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Perceived governance structure and constraints in the pig supply chain in Ghana

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ABSTRACT

This study examined farmers' perceived governance structure including contracting and power relations, and actors' constraints in the pig supply chain. A multi-stage sampling procedure was used to obtain cross sectional data from producers, collectors and processors. The empirical results revealed that contractual relationships between farmers and other actors are uncommon in the pig supply chain, with only 9.9% of the farmers and 12.5% of processors having verbal contracts with other actors in the supply chain. The two most constraining factors of the producers, collectors and processors were the high cost of inputs and poor access to credit. Overall, the producers are perceived to rank highest in terms of bargaining power and information concentration, while collectors and input suppliers have the highest influence on profit and protection from competition. The role of producers' speculation of the market power and training on contracting are critical to enhancing their performance in the pig supply chain.

Keywords: governance structure, market power, contracts, Ghana

Introduction

The livestock sector is important to the Ghanaian economy although its contribution to the gross domestic product remains low (7.5%) (Ghana Statistical Service, 2013). Nevertheless, the sector creates employment opportunities, thereby improving rural livelihood, food security, and financial reserves of the actors in the supply chain (Perera and Jayasuriya, 2008; Sesay, 2016).

The livestock supply chain includes all the activities needed to bring a product (e.g. live animals, meat, milk, eggs, leather, fibre, manure) from production, processing and distribution to final consumers (International Fund for Agricultural Development (IFAD), 2006). The stakeholders include middlemen or firms who perform activities such as transporting, processing, storing, selling, buying, packaging of a product before it finally gets to the consumer. In addition, government agencies that set rules and formulate policies (e.g., Ghana Standard Authority, Food and Drugs Board, Ministry of Food and Agriculture), and information brokers who keep the market players informed about prices and quantities play key roles in the livestock supply chain.

The term 'governance' is defined as the processes by which transactions are coordinated between two or more actors, either within the boundaries of a single organization or between two or more organizations to ensure that they are smooth (Ruuska *et al.,* 2010). Governance structure seeks to explain the rules that operate in a supply chain, how actors are coordinated and regulations that govern value generation in the supply chain. It consists of a set of coordination mechanisms including verbal contact, written contract, spot market contract, horizontal integration, vertical integration that allow supply chain actors to cooperate and minimize opportunistic behavior (Williamson, 1985; Gereffi *et al.,* 2005; Raynaud *et al.,* 2005; Zhang and Aramyan, 2009; Wever *et al.*, 2010). Food supply chain governance increases competition among actors, mitigates conflict, promotes cooperation among actors, and streamlines the supply chain by getting rid of superfluous or unnecessary activities and specifies the roles of the actors, thereby improving product quality and minimizing cheating in the supply chain (Williamson, 1999; Vorst and Beulens, 2002; Adger *et al.,* 2003; Vurro *et al.,* 2010; Vlajic *et al.*, 2012; Lumineau and Henderson, 2012; Rota *et al.,* 2013).

Numerous studies have revealed that livestock farmers get cheated by other actors in the supply chain (e.g. traders and middlemen). This happens because of weak market systems, information asymmetry, poverty and weak bargaining power arising from illiteracy and low social status (e.g. IFAD, 2006; Lightfoot and Scheuermeier, 2007; Jitmun and Kuwornu 2019; Jitmun *et al*., 2019).

Generally, the challenges of the Ghanaian livestock industry vary across key stakeholders. In the case of the producer and processor, poor quality of carcass is a major problem due to improper handling of animals prior to slaughter (Adzitey, 2013; Adzitey *et al*., 2011). The other challenges confronting the sector include high utility costs, low credit support, uncertain government policy, poor information sharing among actors and unfair distribution of ultimate value of output, (indicating poor governance in the supply chain), and limited input services including commercial breeding, access to and availability of veterinary care and extension agents. These result in low productivity of pigs in terms of feed conversion and reproduction rate (IFAD, 2006; Mensah-Bonsu, 2010; International Livestock Research Institute (ILRI), 2011).

Several studies have highlighted the role of governance structure, trust, cooperation and bargaining power in food supply chains, however, empirical evidence of these indicators in the piggery sector in Ghana is scanty or non-existent (Nash, 1950; Rubinstein, 1982; Webber and Labaste, 2010; Zajac and Olsen 1993; Kuwornu *et al*., 2004; 2005; 2006a; 2006b; 2009a; 2009b; 2018a; Kuwornu, 2006; Kuwornu and Saqib, 2017; Promme *et al*., 2017; Saqib *et al*., 2018; Sathapatyanon and Kuwornu, 2019).

The piggery sector is one of the key subsectors of the livestock industry in Ghana, nevertheless is the industry faces numerous challenges including high cost of inputs and imbalance power relations (IFAD, 2006; Mensah-Bonsu, 2010). The governance in the Ghanaian piggery supply cannot be fully understood without analyzing the coordination mechanism (bargaining power, profit, information concentration and protection from competition) that exists among the various actors in the supply chain, as the governance structure and the constraint variables could influence performance of the supply chain. Therefore, the objective of this study are twofold as follows: i) to explore the governance structure among the actors in the pig supply chain, and ii) to examine the constraints faced by the actors in the supply chain.

Materials and methods

Governance structure

The form of contractual agreement, terms and nature of contract that exist among actors in the chain were described using percentages.

