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Optimal Energy Management System for PV/Wind/Diesel-Battery Power Systems for Rural Health Clinic

Ani Vincent Anayochukwu*,[1]

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Abstract: Good operation of a hybrid system can be achieved only by a suitable control of the interaction in the operation of the different devices. This paper presented a supervisory control system that monitors the operations of PV/Wind-Diesel hybrid power generation system with energy storage. The controller was developed in such a way that it coordinates when power should be generated by renewable energy (PV panels and Wind turbine) and when it should be generated by diesel generator and is intended to maximize the use of renewable system while limiting the use of diesel generator. Diesel generator is allocated only when the demand cannot be met by the renewable energy sources including battery bank. The structural analysis of the supervisory control is described in details through data flow diagrams. The developed control system was used to study the operations of the hybrid PV/Wind-Diesel power system for the three hypothetical off-grid remote health clinics at various geographical locations in Nigeria. It was observed that the hybrid controller allocates the sources optimally according to the demand and availability. From the control simulation, we were able to see the performance of the system over the course of the year to see which mode(s) the system spends most time in, the power supplied by each of the energy sources over the year, and the power required by the load over the year. This is a very useful manner to check how the system is being supplied and which source of energy is the most proficient in supplying the load.

Keywords: *Hybrid System, Supervisory control, Power Consumption, Power Supply, Health Clinic.*

1. Introduction

Application of renewable energy for power generation has several benefits (such as clean energy, reduction of electricity cost) but its intermittency has leads to special attention on the mix of renewable energy systems (an electricity production system which consists of a combination of two or more renewable types of electricity generating source) and hybrid systems (an electricity production system which consists of a combination of two or more types of electricity generating source which one of the sources must be diesel generator).

In a mix of renewable energy systems with batteries, the control strategy is simple: the battery charges if the renewable energy exceeds the demand, and the battery discharges if the load exceeds the renewable energy. However, the control strategies of a hybrid system can become very complex if the system includes batteries. Therefore, in a hybrid system it is necessary to determine how the batteries are charged and what element (batteries or diesel generator) have priority to supply energy when the load exceeds the energy generated from renewable sources. A hybrid system uses advanced system control logic (also known as a supervisory control) to coordinate when power should be generated by renewable energy and when it should be generated by sources like battery or diesel generators [1]. Another useful aspect of control system is that it increases renewable energy participation in the load sharing. Without a supervisory controller, it is expected to limit the renewable energy in around 20% [2].

This paper presented a supervisory control system that monitors the operation of the hybrid system with the objective of maximizing renewable energy and limit the use of diesel generator.

2. Hybrid Energy System Configuration

A hybrid power generation system is defined as the interconnection of several power generators (PV panels, wind turbine, and diesel generator) and a set of batteries. The hybrid energy system is based on a generalized three-bus configuration. The three buses are a DC bus, an AC bus, and a load bus. The technologies that generate DC current– PV, wind, and battery – are connected to the DC bus (VDC). Technologies that generate AC current, i.e. diesel generators, are connected to the AC bus (VAC). Only AC appliances are used and are connected to the load bus (IAC). A battery charger is used to convert AC (Ich_AC) current from diesel generator to DC (Ich_DC) current to charge the battery and serve the load. An inverter, or a DC-to-AC converter, is used to convert DC current (Iinv_DC) to AC current (Iinv_AC) (from the DC bus to serve the AC load) as shown in Figure 1.

3. Supervisory Control for PV/Wind-Diesel Hybrid System

As is well-known, a good operation of energy systems can be achieved only by a suitable control of the interaction in the operation of the different devices. A thorough knowledge of the management strategies to be chosen in the preliminary stage is therefore fundamental to optimize the use of the renewable source, thereby, minimize the wear of batteries and use of diesel [3, 4, 5]. In this study, a sliding control was used; using the PV power (PPV) generation as the primary source of energy, wind power (PWT) generation as the secondary source and battery

[1] *Department of Electronic Engineering, University of Nigeria, Nsukka, Nigeria*
* *Corresponding Author: Email: vincent_ani@yahoo.com*

(Pchar_max,disch_max) as the supplement and the diesel as the backup. The system moves between different mode depending on the power needed by the load and the power able to be supplied by each of the sources. Fig. 3 outlines the flow between the different modes.

turbine as well as any excess energy from the PV panels can be used to charge the battery. During the charging of the battery, if the SOC of the battery is at its maximum possible SOC value, the excess power is sent to a dump load [Dump load is a device to which power flows when the system batteries are too full to accept

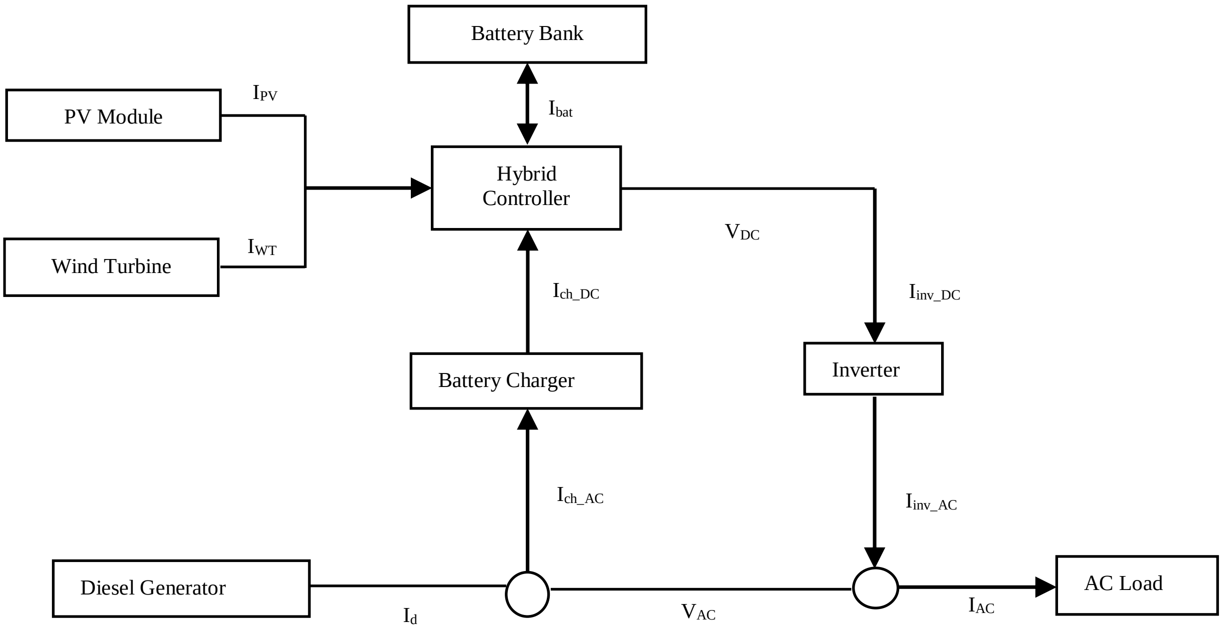

Figure 1. Configuration of the proposed PV/Wind/Diesel Hybrid System

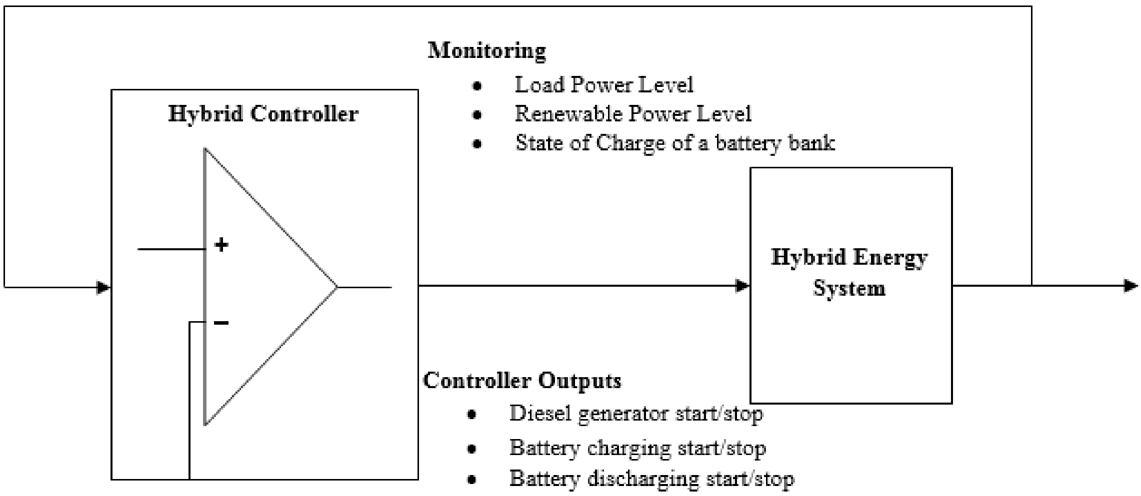

Figure 2. Hybrid System Controller Block Diagram [3].

The controller operates in 4 modes, modes 1-4 according to which of the Hybrid System Components [PV, H, W, DG] is generating the dispatch power to the load. The detailed mode of operational control (sliding) is given below:

3.1.1. Mode 1

Mode 1 uses solely the energy generated by the PV panel to supply the load. When the system is in mode 1, at times, the energy available from the PV panel might be in excess of what is needed by the load and therefore the amount of energy supplied to the load must be matched to the load demand. This is called sliding control. As the wind turbines are connected to the system, but not used to supply the load in this mode, the energy generated by the wind

more power], which can be defined according to the health clinic's needs, charging of phones, etc. The flowchart inside the dotted line shown in Fig. 3 is the charging control circuit. If the SOC of the battery is less than the maximum SOC, the amount of excess power is checked. Battery-Experts [6] advised not to use a charging current of more than 60A. The power is then checked to make sure that the current used to charge the battery will be less than 60A. If the excess power is less than this maximum charging power, the battery is charged with the full excess power. If the power is above that of maximum charging of the battery, the maximum battery charge power is used to charge the battery and the excess is used for the dump load.

3.1.2. Mode 2

Mode 2 uses the power of the PV panels plus the power of the wind turbine to supply the load. In Mode 2, if the energy available from the PV panel and the wind turbine combined is in excess of what is needed by the load, then the full power available from the PV panels is used to supply the load and the power from the wind turbine is supplied using the sliding control to match the power required by the load. The excess energy from the PV panels and the wind turbine can be used to charge the battery, as in Mode 1.

3.1.3. Mode 3

The system enters Mode 3 when the power generated by the PV panels and wind turbine is not sufficient to supply the load. The full power generated by the PV panels, the wind turbine, and the battery (with the condition that if the SOC of the battery is greater than the SOC minimum amount and the power needed to be discharged by the batteries is below the discharge maximum), then the load is supplied. Battery-Experts [6] also advised that the batteries should not supply more than 80A current, and therefore the amount of power needed to be supplied by the batteries must be checked before it can supply that amount.

There is, however a possibility that the amount of power required by the load is not able to be supplied by the PV panels, wind turbine and the batteries, and when this occurs, it enters mode 4.

