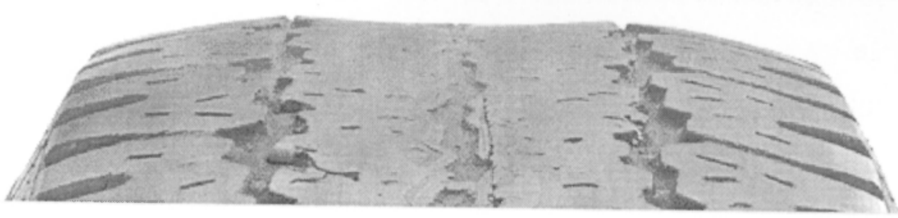


Figure 2.11: Overinflated Tire

It is important to check the vehicle's tire pressure at least once a month for the following reasons:

- Most tires may naturally lose air over time.
- Tires can lose air suddenly if it drive over a pothole or other object or if strikes the curb when parking.
- With radial tires, it is usually not possible to determine under inflation by visual inspection as shown in Figure 2.12. Hence to make sure the tire pressure the pressure should be checked frequently.

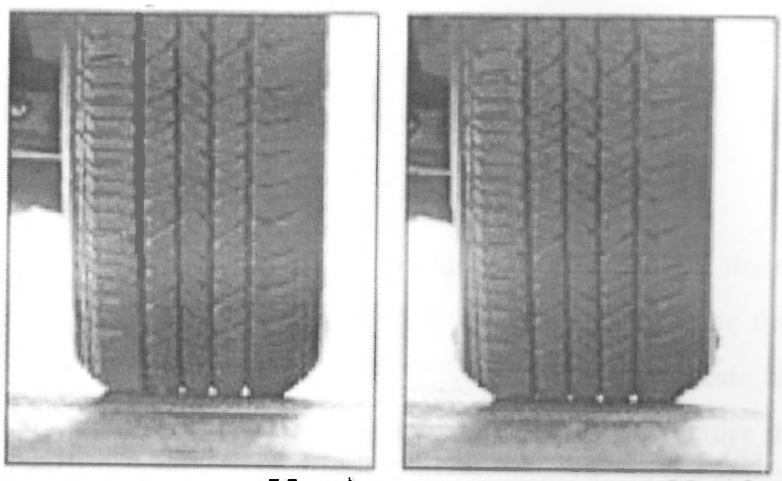


Figure 2-12: Visual inspection of an Underinflated Tire and a Correctly Inflated Tire.

2.2 Tire Inflator

Tire inflator is the machine used to inflate tires and with using a compressor it inflates tire in a controlled manner while indicating the pressure to the operator. Tire inflators are available in gas stations all around the world. Tire inflators available in two types, analog and digital. Digital tire inflators came to market recently and took the place of analog tire inflators which were there for from the time where the first tire is manufactured. The convenience of operation and user friendliness is the main reasons to make digital tire inflators more popular. In the digital tire inflator the operator can set the desired value and wait until the machine automatically stops after finishing the job.

2.2.1 Operation of Tire Inflator

2.2.1.1 The Analog Tire Inflator

In analog tire inflator, an analog pressure gauge is available to get the tire pressure. This analog tire inflators comes in two types, tower type and inline tire inflator as shown in Figure 2.13. In the tower type tire inflators, there is a separate tube available inside the main tube to get the pressure value. The operator of the tire inflator is the controller and by observing the pressure reading operator decide to stop inflation and he manually close the valve. In the inline tire inflator pressure reading is taken near the tire and in this case real time pressure reading is not available. When the operator open the valve the dial shows a false reading and after stopping the valve is comes back to the actual pressure. Hence operator has to stop inflation rapidly to avoid over inflation.

(a)Tower Type

(b) Inline Type

Figure 2.13: Analog Tire Inflators

2.2.1.2 The Digital Tire Inflator

In the digital tire inflator a pressure sensor is available in the other end of the tube which in the tower or the enclosure. Hence the dynamic pressure reading is impossible. But in the digital tire inflator the operator can set the desired pressure value and wait until the inflator finish the job. That is the main advantage of digital tire inflator. Most digital tire inflators make a sound to indicate that the operation completed.

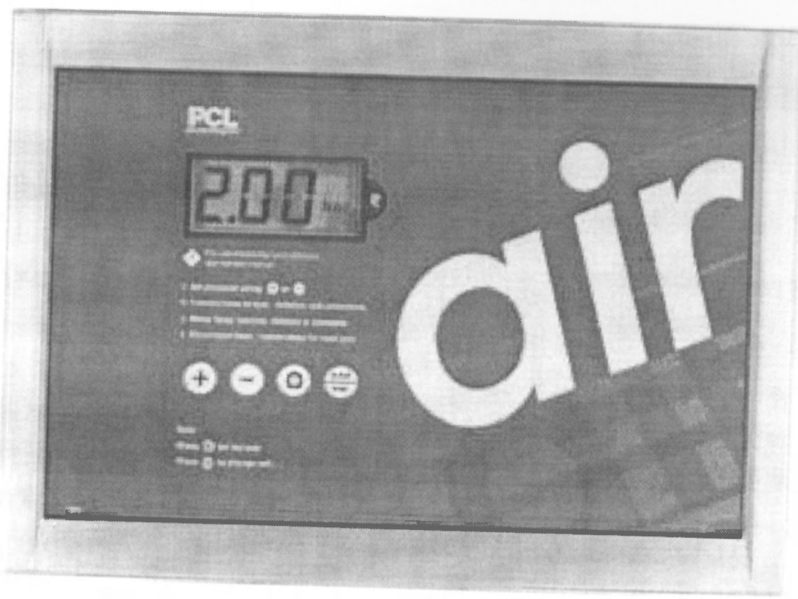


Figure 2-14: Digital Tire Inflator

2.2.2 Controller of the Tire Inflator

The controller of the tire inflator faces few difficulties. The main difficulty is the real time pressure is not available. That is because the pressure sensor can not read the real time pressure due to noises. Only available pressure is the static pressure at stating point. By observing the signal at the pressure sensor using an oscilloscope as shown in Figure 2.15 the variation of pressure is shown in Figure 1.3. To get the next reading the inflation has to be stopped and wait until the pressure settles.

Figure 2.15: Pressure Signal Analysis

Normally the controller available in a tire inflator is an on-off controller. Most of the digital tire inflators work in a constant cycle and that cycle is made small to avoid over inflation. Hence the operation is slower compared to analog tire inflator especially when it comes to a large tire. To change the working cycle in tire inflators, the tire identification is essential.

In this exercise a micro-controller based digital tire inflator was designed and an artificial neural network is used to identify the tires.

2.2.3 The Tire Inflator Model

Initial controller of the model is made simple as possible and tried to use same cycle for all tire types. Tuned the machine to avoid over inflation for small tires and used a standard motor-bike tire as the smallest tire. The inflation cycle has to be made small as 250ms and with this inflation cycle, there is over inflation encountered rarely. But the over inflated value is not dangerous since it is 2-3 psi high with set value. The problem is for large tires such as car tires and van tires the inflation time is not acceptable and to complete the operation, some times it takes 2-3 minutes. For larger tires such as bus tires and truck tires the operation took about 10 minutes to complete and this is not even near the acceptable level.

Secondly by changing the controller to work in several cycles the tire identification is identified as an essential requirement. To identify the tire the method used is to inflate the tire for a standard time interval and read the pressure rise. The pressure rise is directly related to the volume of the tire and from that reading tire can be classified several groups. The tire classified as small tire, medium tire and large tire as shown in Table 2.4. To avoid over inflation the initial inflation time is set to 250ms. The working flow chart is shown in the Figure 2.16 (Appendix A).

Table 2.4: Tire Classification

Tire Type	Pressure Rise for 0.25 s Inflation	Category
3 Wheeler	5	Small tire
Motor Bike	3	
Car	1	Medium tire
Van	0.8	
Lorry	0.1	Large tire
Bus	0.1	

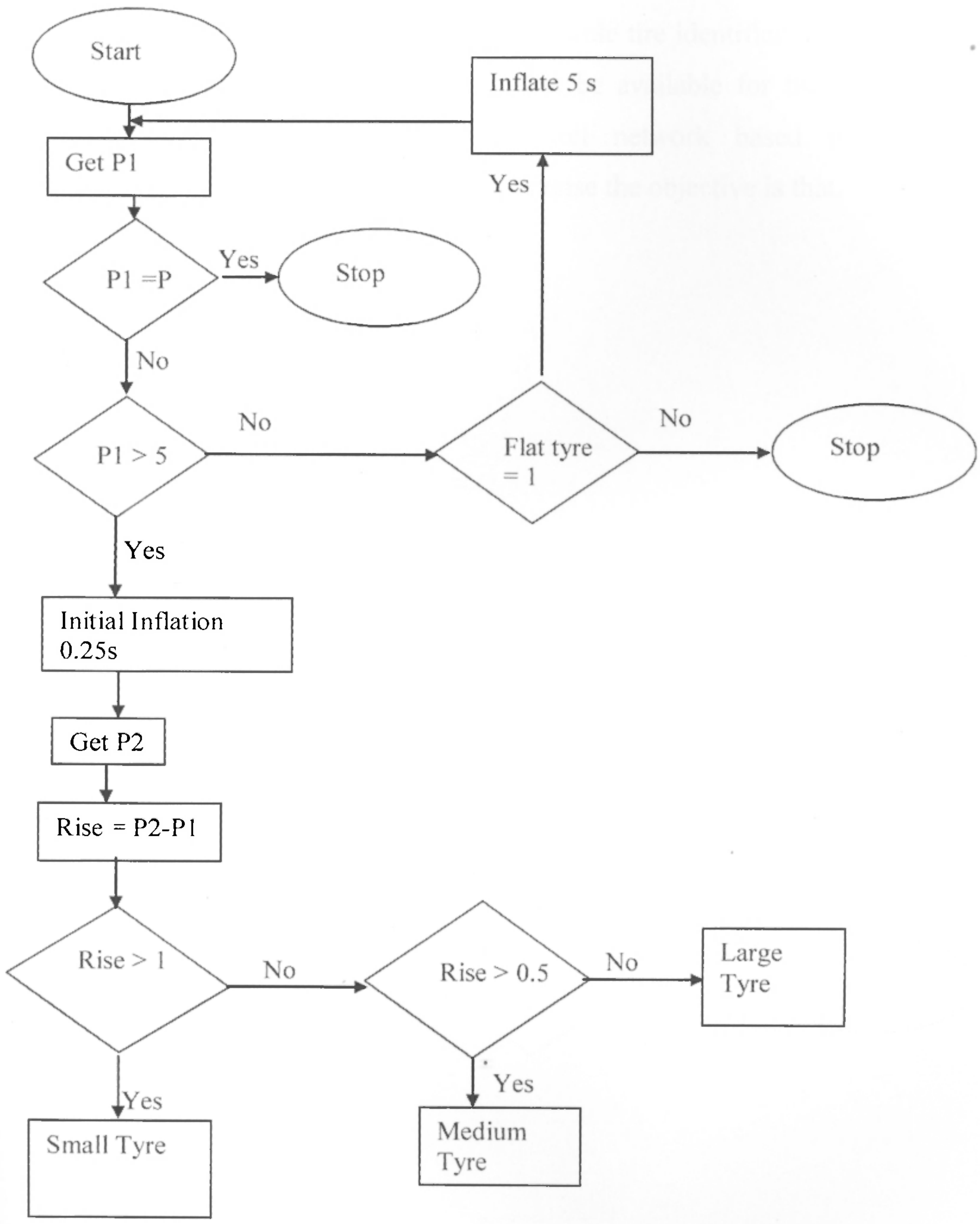


Figure 2.16: Working Flow Chart of the Tire Inflator

With the above algorithm the performance of the machine increased tremendously. But for some noises and operator errors like loosely holding tire connector end up with misclassification. To have accurate and reliable tire identification this method is not enough. Intelligent tire identification must be available for the machine to be optimizing the performance. Artificial neural network based intelligent tire identification system is suggested and in this excise the objective is that.

CHAPTER - 3

3 Theoretical Background

3.1 Introduction to Neural Networks

Artificial Neural Networks commonly referred as "Neural Networks" [4]. This concept immerged while scientists looking for a solution to replicate human brain. In some cases like identification and prediction the human brain tracks the problem more efficiently than other controllers. That is because human brain computes entirely different way from the conventional digital computer.

The human brain is a highly complex, non-linear and parallel computer. (Information processing system)[5]. It has the compatibility to organize its structure constituents, known as neurons, so as to perform certain computations many times faster than the fastest digital computer available today.

For an example the human vision, the human routinely accomplishes perceptual recognition tasks such as recognizing familiar face embedded in an familiar scene in approximately 100-200ms, where as tasks of much lesser complexity may take hours on a conventional computer [6]. Hence we can say the brain processes information super quickly and super accurately. It can also be trained to recognize patterns and to identify incomplete patterns. Moreover the trained network works even if certain neurons failed.

3.2 Engineering of Brain

Discovering how the human brain works has been an ongoing effort that stated more than 2000 years a go with Aristotle and Heraclitus and has continued with the work of Ramony Cajal, Colgi Hebb, and others [5]. Better we understand the brain, the better we can replicate it.

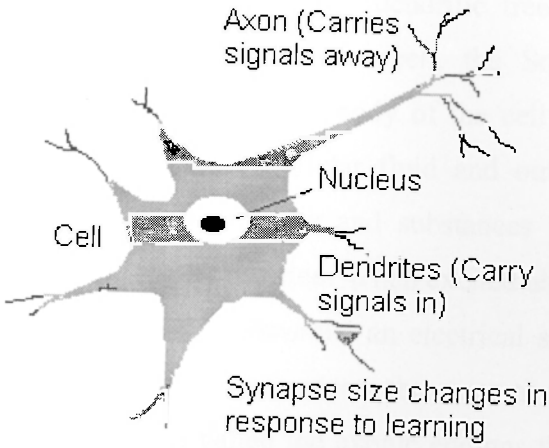


Figure 3.1: The Biological Neuron

3.3 Neuron Physiology

The neuron is the fundamental unit of and the nervous system, particularly the brain [7,8]. It works as an amazing complex biochemical and electric signal processing unit.

3.3.1 Neuron

The work neuron came from Greek which means the nerve cell. Neuron is the fundamental unit of nervous system. Considering its microscopic size it is an amazing processor. Neuron receives and combines signals from many other neurons through filamentary input paths called dendrites.

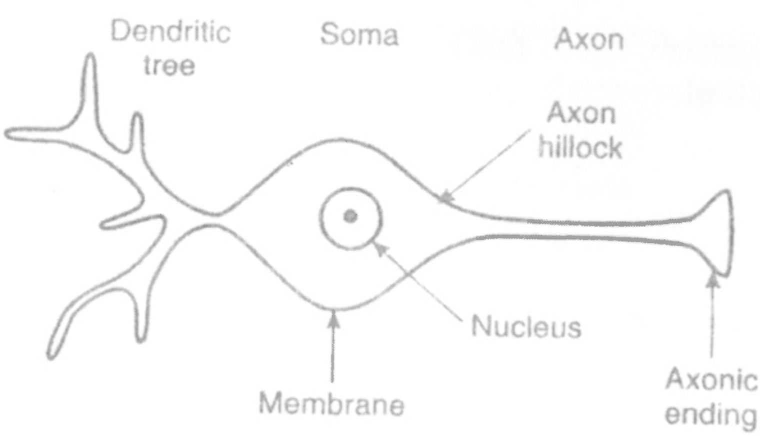


Figure 3.2: Parts of the Neuron

Dendrites are bunched into highly complex "dendritic trees". Dendritic trees are connected with the main body of the nerve cell, the Soma. The soma has a pyramidical or cylindrical shape. The outer body of the cell is the membrane. The interior of the cell is filled with intercellular fluid and out side the cell is with extracellular fluid. The neurons membrane and substances inside and outside the neuron play an important role in its operation. When excited above a certain level, the threshold, the neuron fire. That is it transmits an electrical signal, action potential, along a signal path called axon. The axon meets the soma at the axon hillock and it ends in a tree of filamentary paths called the axonic endings that are connected with dendrites of other neurons.

