Analysis and Summarization of Wavelet Transform Method as an Alternative Method of Fourier Transform

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●要約

我々は、この数年間ウェーブレット変換とその応用に関して理論的な研究が進んでいることを目にした。ウェーブレット変換関連研究では、特に直交ウェーブレット変換に関する理論的な研究にいくつかの進展があることも認める。また、この分野のみならず、信号処理、画像処理、画像圧縮、データ圧縮、および量子力学にまたがる数多くのアプリケーションが登場している。

我々はウェーブレット理論の全体的な学問に関して、現在のシナリオを分析するにあたって、ウェーブレット理論の関連資料が非常に数学的なものであり、この分野を経験していない学習者は、多くの時間がかかってしまう場合があることが分かった。学習者の立場から考えると、この状況は健全な状況ではないと考えられる。したがって、このレポートではできる限り学習者が直感的な観点からウェーブレット変換の概要を理解できるように説明することにする。このレポートでは、信号処理や画像圧縮の一般的な理論から理解を始め、ウェーブレット変換理論の理解へ繋げることと期待する。我々の議論は、フーリエ変換から出発し、ウェーブレット変換に繋げていく。

●キーワード

Wavelet transform
Multi-Resolution Analysis
Daubechies wavelet
Haar wavelet

1. Introduction: What is the Wavelet Transform?

Target of Discussion: Defining the Wavelets and Wavelet transform in formal and informal language.

Recently, the main stream research on image processing including frequency transform methods has been changed from the conventional Fourier transform to other method of transforms as there are some unresolved problems over times and frequency domain. In order to progress our discussion, let's start our explanation from using Fourier transform.

Mathematically depicting, for a signal f(t) $\in L^1 \cap L^2$, its Fourier transform can be written as:

$$f(w) = \int_{-\infty}^{\infty} f(t)\, e^{-i\omega t} \ \mathrm{dt}$$

This function can measure the strength of signal oscillations at each frequency ω. ω being the angular rate, equal to 2 times frequency. A Fourier transform is often represented by its power spectrum-the square of the modulus of f(ω) Vs. ω. For example, the power spectrum of an impulse function has a constant value of unity and is independent of the time at which the impulse occurs. Time of occurrence affects only the phase of each frequency component[1], [2], [3], [5]. A weak point of the Fourier transform is that it cannot define when these oscillations actually occur in the time domain of signal f(t). The reason for this is that the basis function $e^{\text{-has}}$ an infinite region of support hence the poorest resolution in the time domain, although it has the very good resolution in the frequency domain [1], [2], [3]. We can also restate these characteristics of Fourier transforms that it cannot say the frequency and time information at the same time. Therefore the research in signal processing has been shifted to wavelet transform in order to make possible to define the signal (or function) in the both domain. The other advantage of relying upon Wavelets is that their advantage over traditional Fourier methods is in analyzing signals with discontinuities and sharp spikes. More specifically, in Fourier Transform, the time and frequency information cannot be seen at the same time. The basic functions used in Fourier transform is sinusoids functions. It can only provide the frequency information or time function at a time. Temporal information is lost in this transformation process. Strictly speaking, Fourier analysis is ideal for studying stationary data (the data invariant over time) but it is not well suited for studying data with transient events that cannot be statistically predicted from the data past [6].

In order to solve this problem, researchers have started using STFT (Short Time Fourier Transform), which is also called windowing a signal, however, there still persist the problems and the research has been shifted from Fourier transform to Wavelet Transform as a powerful method of analyzing the signal, image compression and for other numbers of purpose. So, in this report our focus of discussion would be in defining wavelet and explain the method of transformation in wavelet functions with the help of some basic formal transformation. Anyway, we will first define what the wavelet and wavelet transform actually is?

First of all let's define wavelet in more informal language. The idea of wavelets is analogous to an object having different shells. This kind of shells can be seen in onion or in cabbage as shown in figure 1 below. Wavelet translates at the maximum resolution takes out the outermost layer and the next layer is taken out at the next lower resolution and so on. Hence, we are extracting each layer using different dilates and translates of the wavelet function. The dilation takes us to the next level of resolution, while translation takes us along a given resolution.

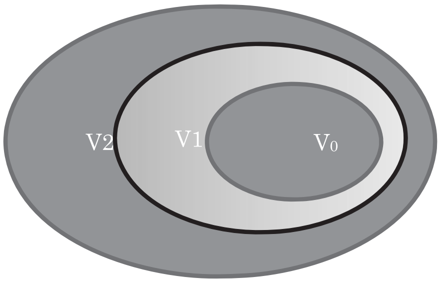

Figure 1: Layered by Layered Shell

To conclude to definition, wavelet is wave like oscillation with amplitude that starts from zero, increase and then decrease back to zero [1], [2], [3], [6]. Mathematically speaking, we can denote a wavelet as below:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\ \psi\left(\frac{t-b}{a}\right) \quad \text{where} \quad a,b \in R, a \neq 0$$

Where' b 'can be taken as location parameter and ' a 'is scaling parameter. Also in order to call this function a wavelet, the time should be limited and it also requires to translate by differentiating the value of b for any given scaling parameter a.

The fundamental idea behind wavelets transform is to analyze according to scale, instead of representing a function as a sum of weighted delta functions (as in the time domain), or as a sum of weighted sinusoids (as in the frequency domain), it represents the function as a sum of time-shifted (translated) and scaled (dilated) representations of some arbitrary function, which is called a wavelet [1], [2], [4].

Next, now we are going to define wavelet transform in more formal language. So, what is Wavelet Transform actually? Wavelet transforms decompose a signal into a set of frequency bands (referred to as scales) by projecting the signal onto an element of a set of basis functions. Although the scales do not live in the frequency domain, projection of the signal onto different scales is equivalent to bandpass filtering with a bank of constant-Q filters. The basis functions are called wavelets. Wavelets in a basis are all similar to each other, varying only by dilation and translation.

To go further, Wavelet transform in terms of signal analysis allows us to view a time history in terms of its frequency components. In Wavelet transform, signal is converted to series of small waves which are named Wavelets. Wavelets are used in order to get frequency and temporal information during certain duration. As human being is more sensitive to identify the low frequency of image signals, wavelet transform is regarded as one of a best tool for us to determine where the low frequency area and high frequency area is. There are generally two types of transform one of which is called Discrete Wavelet Transform and the other is called Continuous Wavelet Transform. The basic principles of Wavelet Transform are summarized as below:

- This method splits the signal into a multiple numbers of signals
- It represents the same signal, but in different frequency
- It can provide the specific frequency in terms of time series or intervals.

In this report, we will focus mainly on Finite Discrete Wavelet Transform method. The reason of selecting Finite discrete wavelet is that our concern of selecting a function is limited to some calculable boundary as the signal in real life never goes for ever. That also means that we are not interested to analyze the signal for ever. For example, if we want to analyze the image, we would like to extract or isolate some features (e.g facial feature etc) of that image and we would localize in special domain. In this way, we will be able to work within a finite wavelet instead of the whole wave. And we call this specific term a wavelet transforms in this report. Furthermore, we would also explain about sub-band coding in the section below. As a concluding definition of the wavelet transform we can say that wavelet transform are used to adopt a wavelet prototype function (mother wavelet). Temporal analysis is constructed with a contracted, high-frequency version of prototype wavelet, whereas frequency analysis is performed with a dilated, low frequency version of the prototype wavelet.

2. Sub Band Coding

Wavelet transform coding is a special kind of sub band coding. This coding concept can be said that the number of bands is equal to the order of transform N and the length of impulse responses of analysis or synthesis filters is less than or equal to N.