For this study, power is defined as the level of importance and influence each actor exerts in reference to some selected indicators i.e. profit, bargaining power, protection from competition, and information concentration (CATRD, 2006; Gerrefi *et al.,* 2005; Dolan and Humphrey, 2000). The cardinal scoring approach adopted by Kaplinsky and Morris (2001) and CATRD (2006) was used to estimate the selected indicators to judge the "importance" and "influence" an actor exerted on other actor(s). The strength for all the actors (i.e. input suppliers, producers, processors and collectors) perceived by each given actor (respondent) on each of the indicators summed up to 100%, from a possible range of 0 to 100 % for each actor. The average of the scores assigned by the actors for each indicator was calculated. The higher the mean score (%), the higher the level of influence for a given indicator. The actor group which receives the highest mean score (%) for each indicator from the scoring of the respondents was considered as the dominant player in the pig supply chain.

Identification and ranking of constraints of pig supply chain actors

The constraints facing actors at each stage of the supply chain were identified from the literature and during the pre-testing of the questionnaire used for the data collection. The respondents ranked these constraints from the most pressing to the least pressing, and they were analyzed using the Garrett ranking technique specified in equation (1) as follows:

$$y = \frac{100(R_{ij} - 0.5)}{N_J} \quad (1)$$

Where: y = % position of the score, R_{ij} is the j^{th} constraint of the i^{th} respondent and N_j is the total number of constraints ranked by the j^{th} respondent. The most pressing constraints were discussed. This technique is appropriate because of the merit it has over Kendall's coefficient of concordance as it controls for inter-regional and environmental differences. The order of merit given by the respondents for the constraints was converted into scores with the help of the ranking table given by Garrett and Woodworth (1969). The constraint with the highest mean score was considered as the most pressing.

Sampling and Data

A multi-stage sampling procedure was employed to solicit data from 123 respondents in the pig supply chain through the administration of three different structured questionnaires for pig farmers, processors and collectors respectively. The respective questionnaires were pre-tested with five farmers, two processors and two collectors.

The first stage of the sampling was to purposively select the Eastern and Greater Accra regions due to considerably high livestock production in the southern part of Ghana. In the second stage, 42 pig farmers were randomly selected in the Greater Accra region from a list of 178 pig farmers obtained from Creating Competitive Livestock Entrepreneurs in Agribusiness (CCLEAr) database and 39 pig farmers were selected from the Eastern region, based on their farm size (above 10 pigs per farm). Thus, data were obtained from a total of 81 pig farmers.

With processors, 40 retail-processors were selected based on their availability and scale of production using the snow-balling technique. Finally, two collectors (local assemblers) were interviewed based on their availability using the snow-balling technique.

Results and Discussion

Governance structure among actors in the supply chain

This section presents the supply chain mapping of the pig industry in Ghana, the existence of contracts, and power relations among actors in the supply chain. The supply chain mapping of the pig industry is presented in Figure 1, and shows the flow of pig and pig products from producers to customers as well as a sequence of linkages among the various actors operating in the chain. The producers obtained inputs from both small- and large-scale input suppliers. The pig producers sold their live animals to processors (54.5%), consumers directly (33.8%) and collectors (9.1%). Only a few (2.6%) of the live animals were sold to organizations like FBOs. Processors processed their purchased pigs into either cut fresh meat (pork, 28.2%) or grilled/roasted pork (71.8%) for sale directly to consumers. The collectors who serve as middle men in the supply chain sold half (50%) of their pigs to processors and the other half (50%) directly to consumers. The study did not identify intermediary retailers between processor and consumers. The study revealed that the collectors in the pig supply chain were very few.

