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Ubiquitous Traffic Management with Fuzzy Logic - Case Study of Maseru, Lesotho

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Abstract: Maseru is the capital city of Lesotho and is a relatively small city with roughly 67 vehicles registered each day. Traffic lights are used with the intension of effectively managing vehicular traffic at junctions. These traffic lights follow a predetermined sequence usually based on historic data. As a result of this design, they inherently fail to efficaciously manage traffic flow when it is abnormal. Vehicles on one side have to wait even though there are no cars on other sides of the road. The consequences of this include increased congestion and atmospheric air pollution. Technological advancements have resulted in the now widely researched Internet of Things paradigm with one of its applications being vehicular traffic management. The focus of this paper is the design of a prototype reactive system based on Internet of Things whose functionality includes traffic lights that are capable of reacting to prevailing conditions. The system makes use of Radio Frequency IDentifier technology and mobile tools to ubiquitously collect traffic data and disseminate value added traffic information.

Keywords: Internet of Things (IoT), Fuzzy Logic, Wireless Sensors, Congestion, Ubiquitous Computing, Ubiquitous Traffic Systems (UTS), Radio Frequency IDentifier (RFID)

1. Introduction

Traffic lights are the most utilized traffic management tools to facilitate traffic flow at busy intersections. The number of new vehicles is growing globally but is not met by an equal increase in road infrastructure [1]. This mismatch leads to a higher demand for road infrastructure resulting in roads being in a state of congestion [2] [3]. When congestion is observed, traffic officials are dispatched who would then use reasoning capabilities to increase the rate of flow. Many proposed solutions use intrusive sensors such as inductive and pneumatic loops [4]. As per their design, these tools disrupt traffic flow during installation and maintenance, moreover these tools are relatively expensive to install and maintain [5]. Other tools which are non-intrusive include visual and acoustic sensors; they too however are comparatively expensive and have accuracy issues. An acoustic sensor would for example be disrupted by noise that is in a city.

Radio Frequency Identifier (RFID) technology presents a more viable solution as it removes the need to excavate roads and is relatively cheap. This technology has numerous applications such as tracking, identification and counting of real life objects. This paper focuses on alleviating intensity of congestion by collaborating IoT based tools with ubiquitous computing while also making usage of fuzzy logic to control the state of traffic lights. Ideally, IoT refers to the connectivity of everyday objects to the Internet, facilitating the communication between the physical and digital worlds and is driven by tools such as environment-aware wireless sensors. The high penetration of mobile devices makes ubiquitous computing (UbiComp) a reality in transportation [6]. UbiComp refers to the transparent provision of value added information to users in a non-intrusive manner. To mitigate congestion, UbiComp can be of value by the provision of traffic information to road users in several formats such as text messages, emails and public broadcasts.

Lotfali Zadeh introduced fuzzy logic in 1965; it enables computers to apply basic human like reasoning using intrinsic human terminology [7]. The basic function of the fuzzy rule base is to represent the expert knowledge in a form of if-then rule structure combined with and/or operators [8]. In traffic management this can be of importance as computers can then, using stored rules make “observations” and decisions much like a human would; it is further useful as intrinsic human terminology such as long and short may be used.

The remainder of the section is organized as follows. We first show the objectives that are to be met followed by background information of related works. The section on vehicle traffic congestion concentrates on giving a narrative of congestion. Implementation and design details are given on the system description section, finally the study is concluded with conclusion and future works.

2. Research Objectives

The goals of this research are: (1) To study and analyze the traffic control system of mid-sized African cities: (2) Design and implement a system prototype that uses an array of IoT-enabled ‘things’ to:

a. Collect traffic parameters from the road infrastructure.
b. Change traffic lights operations to react to the status quo.
c. Communicate to road users the status of roads.