In order to understand the basic principle of sub band coding, let us explain about the redundancy and irrelevancy reduction. Generally, images or video are based on two basic principles. One of which is to remove the redundant source of signal. The other principle is to remove the detailed part at the receiver such that the quality of image is not degraded and cannot be noticed by the receiver. The theory of sub band coding provides an efficient scheme of implementation for redundancy and irrelevancy reduction.

3. Haar Wavelet: The Basics of Wavelet Transform

In this section, we define the different properties of wavelet transform. In fact, wavelet transform is also a special type of sub band coding. However, before explaining the depth of Wavelet transform methods, we will first define what is multi resolution analysis generally known as MRA in terms of Haar Wavelet and then we will introduce Daubechies Wavelet. After understanding these two wavelets we will proceed to more complex idea of wavelet transform.

3.1 Haar Wavelet and Multi-Resolution Analysis

Before understanding multi-resolution analysis, we need to understand what is Haar Wavelet is? In fact, the idea of wavelets can be well understood by using an example of the Haar wavelet. The Haar wavelet is a dyadic wavelet, that is, the piecewise constant approximation is refined in steps of two at a time. The wavelet captures the incremental information between two consecutive levels of resolution. In other words, the Haar wavelet gives the additional information required to go from one resolution to the next higher level of resolution [1].

In computer vision domain, multi-resolution representation technique can be used for motion estimation and object recognition. For example, images can be approximated from a coarse version and break down it to achieve a fine-resolution. Burt and Adelson [2] has proposed such kind of method for image coding calling it pyramid coding. These methods later on turn out to be sub-band coding. From this method any image can be reconstructed by combining multiple resolutions and can be represented hierarchically.

In Wavelet Transforms, it is possible to exhibit multi-resolution by dilating the scaling functions that can provide a higher resolution space that includes the original. Furthermore, Lower resolution coefficients can be computed from higher resolution coefficients through a filter bank structure. Similarly, it is possible to express in a hierarchical manner from a single image by superposition of image components having multiple resolutions. Let us represent the idea of multi-resolution as the following notations:

$$V_0 \sqsubset V_1 \sqsubset V_2 \ldots\ldots\ldots\ldots\ldots\ldots \sqcup V_j$$

Where, let say there exist any function space starts from V_0 which is coarser than others and we break down the function more finer as V_1 and V_2 . The combination of all V spaces will be equal to V_j .

Any function belonging to V_1 is piecewise constant over the unit interval. As shown in above equation, a function belonging to V_1 . Now suppose that a function which is piecewise constant over the interval of 1 is also piecewise constant on the interval of 0.5. Therefore, a function belonging to space V_0 also belongs to space V_1 . In general a function which belongs to space V_m also belongs to space V_m +1. Hence there you can find a ladder of subspaces.

Let's formalize the definition of HAAR Wavelets with the help of piece wise square-shaped functions. In mathematics, the Haar wavelet is a sequence of rescaled "piece wise square-shaped" functions which together form a wavelet family or basis.

In terms of piecewise constant functions, the Haar wavelet can be written as:

$\psi(x) = X_{[0,1/2)}(x) - X_{[1/2,1)}$ Where X is the characteristics function of the set {0,1/2,1}.
Particularly, the Haar wavelet mother function $\psi(x)$ can be describes as:

$$\psi(x) = \varphi(2x) - \varphi(2x-1)$$

$$\psi(x) = \begin{cases} 1 & 0 \leq t < 1/2 \\ -1 & 1/2 \leq t < 1 \\ 0 & \text{otherwise} \end{cases}$$

Similarly, its scaling function is denoted by φ(t) which can be describes as

$$\varphi(t) = \begin{cases} 1 & 0 \le t < 1 \\ 0 & \text{oterwise} \end{cases}$$

φ(x): This denotes the scaling function, in our graph (in figure 2 below) we are labeling it as of phi function.This tells us that scaling function φ(x) = 1 on [0 1] and 0 otherwise.

ψ(x): This denotes the wavelet function, in our graph we are labeling it as of psi function

This tells us that wavelet function ψ(x) = 1 on [0 0.5] and -1 on [0.5 1]. Both of the scaling function and wavelet function of Haar is shown in the graph below:

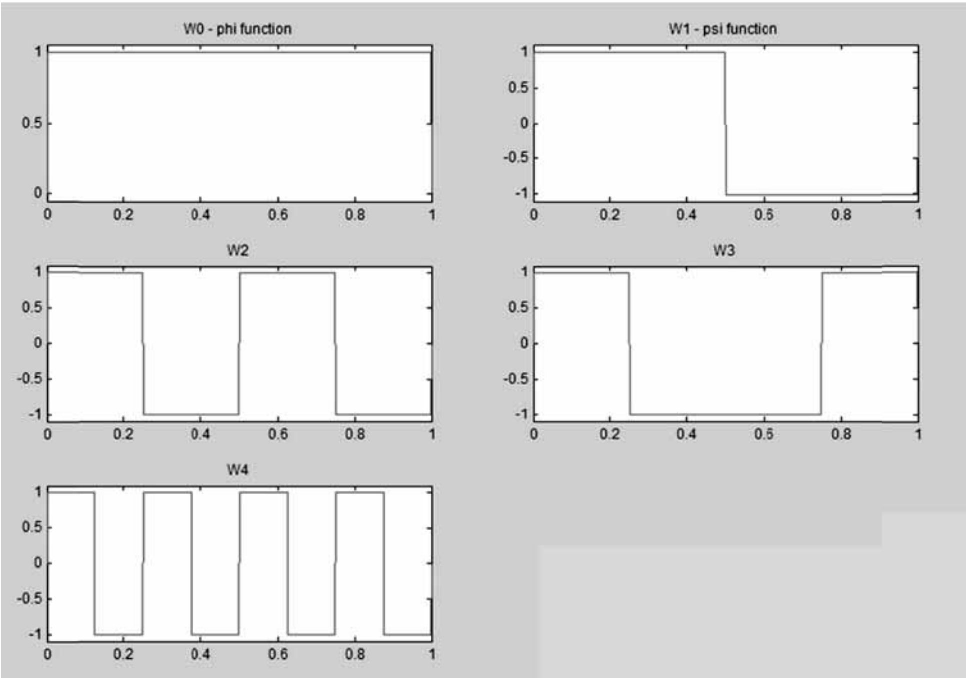

Figure 2:

3.2 Properties of Haar Wavelets

Haar Wavelet's have the following properties:

(1) Any function can be the linear combination of

$\varphi(x), \varphi(2x), \varphi(2^2x), \ldots\ldots\varphi(2^kx)$ and their translation functions

(2) Any function can be the linear combination of constant function,

$\psi(x), \psi(2x), \psi(2^2x) \ldots \psi(2^kx) \ldots\ldots$ and their shifting functions.

3.3 Determining Orthonormal Basis

The set of functions { $2^{j/2}\varphi(2^jx\text{-}k)$; $k \in Z$} constructed through haar wavelet is an orthonormal basis.

Proof:

1.

$$\varphi = \int_{-\infty}^{\infty} \varphi(x))2 \ dx = \int_0^1 1\, dx = 1 \qquad \text{for any integer } j$$

2.

$$\varphi = \int_{-\infty}^{\infty} (\sqrt{2}\varphi(2x))^2 \ dx = \int_0^{1/2} (\sqrt{2}.1)^2 dx = 1 \qquad \text{for any integer } j=1$$

3.

$$\varphi = \int_{-\infty}^{\infty} (2^{j/2}\varphi(2^j x))^2 dx = \int_0^{1/2j} (2^{j/2} .1)^2 dx = 1 \qquad \text{for any integer } j$$

As we know that k is integer and it is only a translation, it does not affect the integration.