The connection or the junction between a neuron's axon and another neuron's dendrite is called a synapse. In Greek synapse means the contact. A synapse consists of the presynaptic terminal, the cleft or the synaptic junction, and the postsynaptic terminal as shown in Figure 3.3.

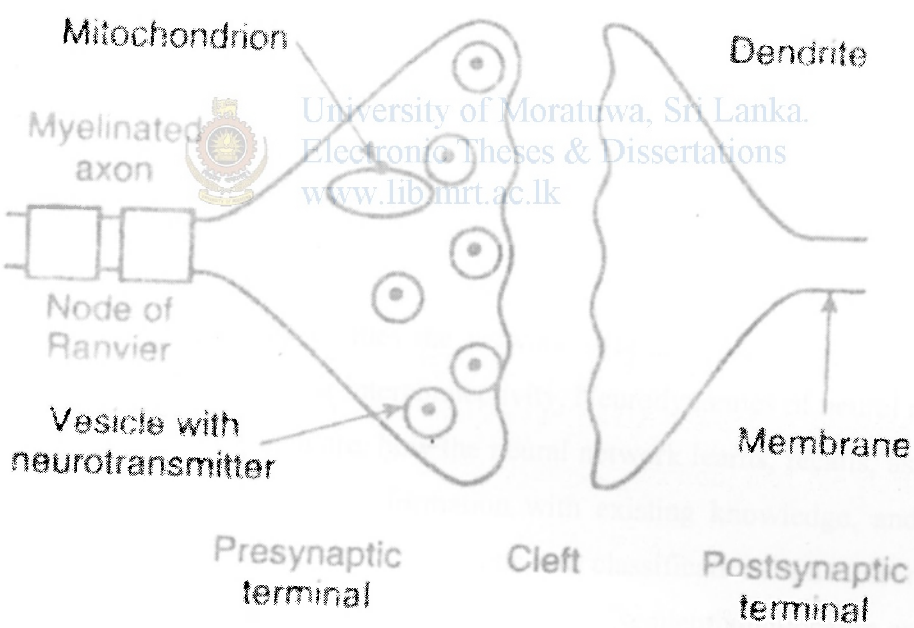


Figure 3.3: The Synapse

A single neuron may have 1000 to 10000 [7] synapse and may be connected to with some 1000 neurons. Not all the synapse are excited at the same time and according to the received sensory Pattern via the synapses probably excites a relatively small percentage of sites, an almost endless number of patters can be presented without saturating the neuron's capacity [9].

When the action potential reaches the axon ending, chemical massage known as neurotransmitters is released. The neurotransmitters are stored in tiny spherical structure called vesicles. Neurotransmitters are responsible for effective communication between neurons. The neurotransmitter drifts across the synaptic junction and initiate the depolarization of postsynaptic membrane and thus voltage across the membrane of receiving neuron, postsynaptic potential changes. Depending on the type of neurotransmitter the postsynaptic potential is excitatory (more positive) or inhibitory (more negative).

Decoding at the synapse is accomplished by temporal summation and spatial summation [9]. The total potential charge from temporal summation and spatial summation is encoded as a nerve impulse transmitted to other cell. All integrated signals are combined at the soma, and if the amplitude of the combined signal reaches the threshold of the neuron, it produces an output signal.

3.4 Artificial Neural Networks

Artificial neural networks emanate from the biological principle described above, and mathematics attempts to describe closely the biological behavior of neurons and the network. The neural network can be divided in to two as architecture and neurodynamics. Architecture defines the network structure, which is the number of neurons in the network and their interconnectivity. Neurodynamics of neural networks defines their properties, which are, how the neural network learns, recalls, associates, and continuously compares new information with existing knowledge, and how it classifies new information, and how it develops new classifications if necessary.

Information processing of neural network is not with a sequential algorithm as in most of the information processors. The information processing of neural networks is based on parallel decomposition of complex information into basic elements [5].

3.4.1 Basic Model of a Neuron

The problem is now how to model this neural network artificially. Serious attempt to create a model of a neuron have been underway during the last 100 years, and remarkable progress has been made [10]. Artificial neuron is the fundamental unit or the building block of the artificial neural network and the model is shown in the Figure 3.4. Even through the term artificial neuron is used it does not even closely describe the biological neuron.

The model artificial neuron has a set of n inputs x_j, where the subscript j takes value from 1 to n. each input x_j is weighted before reaching the main body of the processing element by the weight factor w_j. in addition it has bios term w_0, a threshold value Θ that has to be reached of exceeded for neuron to produce a signal, a linearity factor F that acts on the produced signal R, and an output O after the nonlinear function. O constitute input signal to other neurons.

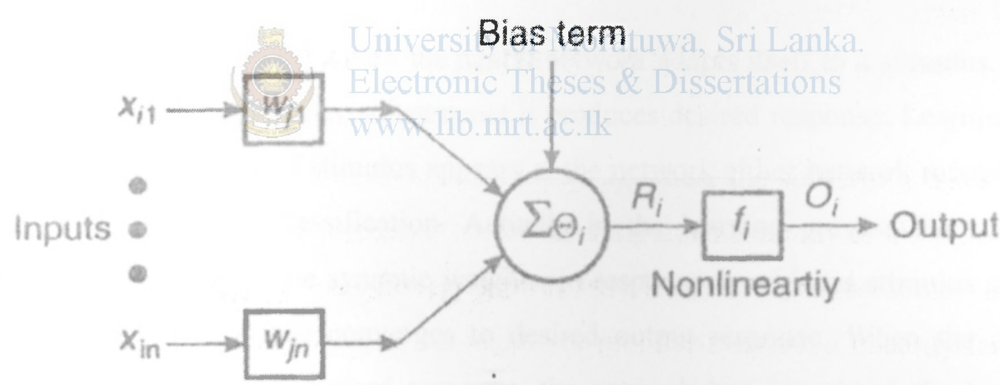


Figure 3.4: Basic Neuron Model

When a neuron is part of a network, an additional subscript, i, is needed to distinguish the neuron. Hence input, weight, activation signals, output, threshold and nonlinear function are written as x_{ij}, w_{ij}, R_i, O_i, F_i respectively.

The transfer function of the basic neuron model is described below

$$O_i = F_i\left(\sum_{j=1}^{l} w_{ij}x_{ij}\right) \quad (1)$$

The neurons firing condition is

$$\sum_{j=1}^{l} w_{ij}x_{ij} \geq \Theta_i \quad (2)$$

The purpose of having non-linearity function is to ensure that the neurons response is bounded. That is the actual response of neuron is conditioned, as a result of small or large activating stimuli is controllable. Commonly used nonlinearities are hard limiter, the sigmoid and the ramp function.

3.4.2 Learning in Artificial Neural Networks

Learning is the process by which the neural network adapts itself to a stimulus. After making the proper parameter adjustments it produces desired response. Learning is a continuous process and if stimulus appears at the network either network recognize it or it develops a new classification. Actually in the learning process the network adjusts its parameters. The synaptic weights, in response to an input stimulus so that its actual output response converges to desired output response. When the output response is same as the desired response, the network has completed the learning process.

For different structures of neural networks the learning process is not the same. As different learning methodologies suit different peoples, different learning techniques suit different artificial neural networks. Some of the common learning techniques are supervised learning, unsupervised learning, reinforced learning and competitive learning.

3.4.3 Characteristics of ANN

In the mathematical perspective the neural networks is a dynamic system that can be modeled as a set of coupled differential equations [5]. The neural networks are characterized by

1. Collective and synergistic computation
   - Program is executed collectively and synergistically
   - Operations are decentralized

2. Robustness
   - Operation is insensitive to scattered failures
   - Operation is insensitive to partial inputs or inaccurate inputs

3. Learning
   - Networks makes associations automatically
   - Program is created by the network during learning
   - Network adapts with or without a teacher

4. Asynchronous operation

3.4.4 Neural Network Topologies

As an artificial neural network consists of many neurons, the interconnectivity between neurons cast them in to different topologies. Some of the most popular topologies are shown in the Figure 3.5. Normally a network may contain an input layer, output layer and one or more hidden layers in between input and output layers. Hidden layers are so named because their outputs are not directly observable.

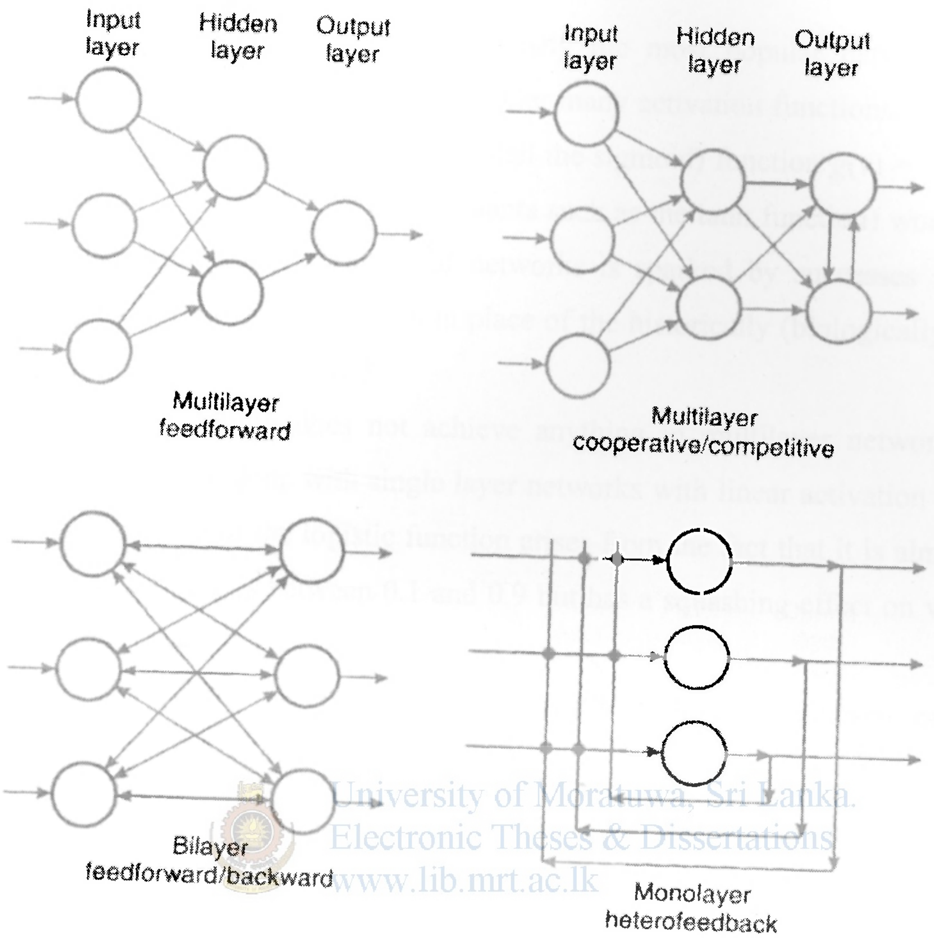


Figure 3.5: Common Neural Network Topologies

3.4.5 Single Layer Networks

Fundamental model of artificial neural networks is the network with one layer of neurons (output layer only, no hidden layers) [11]. The simplest network consists of just one neuron with the function g chosen to be the identity function, $g(v) = v$ for all v.

3.4.6 Multilayer Neural Networks

Multilayer neural networks are undoubtedly the most popular networks used in applications. While it is possible to consider many activation functions, in practice it has been found that the logistic (also called the sigmoid) function $g(v)$ = _ ev 1+ev _ as the activation function (or minor variants such as the tanh function) works best. In fact the revival of interest in neural networks is sparked by successes in training neural networks using this function in place of the historically (biologically inspired) step function (the "perceptron"}.

Using a linear function does not achieve anything in multilayer networks that is beyond what can be done with single layer networks with linear activation functions. The practical value of the logistic function arises from the fact that it is almost linear in the range where g is between 0.1 and 0.9 but has a squashing effect on very small or very large values of v.

In theory it is sufficient to consider networks with two layers of neurons, one hidden and one output layer. This is certainly the case for most applications. There are, however, a number of situations where three and sometimes four and five layers have been more effective. For prediction the output node is often given a linear activation function to provide forecasts that are not limited to the zero to one range. An alternative is to scale the output to the linear part (0.1 to 0.9) of the logistic function. Unfortunately there is no clear theory to guide us on choosing the number of nodes in each hidden layer or indeed the number of layers. The common practice is to use trial and error, although there are schemes for combining optimization methods such as genetic algorithms with network training for these parameters. Since trial and error is a necessary part of neural network applications it is important to have an understanding of the standard method used to train a multilayered network: back propagation. It is no exaggeration to say that the speed of the back propagation algorithm made neural nets a practical tool in the manner that the simplex method made linear optimization a practical tool. The revival of strong interest in neural nets in the mid 80s was in large measure due to the efficiency of the back propagation algorithm.

3.4.7 The Backward Propagation Algorithm

There is a minor adjustment for prediction problems where we are trying to predict a continuous numerical value. In that situation we change the activation function for output layer neurons to the identity function that has *output value=input value*. An alternative is to rescale and recenter the logistic function to permit the outputs to be approximately linear in the range of dependent variable values. The back propagation algorithm cycles through two distinct passes, a forward pass followed by a backward pass through the layers of the network. The algorithm alternates between these passes several times as it scans the training data. Typically, the training data has to be scanned several times before the networks "learns" to make good classifications.

4 Development of the Tire Inflator Model

4.1 Tire Inflator Model

The model of a microcontroller based tire inflator was developed in the lab. The main parts of the inflator are the controller, the pressure sensor, the 5/3 pneumatic valve, the LCD screen, push buttons and the hose and the tire connector as shown in the Figure 4.1.

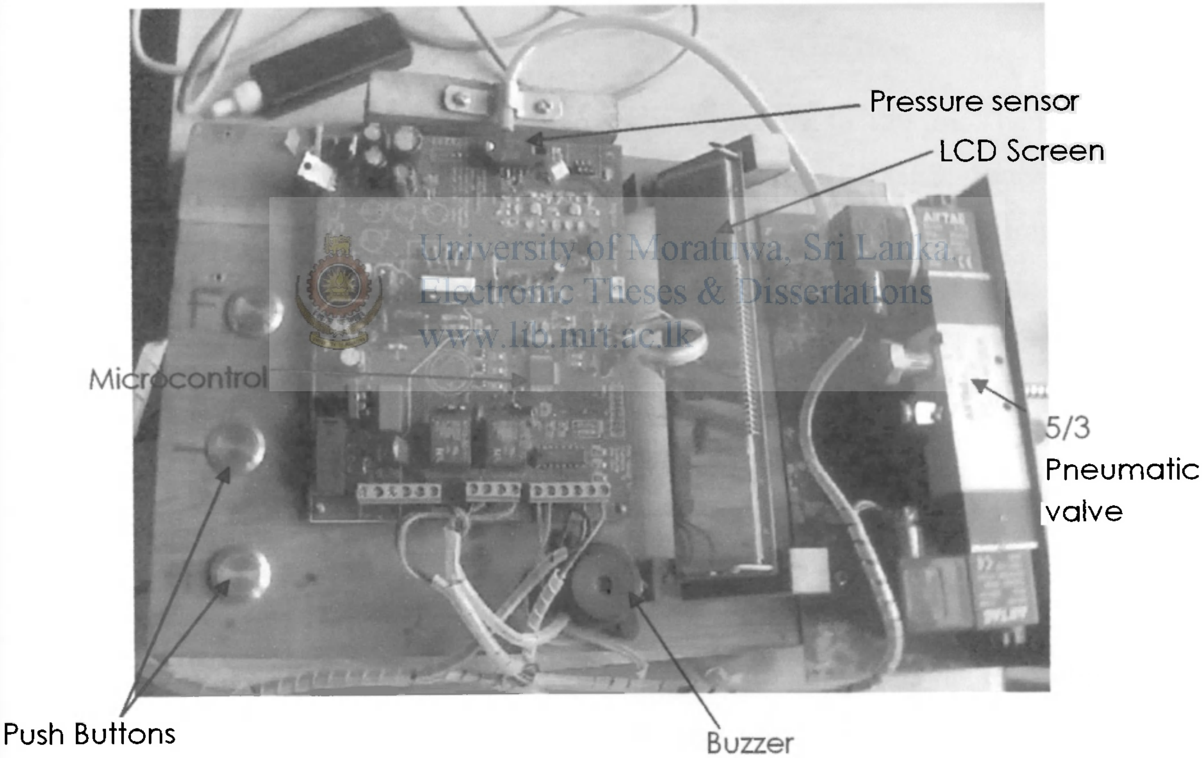


Figure 4.1: The Tire Inflator Hardware.