3.1.4. Mode 4

When the system is in mode 4, it means that the combined power of the wind turbine and the PV panels is not sufficient to supply the load and the battery is at its minimum SOC and therefore

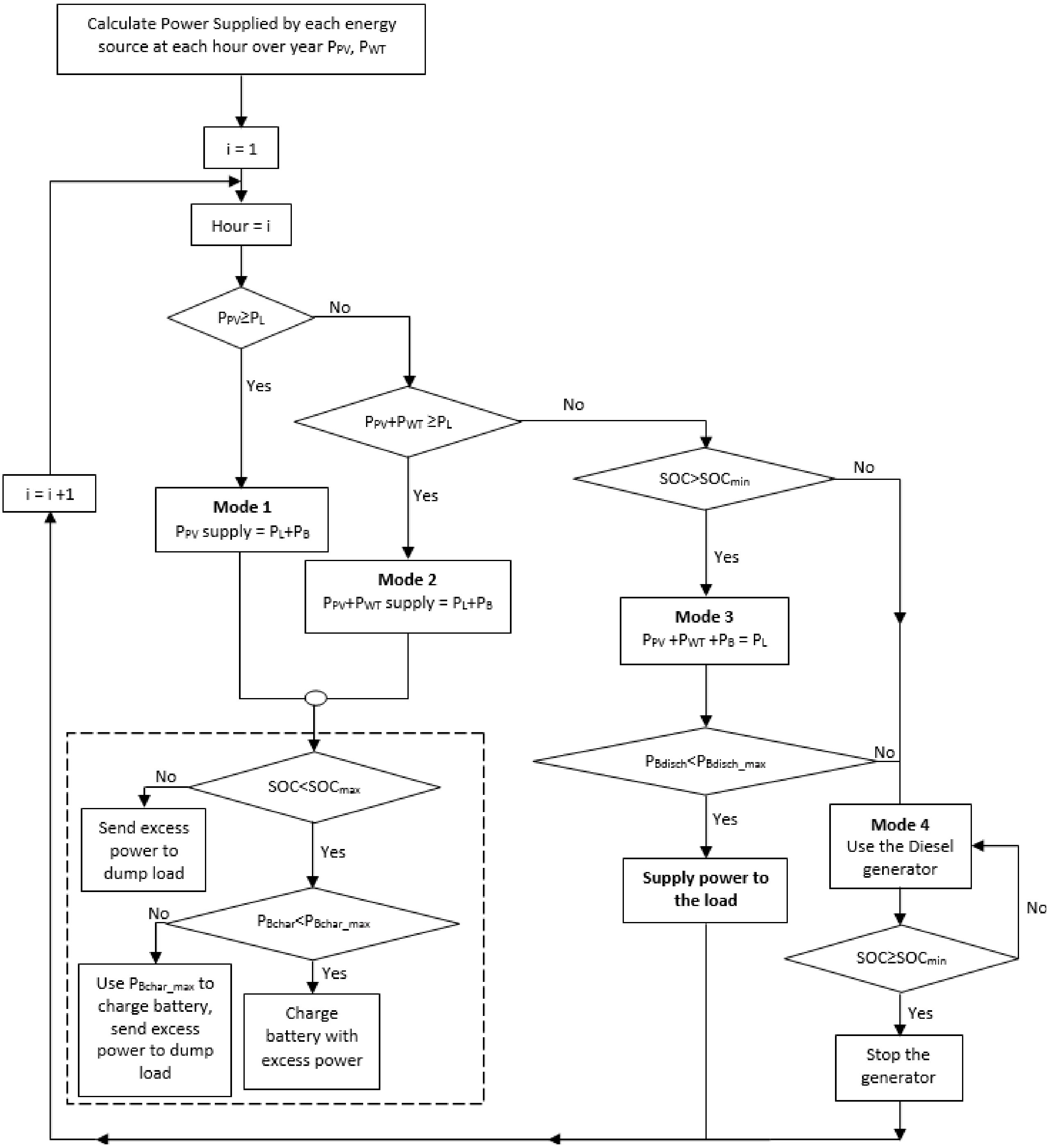

Figure 3. Flowchart of modes of control for PV/Wind/Diesel - Battery Energy System.

cannot be used to supply the deficit of power required, and the hybrid controller connects (starts the generator) to the diesel generator to enable the necessary load to be met.

The operations which activate or deactivate the charging or discharging of the battery, start (ON) and stop (OFF) the diesel generator are managed and done by a hybrid controller unit. The controller unit monitors and manages the load demand and energy supplied as shown in figure 2.

4. Material and Method

The inputs to the control simulator are the technical data of all the components of the hybrid system. These data were: solar insulation (kWh/m2), wind speed (m/s), the load required, and a hypothetical health clinic power configuration, which was gotten from [7]. The tables that contain the parameters are shown in the appendix. The hypothetical health clinic power configuration is composed of hybrid PV (5kW), BWC Excel-R wind turbine (7.5kW), diesel generator (2kW), 24 units Surrete 6CS25P battery and converter (19kW) system.

Initially, the power supplied by the PV panels and the wind turbines is calculated for each hour over the year and stored in matrices, so that power availabi¬lity in each hour can be accessed easily. The control process then begins at hour 1.

5. Results and Discussion

Tables (1, 2, and 3) show the contributions of the different renewable sources (PV and wind) and the diesel generator. These tables (1, 2, and 3) also show how the demand is met by the hybrid energy system (PV, wind, and diesel generator) for the three health clinic locations in the month of July. This month (July) was chosen due to its poor radiation and poor wind speed in Nigeria. The entire operations of the hybrid controller can be seen in figure 3.

Nembe:

The PV power supply is between 8:00h to 19:00h while the radiation peak is at 13:00h as can be seen in table 1. Between 6:00h and 9:00h, and at 17:00h there is no deficit in the system and the renewable energy supplies the load and charges the battery. During these times, there is little or no supply of PV power, but there is good wind power. There is a deficit in other remaining hours due to either higher load that occurs between 10:00h and 15:00h, or due to poor radiation (between 20:00h to 5:00h) and the deficit is being completed by either the battery or the diesel generator. It was mentioned in this paper that the hybrid controller allocates the diesel generator only when the renewable energy with the battery will not meet the load demand. For example in table one, at 21:00h when the renewable energy (no PV supply, the wind power is inadequate, and the battery state of charge is 40.21%) cannot match the load demand then the hybrid controller turns on the diesel generator.

Abaji:

The PV power supply is between 8:00h to 18:00h while the radiation peak is between 12:00h and 14:00h as can be seen in table 2. Between 9:00h and 12:00h there is no deficit in the system and the renewable energy supplies the load and as well charges the battery. During these times, there is an increase in the load demand, but sufficient supply from the PV power and wind power satisfies the load. The demand of the other remaining hours cannot be met by the renewable energy due to either higher load that occurs between 13:00h and 15:00h, or due to poor renewable resources (little or no PV power between 19:00h and 7:00h; poor wind power between 16:00h and 18:00h) and the deficit is being completed by the battery at these very times. Thus, the hybrid controller allots PV, wind, and battery bank to provide the power to the load

Table 1. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Nembe

Time**(h)**	Global solar **(kW/m^2)**	Incident solar **(kW/m^2)**	Wind speed **(m/s)**	AC load **(kW)**	PV power **(kW)**	BWC-Excel-R **(kW)**	Diesel generator **(kW)**	Inverter input (kW)	Inverter output (kW)	Rectifier input **(kW)**	Rectifier output **(kW)**	Battery power **(kWh)**	Battery state of charge **(%)**
0:00	0.000	0.000	3.570	0.503	0.000	0.267	0.000	0.592	0.503	0.000	0.000	-0.325	46.728
1:00	0.000	0.000	3.035	0.503	0.000	0.134	0.000	0.592	0.503	0.000	0.000	-0.458	46.420
2:00	0.000	0.000	3.054	0.503	0.000	0.138	0.000	0.592	0.503	0.000	0.000	-0.453	46.115
3:00	0.000	0.000	2.432	0.503	0.000	0.035	0.000	0.592	0.503	0.000	0.000	-0.557	45.740
4:00	0.000	0.000	2.994	0.503	0.000	0.125	0.000	0.592	0.503	0.000	0.000	-0.467	45.426
5:00	0.000	0.000	3.653	0.503	0.000	0.309	0.000	0.592	0.503	0.000	0.000	-0.282	45.237
6:00	0.000	0.000	4.563	0.503	0.000	0.811	0.000	0.592	0.503	0.000	0.000	0.220	45.355
7:00	0.003	0.003	4.734	0.463	0.013	0.943	0.000	0.544	0.463	0.000	0.000	0.412	45.576
8:00	0.035	0.031	4.685	0.463	0.140	0.906	0.000	0.544	0.463	0.000	0.000	0.502	45.846
9:00	0.029	0.026	4.472	0.463	0.117	0.741	0.000	0.544	0.463	0.000	0.000	0.314	46.015
10:00	0.047	0.042	4.725	0.994	0.191	0.937	0.000	1.169	0.994	0.000	0.000	-0.042	45.987
11:00	0.041	0.037	4.518	1.257	0.167	0.777	0.000	1.479	1.257	0.000	0.000	-0.535	45.627
12:00	0.034	0.031	3.757	1.257	0.138	0.362	0.000	1.479	1.257	0.000	0.000	-0.979	44.969
13:00	0.135	0.123	3.578	3.372	0.552	0.270	0.000	3.967	3.372	0.000	0.000	-3.144	42.855
14:00	0.121	0.110	3.709	1.840	0.494	0.337	0.000	2.165	1.840	0.000	0.000	-1.333	41.958
15:00	0.076	0.069	3.762	1.850	0.310	0.364	0.000	2.177	1.850	0.000	0.000	-1.502	40.948
16:00	0.055	0.049	3.613	0.483	0.223	0.289	0.000	0.568	0.483	0.000	0.000	-0.057	40.910
17:00	0.002	0.002	4.180	0.463	0.008	0.578	0.000	0.544	0.463	0.000	0.000	0.041	40.932
18:00	0.018	0.016	2.177	0.463	0.073	0.021	0.000	0.544	0.463	0.000	0.000	-0.450	40.629
19:00	0.027	0.023	2.713	0.503	0.102	0.061	0.000	0.592	0.503	0.000	0.000	-0.429	40.340
20:00	0.000	0.000	3.819	0.503	0.000	0.393	0.000	0.592	0.503	0.000	0.000	-0.198	40.207
21:00	0.000	0.000	3.444	0.503	0.000	0.227	2.000	0.000	0.000	1.497	1.273	1.500	41.014
22:00	0.000	0.000	3.398	0.503	0.000	0.217	2.000	0.000	0.000	1.497	1.273	1.489	41.815
23:00	0.000	0.000	3.455	0.503	0.000	0.230	2.000	0.000	0.000	1.497	1.273	1.502	42.623