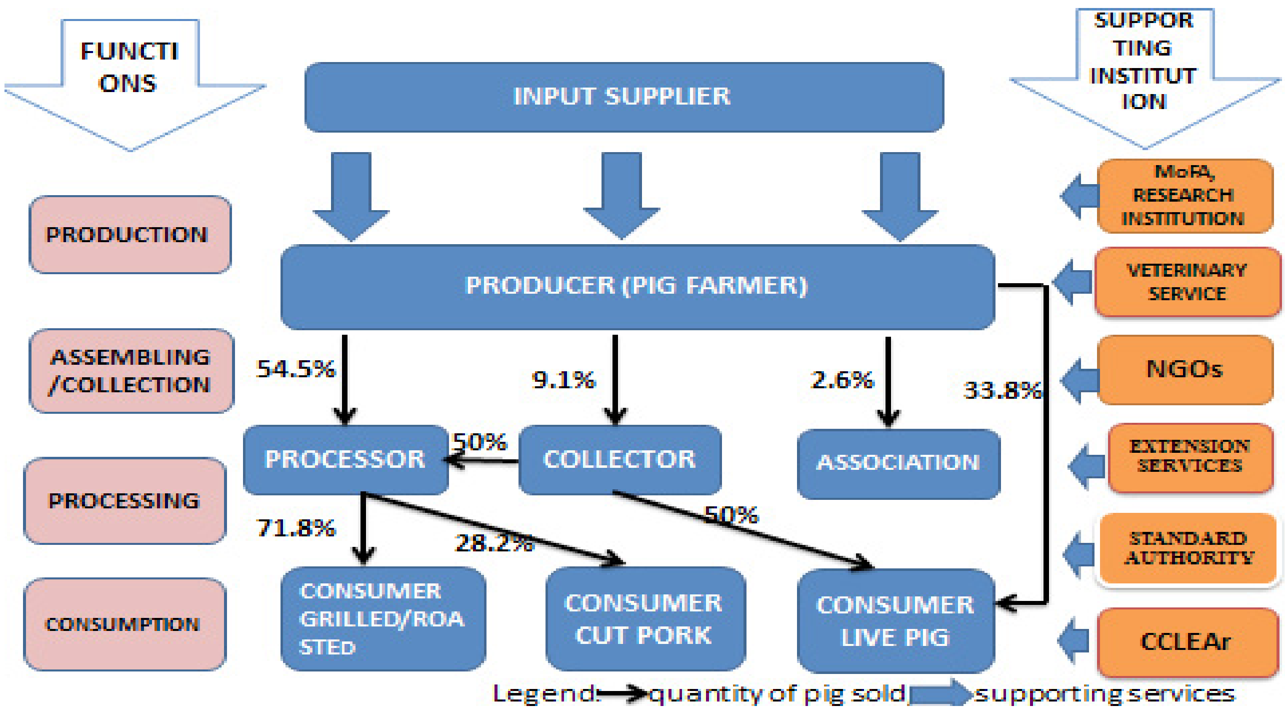

Fig. 1: Linkage among actors along the pig supply chain

Technical advice from MoFA (extension services) and other institutions like CCLEAr provided information on the best practices to be adopted by the producers. Veterinary services provided by mostly private firms enabled the producers and collectors to follow good health practices for their stock. Services offered by the Ghana Standards Authority and the Food and Drugs Authority on food safety standards and phytosanitary control assisted processors to improve on the quality of products that meet the specifications required, especially for the packed products. There was no formal financial assistance to the actors in the pig supply chain. The actors obtained financial assistance from family and friends.

Table 1 summarizes the existence and types of contract among actors in the pig supply chain and Table 2 specifies the nature of these contracts. Contractual relationship between farmers and other actors was uncommon in the pig supply chain. The majority (90.1%) of producers interviewed had no form of contract with other actors in the supply chain, while only 9.9% had contractual agreements with other actors. None of the collectors had any form of contract with their customers. With the processors, 12.5% had contracts with their customers whereas the majority (87.5%) did not have any form of contract with their customers. These results may imply that actors in the pig supply chain lack knowledge and understanding of the importance of contracts. Hence, education on contractual agreements and their relevance may be necessary.

Table 1: Existence and types of contract among the actors along the supply chain

	Producer (N=81)		Collector (N=2)		Processor (N=40)	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Existence of Contract						
Yes	8	9.9	0	0	5	12.5
No	73	90.1	2	100	35	87.5
Total	**81**	**100**	**2**	**100**	**40**	**100**
Type of Contract						
Verbal Contract	8	100	-	-	5	100
Written Contract	0	0	-	-	0	0
Total	**8**	**100**	**-**	**-**	**5**	**100**

Source: Survey data, 2016

Both the producers and processors who had contracts with their customers had verbal contractual agreements. About 63% of the producers who had contracts with their customers were provided with inputs and only a few (25%) obtained technical assistance (Table 2). These results are consistent with Suzuki *et al*. (2008) who revealed that buyers provide Ghanaian pineapple farmers with variety of inputs to guarantee quality and quantity of the final output. The results showed that 50% of the producers with contractual agreements had product supply contracts.

Table 2: Nature of contract that existed among the actors

Nature of contract	**Producer**		**Processor**	
	Yes	No	Yes	No
Provision of inputs	5(62.5%)	3(37.5%)	2(40%)	3(60%)
Provision of technical assistance	2(25%)	6(75%)	0	5(100%)
Provision of finance/ credit	0	8(100%)	0	5(100%)
Supply of product	4(50%)	4(50%)	4(80%)	1(20%)
Provision of transport	0	0	0	5(100%)

Source: Survey data, 2016

Approximately 40% of processors who had contracts with other actors had provision of input as an element of the contracts that existed between them and their customers. The majority (80%) of processors that had contracts with their customers had supply of products/ services as part of their agreements.

Table 3 presents the outcome of a scoring exercise in relation to how the actors perceive the level of importance of the indicators of power relations, which is termed the governance structure. Actors who have higher scores in relation to these indicators are considered as the key governors in the supply chain (Dolan & Humphrey, 2000).

Table 3: Perceived percentage share of power along the pig supply chain

	Indicators			
	Profit	**Bargaining power**	**Protection from competition**	**Information concentration**
Producer perception				
Input supplier	13.6	12.3	32.8	13.9
Producer	18.4	26.3	13.6	31.9
Processor	32.5	25.5	17.6	15.4
Collector	**35.3**	**35.8**	**34.6**	**38.6**
Processor perception				
Input supplier	11.9	11.3	**42.6**	13.0
Producer	**42.1**	**51.9**	28.0	**53.2**
Processor	25.1	21.9	18.3	15.2
Collector	22.1	15.1	14.4	20.0
Combined perception				
Input supplier	13.0	12.0	**35.9**	13.6
Producer	26.1	**34.4**	18.3	**38.8**
Processor	30.1	24.4	17.8	15.3
Collector	**31.0**	29.4	28.0	32.6