4-1-1 The Microcontroller

The microcontroller used for the tire inflator is PIC16F877 and it is used to have required number of inputs and outputs. The analog to digital convertor available in the PIC 16F877 is an extra advantage.

4.1.2 The pressure sensor

Figure 4.2: SX150 Pressure Sensor.

The working pressure range of the tire inflator is form 0 psi to 150 psi. The pressure sensor selected is the SX150 which is from SX Pressure SERIES, SenSym ICT (Appendix B). The other features that considered are the Low Cost, High-Impedance Bridge, Low Noise and Low Power Consumption. The additional advantage is the pressure sensor is capable for bath Absolute and Differential (Gauge) pressure measurements.

4.1.3 Pneumatic valve

The pneumatic valve selection was based on the pressure range and the capability of both inflation and deflation function. Even through only 3 hoses connected to the valve, to have the functionality expected 5/3 valve has to be selected. 5/3 valve is a valve with 5 ports and 3 positions. Two solenoids used to actuate the valve and the normal position of the valve that is no power condition is all ports closed.

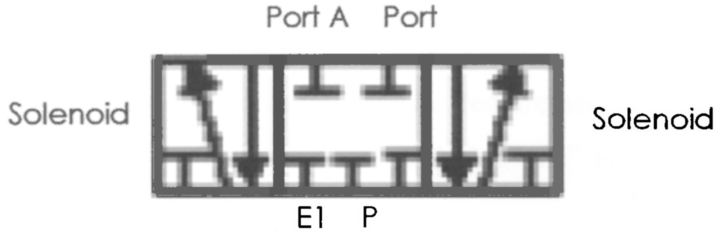


Figure 4.3: 5/3 Valve; 5 Ports, 3 Positions, Center Closed.

The pressure line from the compressor is connected to the port P, and port A is connected to the tire connector. From a "T" connection a line was taken to the pressure sensor. Port B is closed permanently using a "Pneumatic Stopper". When the solenoid 1 is actuated the pressure line is connected to the port A and to the tire and inflation starts. When solenoid 2 is actuated the port A connected to Exhaust 1 (E1) and deflation starts. To avoid over deflation due to high pressure difference, that is pressure difference between tire and the atmosphere is taken as zero, E1 is connected to a flow control mechanism.

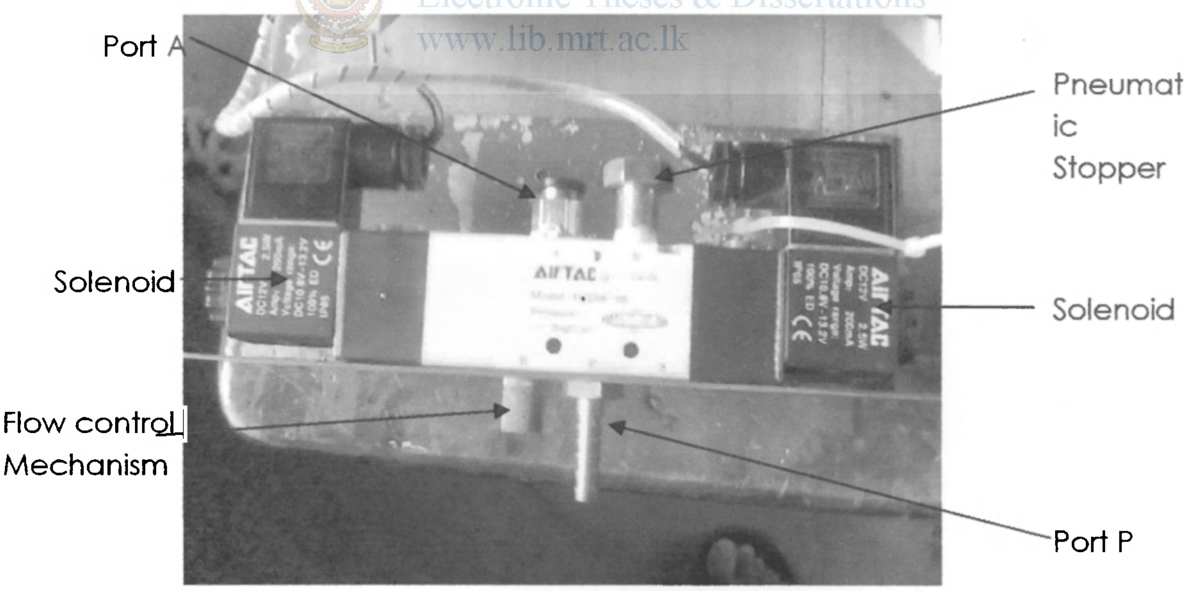


Figure 4.4: Port Allocation of the Valve

The selected valve 24V ac operated one with port size ½" (Appendix C).

4.1.4 LCD Screen

The LCD screen was designed according to the requirements. There are 3 digits available in 1" width to indicate the pressure and also "psi" is displayed at the end (Appendix D).

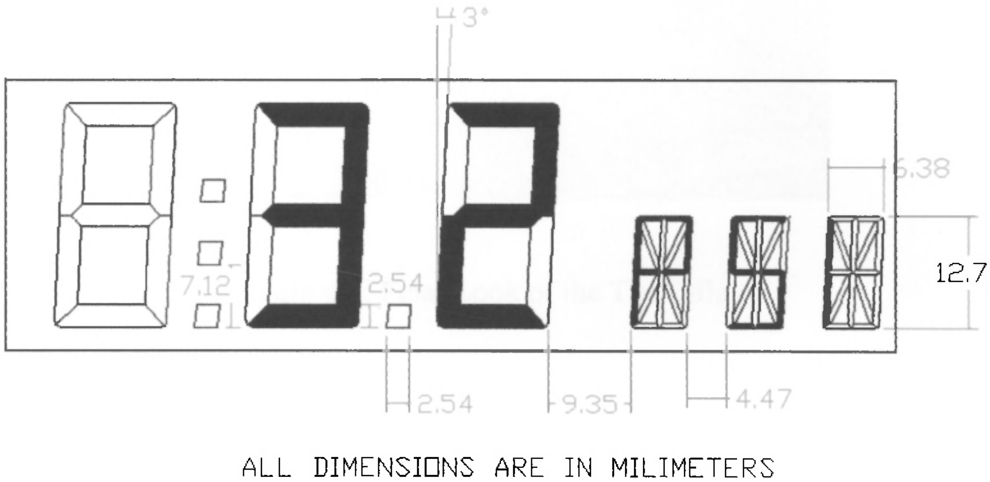


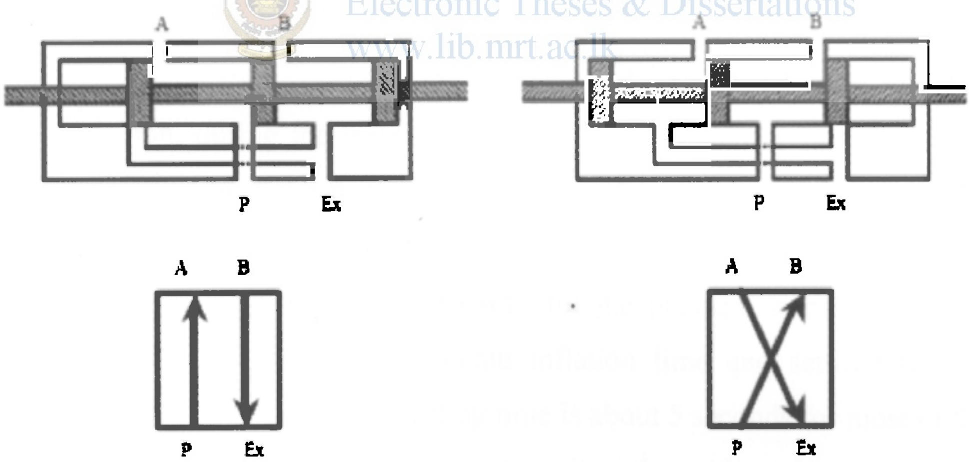
Figure 4-5: The LCD Display

The enclosure of the tire inflator must be with the IP standards and it is made with fiberglass as shown in Figure 4.6. The final look if the tire inflator is shown in the Figure 4.7.

Figure 4.6: Fiberglass Enclosure

Figure 4.7: Final Look of the Tire Inflator

4.2 Working of the Tire Inflator



(a) Inflation (b) Deflation

Figure 4.8: Valve Positions

When the tire connector is connected to the tire, the hose up to the valves port A get filled with pneumatics. The pressure sensor is in between port A and tire and the pressure at tire can be obtained by the pressure sensor. If the pressure is higher than 5 psi the tire inflator recognize it as tire and starts the working cycle (Appendix E). Normally pressure sensor reads the ambient pressure and to start inflation the pressure value of 5 psi used. Some tire inflators available use this technique to start cycle and some provide a start button to start the cycle. The method we use is an automatic one and it is more convenient to the user. The problem with this method is when a flat tire is to be inflated the tire inflator do not recognize it. Hence separate button is provided to start the cycle for flat tires.

Ones the tire inflator identified the presence of tire the tire inflator reads the tire pressure and the set value of the inflator. Set value is the value entered by the user. By comparing the two values the controller decides whether to inflate, deflate or to stop the operation (Appendix E). If the controller reads a pressure value higher then the set value it actuates the pneumatic valve through a relay. The valve position is shown in Figure 4.8(a) and now the pressure port is connected to the tire that is inflation starts. If the measured pressure is lesser than the set value the controller actuate the valve in the other way as shown in Figure 4.8(b) so that the tire is connected to the exhaust that is deflation starts. If the set pressure is equal to the measured pressure the controller indicate it and stop the operation.

In the operation, during the inflation what the pressure sensor reed is the dynamic pressure, which is higher than the static pressure that we looking for. Hence the tire inflator to get the pressure value the inflation has to be stopped. Soon after stopping reading is not possible, since have to wait till the pressure stabilizes as shown in Figure 1.3. The total cycle time contain inflation time and settling time. In the experiments we observed that the settling time is about 5 seconds for most of the tires. To make the machine faster it is required to reduce the settling time and increase the inflation time. To reduce the setting time the pressure wave dampers has to be introduced. The pressure wave dampers are normally expensive and make the machine a marketable one alternate solution has to be introduced.

As the next alternative is to increase the inflation time, there is a risk since tires may reach a high pressure values which may damage the tire. Smaller tires reach higher pressures quickly due to small volume. But large tires increases pressure slowly. To apply the solution accurate tire identification process must be introduced. After tire identification the inflation time have to be decided considering several factors.

1. The volume of the tire
2. Error with the set value.

4.3 Tire Identification

Identification is done according to three inputs the controller gets. One is the initial pressure value of the tire. As the connector is connected to the tire the real value of the tire pressure is obtained. To identify the volume of the tire the second suggested input is to inflate for a "t" time and get the pressure rise. In the Table 4.1 the rise of the pressure of several tire types for an inflation time of 0.25s was given approximately. A clear deviation can be observed as shown in Figure 4.9. The third input is the error value with the set value which is entered by the user.

Table 4.1: Pressure Rise of Several Tires for an Inflation Time of 0.25 s.

Tire Type	Pressure rise for 0.25 s Inflation	Category
3 Wheeler	5	Small
Motor Bike	3	
Car	1	Medium
Van	0.8	
Buss	0.1	Large
Lorry	0.1	

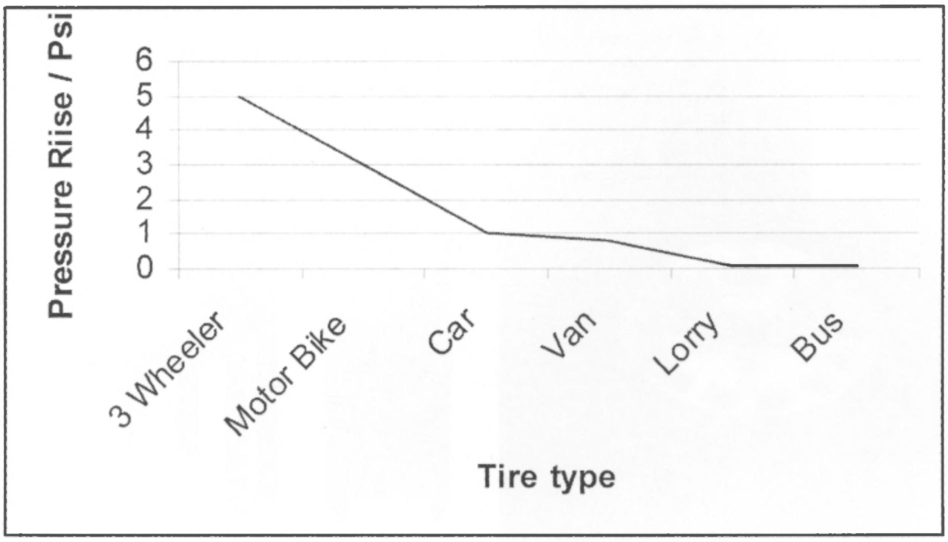


Figure 4.9: Variation of Pressure Rise for Several Tire Types

4.4 Simple On-Off Algorithm

Initial testing was done using a simple on off algorithm. The initial pressure was observed and by comparing with the set value the controller decides to inflate or to deflate. The inflation time is fixed and it is very low to avoid high pressure risk for small tires. Hence the inflation for large tires is very slow and inefficient. The inflation time was set to 0.25 s and the pressure rise in a small tire for this time period is more than 5 psi as shown in the Figure 4.9. But the rise in a large tire is as less as 0.1 psi.

The increase of inflation time to 1 s is risky. That is pressure rise for 1 s in a small tire is about 25 psi and if the starting pressure is more than 20 psi the tire may blow off. In motor bike tires the maximum pressure value is about 45 psi and there is a certain risk of reaching that value. Hence a reliable tire identification system must be developed for tire inflators.

4.5 Tire Identification Systems

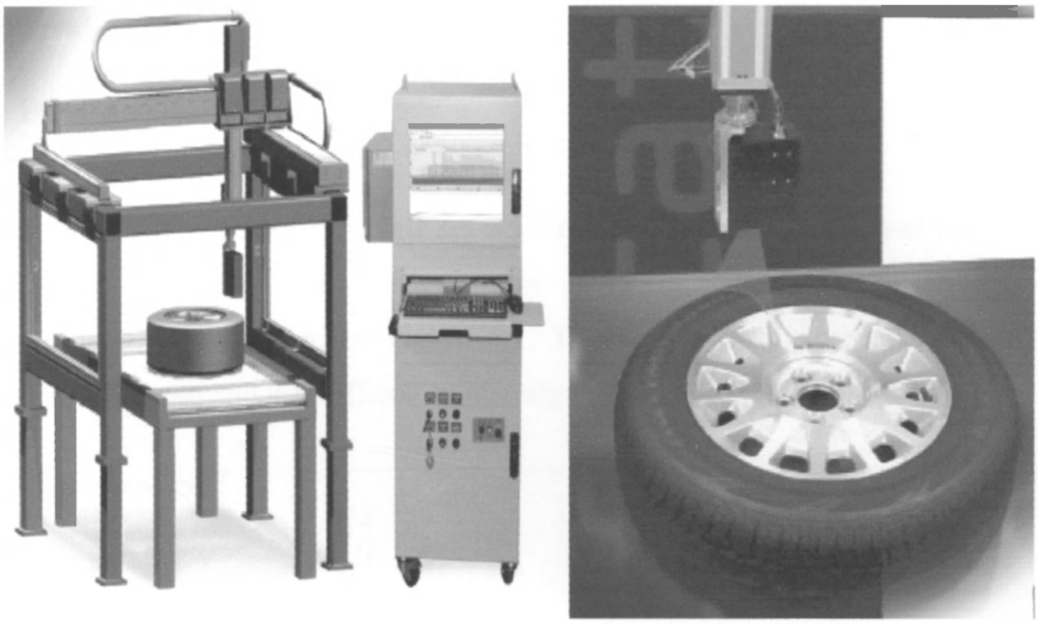


Figure 4.10: IR tire identifier

The technique used to identify tire is using an infrared scanning. Infrared beam is used to read the side wall of the tire and using image processing techniques, the tire is identified as shown in Figure 4.10 (Appendix F).