The figure 3 shows both of the scaling functionφ and the mother wavelet functionψ.

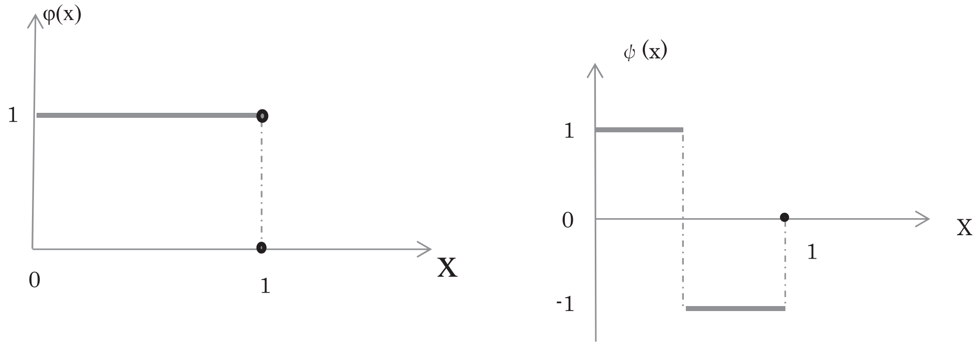

Figure 3: Scaling Function$\varphi(x)$ and Mother Wavelet$\psi(x)$ of Haar

3.4 Example of 1 Level Haar Transform

In order to acquire the general idea of haar transform, let us explain with very simple linear algebraic example as describe below:

Let assume that we have 1D signal f having the length N=2n

The 1-level Haar-Transform for

$f = (X_1, X_2, X_3 \ldots. X_n)$

$f \rightarrow \quad (a^1 \mid d^1)$ Where we use haar level 1 (H_1)

Then,

$a^1 \;=\; (x_1 + x_2)/\sqrt{2},\quad (x_3 + x_4)/\sqrt{2},\ \ldots\ldots\ldots\ldots(x_{N-1} + x_N)/\sqrt{2}$

$d^1 \;=\; (x_1 - x_2)/\sqrt{2},\quad (x_3 - x_4)/\sqrt{2},\ \ldots\ldots\ldots\ldots(x_{N-1} - x_N)/\sqrt{2}$

Now for example;

Let Suppose that f = (7,6,3,5)
$a^1 = (\frac{13}{\sqrt{2}}, \frac{8}{\sqrt{2}})$ and $d^1 = (\frac{1}{\sqrt{2}}, \frac{-2}{\sqrt{2}})$ Now, we need to show that the transformation is reversible in Haar Transform. That means, we can reconstruct the original signal from the following process by using (a^1, d^1) $a^1 = (a_1, \ldots\ldots\ldots, a_{N/2})$ $d^1 = (d_1, \ldots\ldots\ldots, d_{N/2})$ then, $f = (a_1 + d_1)/\sqrt{2}, \quad (a_1 - d_1)/\sqrt{2}, \ldots\ldots\ldots, (a_{N/2} + d_{N/2})/\sqrt{2}, (a_{N/2} - d_{N/2})/\sqrt{2})$ The original signal is $f = \{(\frac{13}{\sqrt{2}} + \frac{1}{\sqrt{2}})/\sqrt{2}, (\frac{13}{\sqrt{2}} - \frac{1}{\sqrt{2}})/\sqrt{2}\ldots\ldots$ $f = (7, 6, \ldots.)$

In this way, we can show the Haar Transformation. Similarly we can do the multilevel haar transformation. We do not go into the details of those multi-levels for now. We just try to build up the concept of haar transformation as shown above.

However, be advised that the Haar wavelet allows us a quick, efficient, and customizable levels of compression. We can derive the orthogonality of the matrix which allows us for quick computation of the inverse by simply computing the transpose so that the image can be quickly uncompressed. However, due to having some discontinuities in haar wavelet, more effective wavelet function called Daubechies is used. We explain Daubechies in the next section.

4. Daubechies Wavelets

In this section we will explain about Daubechies wavelets. In order to understand Daubechies wavelets, lets delve into what is lacking on Haar Wavelets and why we need to learn Daubechies wavelets at first hand. Since Haar wavelet is discontinuous, it is not suitable to apply for the technique of compression of natural images in general. By Daubechies wavelet function, we can eliminate the discontinuity and also is able to achieve more generalized version of wavelet which is called Daubechies. Moreover, Daubechies wavelets is a kind of orthogonal wavelet defining adiscrete wavelet transform and characterized by a maximal number of vanishing moments for some given support [7],[8]. With each wavelet, there is a scaling function which generates an orthogonal multiresolution analysis. In Daubechies wavelet, each wavelet has a number of vanishing moments equal to half the number of coefficients. For example, D2 (the Haar wavelet) has one vanishing moment, D4 has two, etc.

In particular they can fulfill the following properties:

- They perform an orthonormal basis.
- They have n vanishing moments for a given n $\in$ N.
- They have the minimal support of all functions that fulfill the first two conditions.
- They are rather smooth.

4.1 Compactly supported wavelets

The class of compactly supported wavelet bases was introduced by Daubechies [7]. They are an orthonormal bases for functions in L^2 (R). The construction of wavelet functions starts from building the scaling or dilation function, φ (x) and set of coefficients α_k , k $\in$ Z, satisfies the two-scale relation or refinement equation [7]. In the following explanation, we will lead you to know the notion of L^2 (R).

Consider the two functions such as $\varphi(x)$ be the scaling function, and $\psi(x)$ be the wavelet. The scaling function is the solution of the dilation equation,

$$\varphi(x) = \sum_k \alpha k\sqrt{2}\ \varphi(2x-k) \quad (1)$$

$$\psi(x) = \sum_k \beta k\sqrt{2}\ \varphi(2x-k) \quad (2)$$

Where,

$$\beta_{k} = (-1)^k \alpha_{1-k} \quad (3)$$

Here, let's assume that one can build an orthonormal basis from $\varphi(x)$ and $\psi(x)$ by using the dilating and translating to get the following functions:

$$\varphi_{j,k}(x) = 2^{j/2}\ \varphi(2^j x - k) \quad (4)$$

$$\psi_{j,k}(x) = 2^{j/2}\ \psi(2^j x - k) \quad (5)$$

where j,k $\in$ at which j is the dilation parameter and k is translation parameter. We also know that there exist the special coefficients H and G which are related with β_k and α_k are chosen, thought we are not mentioning this in equation. Under the conditions of the previous two equations, for any function f(x) $\in$ L^2 (R) there exists a set $\{\alpha_{j,k}\}$ such that

$$f(x) = \sum_{k=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} \alpha_{j,k}\, \psi_{j,k}(x) \quad (6)$$

and

$$\alpha_{j,k} = \int_{-\infty}^{\infty} \overline{\psi j, k(x)}\, f(x)\, dx \quad (7)$$

This bar sign is a closure that can cover up the boundary patches of the function. And the subscript j is the parameter scaling 2 times Therefore, Equation (7) corresponds to the overallscaling process of two-fold increments will lead to increasing resolution and this phenomenon can be called "Multiresolution analysis".

It is usual to let the spaces spanned by $\varphi_{j,k}$ (x) and $\psi_{j,k}$ (x) over the parameter

K with j fixed, be denoted by V_j and W_j respectively. Then the spaces V_j and W_j are related by,

$V_0 \sqsubset V_1 \sqsubset V_2$ ……………… $\sqcup$ V_j

$V_j = V_{j+1} \oplus W_{j+1}$

At which the situation of $V_0 = V_1 \oplus W_1$ indicates that vectors in V_1 are orthogonal to vectors in W_1

And this also indicates that space V_0 is simply decomposed to multi subspaces.