Source: Survey data, 2016

The results showed that collectors were perceived by producers to have the highest influence on all four indicators, namely profit, bargaining power, protection from competition, and information concentration. However, the processors also had a different view as they perceived producers to have the highest influence in terms of profit, bargaining power and information concentration, and input suppliers to have the highest influence in terms of protection from competition. Overall, the producers had the highest influence in terms of bargaining power and information concentration, whereas collectors and input suppliers had the highest influence in terms of profit and protection from competition, respectively. Contrary to the findings of this study, Owusu-Agyei (2010), revealed that distributors in groundnut value chain in Ghana have the highest influence in terms of profit. Nevertheless, our findings are consistent with Owusu-Agyei (2010) that the distributors had the highest influence in terms of bargaining power, information concentration and protection from competition. Our results are also contrary Clottey (2014) who reported that processors in the Kassena Nankana East District of Ghana were perceived to have the highest influence in terms of profit and bargaining power but to have the least influence in terms of protection from competition and information concentration. In general, it can be concluded that power does not belong to one particular actor in the supply chain, but it is spread in the supply chain, and it could differ from one product to another.

Constraints of actors along the pig supply chain

The results of the constraints facing actors in the pig supply chain are presented in Table 4.

Table 4: Ranking of constraints of producers, collectors and processors of pig

Constraints	Producer		Collector		Processor	
	Mean score	Rank	Mean score	Rank	Mean score	Rank
High cost of inputs	74.84	1st	61.00	2nd	64.48	1st
Poor access to credit	63.70	2nd	82.00	1st	59.55	2nd
Low market prices for product	51.46	3rd	50.00	5th	45.33	6th
Unavailability of market information	47.97	4th	60.50	3rd	55.77	3rd
High transportation cost	47.70	5th	41.00	9th	51.10	4th
Poor quality feed	45.10	6th	24.00	10th	31.55	10th
Poor access to product market	44.59	7th	44.00	8th	46.96	5th
High incidence of disease and pest	43.11	8th	47.50	6th	32.92	9th
Poor access to extension services	42.15	9th	47.00	7th	36.15	7th
High incidence of theft	22.73	10th	52.50	4th	34.45	8th

Survey data, 2016

Pig collectors ranked poor access to credit as their most pressing constraint and poor-quality feed as their least pressing constraint, with mean scores of 82.00 and 24.00 respectively. They argued that their business is capital intensive, but they have no access to credit. The collectors further argued that unlike processors who can purchase their inputs on credit and pay back after selling, collectors are only allowed to buy what they can afford at a particular time. The pig processors ranked high cost of inputs as their most pressing constraint with a mean score of 64.48. They ranked poor access to credit and unavailability of market information as their second and third most pressing constraints, respectively.

Conclusions

Ghana's economy depends heavily on agriculture and approximately 50% of its workforce is employed in this sector, with households earning about 35% of their incomes from agricultural activities. The sector keeps performing poorly, however, it is important in meeting both national and international targets in ensuring food security and poverty reduction (Institute of Statistical, Social and Economic Research (ISSER), 2013; Kuwornu *et al.*, 2018b). The livestock sector is still important to the Ghanaian economy, although its contribution to the national GDP remains low. It creates employment opportunities for the population and improves their rural livelihoods and food security (FAO, 2016; Mensah-Bonsu *et al.*, 2019). In 2013, Ghana's livestock sector contributed about 1.5% to the national GDP and about 7% to the agricultural sector (Ghana Statistical Service (GSS), 2014; Mensah-Bonsu *et al.*, 2019). The piggery sector is one of the key subsectors of the livestock industry in Ghana, nevertheless it is facing numerous challenges including high cost of inputs and imbalance power relations in the supply chain (IFAD, 2006; Mensah-Bonsu, 2010; International Livestock Research Institute (ILRI), 2011). The objective of this study were twofold: first, to explore the governance structure among the actors in the pig supply chain and secondly, to examine the constraints faced by the actors in the supply chain.

The governance structure of the pig industry is characterized by producers' and processors' activities, few active collectors' and no retailers' activities. Contractual relationships among actors in the pig supply chain were uncommon, and in the few cases where they existed the type of contract was verbal. Only 9.9% of the farmers had contractual agreements with other actors and only 12.5% of the processors had contracts with their customers. Skills in contractual agreements and relevance may be necessary as the structure for the pig industry develops. With respect to power relations along the supply chain, producers perceived collectors to have the highest influence on all four indicators of market power (i.e. profit, bargaining power, protection from competition and information concentration). Overall, the producers had the highest influence in terms of bargaining power and information concentration, while collectors and input suppliers had the highest influence in terms of profit and protection from competition, respectively. In general, it can be concluded that power does not belong to one particular supply actor, but is spread along the supply chain. High cost of inputs and poor access to credit are the most constraining factors of the actors (producers, collectors and processors) in the pig supply chain. The findings indicate that the majority of producers are strategizing by using more swill than formulated feed, which is cost increasing. Unavailability of financial institutions locally and the collateral requirements for accessing credit facilities are a hindrance to access to credit. Financial institutions could strategize and open up more agencies in the farm sector in order to reach out to more small-scale agro-businesses with credit and under flexible terms. Cost efficient feed meals are needed by the piggery sector actors and it is important that feed millers and formulators fulfill buyers' needs and expectations for such meals, which would also help strengthen specialization.