Table 2. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Abaji

Time (h)	Global solar (kW/m^2)	Incident solar (kW/m^2)	Wind speed (m/s)	AC load (kW)	PV power (kW)	BWC-Excel-R (kW)	Diesel generator (kW)	Inverter input (kW)	Inverter output (kW)	Rectifier input (kW)	Rectifier output (kW)	Battery power (kWh)	Battery state of charge (%)
0:00	0.000	0.000	4.687	0.503	0.000	0.908	0.000	0.592	0.503	0.000	0.000	0.316	65.720
1:00	0.000	0.000	4.050	0.503	0.000	0.511	0.000	0.592	0.503	0.000	0.000	-0.080	65.666
2:00	0.000	0.000	4.346	0.503	0.000	0.662	0.000	0.592	0.503	0.000	0.000	0.071	65.704
3:00	0.000	0.000	3.690	0.503	0.000	0.328	0.000	0.592	0.503	0.000	0.000	-0.264	65.527
4:00	0.000	0.000	4.142	0.503	0.000	0.558	0.000	0.592	0.503	0.000	0.000	-0.033	65.505
5:00	0.000	0.000	4.478	0.503	0.000	0.746	0.000	0.592	0.503	0.000	0.000	0.155	65.588
6:00	0.000	0.000	3.274	0.503	0.000	0.188	0.000	0.592	0.503	0.000	0.000	-0.403	65.317
7:00	0.011	0.009	3.646	0.463	0.042	0.305	0.000	0.544	0.463	0.000	0.000	-0.197	65.185
8:00	0.072	0.065	3.229	0.463	0.291	0.178	0.000	0.544	0.463	0.000	0.000	-0.075	65.134
9:00	0.060	0.054	4.813	0.463	0.244	1.005	0.000	0.544	0.463	0.000	0.000	0.704	65.513
10:00	0.102	0.092	4.575	0.994	0.415	0.821	0.000	1.169	0.994	0.000	0.000	0.067	65.549
11:00	0.098	0.089	5.128	1.257	0.399	1.248	0.000	1.479	1.257	0.000	0.000	0.168	65.639
12:00	0.100	0.090	5.778	1.257	0.407	1.815	0.000	1.479	1.257	0.000	0.000	0.743	66.039
13:00	0.281	0.255	4.926	3.372	1.145	1.092	0.000	3.967	3.372	0.000	0.000	-1.729	64.876
14:00	0.248	0.225	4.027	1.840	1.012	0.499	0.000	2.165	1.840	0.000	0.000	-0.654	64.437
15:00	0.157	0.142	2.491	1.850	0.640	0.038	0.000	2.177	1.850	0.000	0.000	-1.499	63.429
16:00	0.109	0.099	2.132	0.483	0.446	0.019	0.000	0.568	0.483	0.000	0.000	-0.103	63.360
17:00	0.007	0.006	2.292	0.463	0.028	0.027	0.000	0.544	0.463	0.000	0.000	-0.489	63.031
18:00	0.036	0.033	2.484	0.463	0.147	0.037	0.000	0.544	0.463	0.000	0.000	-0.360	62.789
19:00	0.018	0.016	1.678	0.503	0.073	0.000	0.000	0.592	0.503	0.000	0.000	-0.519	62.440
20:00	0.000	0.000	2.079	0.503	0.000	0.016	0.000	0.592	0.503	0.000	0.000	-0.575	62.053
21:00	0.000	0.000	1.912	0.503	0.000	0.008	0.000	0.592	0.503	0.000	0.000	-0.584	61.661
22:00	0.000	0.000	2.478	0.503	0.000	0.037	0.000	0.592	0.503	0.000	0.000	-0.554	61.288
23:00	0.000	0.000	2.805	0.503	0.000	0.082	0.000	0.592	0.503	0.000	0.000	-0.510	60.945

Table 3. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Guzamala

Time **(h)**	Global solar **(kW/m^2)**	Incident solar **(kW/m^2)**	Wind speed **(m/s)**	AC load **(kW)**	PV power **(kW)**	BWC-Excel-R **(kW)**	Diesel generator **(kW)**	Inverter input (kW)	Inverter output (kW)	Rectifier input **(kW)**	Rectifier output **(kW)**	Battery power **(kWh)**	Battery state of charge **(%)**
0:00	0.000	0.000	4.243	0.503	0.000	0.610	0.000	0.592	0.503	0.000	0.000	0.018	98.009
1:00	0.000	0.000	3.476	0.503	0.000	0.234	0.000	0.592	0.503	0.000	0.000	-0.357	97.769
2:00	0.000	0.000	3.872	0.503	0.000	0.420	0.000	0.592	0.503	0.000	0.000	-0.171	97.654
3:00	0.000	0.000	3.996	0.503	0.000	0.484	0.000	0.592	0.503	0.000	0.000	-0.108	97.581
4:00	0.000	0.000	4.349	0.503	0.000	0.664	0.000	0.592	0.503	0.000	0.000	0.072	97.620
5:00	0.000	0.000	4.289	0.503	0.000	0.633	0.000	0.592	0.503	0.000	0.000	0.041	97.643
6:00	0.002	0.000	5.245	0.503	0.000	1.338	0.000	0.592	0.503	0.000	0.000	0.747	98.044
7:00	0.042	0.038	4.342	0.463	0.169	0.660	0.000	0.544	0.463	0.000	0.000	0.285	98.197
8:00	0.144	0.127	4.177	0.463	0.570	0.576	0.000	0.544	0.463	0.000	0.000	0.601	98.521
9:00	0.128	0.116	3.342	0.463	0.520	0.204	0.000	0.544	0.463	0.000	0.000	0.180	98.617
10:00	0.210	0.190	3.099	0.994	0.854	0.148	0.000	1.169	0.994	0.000	0.000	-0.166	98.505
11:00	0.213	0.193	4.612	1.257	0.868	0.850	0.000	1.479	1.257	0.000	0.000	0.238	98.634
12:00	0.216	0.196	5.224	1.257	0.882	1.322	0.000	1.479	1.257	0.000	0.000	0.525	98.916
13:00	0.472	0.414	4.452	3.372	1.863	0.726	0.000	3.967	3.372	0.000	0.000	-1.378	97.989
14:00	0.410	0.363	4.869	1.840	1.636	1.048	0.000	2.165	1.840	0.000	0.000	0.519	98.269
15:00	0.265	0.239	6.383	1.850	1.076	2.394	0.000	2.177	1.850	0.000	0.000	1.019	98.817
16:00	0.172	0.156	4.724	0.483	0.700	0.936	0.000	0.568	0.483	0.000	0.000	0.235	98.943
17:00	0.023	0.021	5.500	0.463	0.093	1.563	0.000	0.544	0.463	0.000	0.000	0.210	99.056
18:00	0.042	0.038	5.008	0.463	0.171	1.155	0.000	0.544	0.463	0.000	0.000	0.188	99.157
19:00	0.004	0.000	4.563	0.503	0.000	0.811	0.000	0.592	0.503	0.000	0.000	0.168	99.247
20:00	0.000	0.000	5.659	0.503	0.000	1.707	0.000	0.592	0.503	0.000	0.000	0.150	99.328
21:00	0.000	0.000	4.603	0.503	0.000	0.843	0.000	0.592	0.503	0.000	0.000	0.134	99.400
22:00	0.000	0.000	6.542	0.503	0.000	2.561	0.000	0.592	0.503	0.000	0.000	0.119	99.464
23:00	0.000	0.000	6.252	0.503	0.000	2.256	0.000	0.592	0.503	0.000	0.000	0.107	99.521

without allocating the diesel generator.

Guzamala:

The PV power supply is between 7:00h to 18:00h while the radiation peak is between 12:00h and 14:00h as can be seen in table 3. As from 4:00h to 9:00h, 11:00h to 12:00h, and 14:00h to 0:00h there is no deficit in the system and the renewable energy supplies the load and charges the battery. There are deficit between 1:00h and 3:00h, 10:00h, and 13:00h. These were due to no PV power, low wind power, and increased load, respectively, and this deficit is being completed by the battery.

In summary, the renewable energy were found to be variable as well as the demand in all the three hypothetical health clinic locations studied, but the supervisory control allots the sources optimally and the hybrid energy system supplies the demand of the particular health clinic location effectively.

6. Conclusion

In this study, a supervisory control was developed to satisfy the load demand by optimally allocate the renewable energy sources to the maximum extent while limiting the use of diesel generator. From the control simulation results, it was found that the supervisory control allots the sources optimally and the hybrid energy system supplies the demand of the particular health clinic location effectively. The controller also utilizes the battery bank effectively by switching the batteries into charging mode (power positive) whenever excess power is available from the sources, and switches to discharging mode (power negative) whenever there is a shortage of power from sources. The hybrid controller allocates the diesel generator only when the demand cannot be met by the renewable energy sources (PV+Wind) including the battery bank. This is intended to maximize the use of the renewable energy system while limiting the use of diesel generator which is the aim of the study. This reduces the operational hours of the diesel generator thereby reducing the running cost of the hybrid energy system as well as the pollutant emissions.

From this control simulation, the performance of the system is seen over the course of the year as well as which modes the system spends most time in, the power supplied by each of the energy sources and the power required by the load. This is useful to check how the system is being supplied and which source of energy is the most proficient in supplying the load.

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Appendix

Table A1: Solar and wind Resources for Nembe (Bayelsa State) [7]

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.547	5.240	2.900
Feb	0.509	5.130	3.000
Mar	0.454	4.730	2.800
Apr	0.434	4.500	2.300
May	0.408	4.090	2.300
Jun	0.354	3.450	3.000
Jul	0.316	3.110	3.900
Aug	0.336	3.420	4.000
Sep	0.311	3.220	3.600
Oct	0.356	3.600	2.800
Nov	0.433	4.180	2.300
Dec	0.520	4.880	2.600
Scaled annual average		**4.124**	**2.960**

Table A2: Solar and wind Resources for Abaji (Abuja, FCT) [7].

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.652	5.880	2.400
Feb	0.630	6.090	2.300
Mar	0.610	6.270	2.500
Apr	0.577	6.060	2.500
May	0.539	5.580	2.500
Jun	0.497	5.060	2.300
Jul	0.434	4.440	2.500
Aug	0.404	4.190	2.500
Sep	0.460	4.730	2.400
Oct	0.542	5.310	2.000
Nov	0.655	5.980	2.400
Dec	0.668	5.860	2.200
Scaled annual average		**5.449**	**2.375**

Table A3: Solar and wind Resources for Guzamala (Borno State) [7].

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.642	5.610	4.100
Feb	0.666	6.300	4.100
Mar	0.658	6.700	4.500
Apr	0.628	6.620	4.600
May	0.606	6.360	4.200
Jun	0.576	5.970	3.500
Jul	0.523	5.430	3.300
Aug	0.492	5.140	3.100
Sep	0.544	5.570	2.900
Oct	0.612	5.890	3.200
Nov	0.658	5.840	3.800
Dec	0.631	5.350	4.300
Scaled annual average		**5.894**	**3.799**

Table A4: Health Facility's Energy Needs [1].