The above conditions that the wavelets form an orthonormal basis of $L^2(R)$ can now be written as,

$L^2(R) = \oplus_{j\in z} W_j$

In the following diagram we have plotted the scaling and wavelet function of Daubechies having the support N=2

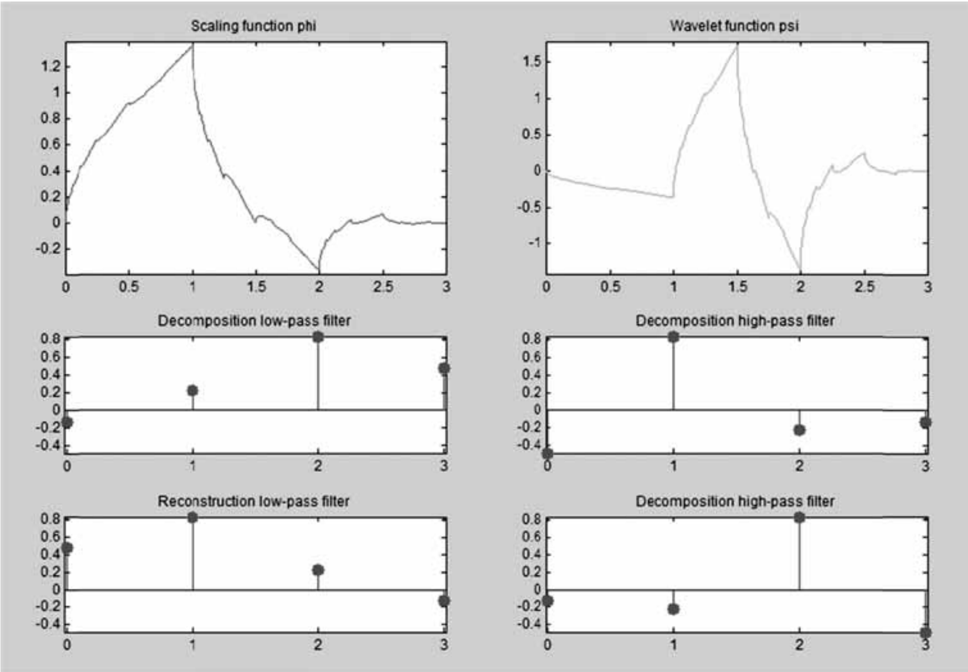

Figure 4:

5. Concluding Remarks

We are aware that most of the real world applications can be reduced to the problem of function representation and reconstruction. Traditionally, the Fourier transform has been used to represent and reconstruct the function. However, more recently wavelets are being used in order to provide more robust and flexible solutions to discretize and reconstruct the functions.

In this report, we applied very simple language to describe the concept of wavelets. We also describe the concept behind Haar Wavelet and Daubechies Wavelet. Though, the Haar wavelet could be taken as a simple application of linear algebra by which one can understand the quick, efficient, and customizable levels of compression of image. Applying the notion of more complex wavelet requires deep understanding and may require great deal of time. Therefore, we conclude that wavelet transform is highly demanding and complex concept which requires large investment of time to understand. The reason of such is due to the lack of literature that explains the application more in theory and with less mathematical. This report though not a very comprehensive piece of literature, it might give an insight and motivation of study for the beginners.

We also understood that Wavelet transform is a useful tool to apply in many disciplines such as geophysics, signal processing, mathematics and image compression. Unlike fourier transform, Wavelet analysis provides a systematic new way to represent and analyse multiscale structures not only in frequency but also in time domain at the same time. The nature of multiscale structures in much kind of systems in the nature and in engineering field is one of the reasons that wavelets are popular.

To conclude, this report has emphasized more on ideas and intuition, avoiding the heavy computations which are usually involved in the study of wavelets. It does not cover the more deepen topics such "discretization of wavelet function and scaling function". In order to have deep idea over this topic, it is recommended to visit the lecture notes of Prof. IZAWA YUJI at the following URL:
http://laputa.cs.shinshu-u.ac.jp/~yizawa/InfSys1/advanced/daubechies/index.htm

Acknowledgement

This paper is based on the Lecture note of Prof. Yuji IZAWA[7] and Other Online Referenced Materials[1], [2], [3][4], [5], [6][8].

Appendix

In orthogonal discrete wavelet, two kinds of filters are used. One of which is called lowpass filter and the other is called highpass filter. The lowpass filter is noted as ϕ and this scales the signal which means that it yields smoothed version of the signal. Whereas, high pass filter which is denoted with ψ (called wavelet) peels off the layer of detail.

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● Abstract

During the past few decades, we witnessed that there is an explosion of research in the theory of wavelets and their applications. We agree that there is a remarkable accomplishment in theoretical literature that includes the development of new bases for many different function spaces and the characterization of orthonormal wavelets with compact support. We can also see that there are huge numbers of applications that span this fields not only to signal processing but also spans to image processing, image compression, data compression, and quantum mechanics.

However, if we analyze the present scenario of the overall literature of Wavelet theory, must of the literature remains highly mathematical, and thus students having less exposure in this field might need a large investment of time in order to develop just a general understanding of wavelets and their potential uses. This situation is not a motivating situation. This report thus might be able to provide an overview of the wavelet transform from an intuitive standpoint in a very simple language and thus reduce the mathematical sophistication in the literature. This report adopts a particular viewpoint that will lead to deepen the understanding of Wavelet in terms of generic understanding of signal processing and image compression. Our discussion starts with a comparable definition of Fourier transform and wavelet transforms.

Monitoring and Management of Unstable Network through Solar Powered Robotic Vehicle

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Roshan Gautam

●要約

本論文では、不安定ネットワークの管理に利用可能なロボット車両の設計・開発を紹介する。特に、我々は赤外線反射センサを用いた車両ロボットのソフトウェアとハードウェアの設計や開発研究を行っている。さらに、TCP/IP ネットワークにおいて、不安定ネットワークに安定的に電源を提供するため、ロボット車両の応用を考える。ネットワークを安定的に運用するために、物理層での解決策としてネットワーク機器の電源供給を試みる。そのようなネットワークで利用するロボット車両の具体的な開発コンポーネントとして、方向制御に利用する DC モータ、組み込み制御プログラムの８ビットマイクロコントローラやギヤーなどを利用する。ロボット車両がサーバルームまで移動するメカニズムとして、パストレースメカニズムを利用することにした。パストレース情報を受け取る光電センサを開発し、リアルタイムでマイクロコントローラに提供され、方向情報をゲットしている仕組みになっている。本論文では、センサーユニットのメカニズム、マイクロコントローラおよびネットワーク管理の面でロボット車両とその応用について議論する。

●キーワード

Robotic Vehicle
Unstable Network Management
Path Tracing Sensors

1. Introduction

Computer network technology consists of electronic computer and communication technology. The history of computer network is not so old; however, it has passed number of phases to achieve the stage of today's Internet. ARPANET (Advanced Research Projects Agency Networks) had contributed to advance this technology as it had brought most of the concept of packet switching technology in 1969 [1],[2]. Network of that time was just a mini-step from a circuit switching to packet switching. However, this mini-step can be taken as a major milestone step in the history of computer networks. The closed and small ARPANET networks has later on enhanced by ALOHAnet in 1970 and by the principle of Ethernet in 1973 and further enhanced by DARPA project. The latest architecture of TCP/IP has first been deployed in January 1, 1983, as the new standard host protocol for ARPAnet [3].