3. Related Works

3.1 Internet of Things (IoT)

IoT is a new paradigm with many definitions; the definition that is adopted for this paper is “*a network that allows the look-up of information about real-life objects and a resolution mechanism to a network of sensors, actuators and autonomous objects interacting with each other directly*” [9]. IoT relates to the connectivity of everyday items to the Internet such that these items can communicate with each other providing not only information about themselves but also data regarding their surroundings [10]. IoT rests on the ability of these things to communicate with each other as well as monitor their surroundings. Below follows a brief discussion on WSNs and RFIDs; the two main technologies on which most researchers assert IoT rests.

3.2 Wireless Sensor Networks (WSNs)

IoT presents a manner in which the physical and digital worlds can communicate. Wireless sensors are tools that are used to monitor the physical world and digitize the observations. The sensors themselves differ in design and functionality, in that they can monitor physical, biological as well as chemical attributes, their application include identification, tracking and monitoring [11]. The ability to connect wireless sensors into a network further enhances the value of their information; this will heighten the accuracy of the data as well as allow acquiring data from distant sources via multiple hops.

In traffic management, IoT becomes very important in that it facilitates the acquisition of citywide data resulting in an idea that has been aptly named smart cities. Smart cities are aware of their parts such as; buildings, temperature, soil integrity and wind speeds [12]. A smart city can be aware of the prevailing conditions on its road infrastructures and be able to communicate such information to road users as well as suggesting alternatives to motorists, with the possibility of enhancing the flow of traffic.

3.3 Radio Frequency Identification (RFIDs)

RFID based applications are proving to be very profitable largely owing to their affordability. This technology is contact-free and relies on the identification of anything that has some kind of barcode attached to it. A simple RFID system includes multiple tags that will be uniquely identified once within a given distance of a reader; there need not be a line of sight between the tag and reader removing some of the challenges that may be met with visual sensors. There are two types of readers; the main type being passive readers, these have no power modules residing on them but rely on power from the tags themselves [13].

There have been different applications of RFID technology in traffic management; these include using the technology to affect the sequencing of traffic light such that emergency and VIP vehicles get first preference [14]. The other most common application of RFIDs that is meant to manage congestion, is similar to the one being suggested here. The uniqueness of our proposed solution is the inclusion of fuzzy logic; further, the focus of the solution is on the volume and modal speed of vehicles [5].

4. Vehicle Traffic Congestion

A lot of research into road congestion has been conducted. The majority of such research was however conducted for Western Societies with many of the proposed solutions being custom made for these nations. These solutions may not be effective let alone feasible for mid-sized African cities. The main reason for this that Africa as a continent has lagged behind in terms of application and development of technology as a whole. This is largely attributed to the landscape and financial constraints. It is the thesis of the authors of this paper that the adoption of Western solutions to African problems may not solve Africa's problems [15].

Congestion is further complicated by absence of a clear and widely accepted measure [16]. Congestion in Kampala-Uganda may not be the same as in Bloemfontein-South Africa. When describing congestion, people use literal terms as opposed to numerical values. This presents a problem that which is that computers do not understanding these terms. The authors contend that this challenge can be taken care of using fuzzy controllers.

Vehicular congestion may be defined as a state during which the demand for road infrastructure is outweighed by the participating vehicles. This may be brought about by a wide array of activities such as weather and accidents; for instance, one of the causes may be ineffective mechanisms that are put in place to mitigate it, such as traffic lights. The consequences of congestions include accidents, wasted time, increased fuel consumption and possibly more detrimental and adverse impact on the environment [17]. In the current configuration of Maseru's system, traffic lights work by circulating through all entries to an intersection, giving each a time to enter the intersection while others remain closed.

There is no way for the traffic lights to react to real-time data. This has regularly led to increased congestion in abnormal situations such as when adjacent roads are blocked or increased vehicles as a result of weather [18]. We may have come across a situation where there is no traffic in the permitted lane while the closed lane has a long queue; this situation leads to wasted resources such as time and fuel while also contributing to atmospheric pollution as well as possibly inciting drivers to ignore traffic regulations.