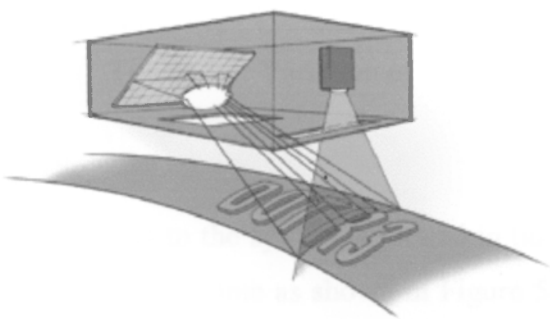


Figure 4.11: IR Scanning

This method is not suitable for tire inflators since it is not an online method. In the available model the tire has to be removed from the vehicle and place on the machine to scan it as shown in Figure 4.11. Tire inflator must be able to finish the task as quickly as possible and the off line method here may be suitable for a tire manufacturing process. On line method has to be developed and for that the data analysis is discussed below.

5 Neural Network Model

5.1 Data Analysis

Using four different tire types, data set was collected and tried to analyze the data to find a method to identify the tires accurately. By using different tire types the inputs were plotted as shown in the Figure 5.1. The inputs show clear intersection for different tire types and it is difficult to identify the tires directly.

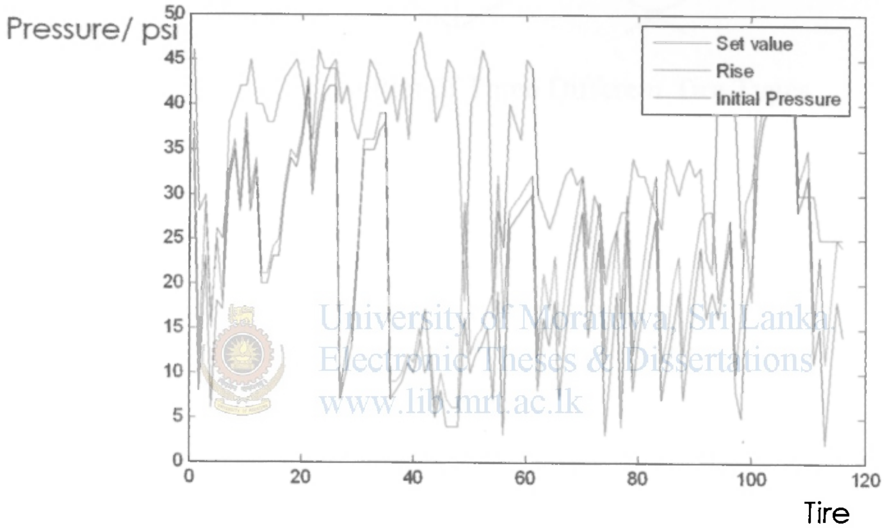


Figure 5.1: Variation of Inputs

For a single tire, the three inputs to the system is plotted in three dimensional spaces and there is a clear intersection available as shown in Figure 5.2. Three input values are taken in three axes's and yellow points are the three wheel tire and purple points are the car tires and blue points are the van tires.

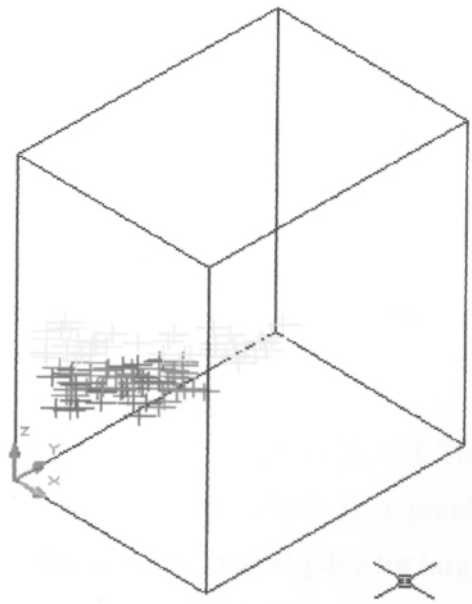


Figure 5.2: The Plot of Three Different Tire Types

The experiment was repeated with data set from four different tire types, three wheel tires, motor bike tire, car tire and van tire.

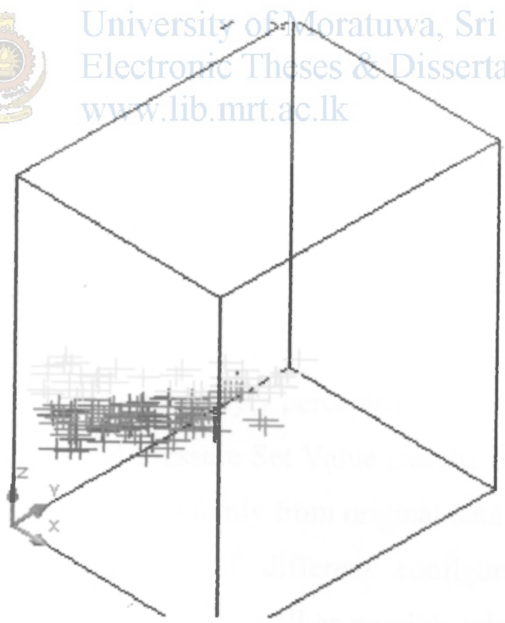


Figure 5.3: The Plot of Four Different Tire Types

Now the intersection of the data set is more complex. For tire identification an artificial neural network is suggested. The extra advantages of neural networks as discussed in the previous chapter encourages for the selection. Neural network have found profound success in the area of pattern recognition. By repeatedly showing a neural network inputs classified into groups, the network can be trained to discern the criteria used to classify, and it can do so in a generalized manner allowing successful classification of new inputs not used during training [12].

5.2.1 Experiments with Artificial Neural Network

Initial test was carried out for a simple perceptron [5, 13]. This design has not showed good results for an acceptable data set. There is a problem associated with the perceptron model. The proposed model must eligible for large knowledge acquisition. A single perceptron is not nearly enough for this problem.

Multilayer perceptron is an artificial neural network composed of many simple perceprones in a hierarchical structure forming a feed forward topology with one or more layers between the input and output layers. The number of hidden layers and the number of neurons per layer are not fixed. Each layer may have a different number of neurons depending on the application.

Back propagation learning algorithm [5, 6] is used as the learning algorithm in the multilayer neural network.

5.2.2 Three Input MPL

Initial testing was carried out for a multilayer perceptron is based on three inputs, for Initial Pressure, Pressure Rise and Pressure Set Value and the out put is the tire type. Also the training data set was taken randomly from original data set.

The design was tested for number of different configurations of multilayer perceptrons. The network is maintained as small as possible while keeping the ability to adapt for new data items may available in the future.

The input voltages of the pressure sensor are the inputs to the network and those are analog signals. An analog to digital converter is used to convert the analog signal to digital signal. Since the three inputs not available at once a memory has to be introduced.

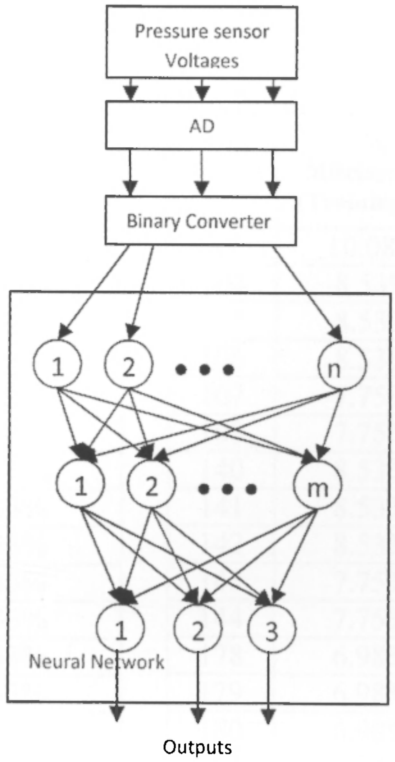


Figure 5.4: Architectural design of the system

5.3 Network with a Single Hidden Layer

The table 5-1 shows one of the results obtained from the three input neural network, which having only one hidden layer. The input layer consists of 3 neurons and in the hidden layer two neurons available and in the output layer contains 4 neurons.

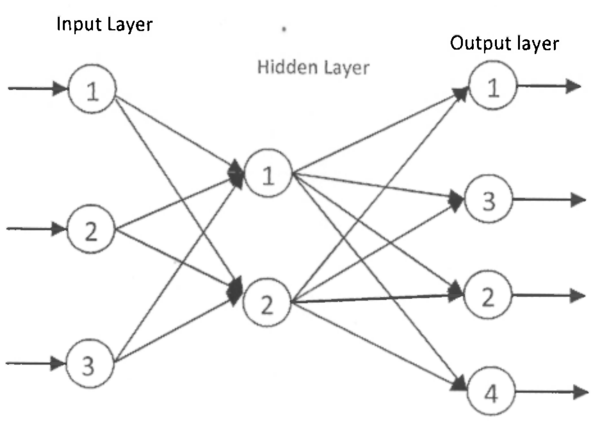


Figure 5.5: Network Model with One Hidden Layer

Table 5.1: Misclassified Percentages for Network with Single Hidden Layer

Iteration	% Misclassified (Training Set)	% Misclassified (Validation Set)
1	58.14%	40.00%
2	58.14%	40.00%
3	58.14%	40.00%
4	44.96%	26.67%
5	43.41%	26.67%
6	39.53%	20.00%
7	36.43%	20.00%
8	33.33%	13.33%
9	28.68%	13.33%
34	21.71%	13.33%
35	18.60%	13.33%
36	17.05%	13.33%
37	17.05%	13.33%
45	13.18%	6.67%
46	13.18%	6.67%
47	12.40%	6.67%
48	12.40%	6.67%
49	12.40%	6.67%
50	12.40%	13.33%
51	12.40%	13.33%
52	12.40%	13.33%
53	12.40%	13.33%
54	12.40%	13.33%
55	12.40%	13.33%
56	12.40%	13.33%
57	13.18%	13.33%
72	13.18%	13.33%
73	13.18%	13.33%
74	12.40%	13.33%
75	12.40%	13.33%
76	12.40%	13.33%
77	12.40%	13.33%
78	11.63%	13.33%
79	11.63%	13.33%
80	11.63%	13.33%
81	11.63%	13.33%
82	11.63%	13.33%
83	11.63%	13.33%
86	10.08%	13.33%
87	10.08%	13.33%
88	10.08%	13.33%
89	10.08%	13.33%
104	8.53%	6.67%
105	8.53%	6.67%
106	8.53%	6.67%
107	7.75%	6.67%
108	7.75%	6.67%
140	8.53%	6.67%
141	8.53%	6.67%
142	8.53%	6.67%
143	7.75%	6.67%
144	7.75%	6.67%
178	6.98%	6.67%
179	6.98%	6.67%
180	6.98%	6.67%
181	6.98%	6.67%
211	6.20%	6.67%
212	6.20%	6.67%
213	6.20%	6.67%
237	6.20%	6.67%
238	6.20%	6.67%
239	6.20%	6.67%
265	5.43%	6.67%
266	5.43%	6.67%
267	5.43%	6.67%
268	5.43%	6.67%
269	5.43%	6.67%
270	5.43%	6.67%
271	5.43%	6.67%
272	5.43%	6.67%
281	5.43%	6.67%
282	5.43%	6.67%
283	5.43%	6.67%
284	5.43%	6.67%
291	4.65%	6.67%
292	4.65%	6.67%
295	4.65%	6.67%
296	4.65%	6.67%
297	4.65%	6.67%
298	4.65%	6.67%
299	4.65%	6.67%
300	4.65%	6.67%

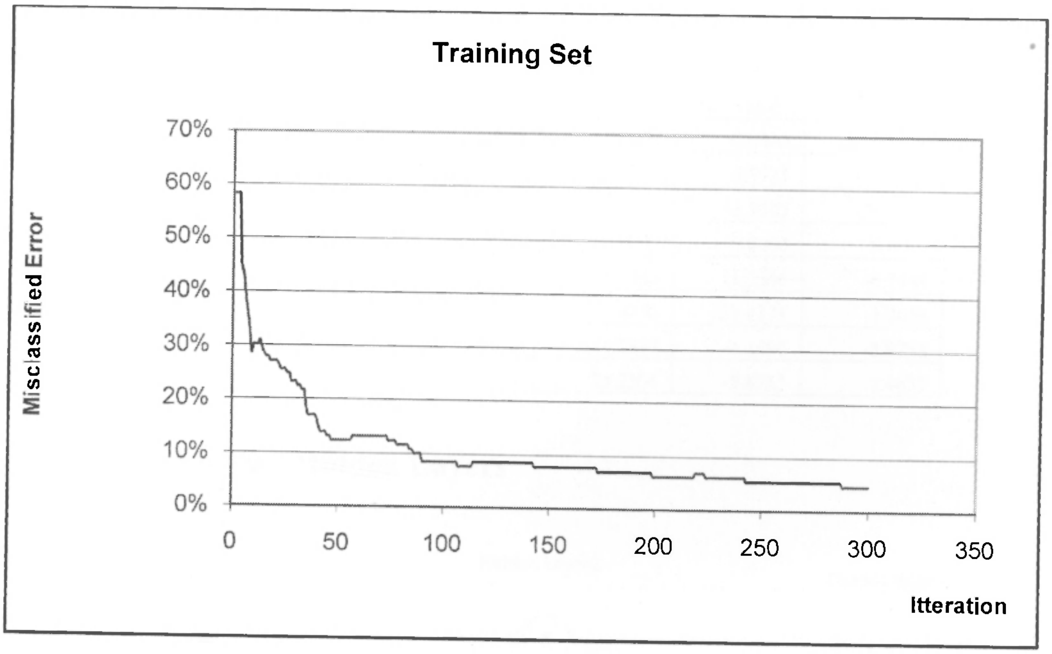


Figure 5.6: Variation of Percentage Misclassified Error for Training Set with Number of Iterations for Network with One Hidden Layer.

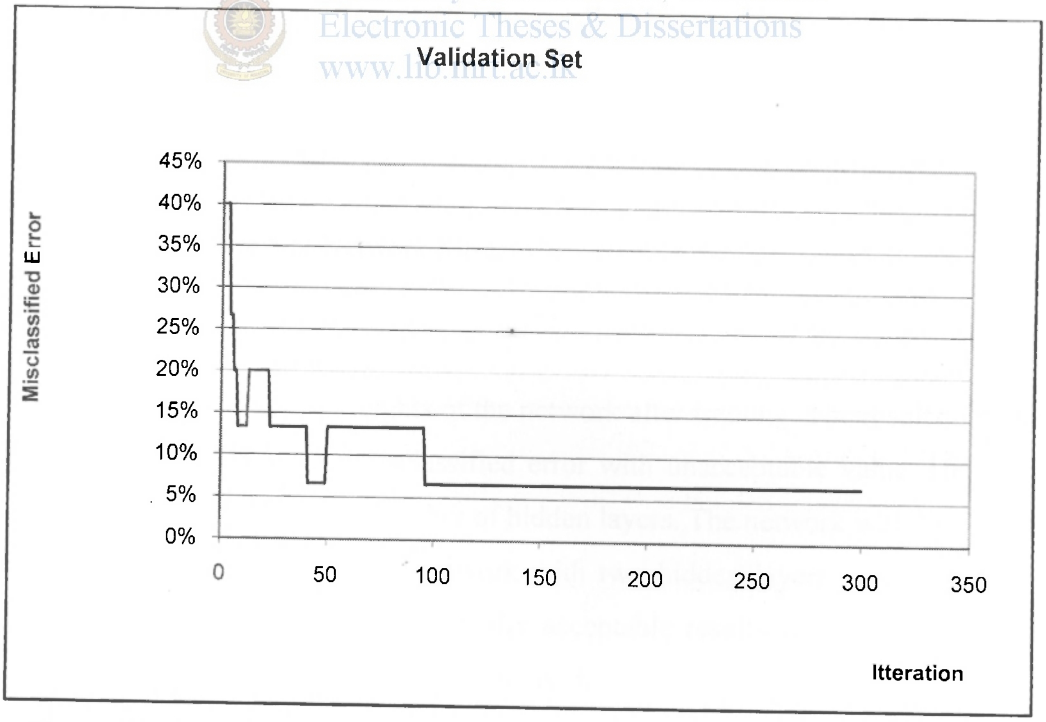


Figure 5.7: Variation of Percentage Misclassified Error for Validation Set with Number of Iterations for Network with One Hidden Layer.