In this paper, we introduce the concept of robotic vehicle which is applied to monitor the unstable power supply of the computer networks. Our robotic vehicle is an electro-mechanical machine which is guided by an electronic circuit. It can be deployed in the field of networks either by autonomous or by semi-autonomous or remotely controlled.

1.1 Unstable Network

The history of networks began from ARPAnet and attained to today's Internet with numbers of advancements. For example, the network media has been changed from copper wire to fiber optics that can carry millions bits of data in a second today. However, this kind of advancement of technology does not cover all parts of the world. There are still the regions where it is very difficult to install and cost millions of dollars to deploy the wired network. Many rural regions such as in Nepal, India, Bangladesh of South-Eastern Asian countries and most of the African countries, especially in developing regions of those countries, do not have good connectivity solutions which are economically viable. In order to provide internet access in these countries, government and INGO are working to provide wireless service in these areas. In our previous studies [4], [5] we have built partial-mesh networks in Himalayan regions and this network is still working thereby providing community networking service in the remote village of Nepal. However, these networks are not stable as compared to the networks built in urban areas. Lack of proper electricity and network infrastructure in rural areas and high installation costs as compared to urban areas are the two major hindrances in building stable wireless network. Wireless Network in rural areas is not stable due to the power outage and link failures due to signal loss.

1.2 Fundamental Idea

Our fundamental idea of keeping network stable relies in two methods. One of which is to monitor the network by using network management protocol such as SNMP. However, SNMP requires that each device understand SNMP protocol and it works above network layer. SNMP is very useful to monitor and notify about the status of network to the network administrator. However, we found that most of the devices used in unstable networks in the developing regions are not utilizing the features of SNMP due to less literacy of network knowledge. There are also various kinds of network management and monitoring tools such as nagios, MRTG, PRTG, Dude and many others by which network administrator can monitor their networks and keep their network under control. These tools are very useful to monitor and manage the networks however in order to properly utilized these tools; network administrator must have knowledge of these tools. This is possible in general scenario, however, this situation is not applicable in the remote areas of developing countries at which this research has been carried out. Most of the available tools are usable while the networks are alive. We still think that it is necessary to create some kind of tools or application so that network can be maintained more stable. Therefore, we realized that in this research, our focus should be on robotic vehicle at which the robot can sensed the down state of the network and proceed to the server to provide the electric power to the node without using SNMP.

2. Flow Diagram

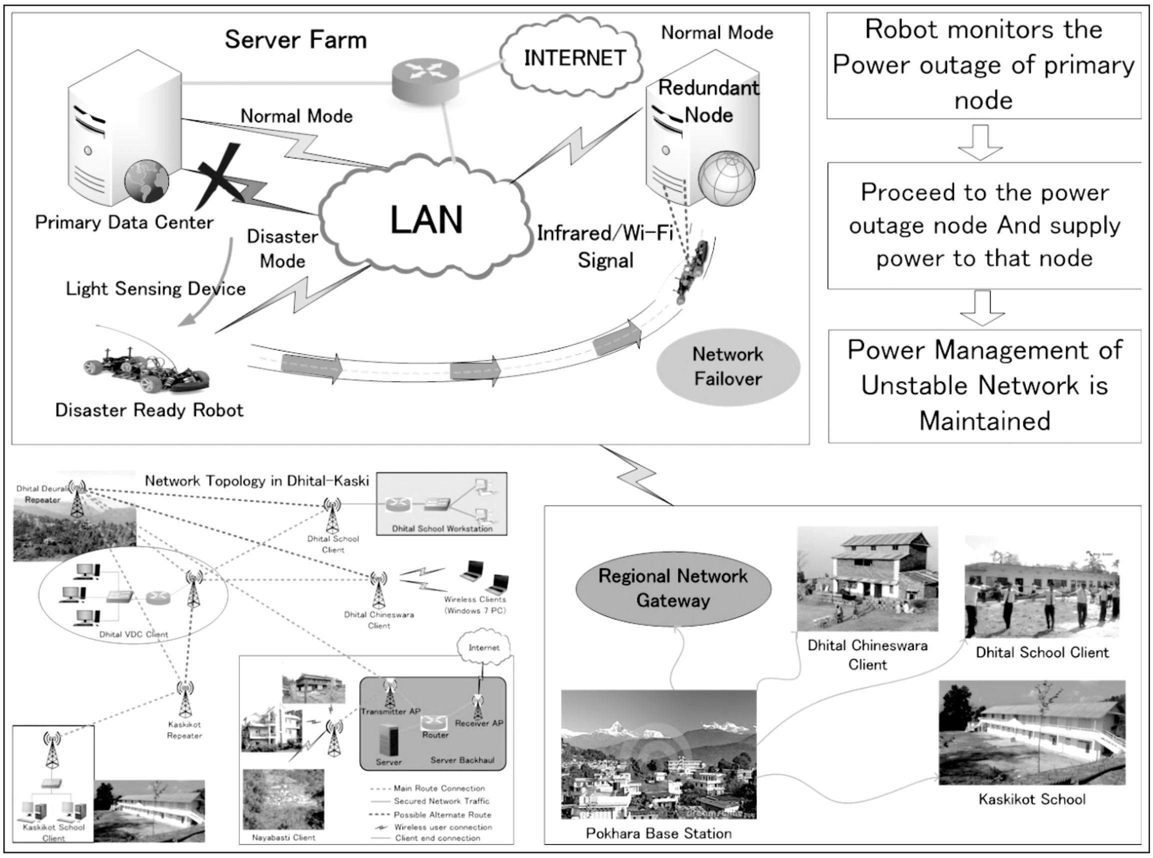


Figure 1: Conceptual Flow Diagram

As shown in the figure 1 above, let us explain about how our robotic vehicle application can contribute to manage the unstable network in WAN, LAN or PAN area networks. Our robotic vehicle is equipped with sensor application attached on its body. While network goes down, this sensor automatically can sense about it and proceed to server room in order to supply the power of the redundant node. The detailed steps are described in the figure 1 above. This figure is our test-bed network built in Nepal during our previous researches [4], [5]. The departure of our research as the first step would start from a development of power monitoring module between the servers. We are focusing to this problem that can be occurred due to an unstable power source. We recognized that unstable network trouble can arise due to other related networks problem such as signal loss, routing problems and many others. In this paper, we limit our research scope only in power monitoring module.

3. System Requirements and Architecture

3.1 Microcontroller and it's Functionalities

A microcontroller is an electronic device that can either be programmed in already prepared device or can be embed the program into it. This device is a compactly designed to govern the operation of embedded systems such as motor vehicles, robots, computer systems and many other appliances. A typical microcontroller includes a CPU, RAM, ROM, I/O ports, and timers like a standard computer, but because they are designed to execute only a single or a few specific tasks to control a single system, they are much smaller and simplified so that they can include all the functions required on a single chip.

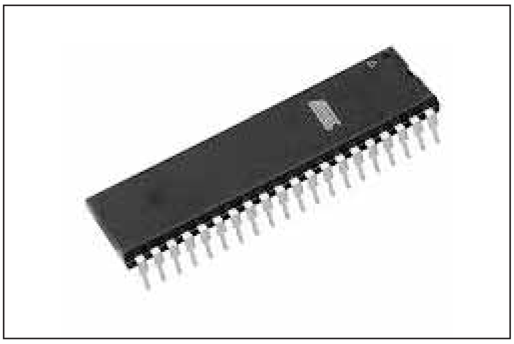


Figure 2: AT89S51 Microcontroller

The microcontroller used in this research is the AT89S51 microcontroller, the figure of which is shown in figure 2 above. This device is used to control the motors of our robotic vehicle. This controlling device has two different kinds of functionalities. One of which is to regulate the motor as per the signal received by sensor units that is attached in it. The other of which is to pursue the vehicle motion either in forward direction or in backward direction. Depending upon the synchronize signals between these two units; the signal received from the path the program embedded in the controller will be executed by which the robotic vehicle has to move accordingly. The whole program is written and burnt into the microcontroller itself as per design decision.