S/no	Power Consumption	Power (Watts)	Qty	Load (watt x qty)	Hours/day	On-Time (Time in Use)
1	Vaccine Refrigerator/Freezer	60	1	60	24	(0.00hr – 23.00hr)
2	Small Refrigerator (non-medical use)	300	1	300	5	(10.00hr – 15.00hr)
3	Centrifuge	575	1	575	2	(12.00hr – 14.00hr)
4	Hematology Mixer	28	1	28	2	(10.00hr – 12.00hr)
5	Microscope	15	1	15	5	(09.00hr – 14.00hr)
6	Security light	10	4	40	12	(18.00hr – 6.00hr)
7	Lighting	10	2	20	7	(09.00hr – 16.00hr)
8	Sterilizer Oven (Laboratory Autoclave)	1,564	1	1,564	1	(12.00hr – 13.00hr)
9	Incubator	400	1	400	24	(0.00hr – 23.00hr)
10	Water Bath	1,000	1	1,000	1	(14.00hr – 15.00hr)
	Communication via VHF Radio		1			
11	Stand-by	2		2	24	(0.00hr – 23.00hr)
12	Transmitting	30		30	4	(09.00hr – 13.00hr)
13	Desktop Computer	200	2	400	5	(09.00hr – 14.00hr)
14	Printer	65	1	65	3	(09.00hr – 10.00hr; 13.00 – 15.00hr)

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SLAM – Map Building and Navigation via ROS[#]

Arbnor Pajaziti*[1], Petrit Avdullahu[2]

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Abstract: The presented work describes a ROS based control system of a Turtlebot robot for mapping and navigation in indoor environments. It presents the navigation of Turtlebot in self-created environment. The mapping process is done by using the GMapping algorithm, which is an open source algorithm and the localization process is done by using the AMCL pack. There are ROS built functions used in order to perform navigation of Turtlebot. The SLAM method implemented in ROS has proven a way for robots to do localization and mapping autonomously. The aim defined in paper to fulfill mapping, localization and navigation of Turtlebot in new and unknown environment is achieved

Keywords: *Map Building, Navigation, ROS, Simulation, Turtlebot*.

1. Introduction

Human beings get the information about their surrounding through vision, hearing the voice through ears, smelling through nose and they do feel the strength of objects through touching. In general human beings get information about reality through senses. A robot cannot explore an unknown environment unless it is provided with some sensing sources to get information about the environment. There are different kinds of sensors used to make a robot capable of sensing a wide range of environments [1]: Odometers, Laser range finders, Global Position System (GPS), Inertia Measurement Units (IMU), Sound Navigation and Ranging (Sonar) and cameras.

The map of environment is a basic need for a robot to perform actions like moving room to room, picking an object from one place and taking it to another one. To perform such actions, the robot should not only know about the environment but while it is moving it should also be aware of its own location in that environment.

The robot simulated is Turtlebot, and in absence of real robot the simulator provided by ROS is used. The aim to achieve is the navigation of the robot in new and unknown environment by using the ROS. As it will be presented, the robot builds the map, localizes itself on the map and performs navigation.

Turtlebot as ROS compatible robot to demonstrate the ROS power has been selected. Robot operating system (ROS) is designed to promote code sharing and enable the development of open-source robotics commons. Sharing code will help the robotics community to progress faster by letting the researchers in the community replicate and extend the results of other research groups. ROS makes it easy to find the software and integrate it into robot systems [2-5]. The complete TurtleBot includes a Kobuki base, Microsoft XBOX Kinect, ROS compatible net book, and turtlebot structure. General description on turtlebot website is "TurtleBot is a low-cost, personal robot kit with open-source software. With TurtleBot, you'll be able to build a robot that can drive around your house, see in 3D, and have enough horsepower to create exciting applications". There are numerous abilities that Turtlebot offers, while there are given part list, assembly instructions and links to suppliers. There is also a possibility to add other components, or to substitute similar components.

1.1. Outline

Section 2 starts with an overview of robotics definition and with an introduction to ROS. There is described a history of ROS followed by ROS compatible robots and ROS concepts. Section 2 is a description of ROS in general. Section 3 describes the SLAM concept and as a solution to SLAM problem there is a review of an algorithm called SLAM with extended Kalman filters. Section 4 starts with an overview of Turtlebot simulation on ROS, and at the end of section 4 a step-by-step simple solution to navigate the Turtlebot is brought.

The main reference for section 3 is the book on [6], and the main reference for section 2 and section 4 is the ROS website referenced on [7].

2. Introduction to ROS

ROS is meta-operating system for a robot. It provides services that one would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It also provides tools and libraries for obtaining, building, writing, and running code across multiple computers. It is named as meta-operating system because it is something between an operating system and middleware. It provides not only standard operating system services (like hardware abstraction), but also high-level functionalities like asynchronous and synchronous calls, centralized database, a robot configuration system, etc. ROS can be interpreted also as software framework for robot software development, providing operating system [7].

2.1. The general organization of ROS

ROS is a thin, message-based, tool-based system designed for mobile manipulators. The system is composed of reusable libraries

[1] *IDEA Teknoloji Çözümleri, Sun plaza BBDO Blok Dereboyu Cd. Bilim Sk. No:5, 34398, Maslak /İstanbul / Turkey*
* *Corresponding Author:email:unsal.gokdag@gmail.com*
# *This paper has been presented at the International Conference on Advanced Technology&Sciences (ICAT'14) held in Antalya (Turkey), August 12-15, 2014.*

that are designed to work independently. The libraries are wrapped with a thin message-passing layer that enables them to be used by and make use of other ROS nodes. Messages are passed peer to peer and are not based on a specific programming language; nodes can be written in C++, Python, C, LISP, Octave, or any other language for which someone has written a ROS wrapper. ROS is based on a Unix-like philosophy of building many small tools that are designed to work together (more on that in a bit). ROS grows out of collaboration between industry and academia and is a novel blend of professional software development practices and the latest research results [8].

2.2. ROS-compatible robots

There is quite a big list of compatible robots. A few of them are:
1. Aldebaran Nao
2. Willow Garage PR2
3. TurtleBot
4. AscTec Quadrotor
5. Lego NXT
6. Stanford Racing's Junior

The list of ROS-compatible robots grows constantly.

Turtlebot - TurtleBot combines popular off-the-shelf robot components like the iRobot Create, Yujin Robot's Kobuki and Microsoft's Kinect into an integrated development platform for ROS applications. TurtleBot is a low-cost, personal robot kit with open-source software.

Figure 1. Turtlebot [7].

2.3. Programming with ROS

ROS is language-independent. At this time, three main libraries have been defined for ROS, making it possible to program ROS in C++, Python or Lisp. In addition to these three libraries, two experimental libraries are offered, making it possible to program ROS in Java or Lua.

There is a project which is still under development named Rosjava. Rosjava is a pure Java implementation of ROS created and maintained by Google and Willow Garage. Under Rosjava, the Rosjava project totally rewrote the ROS core in Java. Google's objective is to have a version of ROS that is fully compatible with Android. Rosjava can be used to control robots for which the operating system is not Linux, but Android.

ROS software is organized into packages. Before writing any programs, the first step is to create a workspace that holds the packages, and then create the package itself. The groovy distribution of ROS contains some major changes to the way software is compiled. Older versions used a built system called rosbuild, but groovy has begun to replace rosbuild with a new build system called catkin. This is important to mention. An example of creating a package is:

catkin_create_pkg example1,

which will create package named example1. Created packages should live in a workspace directory.

3. SLAM – Map Building and Navigation

SLAM is concerned with the problem of building a map of an unknown environment by a mobile robot while at the same time navigating the environment using the map. The term SLAM is an acronym for Simultaneous Localization and Mapping. It was originally developed by Hugh Durrant-Whyte and John J. Leonard. SLAM consists of multiple parts; Landmark extraction, data association, state estimation, state update and landmark update [9]. SLAM is more like a concept than a single algorithm. There are many steps involved in SLAM and these different steps can be implemented using a number of different algorithms. SLAM is applicable for both 2D and 3D motion [9].

3.1. The hardware

The hardware of the robot is quite important. To do SLAM there is a need for a mobile robot and a range measurement device. The mobile robots considered are wheeled indoor robots. Some basic measurement devices commonly used for SLAM on mobile robots are presented here.

Important parameters to consider are ease of use, odometry performance and price. The odometry performance measures how well the robot can estimate its own position, just from the rotation of the wheels. The robot should not have an error of more than 2 cm per meter moved and 2° per 45° degrees turned. Typical robot drivers allow the robot to report its (x, y) position in some Cartesian coordinate system and also to report the robots current bearing/heading [9].

3.2. The description of SLAM

The SLAM problem is defined as a concurrent localization and mapping problem, in which a robot seeks to acquire a map of the environment while simultaneously seeking to localize itself relative to this map.

From a probabilistic perspective, there are two main forms of the SLAM problem, which are both of equal practical importance [6]:

1. Online SLAM problem:

$$p(x_t, m \mid z_t, u_t) \qquad (1)$$

2.Full SLAM problem:

$$p(x_{1:t}, m \mid z_{1:t}, u_{1:t}) \qquad (2)$$

where,

X_t is the pose at time *t*,
m is the map,
Z_t is the measurements, and
U_t is the controls.

The graphical model of online SLAM problem is shown in figure 2. The goal of online SLAM is to estimate a posterior over the current robot pose along with the map.

3.3. SLAM with Extended Kalman Filters

The earliest SLAM algorithm is based on the extended Kalman filter. In a nutshell, the extended Kalman filter SLAM algorithm applies the EKF (Extended Kalman Filter) to online SLAM using maximum likelihood data association. In EKF maps are feature-based; they are composed of point landmarks. For computational reason, the number of landmarks is usually smaller than 1000. The extended Kalman filter tends to work well the less ambiguous the landmarks are. For this reason EKF SLAM requires significant engineering of feature detectors [2].
The EKF SLAM algorithm can only process positive sightings of landmarks. It cannot process negative information that arises from the absence of landmarks in sensor measurements.

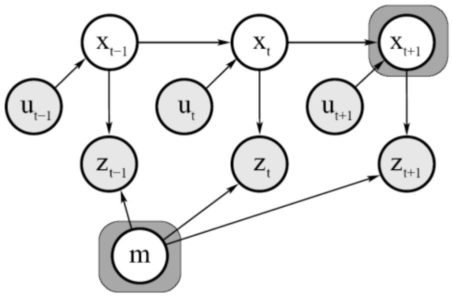

Figure 2. Graphical model of the online SLAM problem [6].

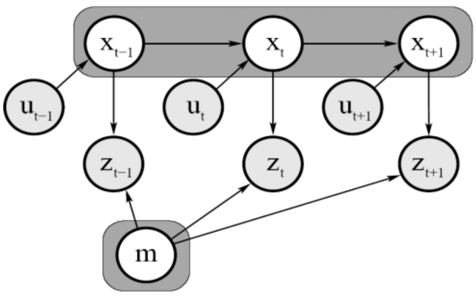

Figure 3. Graphical model of the full SLAM problem [6].