This study is not without limitations, for example, it examined the governance structure and constraints in the pig supply chains in the Eastern and Greater Accra regions of Ghana. Expanding these investigations to other regions of the country would be an excellent opportunity for future research. Finally, a more detailed cost-benefit analysis (including net present value, internal rate of return, and payback period) of the pig supply chain actors in other regions of the country while taking account of the size of enterprises of the supply chain actors would be another great avenue for further research.

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Microbiological quality of artisanal honey sold in informal markets: A case study in Accra, Ghana

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ABSTRACT

An increase in consumer consciousness for health has contributed to an increase in honey consumption in Ghana. In Accra, artisanal honey is often retailed unprocessed and packaged in recycled plastic bottles, yet consumers show confidence in its safety. There are however no data to support such confidence in unprocessed artisanal honey sold in informal markets. Bacteriological studies conducted in other parts of the world have reported the presence of hygiene indicators such as aerobic bacteria and coliforms, fungi, and bacterial spores of public health importance. The aim of the study was to assess intrinsic properties and microbial quality of artisanal honey in Accra. Thirty honey samples were purchased from five informal markets in Accra. Random sampling was used to select two retailers from each of the five markets. The intrinsic parameters, pH and moisture content, were measured for each sample and correlated with concentrations of yeast and mould, total aerobic bacteria, coliforms and aerobic spore-forming bacteria. The results showed that the pH and moisture of the samples ranged from 3.77-5.40 and 15.38%-19.71% respectively. These were within the reference limits of 3.5-5.5 for pH and <20% for moisture. Coliforms, yeasts, moulds, aerobic spore-forming bacteria and aerobic viable bacteria in artisanal honey exceeded the 2 log CFU/gm limit recommended by the International Commission for Microbiological Specification of Foods. There was no correlation between their intrinsic properties and microbial quality, indicating that the presence of microorganisms was a result of recent contamination, likely from poor handling and storage practices. Although the physical properties did not favour the growth and survival of microbes, their presence in excess of the recommended limit suggests unhygienic handling and storage. Training of processors and retailers on good hygienic practices will control the introduction of contaminants into artisanal honey.

Keywords: Artisanal honey, quality, safety, intrinsic properties

Introduction

Honey is an amber yellow or dark yellowish glutinous fluid made by bees. It is defined as a natural food produced by honey bees from the nectar of plants, secretions of living parts of plants or excretions of plant sucking insects on the "living parts of plants" (Codex Alimentarius Commission, 2001). Honey is made up of sugars, mainly glucose, fructose and sucrose, and other minor components including water, proteins, fats, vitamins, minerals and antimicrobial agents (Buba *et al.*, 2013). Honey is highly stable. This is largely due to its intrinsic properties such as low pH, high solute content, low water activity and the presence of natural antimicrobial compounds. Some intrinsic properties such as pH and moisture content are monitored as indicators of commercial quality of honey (Thrasyvoulou *et al.*, 2018). Globally, honey is used as a sweetener and as an ingredient in bakery, confectionary, breakfast cereals, dairy, dressing, sauces, ice cream, spreads and snack bars (Bellik and Iguouaada, 2010). However, in Ghana, the uses of honey are limited. Honey is normally consumed in its unprocessed state mostly as spreads. It is also used as an ingredient in pharmaceuticals and traditional medicinal preparations, and to a lesser extent in confectionaries, cosmetics and baking (Wagner *et al.*, 2008).

In Ghana, most of the honey commercially available are artisanal. Artisanal honeys are traditionally produced raw, unprocessed, unpasteurized and unhomogenized. On the local market, they are commonly available in recycled water and soft drink polyethylene terephthalate (PET) bottles, and in other recycled packaging materials such as beer bottles and oil gallons (Akangaamkum *et al.*, 2010). These honey are characteristically dark and viscous as it is assumed that the light and thin ones are diluted and of inferior quality (Akangaamkum *et al.*, 2010).

Currently, quality control for artisanal honey production in Ghana is rare. Due to the high sugar concentration, low moisture content and additional presence of antimicrobial agents such as methylgloxal and peptide bee defensin-1, honey is not a suitable medium for microbial growth or long-term survival of vegetative cells (Sinacori *et al.,* 2014; Stanway, 2013; Iurlina and Fritz, 2005). Nonetheless, honey is not microbiologically sterile. Low concentrations (< 2log cfu/g to 4log cfu/g) of total bacteria including yeast and mould and bacterial spores have been reported in honey (ICMSF, 2011; Snowdon and Cliver, 1996). These microorganisms are suggested to be contaminants from air, dust, the honeybee's digestive system and handlers (Olaitan *et al.,* 2007). The presence of these microorganisms has implications for the commercial and sanitary quality of honey. Of particular concern is the presence of pathogens like *Clostridium botulinum* and *Bacillus cereus* spores, and other general foodborne pathogens, such as pathogenic *E. coli, Salmonella* and *Staphylococcus aureus,* that cause serious foodborne illnesses such as infantile botulism, emetic food poisoning and gastroenteritis respectively (Hartheway, 1993; Snowdon and Cliver, 1996). Such organisms have traditionally been known to contaminate honey through postharvest activities (Snowdon and Cliver, 1996).

In recent times, there has been an increase in the consumption of honey both locally and worldwide due to its nutritious and therapeutic properties. Most honey producers and consumers in Ghana prefer the unprocessed honey because it is presumed to be natural and safe. Since the production of artisanal honey is not regulated in Ghana, the microbiological safety of artisanal honey can be underestimated, especially because production and packaging are done under uncontrolled conditions which offer opportunities for microbial contamination. This case study therefore aims to provide baseline information on the assessment of safety and quality of artisanal honey sold in some informal Ghanaian markets in Accra.