3.2 Electronic Circuit and it's Analysis

Electronic circuit used in our robotic vehicle is shown in the figure no 3, 4 and 5 below.

This circuit is built on the basis of path tracing and motor control objective. Path tracing is responsible for tracking the black and white colored path. Since infrared signals are absorbed by the black surface these signals could not reach the microcontroller via sensors. However, when the sensor steps into white surface then microcontroller gets the signal and it gives control signal for motor to change the current direction that its following and vice versa. This feature is designed in IR sensing unit.

Similarly, voltage control unit VCU is responsible for providing a controlled and uninterrupted voltage to devices used for smooth operation of the circuit. Accordingly, DC motor control is responsible for direction and forward-backward movement. We have installed 2 DC motors in our vehicle. One of which is used for forward-backward motion and the other is for direction control. In order to regulate these motions, we have also designed it in our circuit. These circuit sections responses according to the signal changes in input IR sensors. For example, if left sensor on around left wheel transmits signal to microcontroller then microcontroller understands that left wheel has tracked into white portion of the path then it immediately sent motor the corresponding command to change the direction to right. This results that left wheel goes to black track and follow the path. Similarly if right sensor gets signal then microcontroller understands that vehicle is required to turn into left direction and it immediately sends command for motor to change its direction to the left. In this way, our circuit with the help of sensors keeps the right path and move to the target. Forward-backward motor is responsible for forward-backward movement of vehicle. As soon as microcontroller senses that server in our network is off then microcontroller will immediately sent control command to this motor and vehicle moves forward to the server room to supply the power. Both of the forward-backward control and direction control units are designed as shown in the figure 3 below.

Track is designed in such a way that width of path is slightly greater than the width of wheel of vehicle and only one sensor (either left or right) has a chance of falling on white track at a certain time. Initially both will be on black track and when they change the path then they will reach to white track and microcontroller immediately response this and again sends signal so that both wheel always lies in black track.

Switching commands are responsible to control forward-backward motor and also responsible for switching on the server by sending the command to IR based remote control system attached on vehicle that sends command to the offline server and thus offline network is healed.

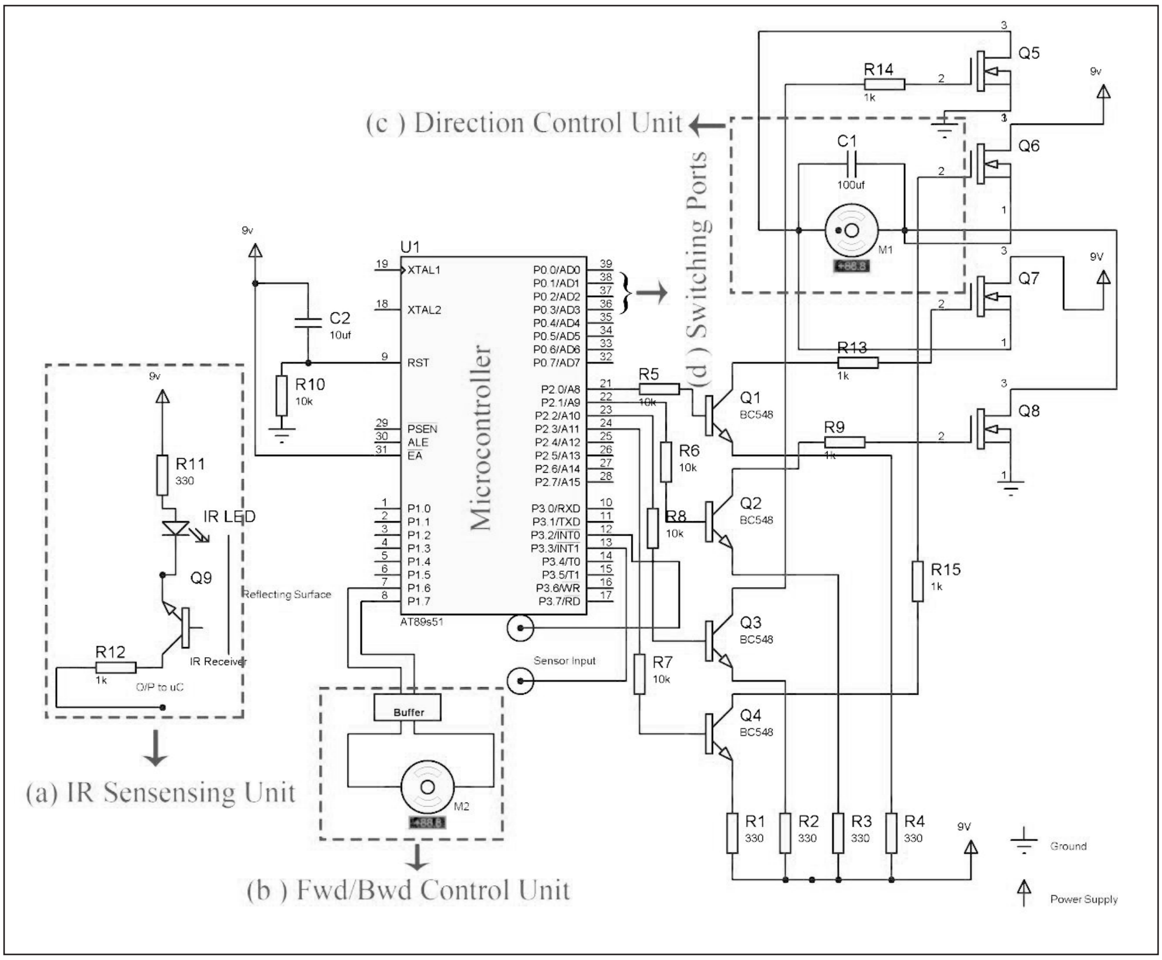


Figure 3: Electronic Circuit for Path Tracing and Motor Control

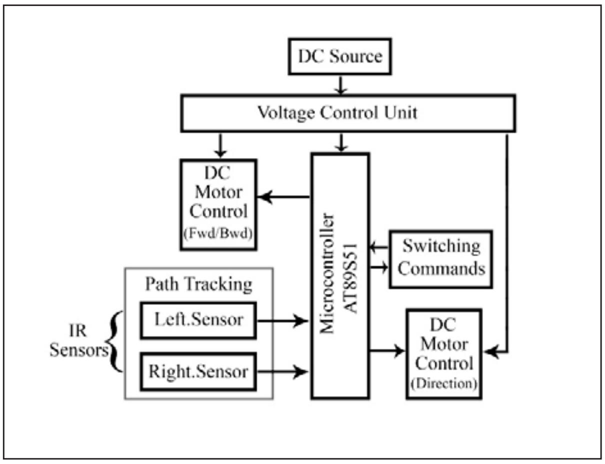


Figure 4: Over all flow diagram

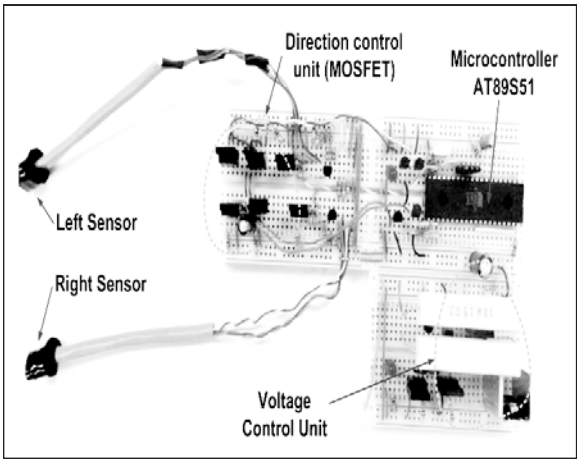


Figure 5: Snapshot of Bread-Board

3.2.1 Path Trace

To experiment robotic vehicle, we designed a 6.5 m oval shaped track-line in our lab. In order to move along the track line, the IR sensor detects the track line and signals from the sensor will execute corresponding command lines in the program embedded in the microcontroller. Accordingly, it regulates DC motor in order to control the motors' direction and speed. Presently developed track tracing system is able to control the vehicle in order to retain in the track and prevent from run out of the track-line.