Prior to automation, a traffic official would manage traffic flow by visually measuring lane density while maintaining a degree of fairness. Fuzzy logic is best suited as it allows the digitization of real-life situations and rules much like a human would think; a human being may cerebrate in this manner "if there is higher density on the north-south entry in comparison to east-west then give more time to the north-south and keep its priority higher as long as the lane retains a higher density but maintaining a degree of fairness".

4.1 Ubiquitous Traffic Systems (UTS)

The concept of UTS is somewhat synonymous with Intelligent Traffic Systems (ITS) [19]. In that ITS is the application of technology in transportation infrastructure and within vehicles with the goal of improving traffic management; the technologies include communications (Internet and Bluetooth), electronics (WSNs) as well as software components. Improvement of traffic management refers to a variety of traffic aspects such as access, availability and flow. For this paper, the intention is to improve the flow of vehicles on a road network by increasing the number of cars that go past a certain junction.

The goal of Ubiquitous Computing (UbiComp) is to provide computing power in every aspect of human life; the intention is to augment computing by having computers that are aware of their surroundings. The placing of "environment-aware" computers everywhere results in availability of digitized real time data. When information about the environment is readily available, it makes it possible to realize the second goal of UbiComp which is to have value added information transparently available to users in all platforms and formats.

It is important to note that UTS is not altogether a new concept [19]. It may be viewed as an extension of the already existing ITS. UTS has rather become possible in recent years with the advances in mobile technologies. UbiComp is largely user-oriented while UTS seeks to fully immerse the road user by ensuring effortless acquisition of traffic information about a trip either before or during the trip.

5. System Description

5.1 Cross Junction Configuration

There are two RFID readers embedded on the side of the road on each lane approaching the junction, with one reader being placed upstream (r_1) and the other placed at a given distance d from the downstream one (r_2) as shown on figure 1. With tags placed in the cars that are to pass the junction, r_1 is used to count the number of vehicles approaching the junction from either entry point. The first and second readers are used in tandem to ascertain the modal speed at which traffic is flowing in that lane sampled at time intervals. The modal speed is a more appropriate measure as it would be less affected by outliers that may come as a result of reckless drivers or VIP vehicles. As the vehicles in a lane go past r_2, the count of cars in the particular lane is reduced

The readers are embedded on the side of the road as reflected in figure 2 and their placement is such that the readers will only sense the tags that are approaching the junction i.e. on the northern road the readers on the approaching lane are not within range of the tags in the vehicles that are leaving the junction on the same road. Combination of tags and readers are used to find the two parameters that are fed to the fuzzy algorithm; these being the road density and modal speed.