Materials and Methods

Sampling

This study was conducted using 30 samples of artisanal honey collected from 5 different local markets in Accra. These markets were selected based on their proximity to University of Ghana main campus and how busy they are. Also, random sampling was used to obtain three samples each from two different sale points in each market. The samples were transported at ambient temperature to the microbiology laboratory and stored in a cool dry place until analysis was done the following day. The study used Kaneshie, Madina, Malam, Makola and Agbogbloshie markets in Accra. The markets were coded MD1 to MD5 in no particular order. The purchase points were tagged as distributor 1 and distributor 2.

Moisture and pH Determination

The percent moisture of the honey was determined in triplicate using the refractive index and the Wedmore conversion table. The refractive index of the honey was measured using the Carl Zeiss Abbe Refractometer (Germany). The refractive index measured was corrected for a standard temperature of 20°C by adding or subtracting 0.00023 per every degree Celsius increase or decrease. The corrected index was converted to percent moisture using the Wedmore table.

The pH of the honey was determined in triplicates. A 10% (w/v) of honey was prepared in de-ionized water and the pH was determined using the Oakton Water Proof Hand-Held pH/ Conductivity/ Temperature meter (Eutech Instruments, Singapore).

Microbiological Analysis

Ten grams of each of the honey samples were homogenized in 90 ml of sterile 0.1% buffered peptone water in a stomacher. These served as 10^{-1} dilution. Additional serial dilutions were subsequently prepared with sterile 0.1% buffered peptone water. Serial dilutions were pour plated in duplicate with Standard Plate Count Agar (PCA, Park Scientific) for mesophilic bacteria, Malt Extract Agar (MEA, Merk) for yeast and mould, Eosin Methylene Blue Agar (EMB, Oxoid) for coliforms and Nutrient Agar (NA, Park Scientific) for aerobic bacterial spores. Honey samples cultured on Nutrient Agar were heated at 85 ˚C for 15 min to activate bacterial spores prior to inoculation. The inoculated PCA, EMB and NA plates were incubated at 37 ˚C for 24 hours prior to enumeration. Inoculated MEA plates were incubated at 25 ˚C for 5 days prior to enumeration.

Statistical Analysis

Colony counts for total mesophilic bacteria, coliforms, yeast and mould and aerobic spores were subjected to one-way ANOVA with a p-value of <0.05 using Stats Graphic Centurion Version 1.5. Least squares were used to determine statistical differences in bacterial counts, pH and moisture, and between honey distributers from different markets. Pearson Correlation was used to draw a relationship between the pH, moisture and the various counts.

Results and Discussions

Moisture and pH of honey

The moisture content and pH of honey samples is presented in Table 1. The moisture content of these samples ranged between 15.38±0.25 and 19.71±0.04 which meets the Codex Alimentarius standard of ≤ 20% for moisture in honey (Codex Alimentarius, 2001). The varying moisture content of the honey samples may have been a result of the different bee-hive handling practices, the type of harvesting and extraction methods applied by the producers, the harvesting season, the degree of maturity reached in the hive and some other environmental factors (Feas *et al.,* 2010). The low moisture content of all honey samples tested suggests that these market samples do not support microbial growth. Microbial growth in honey will cause quality deterioration through sugar fermentation (Tornuk *et al.,* 2013).

Table 1: Mean pH and moisture contents of the honey from informal markets in Accra

Source (Markets)	Distributors	pH	Moisture
MD1	1	$4.53±0.04^{d, e}$	$19.71±0.04^{g}$
	2	$4.10±0.01^{b, c}$	$18.24±0.04^{e, f}$
MD2	1	$5.40±0.11^{g}$	$15.91±0.04^{a, b}$
	2	$3.77±0.40^{a}$	$16.86±1.37^{b, c}$
MD3	1	$4.30±0.06^{c, d}$	$19.16±0.38^{f, g}$
	2	$4.66±0.21^{e}$	$17.11±0.38^{c, d}$
MD4	1	$4.35±0.03^{c, d}$	$15.38±0.25^{a}$
	2	$5.06±0.03^{f}$	$17.27±0.35^{c, d, e}$
MD5	1	$4.17±0.25^{c}$	$18.04±1.24^{d, e}$
	2	$3.84±0.21^{a, b}$	$19.31±0.56^{f, g}$
Overall P-value		0.000	0.000

All the values with the different superscript letters within the same column are statistically different at a p-value of <0.05

The pH of the honey samples ranged between 3.77 and 5.40. A similar pH range of 3.58-5.12 was found by Kacaniova *et al.* (2007) and Mahindru (2007) who reported honey pH values between 3.5 and 5.5. The pH of honey is influenced by the presence of organic acids, most importantly gluconic acid and its mineral content (Kacaniova *et al.,* 2007). While a high concentration of organic acids in honey reduces its pH, a high concentration of minerals increases the pH. Rehman *et al.* (2008) suggested that honey with pH above 5 is of low quality and purity, as adulterated honey has higher pH than pure honey which ranges between 3.2 and 4.5. In this study, honey from MD2 distributor 1exceeded this range (pH 5.40±0.11). which may influence its overall quality.