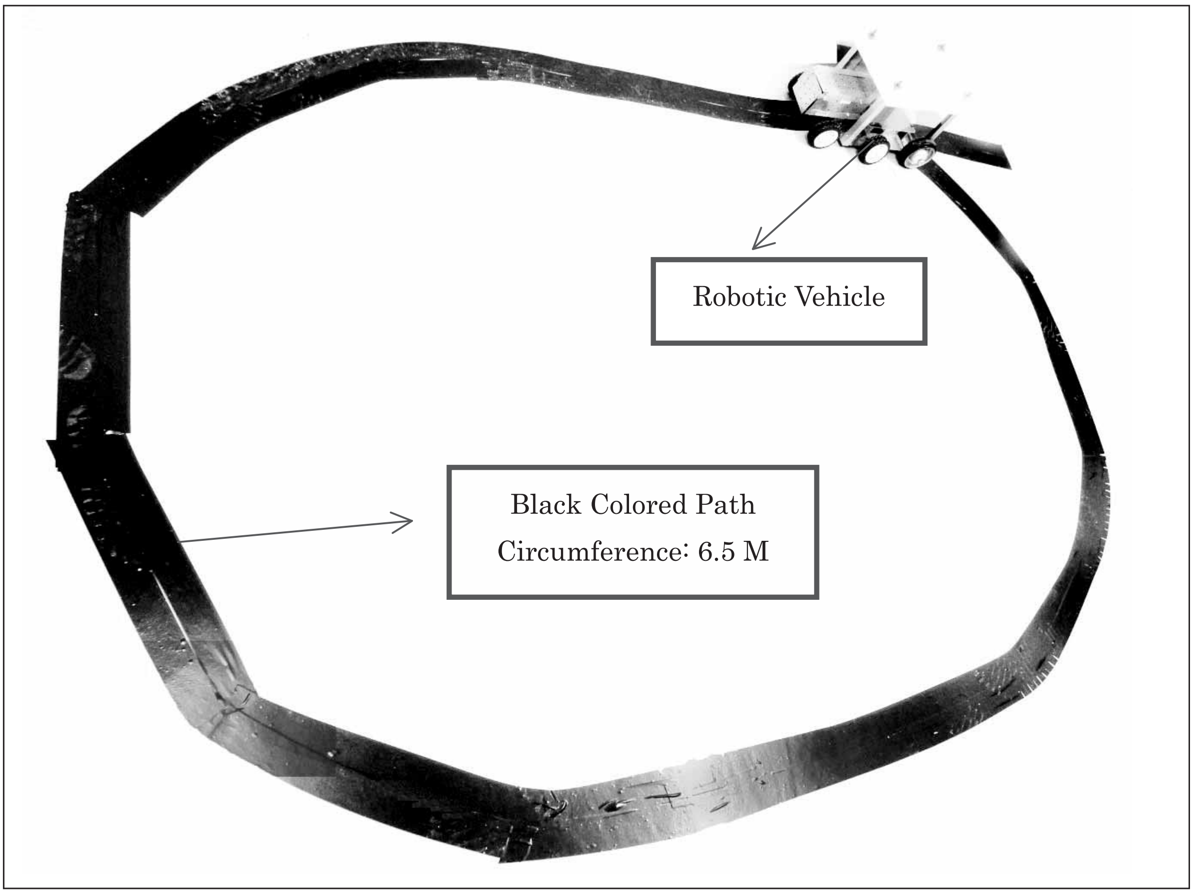
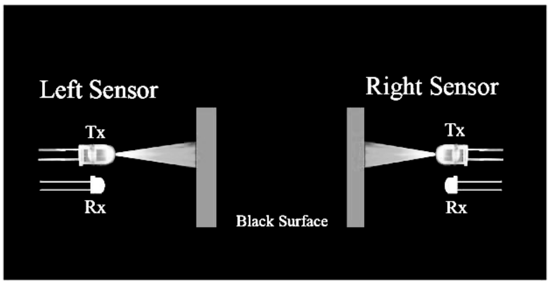


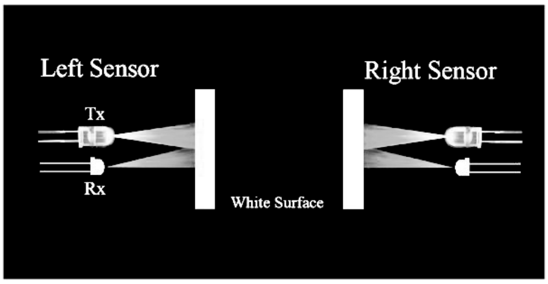
Figure 6: Experimented Path

3.2.2 IR Sensor

IR Sensors [6],[7] work by using a specific light sensor that detects the certain light wavelength in the Infra-Red spectrum. In our robotic vehicle, we are using 2 units of IR sensor as shown in figure no 7. These IR sensor units are made of LED and photo transistor (IR Receiver). Led produces light at the same wavelength and strike it in the frontal object. Our frontal object is a black labeled path. In our case, we are using the feature of IR sensor in order to sense the white object. For example when our vehicle get off the black labeled track and the light hits other surface, the sensor start to sense the reflected light as the light emitted from LED reflects into the light sensor. This mechanism is shown in the figure 7 more clearly.



a) IR receiver is not getting reflected light



b) IR receiver is getting reflected light

Figure 7: IR Sensor

3.3 Power System

Our power system used in this robotic vehicle is solar energy. Solar energy is regarded one of the comprehensive renewable resource by which the solar cell made up of semiconducting materials such as silicon that allows the electron energy to flow freely while sun light struck its surface. In our robotic vehicle, our battery is charged by solar panel.

The solar powered robotic vehicle aims to operate and manage the networks is a totally new concept. By this concept, network administrator can save his/her time by reducing the number of field visits while there is power outage. The robotic vehicle has a capability to sense the power outage and also the capability to be operated through solar energy which is consumed by the robot itself. The main advantage of this method is that there is time savings for network administrator and also it can be operated without producing CO_2

4. Other Parts and Vehicle Anatomy

4.1 DC Motors

We have used dirt tuned motor manufactured by Tamiya Pvt Ltd. This motor is equipped with worn out brushes which can be replaced too. Heat sink type end bell allows effective heat dissipation.

Figure 8: Dirt Tuned Motor

This motor is 27 turn type motor that can works in the range of 6-12 V though the correct usable voltage is 7.2. The efficiency of RPM at no load produces 17,000 rotations per minute. Torque at best efficiency is 37.24mN.m. Both of the torque and rpm works at the usable voltage of 7.2 V as described in Tamiya official website. The main function of this motor is to run as per the digital signals received from the microcontroller and produce the rotation and transfer this rotating energy into the gearbox.