Table 5.2: The Final Network Weights

	Bias	Initial Pressure	Set Value	Pressure Rise
Hidden Layer 1_bias	0.0000	0.0000	0.0000	0.0000
Hidden Layer 1_Neuron1	8.8949	-0.5282	4.5123	-16.7135
Hidden Layer 1_Neuron2	5.1024	-3.4545	13.2085	-26.7500
Output Layer bias	0.0000	0.0000	0.0000	0.0000
Output Layer_Neuron1	-8.5622	1.7583	11.7546	-6.7484
Output Layer_Neuron2	-1.8779	3.8150	-21.4371	1.2653
Output Layer_Neuron3	4.0379	-14.0837	-4.3990	-8.9758
Output Layer_Neuron4	-17.9411	21.2304	-5.8783	1.4652

5.4 Network with Two Hidden Layers

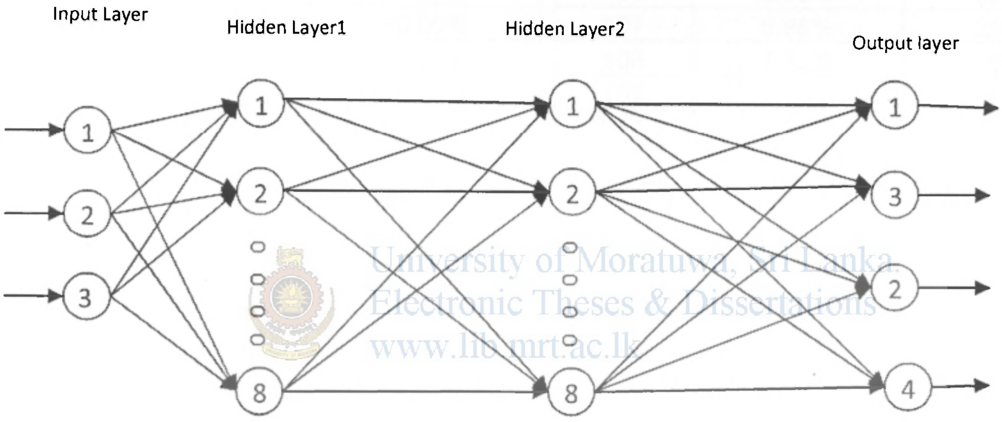


Figure 5.8: Network Model with Two Hidden Layers.

The Table 5.2 shows the final weights of the network after training. The results obtained are not acceptable. There is a misclassified error with unacceptable value. Hence the problem was tried increasing the number of hidden layers. The network with two hidden layers showed improved results. A network with two hidden layers was tested while changing the number of neurons and finally acceptable results were obtained with a network having eight neurons in each hidden layer.

Table 5.3: Misclassified Percentages for Network with Two Hidden Layers

Iteration	% Misclassified (Training Set)	% Misclassified (Validation Set)
1	55.81%	60.00%
2	55.81%	60.00%
3	55.81%	60.00%
4	44.96%	53.33%
5	31.01%	46.67%
8	26.36%	46.67%
12	23.26%	46.67%
13	22.48%	40.00%
17	21.71%	46.67%
18	21.71%	40.00%
19	21.71%	40.00%
24	18.60%	40.00%
25	19.38%	33.33%
31	17.83%	33.33%
32	14.73%	33.33%
33	13.95%	26.67%
40	13.18%	33.33%
41	15.50%	33.33%
42	14.73%	40.00%
46	8.53%	33.33%
47	6.98%	26.67%
48	5.43%	20.00%
49	5.43%	26.67%
50	6.98%	26.67%
51	6.20%	26.67%
52	5.43%	20.00%
53	5.43%	20.00%
59	6.98%	26.67%
60	6.20%	26.67%
61	7.75%	20.00%
62	7.75%	26.67%
69	6.98%	20.00%
70	6.98%	20.00%
71	8.53%	26.67%
72	10.85%	26.67%
73	7.75%	26.67%
76	10.08%	26.67%
77	8.53%	26.67%
78	8.53%	26.67%
79	8.53%	26.67%
88	10.08%	26.67%
89	8.53%	26.67%
90	7.75%	26.67%
91	7.75%	26.67%
92	8.53%	20.00%
93	8.53%	26.67%
94	6.98%	26.67%
95	6.98%	33.33%
96	8.53%	26.67%
97	6.20%	20.00%
98	9.30%	20.00%
99	10.85%	26.67%
106	6.98%	26.67%
107	6.98%	26.67%
108	7.75%	26.67%
109	7.75%	26.67%
110	7.75%	26.67%
111	7.75%	20.00%
112	8.53%	26.67%
113	7.75%	33.33%
119	7.75%	26.67%
120	9.30%	33.33%
129	7.75%	20.00%
130	6.98%	20.00%
137	5.43%	13.33%
138	5.43%	13.33%
139	6.98%	20.00%
141	7.75%	20.00%
142	7.75%	20.00%
150	6.20%	20.00%
151	6.20%	13.33%
152	6.98%	6.67%
153	6.20%	6.67%
154	5.43%	0.00%
155	5.43%	0.00%
156	5.43%	0.00%
157	4.65%	0.00%
158	4.65%	0.00%
159	4.65%	0.00%
160	4.65%	0.00%
161	4.65%	0.00%
162	4.65%	0.00%
163	5.43%	0.00%
166	3.88%	0.00%

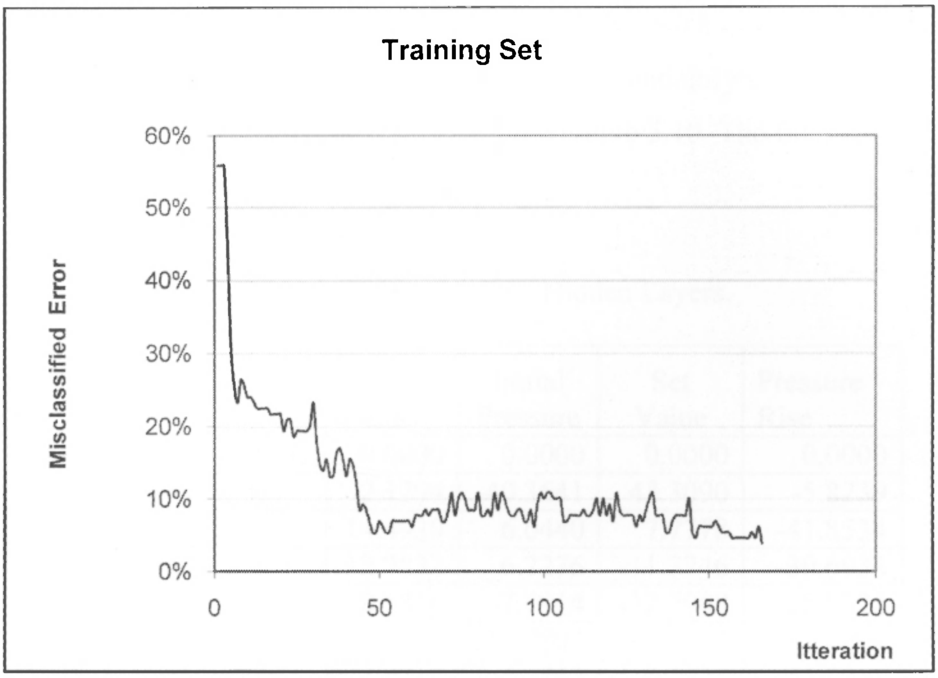


Figure 5.9: Variation of Percentage Misclassified Error of Training Set with Number of Iterations for Network with Two Hidden Layers.

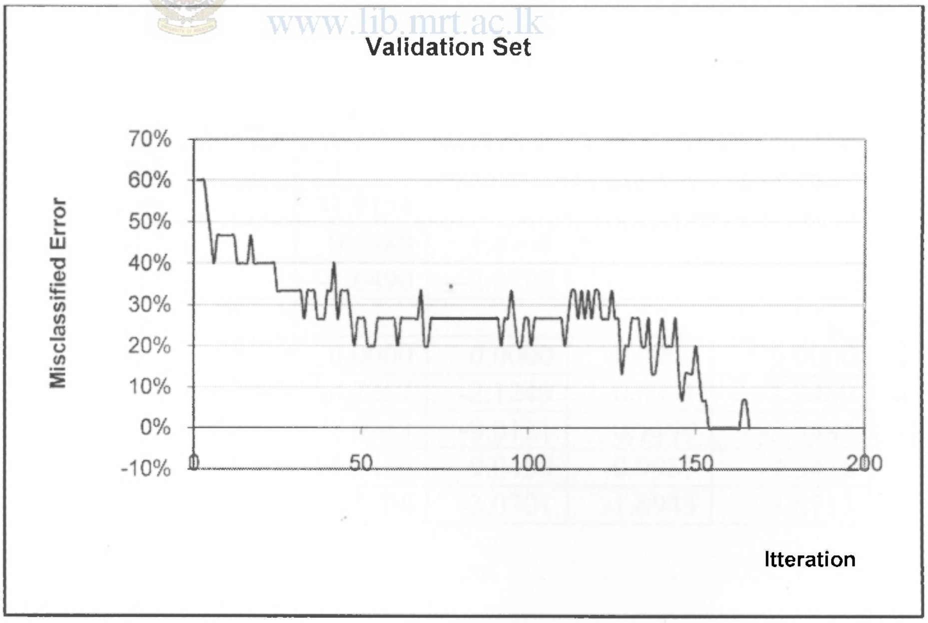


Figure 5.10: Variation of Percentage Misclassified Error of Validation Set with Number of Iterations for Network with Two Hidden Layers.

The Figure 5.9 shows the reduction of Percentage error with the number of iterations for, the training set of data. For the validation set selected randomly from the training set, the reduction of percentage error was shown in the Figure 5.10. The final weights of the network are shown in the table 5.4 below.

Table 5.4: The Weights of the Network with Two Hidden Layers.

	Bias	Initial Pressure	Set Value	Pressure Rise
Hdn1_bias	0.0000	0.0000	0.0000	0.0000
Hdn1_Nrn1	2.1294	-40.3641	43.3090	-5.8239
Hdn1_Nrn2	14.4930	6.0440	7.7778	-41.8534
Hdn1_Nrn3	12.7822	6.2276	-11.3746	-30.6933
Hdn1_Nrn4	8.6816	-7.7914	-32.7908	28.0323
Hdn1_Nrn5	14.3174	19.7503	-56.1877	31.8094
Hdn1_Nrn6	34.0317	-5.4851	-19.2936	-51.2354
Hdn1_Nrn7	1.4966	8.8614	-43.7688	23.7069
Hdn1_Nrn8	5.3311	1.0419	13.4489	-15.8733
Hdn2_bias	0.0000	0.0000	0.0000	0.0000
Hdn2_Nrn1	-0.3951	-2.1038	-4.1105	-3.9292
Hdn2_Nrn2	-0.4401	0.7048	-0.6291	-0.5194
Hdn2_Nrn3	-2.1541	1.5927	6.8154	4.6622
Hdn2_Nrn4	-0.3304	2.4992	0.5586	0.7975
Hdn2_Nrn5	-1.1079	5.5634	3.9045	0.1310
Hdn2_Nrn6	-1.9154	-1.0563	2.5557	2.4433
Hdn2_Nrn7	0.4988	1.8968	-5.7606	-3.9696
Hdn2_Nrn8	-1.6490	-2.0790	-1.0230	0.1499
Op_bias	0.0000	0.0000	0.0000	0.0000
Op_Nrn1	-4.7057	-2.1249	0.8371	1.2469
Op_Nrn2	1.0913	-9.0121	0.1490	-3.5484
Op_Nrn3	-4.1180	9.0450	-0.9987	-3.3435
Op_Nrn4	-0.6106	-3.0301	-1.6943	3.8713

Table 5.5: Predicted Values with Actual Values.

TRUE	Predicted			
	Van tire	Three wheel tire	Motorbike tire	Car tire
Van tire	9	0	0	0
Three wheel tire	0	1	0	0
Motor bike tire	0	0	3	0
Car tire	0	0	0	2

The model crated with two hidden layers is up to the acceptable accuracy and this network can be used to identify tires in the tire inflator. As shown in Table 5.5, the predicted values for 15 random samples from the network tally with the actual tires with zero present error. With compared to the network with only one hidden layer, the network with two hidden layers leant quickly.

CHAPTER - 6

6 Discussion, Conclusion and Future Developments

6.1 Discussion and Conclusion

The tire identification using artificial neural networks is investigated. The available methods for tire identification, such as discussed in the section 4.5 are off line methods and the mechanism is complex and expensive. The method suggested in this experiment can be including directly to an available digital tire inflator, since it incorporated to the controller of the tire inflator. The tire identification can be done either on line or off line.

The marketable tire inflators must not be too expensive and should be with a comparatively reasonable price. The suggested tire inflator with the intelligent tire identification facility does not need any other expensive mechanisms and can be marketed for a reasonable price.

The extra accuracy and reliability provided by the artificial neural network is an added advantage and hence the system is robust and durable.

In tire identification method, as an input, the pressure rise of the tire for a standard time interval is taken. Some times in the inflation operation the operator who holds the tire connector to the tire may not be holding the tire connector properly. This may end up with small pressure rise and the controller may identify the tire as a large tire. The user errors such can also be eliminated with the neural network based intelligent tire identifier.

The tire market expands rapidly these days and different tire types arrive to the market with different tire sizes more frequently. The ability of neural networks to learn is an extra advantage to adapt to the situation.

However the experiment is conducted for four different types of tires. Further data should be obtained from other tire types also and extensive training and testing will enable to improve the neural network configuration for the tire identification.

6.2 Future Developments.

The experiment was conducted for four different tire types only and it must be tested for other tire types also. Finally expected to identify the tire volume directly and to do this enormous amount of data must be collected.

After identifying the tire, the tire inflator must predict the inflation time period to achieve the set value without over inflation. The controller of the tire inflator can be developed to predict the inflation time with an advanced controller. Soon after the neural network identifies the tire the inflation time predictor can work with the help of this information. Developing a controller to achieve the set value of tire with one inflation cycle is the goal in the future.