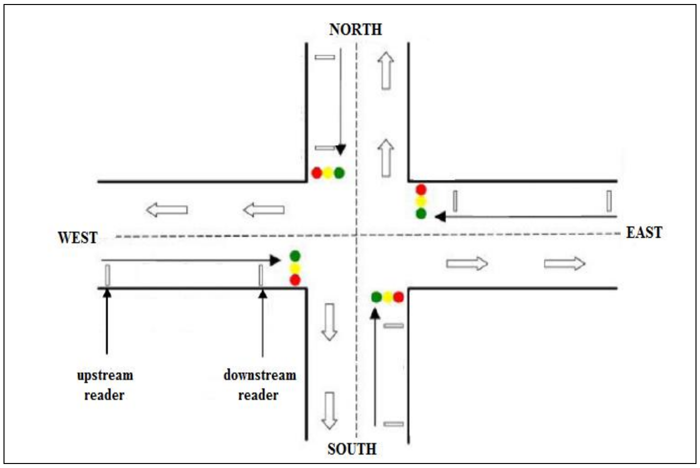

Figure 1: RFID reader placement in a cross junction

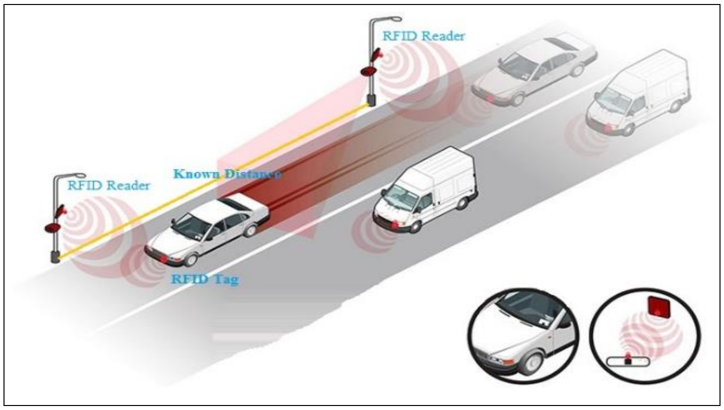

Figure 2: Readers on the Road and Tags in Cars

Assumption made during the design:

a. The junction is an isolated four-way junctions;
b. No left or right turns are allowed on red lights;
c. When traffic is allowed to flow to the north, traffic is also allowed to flow to the south; and
d. No U-Turns may be made in the lanes approaching the junction.

5.2 Fuzzy Logic Controller

There are two input namely variables, vehicle density and modal speed each of which has five Gaussian member functions; veryLow, low, average, high and veryHigh. When there is a comparatively low number of cars within the observation segment of the road, the input variable vehicle density is set to veryLow. The value of the variable will change as necessary when the number of cars in the lane increases from veryLow to veryhigh; see table 1. Just as with vehicle density, the value of the modal speed variable relies on the observed speed within the observation segment of the same road also with the value changing from veryLow to veryhigh as the speeds increase. The two input variable are mapped via fuzzy tools (fuzzy control structure shown on figure 3) onto two output variables the first of which is Level of Service (LOS).

Table 1: Description of Input Variables

	Input Variable			
Member function	**VehicleDensity**		**ModalSpeed**	
	Center	Width	Center	Width
veryLow	0.0	1.062	0.0	10.620
low	2.5	1.062	25.0	10.620
average	5.0	1.062	50.0	10.620
high	7.5	1.062	75.0	10.620
veryHigh	10.0	1.062	100	10.620

As mentioned above, there exists no universally acceptable measurement for congestion. There is however an index named LOS that is used to categorize the flow of traffic based on the expected delay a driver will incur from a road network (see table 2). Using the control rules on table 3, the output of the fuzzy controller is mapped onto a particular LOS, i.e. when there is a *veryLow* vehicle density or the modal speed of vehicles on a given lane is *veryHigh*, the resultant output from the fuzzy controller may be mapped onto LOS A or B depending of the value of the output. This output is the one that is to be ubiquitously communicated to road users so as to notify them of the status of a junction.

Table 2: Level of Service; adapted from [20]

LOS	**Speed (km/h)**	**Description**
A	> 80	No Delay
B	< 90	Minimal delays
C	< 60	Intermediate delays
D	< 30	Significant delays
E	< 10	Maximum Delays

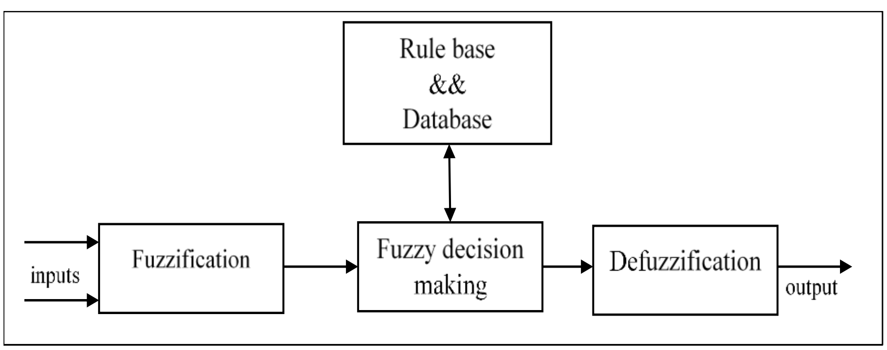

Figure 3: Fuzzy Logic Controller

Table 3: Some of the Control Rules

vehicle density	**operator**	**modal speed**	**rule**	**LOS**
veryLow	OR	veryHigh	THEN	veryHigh
low	AND	high	THEN	High
average	OR	average	THEN	Average
high	AND	low	THEN	Low
veryHigh	OR	veryLow	THEN	veryLow