There was no correlation between the moisture content and pH in the honey samples tested (Table 2). However, in a similar study conducted by Ananias *et al.* (2013), there was a positive correlation between moisture and pH, which they attributed to the high activity of the glucose oxidase enzyme responsible for acid production as a result of the high moisture content in their honey samples.

Table 2: Pearson correlation co-efficient between the various plate counts, moisture content and pH in the honey samples

	Correlation Co-efficient				
	pH	Viable Cells	Coliforms	Yeast & Moulds	ASFB
Moisture	-0.388 (p-value=0.268)	-0.398 (p-value=0.255)	-0.396 (p-value=0.258)	-0.674 (p-value=0.033*)	-0.332 (p-value=0.349)
pH	1.000	0.249 (p-value=0.488)	-0.136 (p-value=0.704)	0.803 (p-value=0.005*)	-0.810 (p-value=0.810)

*Significant difference at a p-value <0.05
ASFB – Aerobic Spore-forming Bacteria

Microbiological Analysis

During sampling, it was observed that about 70% of the honey purchased in the various markets were packaged in used or recycled mineral water and soft drink plastic bottles. Others were in new plastic bottles. Akangaamkum *et al.* (2010) made the same observation in their study. The recycled bottles commonly used as packaging materials for honey could be a significant source of contamination (Sherwani *et al.,* 2013) as there were no controls for handling, storage and sanitization prior to use. It was also observed that the new bottles meant for packaging were kept under uncontrolled conditions, thus exposing them to dust and possibly pest infestation. The mean mesophilic counts in honey samples ranged from 2.96±0.57 to 3.98±0.31 log cfu/g with the highest from MD2 distributor 1 and the lowest from MD5 distributor 1 (Table 3). This result corroborates that of 2.00 to 3.96 log cfu/g reported by Tornuk *et al.* (2013). The high numbers of viable bacteria may be associated with a recent contamination from a secondary source (Kacaniova *et al.,* 2007). The aerobic bacteria count of honey is known to be influenced by the type of honey, the age of the sample and the harvesting season (Wanjai *et al.*, 2011). It also depends on the sanitary condition of the processes used to obtain the final product.

The coliform counts were between 3.67±0.86 to 4.82±0.35 log cfu/g with distributor 1 from MD2 and distributor 1 from MD5 having the highest and lowest count respectively. Their presence in honey is known to be an indicator of unsanitary conditions during production and handling of honey, and has implications on commercial quality.

Table 3: The mean counts of the honey samples sourced from informal markets in Accra

			Count (log cfu/g)			
Source (Markets)	Distributors	Packaging	Mesophilic count (±SD)	Coliforms (±SD)	Yeast & Moulds (±SD)	ASFB (±SD)
MD1	1	Fresh bottles	3.14±0.17$^{a, b}$	3.67±0.86^{a}	3.56±0.24$^{a, b}$	3.22±0.21$^{b, c}$
	2	Recycled bottles	3.80±0.29$^{c, d}$	3.71±0.36^{a}	3.84±0.38$^{b, c, d}$	3.46±0.29$^{b, c}$
MD2	1	Fresh bottles	3.98±0.31^{d}	4.08±0.21$^{a, b, c}$	4.13±0.41^{d}	3.33±0.27$^{b, c}$
	2	Fresh bottles	3.75±0.41$^{c, d}$	4.07±0.41$^{a, b, c}$	3.62±0.06$^{a, b, c}$	3.25±0.28$^{b, c}$
MD3	1	Recycled bottles	3.78±0.03$^{c, d}$	3.79±0.28$^{a, b}$	3.66±0.32$^{a, b, c, d}$	2.59±0.36^{a}
	2	Recycled bottles	3.43±0.11$^{a, b, c}$	3.95±0.06$^{a, b}$	4.07±0.24$^{c, d}$	3.17±0.24$^{b, c}$
MD4	1	Recycled bottles	3.47±0.24$^{b, c}$	4.68±0.03$^{c, d}$	3.86±0.12$^{b, c, d}$	3.54±0.14$^{c, d}$
	2	Recycled bottles	3.44±0.19$^{a, b, c}$	4.20±0.07$^{a, b, c, d}$	4.07±0.09$^{c, d}$	3.00±0.11$^{a, b, c}$
MD5	1	Recycled bottles	2.96±0.57^{a}	4.82±0.35^{d}	3.66±0.44$^{a, b, c, d}$	4.10±0.13^{d}
	2	Recycled bottles	3.24±0.17$^{a, b}$	4.40±0.51$^{b, c, d}$	3.54±0.27^{a}	2.97±0.77$^{a, b}$
Overall P-value			0.006	0.019	0.035	0.003

Values with the same subscript letters in the same column are statistically the same since there is no significant difference between them at a p-value <0.05; ASFB-Aerobic Spore-Forming Bacteria

The yeast and mould counts also ranged from 3.54±0.27 to 4.13±0.41 log cfu/g with the lowest and highest value from MD5 distributor 2 and MD2 distributor 1, respectively. Also, all the honey samples' counts were above 2 log cfu/g, the maximum level of yeast and mould count allowed for trade in the Southern America Common Market (MERCOSUR) (Ananias *et al.,* 1996). According to Ananias *et al.* (1996), high yeast and mould counts in honey are normally related to contamination from post-harvest activities such as handling, the environment and the equipment used during processing. Studies have also shown that high moisture levels (above 19%) in honey, coupled with low pH and high storage temperatures, increase the risk of yeast and mould growth in the honey, as their presence can cause fermentation spoilage in the honey. Yeast and mould count is therefore an indicator of the sanitary or commercial quality of honey (Giraldo *et al.,* 2013). This finding further suggests that the samples used in this study were at risk of spoilage.