7. References

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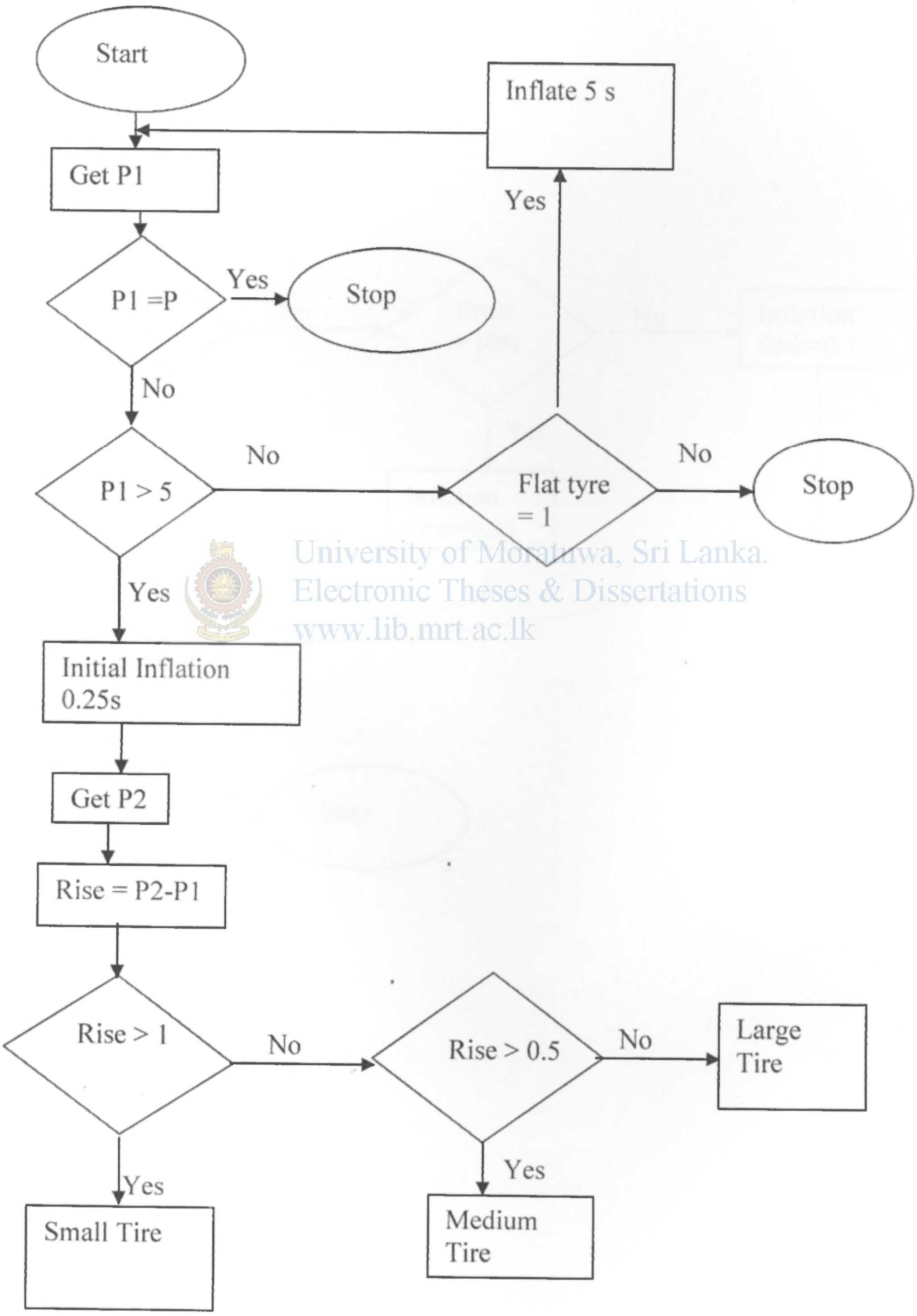
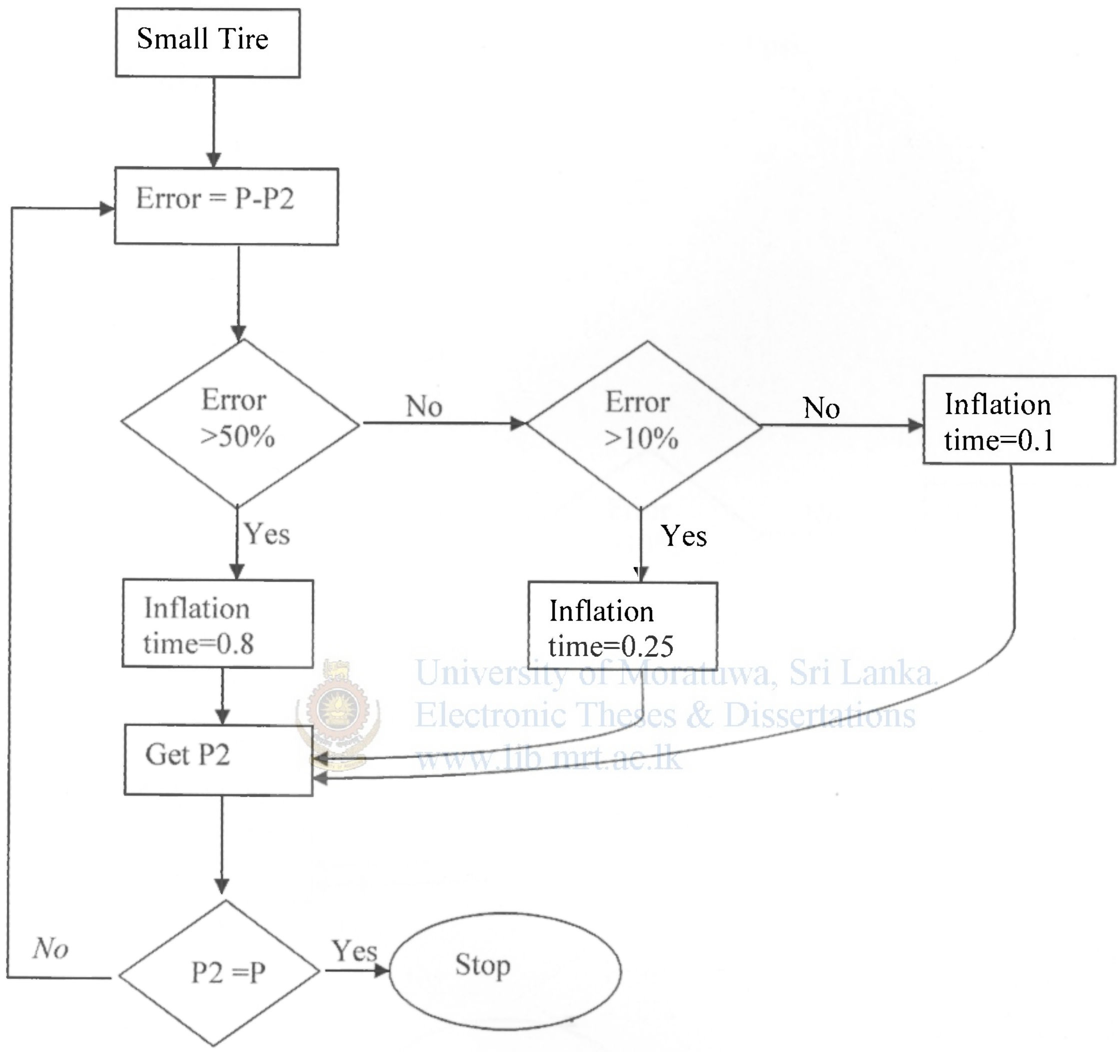
Appendix A

Algorithm for tire inflator



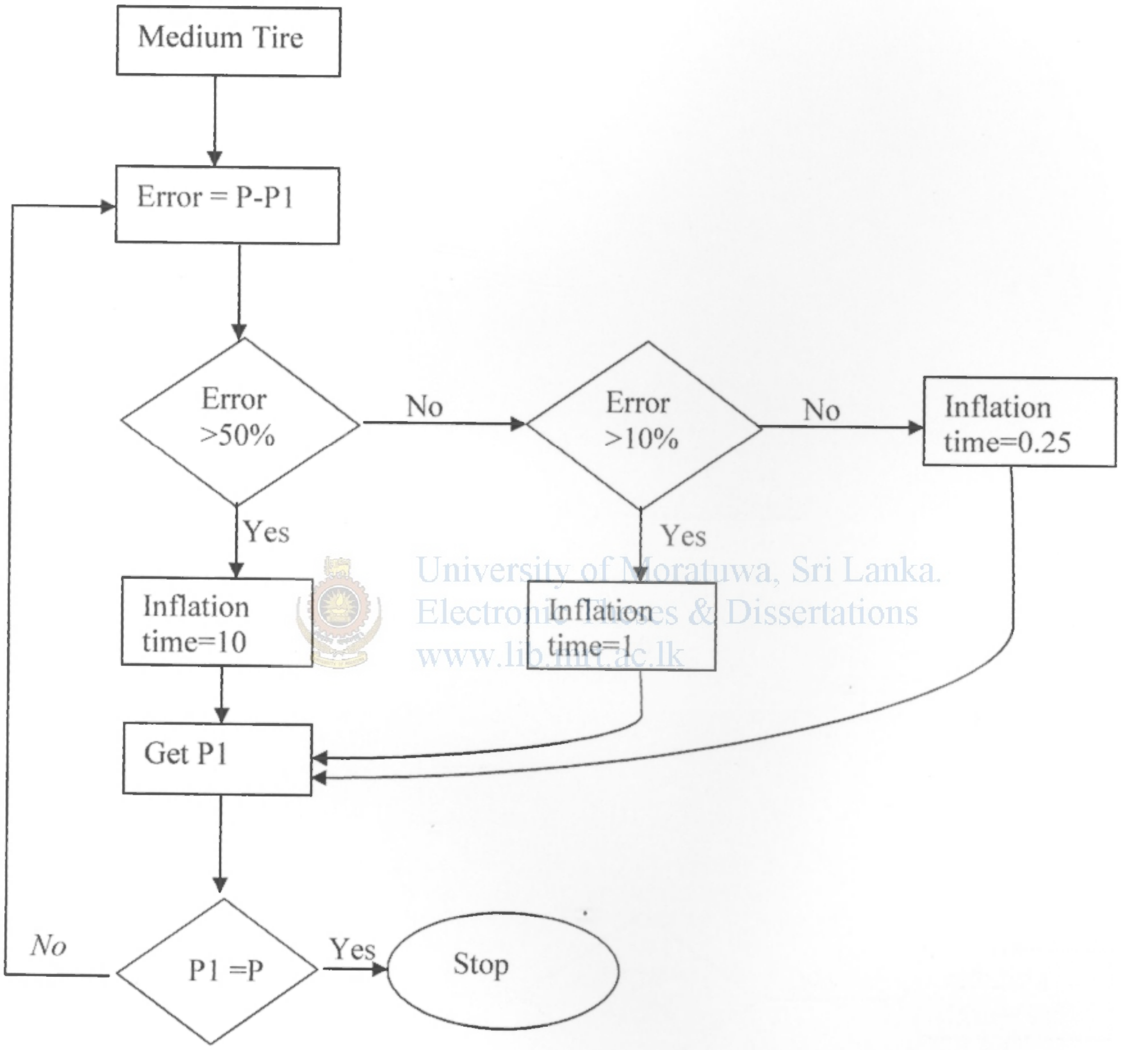
If it is small tire then the range must be 15psi to 30psi.



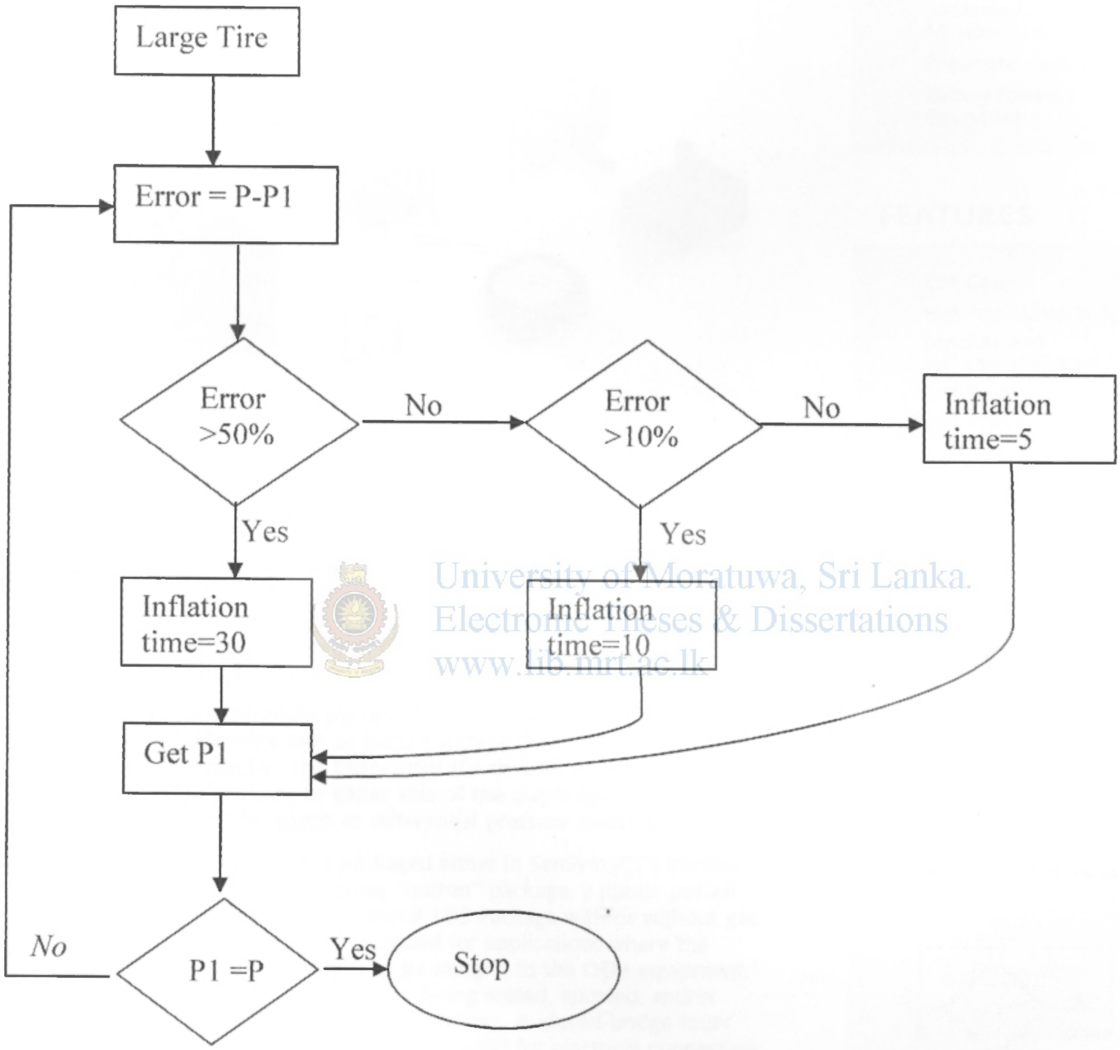
Example

P=20
Get P1, P1=15

If it is Medium tire then the range must be 30 psi to 50psi.

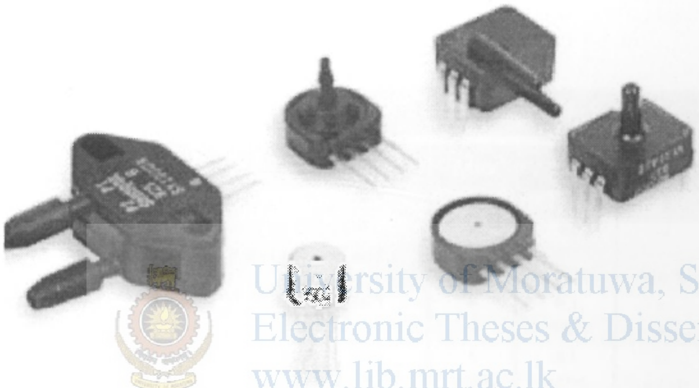


If it is Large tire then the range must be 50psi to 130psi.



Appendix B

Low Cost Pressure Sensors



The SX Series of pressure sensors provide the lowest cost components for measuring pressures up to 150 psi. These sensors were specifically designed for use with non-corrosive, non-ionic media, such as air, dry gases, and the like. Convenient pressure ranges are available to measure differential, gauge, and absolute pressures from 0 to 1 psi (SX01) up to 0 to 150 psi (SX150).

The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the diaphragm and can be used for gauge or differential pressure measurements.