The second output is the extension in seconds a green phase may be allocated; this simply put is the additional time a traffic light will let traffic flow given that the lane holds a higher priority as per the lane density and modal speed while guaranteeing fairness. Three member functions were definedin this respect: veryHigh, Minimal and None. A single lane will be extended 20, 10 and 0 additional seconds respectively. When an observation has been made that there is a higher vehicle density and lower speed on the north entry than on the east entry, the fuzzy controller will ascertain the extra time to allocate to the north entry.

5.3 Ubiquitous Communication of Traffic Conditions

Ubiquity is addressed by the provision of value added traffic information to road users on multiple platforms prior to a trip as well as via request. Road users can then have access to traffic information on numerous communication devices, which will make the system easy to use and transparent. To address privacy issues, users can subscribe to have information sent to them, select a preferred platform and can opt out at any time. In the current implementation of the proposed solution, five platforms are used to provide users with information as seen on the presentation layer of the theoretical framework on figure 4. In addition, users are able to send formatted text messages to the system and query the status of the road and get in response the LOS of the queried junction (see figure 5).

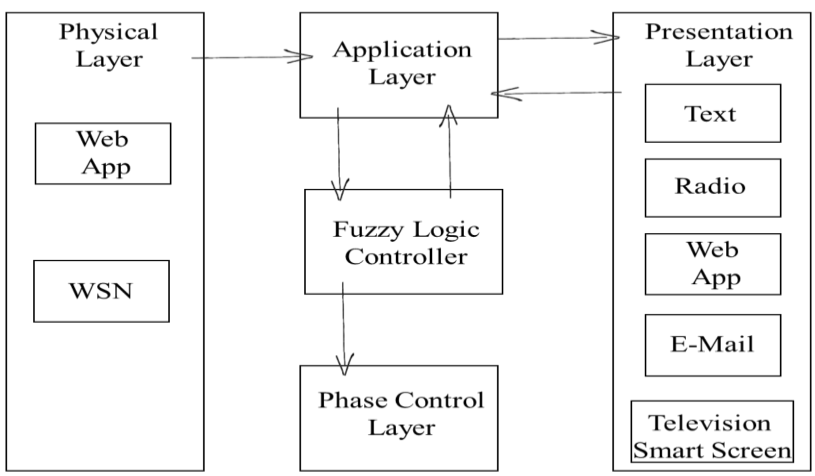

Figure 4: Ubiquitous Traffic System Framework

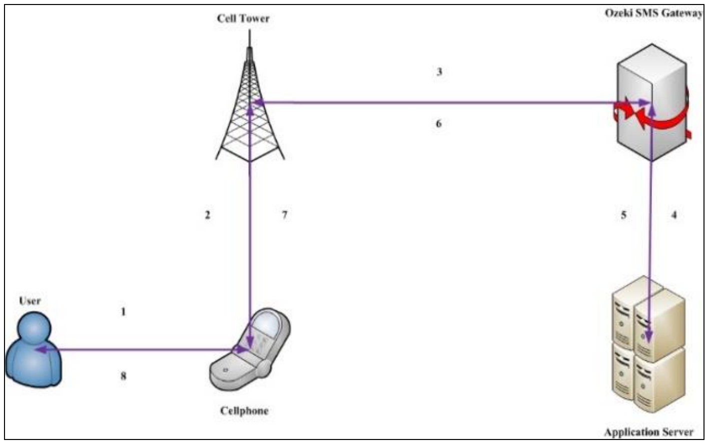

Figure 5: SMS Request and Response

6. Results and Findings

A survey was conducted in Maseru and Bloemfontein whose goal was to observe if there is any relationship between levels of congestion and concentration of CO_2. Junctions used in the experiment were purposively sampled with observations made over a 30-day period. The results showed that there is a positive correlation between the level of congestion and concentration of CO_2. Assuming that vehicle density increases and decreases between 6:30 am and 9:00 am respectively the resulting CO_2 concentration is shown on figure 6.