The SLAM algorithm for the case with known correspondence addresses the continuous portion of the SLAM problem only. In addition to estimating the robot pose, the EKF algorithm also estimates the coordinates of all landmarks encountered along the way. The combined state vector is given by

$$y_t = \begin{pmatrix} x_t \\ m \end{pmatrix} = \begin{pmatrix} x & y & \theta & m_{1,x} & m_{1,y} & S_1 & \ldots & m_{N,x} & m_{N,y} & S_N \end{pmatrix}^T \quad (3)$$

where x, y, and θ denotes the robots coordinates at time t
$m_{1,x}$, $m_{1,y}$ are the coordinates of the i-th landmark, for i=1… N, and
S_i is its signature.
The dimension of this state vector is 3N+3, where N denotes the number of landmarks in the map.
Figure 4 illustrates that the EKF SLAM algorithm for an artificial example.

4. Results and Discussion

Turtlebot in Gazebo with a simulated laser build a map of an environment with the GMapping algorithm has been setup. It was assumed that the workspace environment has been created. When the workspace is created, new packages need to be put in a path that is in the variable $ROS_PACKAGE_PATH. Echo this variable and confirm if the package path has been set.

Instructions for ROS Fuerte have been used. All commands used in this paper are stated on documentation status for ROS Fuerte. As mentioned earlier, there is a difference between ROS versions.

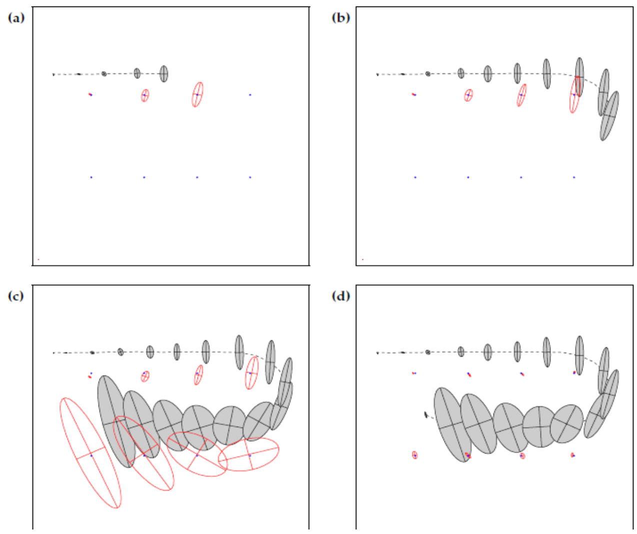

Figure 4. EKF applied to the online SLAM problem [6].

ROS package called 'ros' that depends on these packages has been created:

- ***turtlebot_gazebo*** – this package contains launchers, maps and world descriptions for the TurtleBot simulation with Gazebo.
- ***turtlebot_teleop*** – this package provides launch files for teleoperation with different input devices.
- ***gmapping*** – this package provides laser-based SLAM, as a ROS node called slam_gmapping.
- ***amcl*** – this package provides probabilistic localization system for a robot moving on 2D. It implements the adaptive Monte Carlo localization approach, which uses a particle filter to track the pose of a robot against a known map.
- ***move_base*** – this package provides an implementation of an action.

The roscreate-pkg command-line tool creates a new ROS package.

```
# roscreate-pkg ros turtlebot_gazebo turtlebot_teleop gmapping amcl move_base
```

By executing this command, these files will be created:

- manifest.xml,
- CMakeLists.txt,
- mainpage.dox, and
- Makefile.

In order to simulate a turtlebot in an appointed environment a launch file has to be created. Simple office space environment where the turtlebot can move around and navigate are to be added. Launch file '*turtlebot_office.launch*' can be created within the folder *launch*.

```
# mkdir launch
# gedit launch/turtlebot_office.launch
```

While gedit command-line is used to create or edit files, in our case it is used to create turtlebot_office.launch file, and write the following code into the created file:

```
<launch>
<param name="/user_sim_time" value="true" />
<node name="gazebo" pkg="gazebo" type="gazebo" args="-u
$(find gazebo_worlds)/worlds/simple_office.world" />
<node name="gazebo_gui" pkg="gazebo" type="gui" />
<include file="$(find turtlebot_gazebo)/launch/robot.launch" />
<include file="$(find turtlebot_teleop)/keyboard_teleop.launch"
/>
</launch>
```

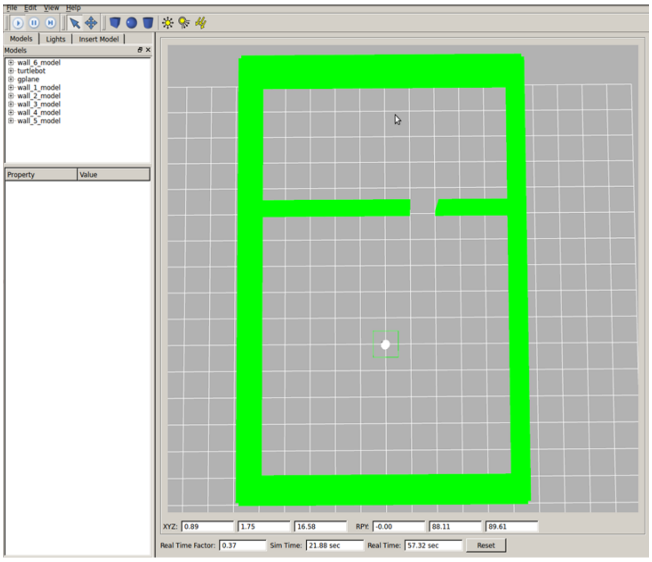

Figure 5. The simulated world with turtlebot in gazebo.

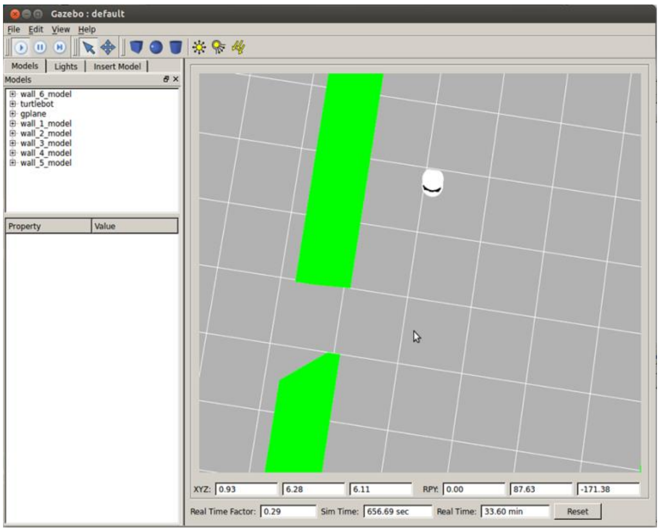

Figure 6. Turtlebot while operating with joystick or keyboard.

This file is used by roslaunch command.
The roslaunch package contains the roslaunch tools which read the xml format files. The standard format of the roslaunch command is

roslaunch *package-name launch-file-name*.

After executing the roslaunch command the simulated robot and environment appears.
Also there is the turtlebot teleoperating pack (turtlebot_teleop) included, which means that the turtlebot will move, if joystick or keyboard is used.
The navigation on given map is depicted in figure 7. First we have to be sure that Gazebo, map server, amcl and rviz are running [10]. By executing this command in new terminal the turtlebot will be ready to perform navigation on the given map.

```
# roslaunch ros move_base_turtlebot.launch
```

From Rviz tool the navigation goal can be set, by clicking the ‘2D Nav Goal’ button, setting it somewhere in the map, then the robot will start moving towards the destination [11].

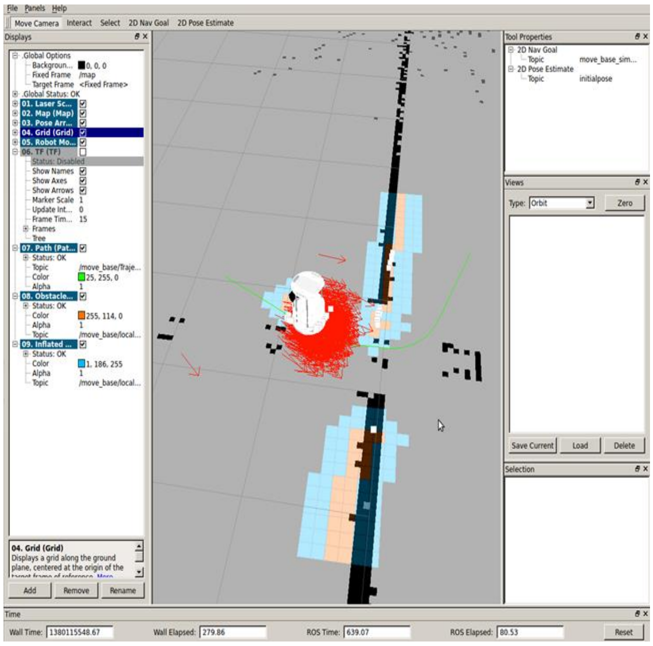

Figure 7. Navigation of Turtlebot.

5. Conclusion

ROS is a very powerful control system. There is an increased tendency of supporting a larger variety of robots by ROS. ROS provides Gazebo simulator, and it is used for simulating the robot and the environment together. For visualizing the data published from Turtlebot the RVIZ tool is used. The combination of Gazebo and RVIZ brings the feel of real demonstrations.
Once mapping and localization are successfully done then navigation can be easily achieved. The ROS navigation stack uses plugins for local and global planning which makes ROS very useful and very simple to navigate in undefined environments. In this paper the move_base package has been used for implementing path planning, which accomplished autonomous navigation.

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Rainfall Runoff Modelling Using Generalized Neural Network and Radial Basis Network

C Chandre Gowda[1*], S G Mayya[1]

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Abstract: Rainfall runoff study has a wide scope in water resource management. To provide a reliable runoff prediction model is of paramount importance. Runoff prediction is carried out using Generalized Regression neural network and Radial Basis neural network. Daily Rainfall runoff model was developed for Nethravathi river basin located at the west coast of Karnataka, India. The comparative study showed Radial basis neural network performed better than generalized neural network during its evaluation by statistical performances.

Keywords: *Generalized regression neural network, Radial basis neural network, Runoff Modelling*.

1. Introduction

Rainfall runoff modelling helps in well planned water resources management. The study on rainfall runoff relationship also helps in planning and developing distribution policies from the available water resources. Modelling Rainfall runoff with better accuracy and consistency is a difficult task, faced by many researchers. Modelling rainfall runoff is complicated, since it involves many parameters and it is nonlinear in nature. Many modelling methods exist but majorly modelling is classified as physical models and soft computing models. Selection of the inputs for the model is one of the important criteria in the rainfall runoff modelling. A main issue for using the physical model is that they require precise and large number of data set, and it includes more number of parameters also. The soft computing techniques have been suggested as a good alternative for the physical modelling, with minimum constraints. There are many parameters which influence the rainfall runoff modelling, but among them rainfall, temperature, land use land cover and infiltration are significant. In the present study two neural network (NN) models generalized regression neural network (GRNN) and radial basis neural network (RBNN) are used for rainfall runoff modelling. Neural network models have gained lot of interest, due to their adaptive nature and quick learning ability. Ability of RBNN has been used in runoff forecasting with orthogonal least square algorithms [1]. RBNN has many applications and has been used in many studies due to its prediction ability [6]. RBNN was used in simulation of sediment yield [2]. GRNN has good forecasting capability and it has been used in many ungauged predictions [3]. NN models are data driven models they converge at all possible cases. The ability of NN models having short training period and higher prediction accuracy has made it as one of the alternate method for rainfall runoff modelling [4]. It has been observed in the study that GRNN never show any solution which cannot be achieved in reality [5], [6]. GRNN model do not stuck up in local minima like typical NN models. It was found that NN are able determine a use full relationship between antecedent rainfall and runoff [7]. The relationship of antecedent rainfall and runoff also depends on the time of concentration. Rainfall runoff modelling by combing a liner model with neural network has been already achieved in the study [9] and was successful in showing the capability of NN in prediction. NN show good prediction accuracy than other statistical methods for rainfall runoff modelling [10]. NN has also been used in different application, such as determination of Earthquake deformation [11].