This product is packaged either in SenSym ICT's standard low cost chip carrier "button" package, a plastic ported "N" package, or a metal TO5 Package with or without gel. All packages are designed for applications where the sensing element is to be integral to the OEM equipment. These packages can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting. A closed-bridge four-pin SIP configuration is provided for electrical connection to the "Button" or "N" Package. The TO5 Package offers a 5-pin open-bridge configuration. A DIP Package is also available, which mounts on a PC board like a standard IC with through-hole pins. This extremely small size package enables the use of multiple sensors in a limited available space application.

Because of its high-impedance bridge, the SX Series is ideal for portable and low power or battery operated systems. Due to its low noise, the SX is an excellent choice for medical and other low pressure applications.

Contact your local SenSym ICT representative, the factory, or go to Sensym ICT's Web site at www.sensym-ict.com for additional details.

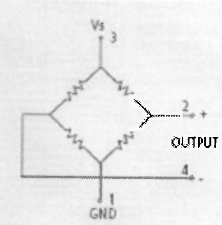
APPLICATIONS

- Medical Instrumentation
- Barometric Measurement
- Pneumatic Controls
- Battery Powered Equipment

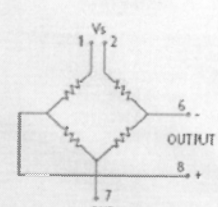
FEATURES

- Low Cost
- High-Impedance Bridge
- Absolute and Differential (Gauge)
- Low Noise
- Low Power Consumption for Battery Power

EQUIVALENT CIRCUITS



BUTTON, NIPPLE AND "N" PACKAGE



TO AND DIP PACKAGE

invensys

PRESSURE SENSOR CHARACTERISTICS

Maximum Ratings (For All Devices)

Supply Voltage, V_S	+12 Vdc
Temperature Ranges:	
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Common-Mode Pressure	150 psig
Lead Soldering Temperature (2-4 Seconds)	250°C

PERFORMANCE CHARACTERISTICS(1)

Characteristics	Min	Typ	Max	Unit
Zero Pressure Offset[5]	-35	-20	0	mV
Temperature Coefficient of Offset[6]	–	+4	–	µV/V/°C
Combined Pressure Non-Linearity and Pressure Hysteresis[3]	–	0.2	±0.5	%FSS
Long Term Stability of Offset & Span[8]	–	0.1	–	%FSS
Response Time[7]	–	100	–	µsec
Input Resistance	–	4.1	–	kΩ
Temperature Coefficient of Resistance[6]	+690	+750	+810	ppm/°C
Temperature Coefficient of Span[6]	-2550	-2150	-1900	ppm/°C
Output Resistance	–	4.1	–	kΩ
Repeatability[4]	–	0.5	–	%FSS

SX PERFORMANCE CHARACTERISTICS(1)

Part Number	Operating Pressure (psi)	Sensitivity (mV/V/psi)	Full-Scale Span[2] (mV)			Burst Pressure (psi)
		Typ	Min	Typ	Max	
SX01	0-1	4.0	15	20	25	20
SX05	0-5	3.0	50	75	100	20
SX15	0-15	1.5	75	110	150	45
SX30	0-30	0.75	75	110	150	90
SX100	0-100	0.3	100	150	200	150
SX150	0-150	0.15	75	110	150	200

*Maximum Pressure above which can cause permanent sensor failure

ORDERING INFORMATION

To order, use the following part number(s):

Pressure Range	Order Part Number				
	Button Package	Nipple Package	"N" Package	TO Package	DIP Package
0 to 1 psid or psig	SX01D	SX01DP1	SX01DN	SX01GSO	SX01GD2, SX01DD4
0 to 5 psid or psig	SX05D	SX05DP1	SX05DN	SX05GSO	SX05GD2, SX05DD4
0 to 15 psia	SX15A	SX15AP1	SX15AN	SX15AHO	SX15AD2, SX15AD4
0 to 30 psia	SX30A	SX30AP1	SX30AN	SX30AHO	SX30AD2, SX30AD4
0 to 100 psia	SX100A	–	SX100AN	SX100AHO	SX100AD2, SX100AD4
0 to 150 psia	SX150A	–	SX150AN	SX150AHO	–
0 to 15 psid or psig	SX15D	SX15DP1	SX15DN	SX15GSO	SX15GD2, SX15DD4
0 to 30 psid or psig	SX30D	SX30DP1	SX30DN	SX30GSO	SX30GD2, SX30DD4
0 to 100 psid or psig	SX100D	–	SX100DN	SX100GSO	SX100GD2, SX100DD4
0 to 150 psid or psig	SX150D	–	–	SX150GSO	–

SPECIFICATION NOTES (for all devices)

Note 1: Reference Conditions
T_A = 25°C
Supply
V_S = 5 Vdc
Common Line Pressure = 0 psig
Pressure Applied to P1

Note 2: Full-Scale Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Full-Scale Span is ratiometric to the supply voltage.

Note 3: Pressure Hysteresis - the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
Pressure Non-Linearity - the maximum deviation of measure output, at constant temperature (25°), from "best straight line" through three points (offset pressure, full-scale pressure, one-half full-scale pressure).

Note 4: Maximum difference in output at any pressure within the operating pressure range and the temperature range within 0°C to +70°C after:
a) 100 temperature cycles, 0°C to +70°C
b) 1 million pressure cycles, 0 psi to Full-Scale Span

Note 5: The zero pressure offset is 0 mV Min, 20 mV Typ and 35 mV Max for part numbers SXxxxGD2 and SXxxxDD4.

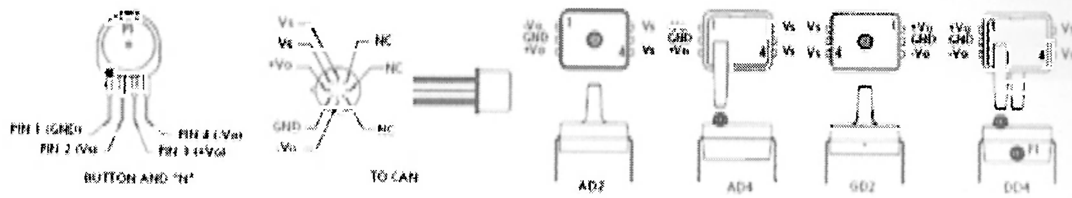
Note 6: Slope of best straight line fit from 0°C to 70°C. For operation outside this temperature range, contact factory for more information.

Note 7: Response time for a 0 psi to Full-Scale span pressure step change, 10% to 90% rise time.

Note 8: Long term stability over a one year period.

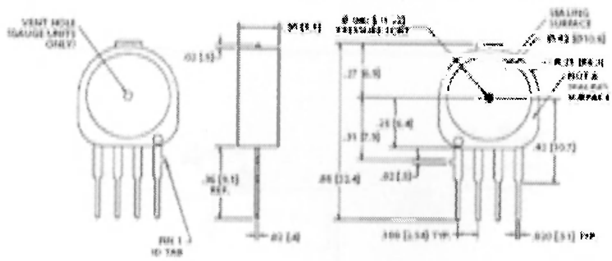
Note 9: This parameter is not 100% tested. It is guaranteed by process design.

ELECTRICAL CONNECTIONS

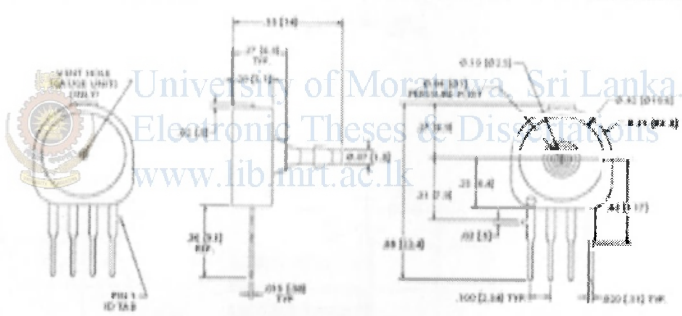


PACKAGE OUTLINES

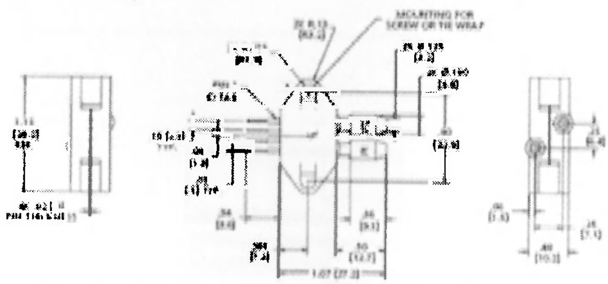
Button Package



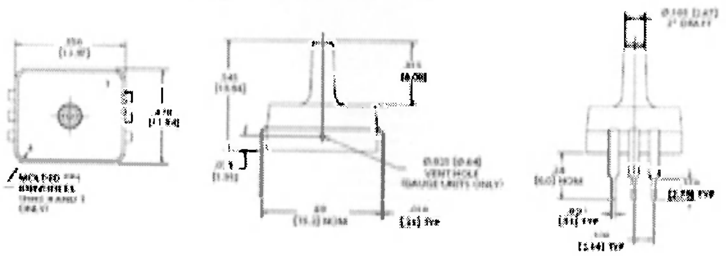
Nipple Package



N Housing Package

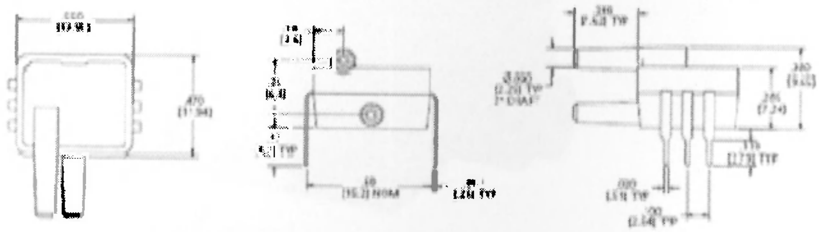


D2 Dip Package

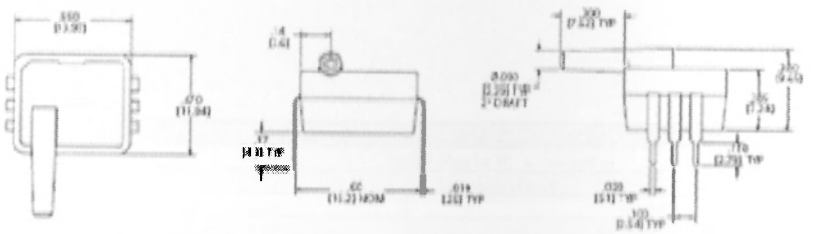


PACKAGE OUTLINES (con't)

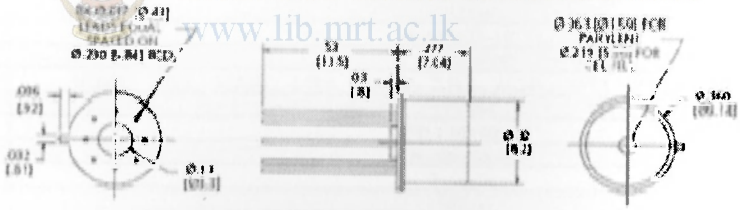
DD4 Dip Package



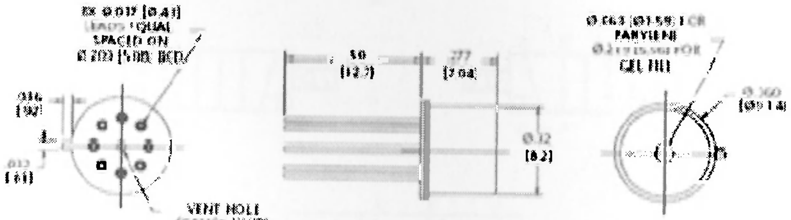
AD4 Dip Package



TO5 Package



TO39 Package

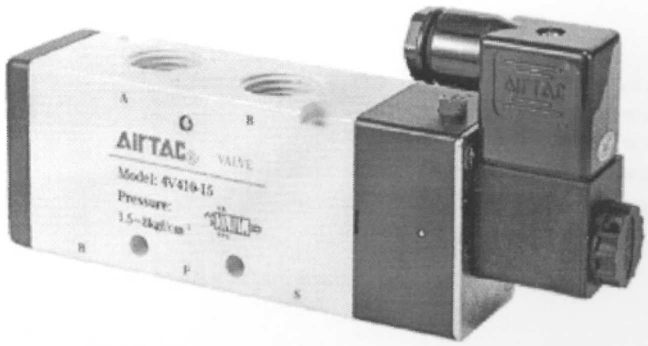


invensys
Sensor Systems

T 408 954 6700
FAX 408 954 9458
SenSym ICT
1804 McCarthy Boulevard
Milpitas, CA 95035
www.sensym-ict.com

Appendix C

4V400 Series Solenoid Valve(5/2 5/3 way)

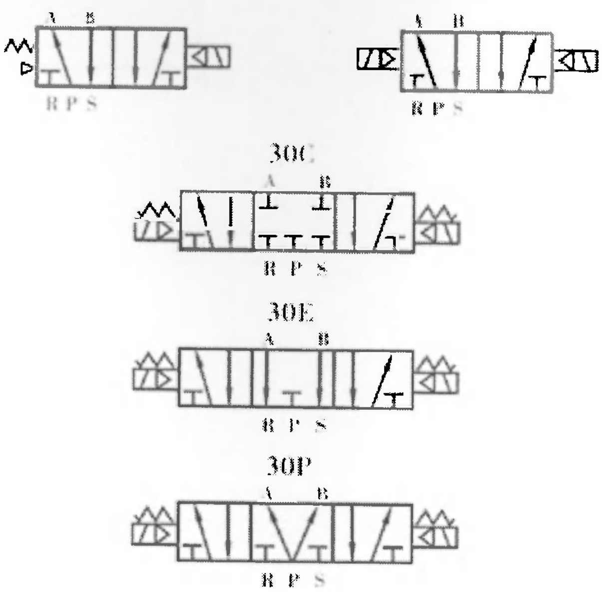


Product Information

Specification:

Item/Type	4V410-15	4V420-15	4V430C-15	4V430E-15	4V430P-15
Fluid	Air (be filtered by 40 μm element)				
Operation	Internally piloted				
Valve type	5 port 2 position		5 port 3 position		
Orifice size	50mm²(Cv=2.79)		30mm²(Cv=1.68)		
Port size	In=Out=Exhaust=1/2"				
Lubrication	Not required				
Pressure range	1.5~8.0bar				
Proof pressure	12 bar				
Temperature	-5~60℃(23~140℉)				
Voltage range	-15%~+10%				
Power consumption	AC380V: 2.5VA, AC220V: 2.0VA, AC110V: 2.5VA, AC24V: 3.5VA, DC24V: 3.0W, DC12V: 2.5W				
Insulation	F class				
Protection	IP65 (DIN40050)				
Connection	Socket with plug				
Max frequency	3 cycle/sec				
Min activating time	0.05 sec				
Weight	590g	770g	770g	770g	770g

Symbol:



Ordering code:

4V 4 10 — 15 — AC110V

Model

4V: 5 port 2 (3) position solenoid valve

Code

4: 400 Series

Valve type

10: Single solenoid 5/2 way
20: Double solenoid 5/2 way
30C: Double solenoid 5/3 way closed center
30E: Double solenoid 5/3 way exhaust center
30P: Double solenoid 5/3 way pressure center

Port size

15:1/2"

Voltage

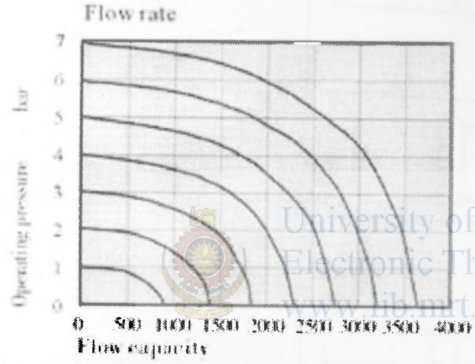
DC12V
DC24V
AC24V 50
AC110V 50
AC220V 50
AC380V 50

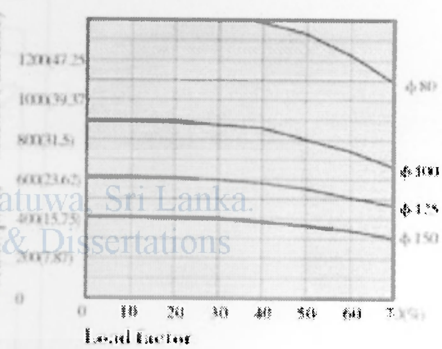
※ Note Please refer to page 272 for manifold type and ordering.