4.2 Gears Mechanism

Gears are special kinds of wheels with teeth. Robotic vehicle cannot properly move without gears.

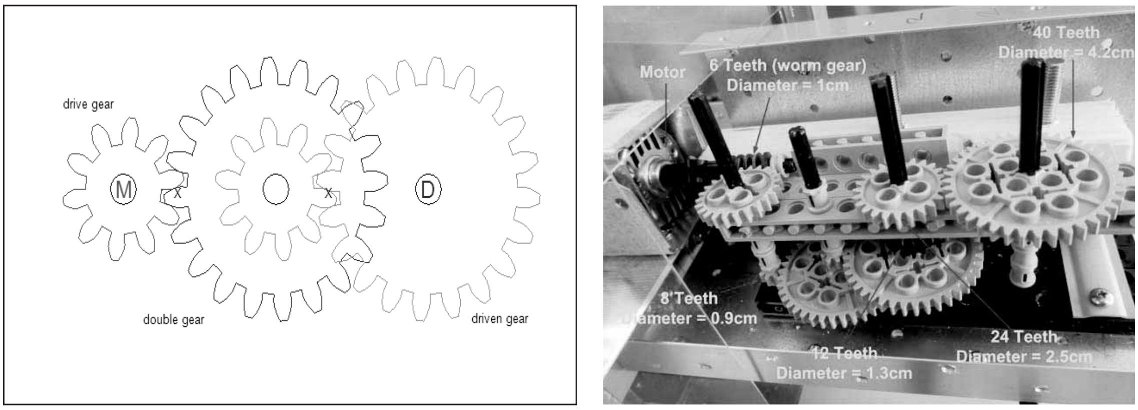


Figure 9: Gear Principle and Snap Shot of Gears (Lego) Used in Robotic Vehicle

Gears in robotic vehicle are used to transfer motion or power from one moving part to another more efficiently.

Let's describe the gear principle of our robotic vehicle by using the figure 9 above. Our robotic vehicle has numbers of gears which are used in order to increase the efficiency of torque received from motor indicated M in above. The total numbers of gears used for forward and backward motion is 9. Similarly we are also using gears in our direction control section too. The complete specification of the gears is mentions in table 1 and table 2 below. When our motor receives the signal from microcontroller, it starts to rotate and the speed of which will increased. First of all, it transfer the torque to driving gear and transmit to double gear and finally to the driven gear.

We are using 3:1 ratio in order to build a mesh gear as shown in the figure 9. We started to receive the torque from small gears and transfer this spin to larger gears. As the circumference of driven gear is larger than drive gear, the speed at the end decreased. This sort of mesh design is intentional as we want more torque in our drive gear so that it can pull more loads. Most of the parts of our vehicle are steel made and thus making it heavier. In order to pull this vehicle, we require more torque rather than speed in our drive gear. In order to understand relation between force and torque, let see the equation below.

$$\tau = r \times F$$

Where, torque is denoted by τ, moment arm by r and force by F. As the distance of r (Moment arm) is larger in drive gear, the amount of torque is increased. In this way, we are amplifying the torque at the output gear.

Table 1: Gear Specification for Direction Change

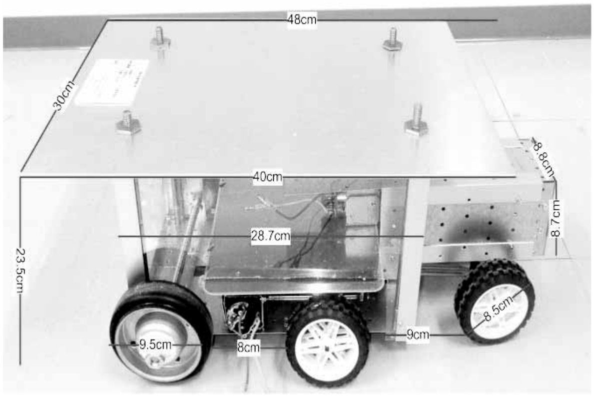
Numbers of Teeth	Diameter (in cm)	Quantity Used	Remarks
6	1	1	Worm Gear
8	0.9	2	
12	1.3	1	
24	2.5	2	
40	4.2	3	

Table 2: Gear Specification for Forward-Backward Movement

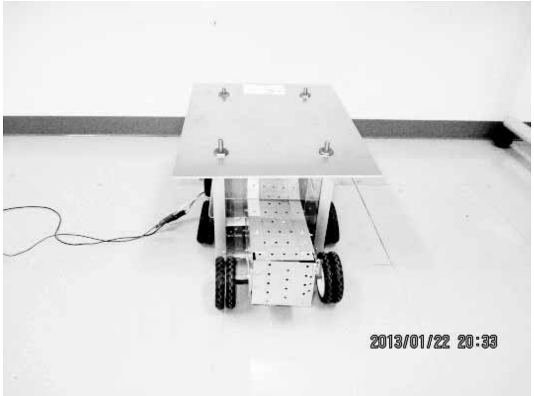
Numbers of Teeth	Diameter (in cm)	Quantity Used	Remarks
8	0.9	3	
12	1.3	2	
24	2.5	2	
40	4.2	3	

4.3 Conceptual Prototype of Robotic Vehicle

The complete conceptual prototype of robotic vehicle is shown in figure 10. The total length of robotic vehicle is 48 cm and the height is 24 cm.



a) Side View



B) Front View

Figure 10: Body of Robotic Vehicle

5. Future Works

We are implementing a prototype of the robotic vehicle that can be used in order to manage the networks. Our departure of research starts from stabilizing the power networks by providing and monitoring the redundant power supply. In our future work, we want to collaborate our robots with other monitoring tools such as Nagios, SNMP, PRTG so that our robots can be notified by those tools in order to rescue the networks from being offline for a longtime. The key component of this research includes microcontroller based control system, path tracing IR sensor devices and solar powered DC motors. Currently, we have not implemented the obstacle detections unit in its path, however, in our future work we will implement the IR sensor device that can detect the obstacle in its path and reflect back to the microcontroller so that it can regulate the motor to avoid the obstacle. Theoretically, it is possible to avoid the obstacle as infrared waves get reflected back to the robot and can be programmed accordingly.

6. Conclusion

In this paper, a new concept of utilization of robotics vehicle in order to manage networks is proposed, and the construction of a solar powered path tracing robotic vehicle that employs such mechanism is described. The power system of the robotic vehicle is equipped with solar unit. Moreover, DC motor supported with gear mechanism is constructed as a means to attain faster movement.

To conclude, the main purpose of this research lies in the usage of robotic vehicle system in the management of network, based on renewable energy. On this basis, our research presents the concrete methods of a path tracing mechanism and solar powered mechanism in order to achieve the reliability of networks. On the other hand, it also proposes the new concept and un-experimented usage of robots in this field. We believe that this research has contributed a major milestone in the field of robotics thereby combining multi-discipline of network engineering, robotics and electronic vehicle in the common research platform.

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● Abstract

This paper introduces the design and development of the autonomous tracing robotic vehicle that can be utilized in unstable network. Particularly, we have done the research to develop the path tracing module in terms of the software and hardware design which realizes the autonomous tracing vehicle using the infrared reflective sensors. Furthermore, the concept of robotic vehicle in order to provide stable power system in TCP/IP network is presented. In order to accomplish such situation, this system utilize 8 bit microcontroller in order to regulate the DC motor for motion and direction control and reach to the server and supply the power. Path tracing

mechanism is developed by using photoelectric sensors that receive the path tracing information and provides to the microcontroller in a real time. The mechanism of sensors units, role of microcontroller and the anatomy of our robotic vehicle and its utilization in terms of network management is discussed.