RBNN is one of the neural network models having radial basis function as a component and its response depends on distance from centre points. GRNN is also one among neural network models used mainly in pattern recognition. In the present study GRNN and RBNN methods are used for rainfall runoff modelling. In the study neural network tool box in MAT Lab is used for rainfall runoff modelling. The modelling of runoff using antecedent precipitation and runoff for GRNN and RBNN has been attempted in the study, which is not previously carried as per literature. The study objective is to do comparative analysis and suggest a better model for daily runoff prediction among these two models.

2. Research Method

2.1. 2.1. Generalized Regression Neural Network

Specht (1991) proposed generalized regression neural network (GRNN) [11]. Like typical feed forward back propagation neural network, GRNN does not need iterative training procedure for approximation of solutions. GRNN show consistent approximation, if a large number of training set is used then the error move towards zero with smaller constraints on the function. GRNN is based on Nadaraya Watson kernel regression and it is used to estimate the solutions similar to regression techniques. GRNN is a process used in prediction of probability density function of dependent and independent variables. GRNN consists of four layers. First layer is the input layer which depends on number of inputs considered. The first layer is connected to the second layer, which is called as pattern layer. Each neuron in pattern layer passes through training pattern, which is processed as output. The pattern layer is then summed up in third layer, called as summation layer. The fourth layer is the output layer with output neuron. Exponential activation is used at pattern layer and linear activation is used at output layer. GRNN has been used in many

[1] *Department of Applied Mechanics and Hydraulics NITK Surathkal, Mangalore, India.*
* *Corresponding Author: email: chandregowdac@gmail.com*

hydrological applications, modelling etc. The Kernel regression for estimation of functional relationship between response y and independent variable X is given by the equation (1) having x1, x2, x3, x4 and x5 as inputs variables.

$$E[y][X]=\frac{\int_{-\infty}^{\infty} y f(X,y)dy}{\int_{-\infty}^{\infty} f(X,y)dy} \quad (1)$$

E[y][X] = Estimation function, X and y are variables

$f(X,y)$ = probable density function of random variable **X** and scalar variable **y**

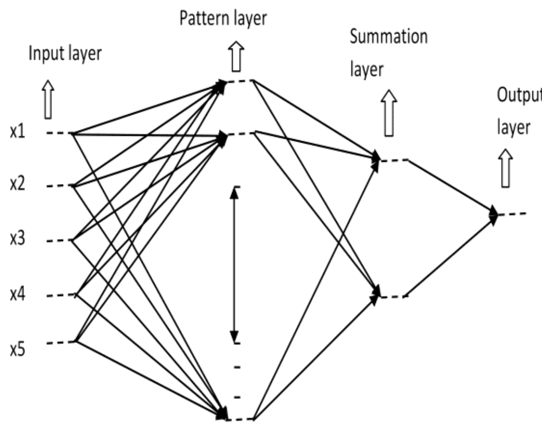

Figure 1. Schematic Representation of Generalized Regression neural network

2.2. Radial Basis Neural Network

Radial basis neural network (RBNN) was developed by Powell (1987) and Broomhead and Lowe (1988). RBNN architecture will have an input layer, single hidden layer and output layer. The network consists of an input layer, hidden layer with Gaussian transfer functions at each neuron and an output layer with linear transfer function. Neurons in the hidden layer have Gaussian transfer function characterized by separate set of mean and standard deviation values. Weights, mean and standard deviation are updated by partial derivation with respect to the corresponding variable [8]. RBNN has been used in many applications such as modelling, prediction and classification. Gaussian function is given by equation 2.

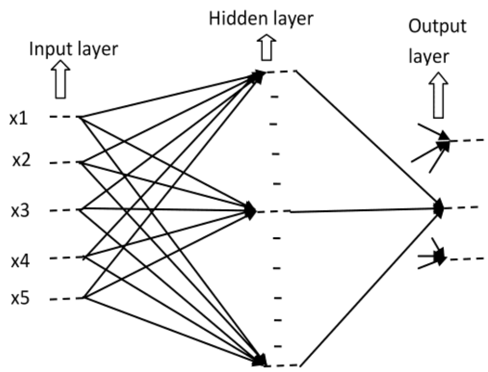

Figure 2. Schematic Representation of Radial basis neural network

$$f(x)=\exp\left[-\frac{\|x-\mu_j\|^2}{2\sigma_j^2}\right] \quad (2)$$

Where μ is the mean and σ is standard deviation.

3. Study Area

Nethravathi River originates in Western Ghats of Karnataka, India and reaches Arabian ocean at Mangalore. It lies between 74º 45' E to 75º 20' E longitude and 12º 30' N to 13º 10' N latitude (Fig. 3). The area of the catchment is 3184 km2. Annual rainfall over the basin varies between 1500 mm and 4500 mm. It receives 70 to 80 percent of rainfall during monsoon months (June to September) and remaining in the other months, the basin is major source of water for Mangalore city, Karnataka. Rain fall runoff model has been developed, using daily rainfall and runoff data for 22 year for the modelling purpose. Average rainfall of the basin was computed from Thiessen method for the rain gauge stations. Since rain fall is the main contributor for runoff. Rainfall and Runoff were selected for modelling purpose. Other parameters were neglected.

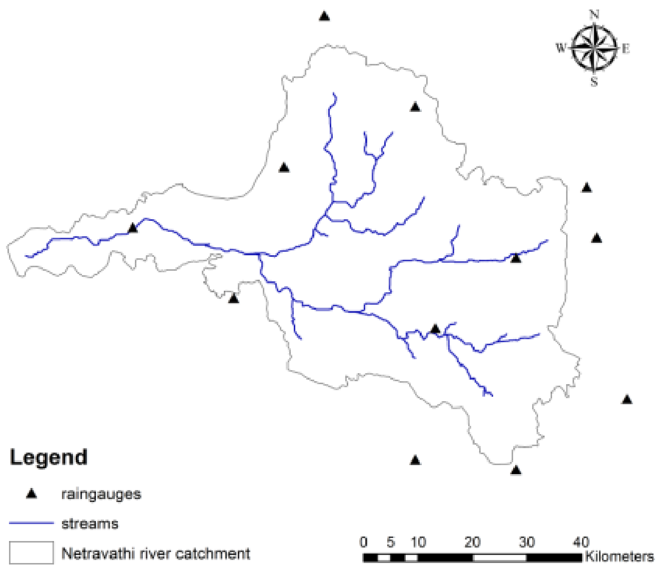

Figure 3. Nethravathi River Basin

4. Results and Discussion

In the present study GRNN having four layers, input layer having five input neurons with exponential activation at pattern layer and linear activation at output layer is adopted, For RBNN five inputs with Gaussian transfer function at hidden layer and linear activation at output is adopted

Rain fall runoff model was developed using GRNN and RBNN. Rainfall runoff modelling was done considering the antecedent runoff and rainfall as the inputs to the model to predict the next day runoff.

The model is $Q_t = f(P_t, P_{t-1}, P_{t-2}, Q_{t-1}, Q_{t-2})$;

Inputs = P_t, P_{t-1}, P_{t-2}, Q_{t-1}, Q_{t-2} ; Output = Q_t ;

t = current time period; t-1 = lag of 1 day, t-2 = lag of 2 days; output = daily stream flow; Input = daily precipitation, (lags) antecedent precipitations and antecedent stream flow. The inputs to the model was selected by correlation analysis, which showed that previous two day of lags are more prominent for the runoff of today. Nash Sutcliffe efficiency (NS), Coefficient of determination (R2) Mean absolute error (MAE) and Root Mean Square Error (RMSE) were used to check the performances of the models (Table 1).

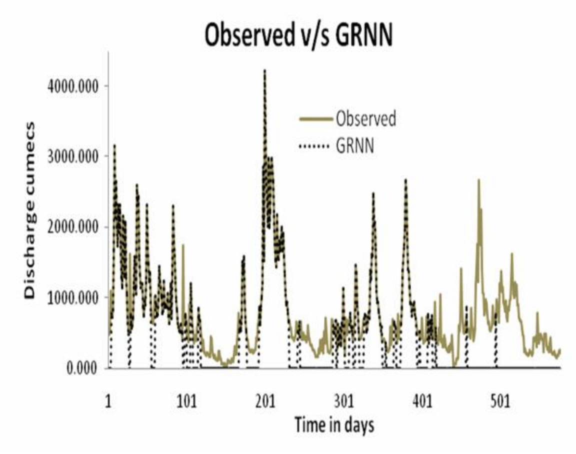

Figure 4. Time series plot of Observed and GRNN predicted flow

Rainfall runoff model for seasonal flow has been done in the study. 70% data was used for training and 30% for testing. RBNN and GRNN both the models show reasonably good R^2 value, but RBNN model shows a better NS value than GRNN during testing cases (Table 1).

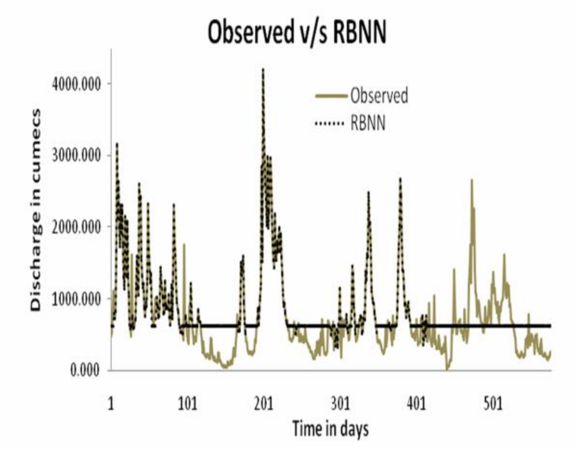

Figure 5. Time series plot of Observed and RBNN predicted flow

The other performance indicators MAE and RMSE of RBNN model are much lower than the GRNN model. GRNN model show a very less value of NS value of 0.359 (Table 1), which shows that the model has failed to capture the nonlinearity of the rainfall runoff model. Fig 4 and Fig. 5 show the time series plot of GRNN and RBNN models. It is observed that the GRNN model captured some of the peaks (Fig. 4), But its most of the points are zeros.