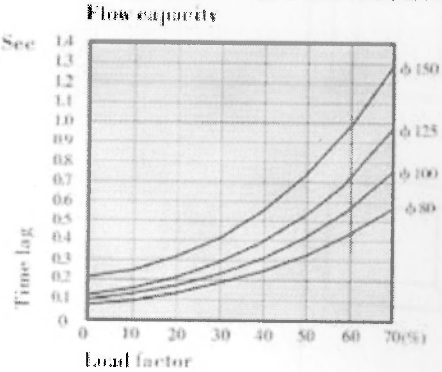
Characters:

Flow characteristics:

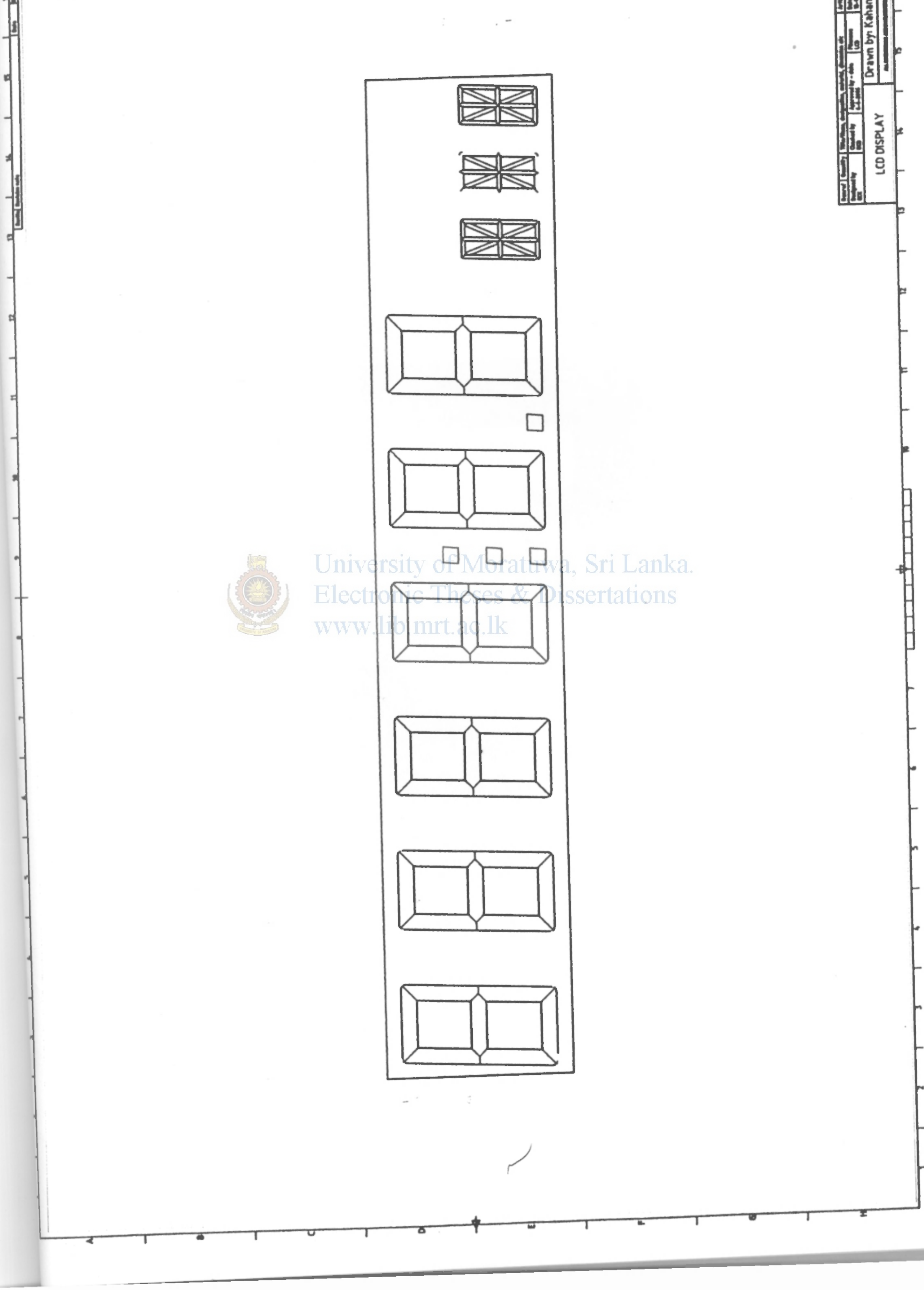
4V410-15





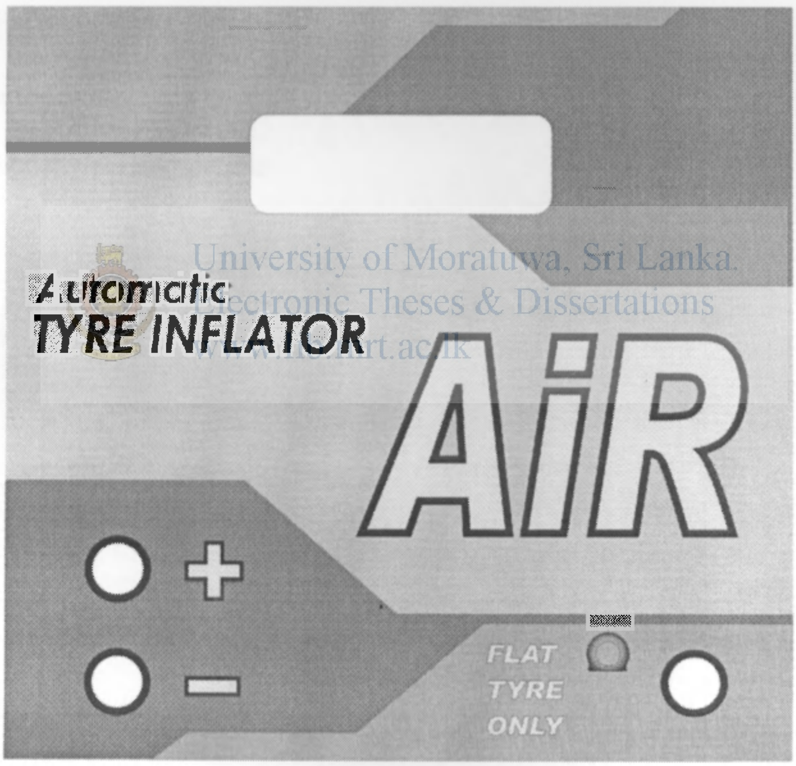


Appendix D



Appendix E

Digital Tyre Inflator



USER'S MANUAL

1.1 Digital Tyre inflation overview

Congratulations for becoming an owner of the first locally made high performance Digital Tyre Inflator. This manual outlines the details required for installation, operation and maintenance of the Digital Tyre Inflator.

Your digital tyre inflator has a dual acting pneumatic valve controlled by an intelligent microcontroller based electronic hardware and software system that controls the inflation and deflation process.

The automatic process will only commence when there is more than 5 psi pressure in the tyre when the hose is connected to the tyre.

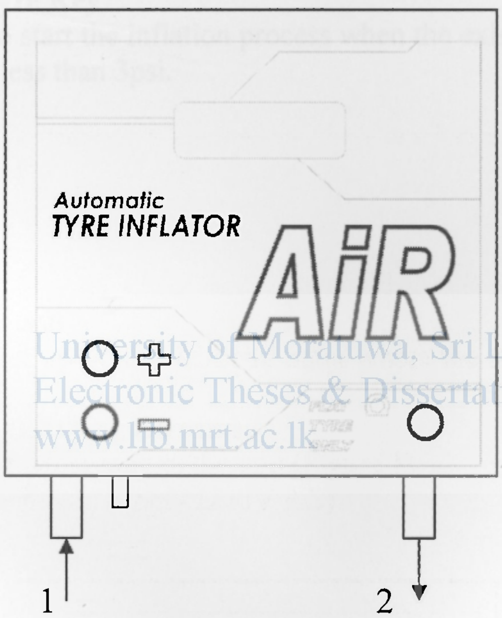
1.2 General Specifications

Equipment compatibility standard	IP65 – class II
Operating Temperature	$25^0C - 55^0C$
Supply voltage	220-230V AC, 50Hz
Current	800mA max.
Internal fuse	315mA
Maximum inlet air supply	150 psi
Recommended Air Supply	10 psi above the set pressure of the unit
Maximum operating pressure	145 psi
Minimum operating pressure	5 psi
Accuracy	± 1 psi
Display increments	1 psi
Units of measurement	psi

2.1 Operational details:

2.1.1 Installation

1. Unpack the unit
2. Hold the unit up on the wall and mark where the three holes are to be drilled.
3. Secure the unit using fasteners.
4. Connect the Air supply to the unit (Figure 1)
5. Connect the power supply (220V AC)



1 - Air inlet from the compressor – must be filtered air free from moisture. Pressure maximum of 150 psi.

2 – Air outlet to the Tyre

Figure 1

2.2 Keypad functions

- **+** Key
  Increase the set pressure

- **−** Key
  Decrease the set pressure

- **Flat Tyre Key**
  Used to start the inflation process when the existing pressure in the tyre is less than 3psi.

2.3 Inflation and Deflation with LCD display

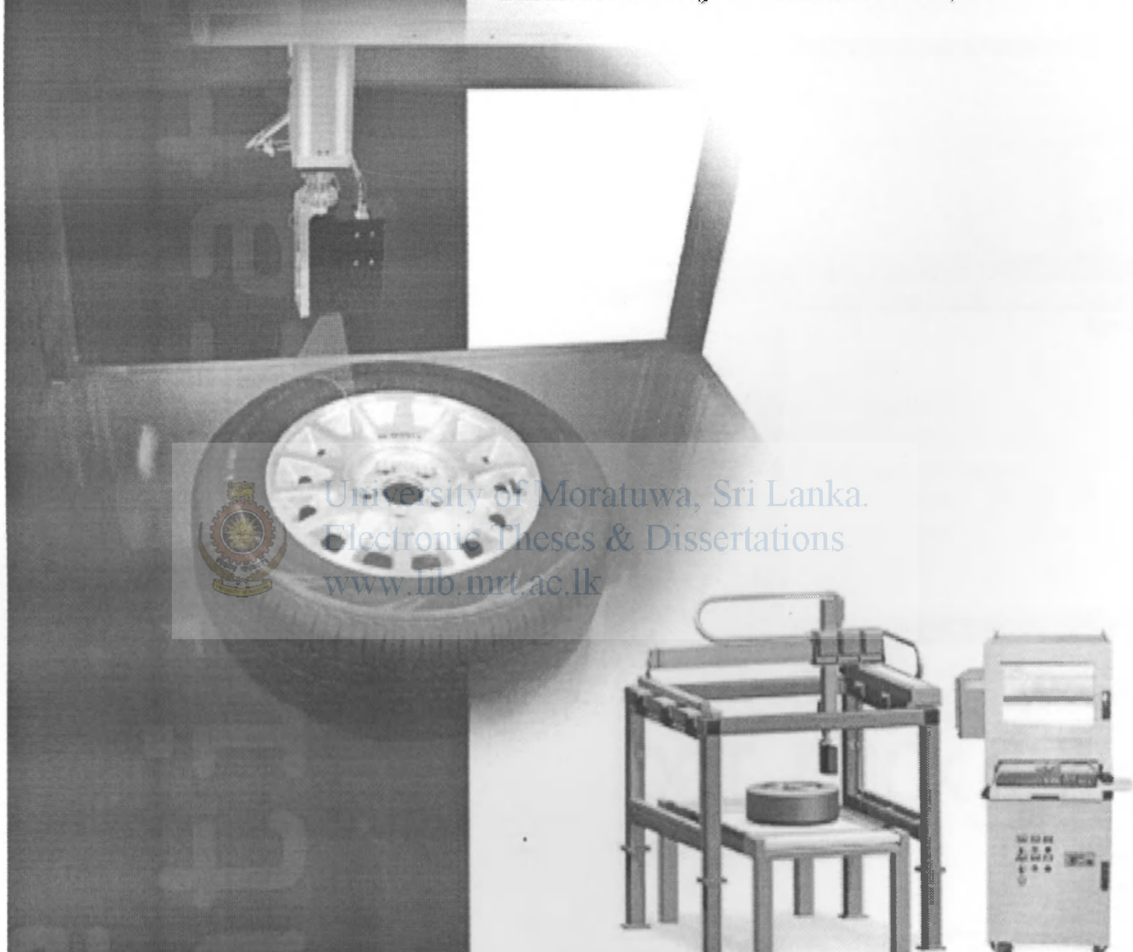
1. Turn the power on
2. Set the required inflation of deflation pressure using the keypad
3. The unit will beep and flash when it reaches the correct tyre pressure.
4. Disconnect the tyre connector from the tyre when the unit flashes and beeps.

Appendix F

Tire ID

Tire Identification System

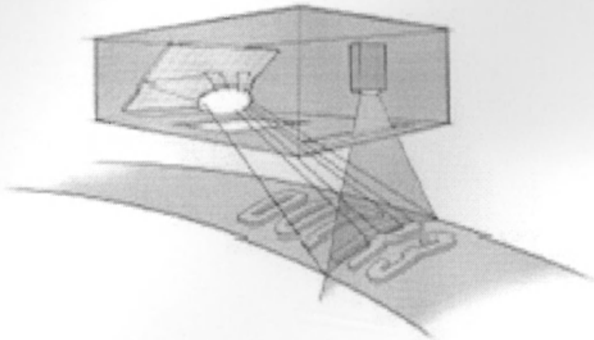
The **Tire Identification System** utilizes Bytewise Sheet-of-Light Laser Profile Sensors (VHSL) to digitize the tire surface geometry, search the geometry data set for a specified pattern, and convert the pattern into human readable and machine readable text. Identification is performed on molded characters including DOT Codes and mold pattern numbers.



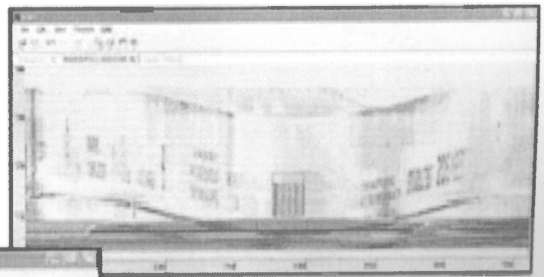
Features	Benefits
• VHSL Sensor	• Sensor combines detector and laser light source so as to reduce problems due to lighting angle or distance • Designed to recognize black characters on a black background.
• Free-standing mechanical system	• Gantry structure straddles user's tire handling conveyor. • No precision tire-centering or rotating required. • Automatic tire size and location detection.
• Easy to use Software	• Easy Teach Routines. • 3-D Visualization of scanned characters.

Operational Overview — Tire Identification System

How It Works

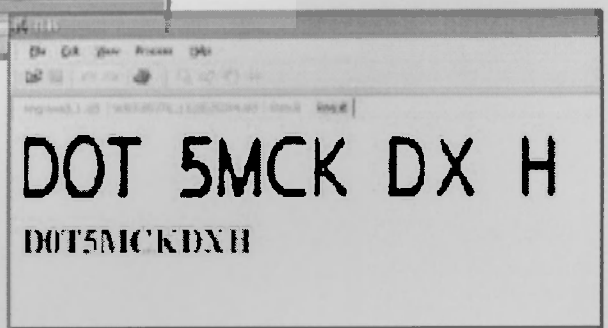


Software



Raw Data Scan

Zoom View of DOT Code Characters



Zoom View of Translation Window

Specifications

Measurement Parameter	
Scan Time	2sec
Process Time	<2sec
Minimum Character Size	4x4x1mm (LxWxH)
Scan Path Width	50mm
Laser Classification	IIIa CDRH