From the second survey that was conducted to view motorist's observations and feelings regarding congestion, it was observed that 80% of private vehicle owners who travel less than 20 km a day mostly travel alone with an average increase of 30 minutes when there is congestion. More respondents reported to have viewed congestion or longer queues at signaled intersections as opposed to those that are not signaled with longer queues being seen in the mornings and afternoon. No respondent reported to have gotten traffic updates on their mobile devices and 26% reporting to have received reports on television. 93% of respondents agreed that they had observed levels and frequency of congestion increase over the past 5 years with 59% prepared to pay extra to not be stuck in congestion.

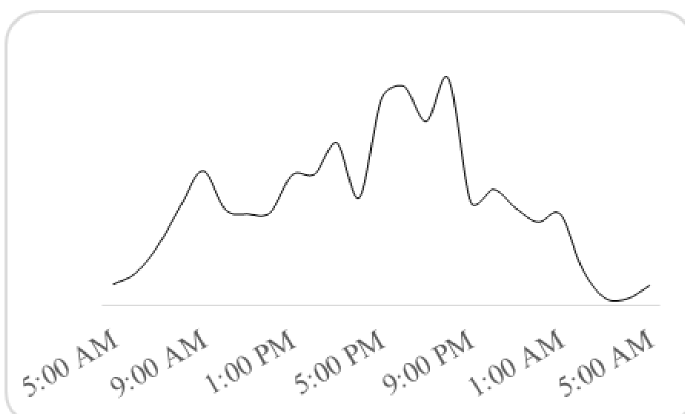

Figure 6:CO_2 Reading over 24 Hours

7. Conclusion and Further Works

This paper proposes a traffic management system that has the ability collect data from disparate sources, react in real-time data and distribute important information ubiquitously to road users. The proposed architecture uses key technologies: Internet of Things, wireless sensors, mobile technology and fuzzy logic methods. Using Maseru city as the case study, the objective is to have a system that will reduce intensities of vehicle congestion by using fuzzy controllers to adaptively "change" the workings of traffic lights by having the green phase extended when necessary and allocate the entries to an intersection priority based on the vehicle densities and flow on the road.

The provision of traffic information to road users should in theory reduce the occurrences and intensities of congestion. Motorists will be less likely to drive toward a junction they have prior knowledge that it is congested. Consequently, there will be less cars being driven into an already congested road and therefore the demand for that piece of road decreases with time. In addition, the traffic lights will extend the green phase of whichever lane has less LOS ensuring that the wait time of vehicles is reduced hence resulting in faster flowing traffic. Finally, less waiting time should reduce the carbon footprint of vehicles, save time and energy costs.

What has been achieved thus far is observation and analysis of relationship between road density concentrations of carbon dioxide gas in that vicinity. This experiment was conducted to validate one of the results of congestion. In addition, analysis of road user's views on congestion has been completed. This survey was conducted to ascertain if road users do see congestion as an adverse event that needs to be extenuated. The design and programming of the fuzzy controllers has also been completed. Simulations are to still to be done to verify the expected features.

Further works include modules that will be able to predict congestion; it is always better to be able to make precautions for an adverse event before it occurs. It is also desired to extend the application to work for a system of connected junctions. The flow of traffic on one junction will have an impact on those adjacent to it, and it will then make sense to have the junctions "communicate" to better manage the vehicles that are moving from one junction to another.

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