Table 1. Performances of the models during testing

Models	Nash Sutcliffe efficiency	Coefficient of Determination (R^2)	Mean Absolute Error (m^3/s)	Root Mean Square Error (m^3/s)
RBNN	**0.765**	**0.781**	**183**	**294**
GRNN	0.359	0.726	313	486

In Fig.5, it is observed that RBNN model shows good prediction, but its points never fall below 620cumecs. From Fig. 5 it is evident that RBNN model has also captured the peak but it shows a constant value for all the other points where the observed values are less than 620 cumecs. From Table1 it can be noted that even though both models show descent R^2, amongst them RBNN model performing better with higher Nash Sutcliffe efficiency and lower Mean absolute error and RMSE.

5. Conclusion

In the study the applications of NN methods for runoff modelling, adopting GRNN and RBNN is examined. A comparative analysis of RBNN and GRNN is attempted. Using antecedent precipitation and runoff as inputs, rainfall runoff model is established. The performance of RBNN and GRNN models are compared and evaluated from performance indicators such as coefficient of determination, Nash Sutcliffe efficiency, Root mean square error and mean absolute error. From the performances of the GRNN and RBNN model it is observed that, RBNN model perform well when compared with GRNN due to good mean and standard deviation. From the results it is suggested that among these two models RBNN is a good prediction model. So, RBNN can be used for predicting runoff, which results for enhanced water shed management..

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Avoiding Premature Convergence of Genetic Algorithm in Informational Retrieval Systems

Ammar Sami Aldallal[*1]

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Abstract: Genetic algorithm is been adopted to implement information retrieval systems by many researchers to retrieve optimal document set based on user query. However, GA is been critiqued by premature convergence due to falling into local optimal solution. This paper proposes a new hybrid crossover technique that speeds up the convergence while preserving high quality of the retrieved documents. The proposed technique is applied to HTML documents and evaluated using precision measure. The results show that this technique is efficient in balancing between fast convergence and high quality outcome.

Keywords: *Crossover, genetic algorithm, convergence rate, information retrieval, premature convergence.*

1. Introduction

Genetic Algorithm (GA) is one of the evolution based algorithms which became an important approach to solve complex problems. When optimization problem requires little knowledge about the problem that needs to be optimized, GA is one of the best adopted approaches. It is characterized by the highly parallel, random and self-adaptive algorithm which has many merits over traditional methods such as global optimization. However, GA usually has the drawbacks such as premature convergence and slow convergent speed. Premature convergence means although GA has not reached a global or satisfactory optimum, it can't produce better offspring which outperforms its parents. When premature convergence occurs, it is difficult for GA to get rid of a local optimum and reach a global optimum [1]. Premature convergence is the main obstacle to a genetic algorithm's practical application. In order to overcome genetic algorithm's premature convergence, we should first have a good understanding of convergence of GA [1]. The premature convergence of a genetic algorithm arises when the genes of some high rated individuals quickly reach to dominate the population, restricting it to converge to a local optimum. In this case, the genetic operators cannot produce any more descendent better than the parents [2]. Hence, the algorithm ability to continue searching for better solutions substantially reduced.

The genetic algorithm convergence rate is been used to judge the computational time complexity of finding a global optimal solution. Therefore, it is very important to study the convergence rate of GA. Firstly, the convergence of GA must be guaranteed before analysing and evaluating solution. Based on that, the optimization efficiency of the algorithm can be judged and its results are utilized to improve the algorithm.

This work will analyse the convergence rate of GA applied to information retrieval (IR) system through what is named Genetic Algorithm-based Information Retrieval (GABIR), where the outcome of this system is measured using precision measure

[1]*Ahlia University – Bahrain*
**Corresponding Author: Email: aaldallal@ahlia.edu.bh*
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1.1. What is Genetic Algorithm?

Genetic algorithm is a probabilistic algorithm used to simulate the mechanism of natural selection of living organisms and it is often used to solve problems having expensive solutions. This is basically due to the principles of selection and evolution employed to produce several solutions for a given problem. Generally speaking, GA's search space is composed of candidate solutions (chromosomes) to the problem. Each chromosome has an objective function value known as fitness value. This measure is used to favour selection of successful parents for producing new offspring. Offspring solutions are produced from parent solutions by the application of selection, crossover and mutation operators [3]. Offspring forms the second generation of possible solution. Several generations are then created by applying these operators until one of the two following criteria is satisfied. Either no more enhancements in terms of the fitness value of the entire chromosomes are achieved compared with previous generation or the maximum predefined number of generations is created. In all cases, the system will return the optimal solution from the last generation.

1.2. GA in Information retrieval

Most studies argue that IR can be seen as a standard optimization problem [4], where it has search space S represented by the set of documents D, a set of possible solutions S^+ (the possible documents related to the user query), such that $S^+ \subseteq D$ and evaluation function f to evaluate the relevance of each of these possible documents related to the user query. Finally, a search engine tries to output documents that maximize f. The optimal solution is a document or set of documents that have the maximum score returned by the function f. It is found that such an optimization problem can be solved efficiently using Genetic Algorithm [5, 7]. In addition, GA requires less processing resources compared with IR models, since there is no need to apply the searching technique to the training set before finding the optimum solution, which delay the output process. Moreover, there is no need also to evaluate all documents in the search space in order to find the optimum solution, which is computation extensive.

The rest of the paper is organized as follows: Section 2 reviews the related work done on the convergence of GA. Section three presents the proposed technique to improve the convergence rate. Section 4 describes the document set used to evaluate GABIR, while Section 5 states the evaluation measure. The experiments conducted and analyses of the obtained results are presented in Section 6. Finally, Section 7 concludes the work and suggests methods to further enhance the convergence rate.

2. Related work

Many researchers and experts have made a thorough and extensive study on convergence rate of GA. Apart from IR systems, [1] and [8] developed techniques based on Markov chain to improve the GA convergence. The approach of [1] suggests a study on calculation of the first expected hitting time based on the absorbing Markov chain. The premature convergence was avoided through self-adaptive crossover and mutation probability and close relative breeding avoidance method. [8] formulated a model for a class of genetic algorithms, which analyses the convergence rate of this class of genetic algorithms in a different way, and proved that the convergence rate is linear based on property of Markov chain. They showed that this technique is applicable to arbitrary coding, arbitrary crossover, arbitrary mutation and arbitrary selection. However, these two studies established a theoretical mathematical model of Markov chain and were lagging in providing experimental results to measure their efficiency.

The authors in [2] proposed two techniques to prevent premature convergence in GA. One of them is the dynamic application of many genetic operators based on the average progress, and the second one is the population partial re-initialization.

Generally speaking, the number of generations required to produce the final result reflects the speed of convergence. When applying GA to IR systems it is found that number of generations is mentioned as a parameter of the implemented GA models where it ranges between 20 [9] and 500 [10]. The speed of convergence is not discussed separately as a factor to enhance the system performance. Nevertheless, their researches will be considered here to highlight the speed of convergence compared with results achieved. They present the number of generations in their results either graphically [9, 11] or in a tabular format [6, 10, 11] represented the results graphically and the maximum number of generations was 90 for the first experiment and 60 for the second one, whereas the number of generations in [6] is 30 when examining the HTML tag weight using GA. On the other hand, [9] plotted the results of average fitness per generation and show that the maximum number of generations is 20 which somehow indicates the speed of convergence for this model. This small number reflects fast convergence but the quality of the results in terms of precision and recall are lower. Nevertheless, there is no special importance given to this factor. Therefore these figures will not reflect the actual speed of convergence but will be utilized when compared with the proposed model. [17] produces recall of 1 when the number of generation is very huge where it is 1200. While [3, 12] converges within 100 generations. Much apart from these figures is the number of generations required to divert by the approach proposed in [4] which is 12000 generations. Obviously, this gives an idea about the slow performance of such approach which aims to produce high average mean quality of the retrieved documents. However, the achieved quality for this approach was only 25%.

One of the main operators that heavily affects the convergence is crossover. In literature, many techniques of crossover have been developed and analyzed to study their effect on the output from several perspectives [13]. The most common crossover technique is one-point crossover [3, 5, 12, 14-22]. It chooses single point randomly within the chromosome and copies the values of parents 1 and 2 before or after this point to the same locations in the new offspring 1 and 2. Then, the values after or before this point are exchanged by copying them to the new offspring such that genes of parent 1 are copied to offspring 2 and that of 2 are copied to offspring 1.

Another well-known crossover techniques are two-point crossover [23, 24], and inversion crossover [25]. In one-point and two-point crossover two offspring are produced from two parents. These offspring inherit mixed properties from the two parents which may or may not perform better than the parents. Consequently, the convergence may slow down. Close to this performance is the inversion crossover. In this technique the order of genes between 2 randomly chosen positions within the chromosome is reversed. One offspring is produced from two parents in this technique; hence, its performance differs only in the arrangement of genes within the chromosome, and if the order is not important then this technique has no effect of overall performance of the chromosome and as a result, this technique may lead to premature convergence.

While many approaches are developed by researchers to enhance the convergence speed in GA, this work is featured by introducing a new crossover technique as well as adopting specific GA operator techniques that are expected to enhance convergence speed while maintaining the high performance of the IR system.

3. The GABIR approach and its effect on convergence

GA is controlled by set of operators. These operators are: selection, crossover and mutation, while the fitness function is used to evaluate each chromosome during selection and after producing new generation. The technique of implementing each operator actually influences the convergence of the GA system. This works examines several techniques of implementing each operator on IR system and studies the convergence of GA using each technique and analyses its performance.

3.1. Initial Generation Creation

When looking at the methods of creating initial generation, there is a trade-off between creating initial generation in a fast way with low quality or slower way but with high quality. Fast creation is done by selecting individuals randomly without any selection criteria.

However, this method may stick at a local optimum solution causing the results to be less effective due to fast convergence [12]. To overcome this drawback, random selective technique is applied to select individuals based on some criteria. Although this method slows down the creation of initial generation, it provides a higher probability to find optimal solutions rapidly and avoids fast convergence with local optima.

Several well-known selection techniques where proposed and heavily applied in GA such as heuristic creation operator [4] and random selection [12, 14, 16, 22, 23, 26, 27].

3.2. Parent selection

Next operator of GA is parent selection. The most popular one is *simple random sampling selection* also called *proportional selection*. It has been applied by many researches [3, 6, 14, 18, 23, 28, 34]. This method performs roulette-wheel selection, where each individual is represented by a space that proportionally corresponds to its fitness. Stochastic sampling is used to choose individuals by repeatedly spinning the roulette wheel. This method may speed up the convergence with small fraction and avoids early premature convergence since good individuals have high probability of being selected for crossover.

In *tournament selection* [16], a group of i individuals are randomly chosen from the population. This group takes part in a tournament and an individual with highest fitness value wins. In many cases i is chosen to be two, and this method is called *binary tournament selection*. To further enhance this selection, i is selected to be four so each time from each 4 individuals, the best is selected.

3.3. Design of Hybrid Crossover

The proposed crossover operator to be implemented here is a combination of reordering crossover [18], fusion crossover [18] and one-point crossover. When genes within a chromosome are ordered based on their fitness value and the order is important, then the crossover applied to such chromosomes is called a reordering crossover. In fact, the order of genes in the GABIR is important as it represents the ranked documents that will be displayed to the user. If one offspring is to be produced from the crossover process rather than two, then it is called a fusion crossover [29]. Combining these two techniques together and applying a one-point crossover on them forms the proposed hybrid crossover suggested in this paper.

The hybrid crossover operates in the following manner. Suppose there are two parents x and y of length L. These two individuals are selected randomly using binary tournament selection from current population p_i to produce one offspring O of population p_{i+1}. Firstly, the chromosome's genes are ordered based on their fitness value from higher to lower from the previous generation. Then a one-point crossover is applied by choosing cross point cp randomly over the range [1.. L]. The selected cross point divides the chromosomes into two parts. The first O's genes [O_0, .., O_{cp}] are copied from the candidate parent that has the greatest gene's value at position L_0, suppose it is x in this example. The remaining genes of O are copied from the second parent starting from the leftmost position until the offspring O is filled up or until it reaches the specified location cp. Through the process of copying the remaining genes from the parents, the uniqueness of the copied gene must be considered, i.e., each gene can occur only once in the new offspring O. This is implemented by excluding the genes that already exist in O. When O is not filled up to the specified length, the fitness values of other genes in both parents are compared starting from location cp+1. The gene that has a higher fitness value contributes to O. This is done in order to generate offspring with appropriate genes from each parent and to guarantee that the length of O is maintained at L.

In the one-point crossover, GA selects one point randomly to perform exchange of genes. A reordering crossover is applied to chromosomes having their genes ordered based on their fitness value from higher to lower. The rationale behind using the ordered crossover technique over other techniques is the need to inherit the good genes and maintain the good building blocks while passing them to the resulting offspring.

In fusion crossover, only one offspring is generated from the two selected parents. In this technique, the offspring inherits the genes from one of the parents with a probability according to its performance. The advantage of this technique is that the good genes of both parents are inherited simultaneously to the offspring, producing high quality offspring and increasing the speed of convergence.

Combining the three techniques of crossover into one process expected to allow fast convergence with high quality offspring. The ordered technique gathers the good genes into one side of the chromosome. Then the one-point crossover copies these gathered genes from the heavy side of both parents to one offspring only. This results in an offspring having the best genes of both parents.

Graphical illustration of hybrid crossover is shown in Fig. 1 in which numbers in each chromosome represent the fitness value of the gene at that position. The crossover will take place between two previously selected candidates x and y (Step A). The cross point cp is selected randomly to perform a one-point crossover (Step B). In this example cp=3. Because the first gene of x has a greater fitness value than the first gene of y, x's genes to the left of the cross point are copied to the offspring. To complete the genes of O, y's genes to the left of the cross point are copied to the offspring as well. Then a competition between the genes to the right of the cross point in both x and y is done to decide which parent's genes will be copied the remaining space in the offspring. Because the gene at position cp+1 in y has a greater value than that of x's, then y's genes are copied into O (the right bold set of genes in step C). Once all positions in the offspring are populated with genes, these genes are ordered from higher to lower based on their fitness value (step D).

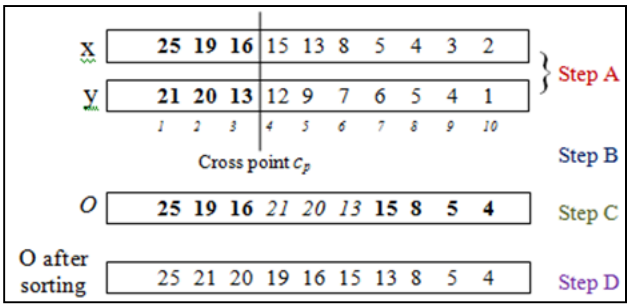

Figure 1. Example on hybrid crossover technique

3.4. Fitness function

Among several fitness functions developed by researcher Proximity fitness function proposed in [33] is been adopted in this work due to its high efficiency in IR systems.

4. Document Set Description

The documents that will be evaluated by GABIR can be either plain text, semi-structured (i.e., HTML (HyperText Markup Language) documents) or structured. Because most of web-documents are written in HTML [6], this format is adopted for implementing GABIR.

In similar studies, researchers tend to use ready-made data sets which use vector space indexing models such as TREC and ACAM data sets. These sets include documents, vector space index, queries and their results. However, these sets are not suitable for the proposed model because of the indexing model on the one hand, and due to the additional data that need to be included in the index which is not supported by these data sets on the other hand.

The document set or search space used in this work is a set of HTML web documents. This set is the Carnegie Mellon University data set (WebKB). It is a set of HTML documents from the departments of computer science at various universities collected in January 1997 by the World Wide Knowledge Base project of the CMU text learning group. It consists of 8284 documents [35] and used by several researches [30]. This set consists of seven categories, named: course, department, faculty, project, staff, student and others, in additional to another 60 web documents downloaded from the Web by passing different keywords to the Google search engine. Hence, the total number of HTML documents in the set is 8344. Table 1 shows the categories of the document set as well as the number of documents in each category. This document set is expected to be reasonable to analyze the proposed model since this size is in the range of document size used in similar researches. In the literature, the data set used to test most GA-based IR systems is CISI [3, 12]. This data set consists of 1460 documents and was tested against 76 to 112 queries. Table 1 shows some statistics for the documents and queries used to test GABIR.

Table 1. Statistics of the test collection used in the proposed model

Parameter Name	Value
Number of documents	8344
Number of queries	100
Number of unique indexed terms	128213
Average number of terms per query	2.69
Average number of relevant documents per query	16.82
Average number of indexed terms per document	410.28

5. Evaluation Measure

When evaluating the convergence rate of GA system, there is a tradeoff between premature fast convergence, and slow convergence with high performance. Hence, in order to balance between these outcomes, the results of the proposed system are evaluated by using precision measures. Precision is defined as the percentage of relevant retrieved documents to the total number of retrieved documents.

One of the popular measures used to evaluate the IR systems is precision at Rank N (P@N), where N is multiples of 10 [3, 11]. Rank N here means the top N ranked documents of the retrieved documents. In this method, the retrieved documents are ranked in descending order based on the fitness value (relevance to the query) and the average of precision is calculated. Therefore, this measure evaluates the system based on the percentage of the total retrieved documents.

When the maximum value of N is 100, this measure is called 11-point average precision [31, 32] and it is widely used to evaluate IR models, since it measures the performance at the points 0, 10, 20, 30 up to 100 top ranked retrieved documents, where point 0 means the first retrieved document or the top ranked document. However, this work applies the measure P@10 for seek of assessing the convergence rate rather than assessing the overall retrieved documents.

6. Experiments and Results

In order to investigate the speed of convergence of GABIR, several experiments were conducted. In each experiment, all operators along with their parameters are fixed except for the one under consideration. These operators and parameters are listed in Table 2.

To evaluate each outcome, 10 runs are executed and the average result is considered in the analysis. Since GA consists of four operators: initial generation creation, parent selection, crossover, and mutation, the following experiments are conducted: first experiment applies the hybrid crossover on two selection methods: random selection and random selection with selective criterion. The applied selective criterion is to consider the documents that consist of the queried keywords. The second experiment applies the hybrid crossover on two parent selection methods: binary tournament selection in which the best one is always selected and the second one is binary tournament selection which favours better parent with probability ≤ 0.75. By fixing the selection method, third experiment compares between three crossover techniques. The first one is hybrid crossover. The second one is one-point crossover which has non-ordered genes and produces two offspring. The last one is a two –point crossover that produced one offspring. By adopting hybrid crossover technique, the fourth experiment utilizes different fitness functions. These fitness functions are term proximity fitness function [33], Okapi-BM25 [14] and Bayesian inference network model [6]. For details about these fitness functions, reader is recommended to review author's previous work [33]. The average number of generations formed by GABIR was 22.26 which demonstrate its fast convergence.

Table 2. Parameter setting of GABIR

Parameter Description	Value
Population size	Fixed at 125
Maximum number of generations	50
Chromosome length	125
Crossover rate	1
The number of best individuals copied to the next generation (Elitism)	1
Mutation rate	0.7

Meanwhile, the quality of the retrieved documents in terms of precision measure is very high compared to that of other techniques. The main reason of the combination of the low number of generation and high precision is the way the GABIR's hybrid crossover is implemented along with the operators' techniques adopted. As illustrated in Table 3, the main contribution to the high convergence (smaller number of generations) is coming from the hybrid crossover technique. It converges 20.5% faster than non-ordered crossover but it was slower than 2-point crossover by 63%. However, the performance of these two crossover techniques (non-ordered crossover and 2-point crossover) was very poor in terms of precision. The convergence of 2-point crossover provides an example of premature convergence, where it converges very fast (only 13 generations) but the quality of the retrieved results in terms of precision was too low which is 40%. The reason of why hybrid crossover achieved best results is influenced by nature of the technique. It pushes the high quality genes towards the left of the chromosome by ordering the genes and then it combines and passes the best genes of both parents to one offspring.

Considering other GA operators, it is found that each operator technique has an effect on the convergence. The first effect comes from the initial selection technique. When applying selective random selection to GABIR, the speed of convergence is faster than applying pure random selection by 10.8%.

Smaller effect on convergence results from the parent selection, where *binary tournament parent selection-100* is 2.8% faster than *binary tournament parent selection-75*. Another great improvement in convergence speed is achieved from the adopted fitness function. The term proximity fitness function was faster than both OKPI-BM25 and Bayesian network inference by 46.6% and 5.6% respectively.

Table 3. The average convergence of each GA operator technique

Operator Name	Technique Name	Average Convergence	P@10
Initial selection	Initial generation with selective criterion (selective random selection)	**22.26**	**0.85**
	Random selection of initial generation (pure random selection)	24.96	0.6
Parent selection	Binary tournament selection which always favours better parent (Parent Selection-100)	**22.26**	**0.85**
	Binary tournament selection which favours better parent with p ≤ 0.75 (Parent Selection-75)	22.90	0.83
Crossover method	**Hybrid crossover**	**22.26**	**1**
	Non-ordered crossover representation	28	0.58
	Two –point crossover producing one offspring	13.65	0.4
Fitness function	Term proximity fitness function	**22.26**	**0.85**
	Okapi-BM25	41.66	0.55
	Bayesian inference network model	23.58	0.49

7. Conclusion

This paper proposed GA-based information retrieval (GABIR) system that combines the fast convergence and high performance. The key feature of this system is the proposed *hybrid crossover* technique. It is constructed by applying 1-point crossover to the ordered chromosome to produce one offspring which combines the best genes of both parents. This technique is applied as part of GABIR to retrieve HTML documents based on user query. Several experiments were conducted to examine the performance of GABIR. These experiments study the influence of convergence on the quality of the retrieved results in terms of precision measure.

The performance of GABIR that adopted the hybrid crossover outperforms other operators. It managed to enhance the convergence rate by up to 63% for some operators such as Okapi-BM25 fitness functions with enhancement in the quality by 55%

To generalize the results and further demonstrate its efficiency in the IR domain, it needs to be compared with additional crossover techniques such as the uniform crossover, and need to be applied to larger document set. This work is implemented on chromosome with fixed length and can be further improved by examining the performance on variable length chromosomes in terms of precision and convergence speed.

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