In honey, aerobic bacterial spores are predominant and can be detected in bee larvae (Farris *et al.,* 1986). Farris *et al.* (1986) also stated that the presence of these spores in honey is often attributed to the unsanitary conditions under which they are processed and other secondary sources of contamination. The aerobic spore-forming bacteria count ranged from 2.59±0.36 to 4.10±0.13log cfu/g with the highest and lowest count coming from MD3-distributor 1 and MD5-distributor 1, respectively (Table 3).

In general, the results showed that distributor 1 from MD1 had the least microbial load as the packaging material used was new. It may also be attributed to some good hygienic practices adopted during harvesting, extraction and processing. However, the honey sample from MD2-distributor 1 had the highest colony counts and their honey was also packaged in new plastic bottles. Nonetheless, the storage conditions of these plastic bottles may have rendered them non-sterile and increased the risk of contamination as they were left in the open and mixed with some of the other retail products sold. This may have been the cause of the high counts since microbes present in honey are normally from secondary contamination sources, in this case the handling and packaging.

Lastly, this study showed a negative correlation between moisture and yeast and mould counts, and a positive correlation between pH and the yeast and mould counts (Table 2). This means that the yeast and mould counts were affected by pH and moisture in one way or the other. There were also no correlations between moisture, pH and the other microbial counts. Ananias *et al.* (2013) suggest that in order to get accurate and precise information on this relationship, determination should be done over some period of time.

Conclusion

All honey samples studied had moisture content < 20% which is the standard set by Codex Alimentarius Commission. Also, all the values obtained for pH fell within the reference range of 3.5 to 5.5. These indicate that the honey is of good physico-chemical quality.

In contrast to the physio-chemical quality, all the microbial counts were higher than the standard of 2.0 log cfu/g, suggesting low commercial quality.

It is recommended that beekeepers, honey producers and honey distributors should be trained on the total quality of honey, most importantly the effect of their processing, handling activities and packaging on the microbial quality of their product and its implications for shelf life stability and consumer health.

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Tail Index Estimation of the Generalised Pareto Distribution using a Pivot from a Transformed Pareto Distribution

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ABSTRACT

In extreme value analysis, the Generalised Pareto (GP) is an important statistical distribution for modelling tails of several phenomena. The tail index for this distribution plays a vital role as it determines the tail heaviness of the underlying distribution and it is the primary parameter required for the estimation of other extreme events. The estimation of the tail index of the GP distribution is addressed in this paper. The standard methods, such as maximum likelihood and probability weighted moments, are known to perform badly in small samples and to provide estimates that are inconsistent with observed values respectively. In this paper, the parameters of the GP distribution are estimated using a transformation to the Pareto distribution. Unlike the GP distribution, explicit expressions exist for the maximum likelihood estimators of the parameters of the Pareto distribution. In addition, a linear transformation of the distribution function enables the estimation of the tail index independent of the scale parameter. The proposed estimators are compared with the maximum likelihood estimator through a simulation study. The results show that the performance of the estimators was better, and at worst, approximately equal in performance to the standard method. We illustrate the application of the estimators with real data on insurance claims.

Keywords: Generalised Pareto, Pivot, Transformation, Pareto distribution, estimation

Introduction

The generalised Pareto (GP) distribution is a three (or two) parameter distribution for modelling several tail phenomena such as extreme wind speeds (Holmes and Moriarty, 1999), water levels in a hydroelectric dam (Minkah, 2016), computation of Value-at-Risk (Gilli and Këllezi, 2006) and extreme earthquake characterisation (Pisarenko and Sornette, 2003). The generalised Pareto (GP) distribution was shown in the seminal papers of Balkema and de Haan (1974) and Pickands (1975) as the limiting distribution of the excesses or the exceedances over a sufficiently large threshold. The most common methods for estimating the parameters of the GP distribution are maximum likelihood and (probability weighted) moment estimators. However, these estimators are known to perform badly in small samples and/or in data sets with some contamination i.e. with some unusually large or small values. In this paper, we make use of a transformation from generalised Pareto distribution to GP distribution and subsequently, the estimators are obtained based on a least squares method via a pivotal quantity.

Consider the independent and identically distributed (i.i.d) random variables $X_1, X_2, ..., X_n$ with unknown underlying distribution function *F*; and corresponding ordered values (in ascending order) $X_{1,n}, X_{2,n}, ..., X_{n,n}$ Thus, $X_{1,n}$ and $X_{n,n}$, are the sample minimum and maximum respectively. The distribution function and the density function of the three-parameter generalised Pareto distribution are given by

$$F(x)=\begin{cases}1-\left(1+\frac{1}{\alpha}\left(\frac{x-\mu}{\sigma}\right)\right)^{-\alpha}, 1+\frac{1}{\alpha}\left(\frac{x-\mu}{\sigma}\right)>0, \sigma>0, x\geq\mu, & if\, \alpha\neq 0\\ 1-\exp\left(\frac{x-\mu}{\sigma}\right), x\geq\mu, \sigma>0 & if\, \alpha=0\end{cases} \quad (1)$$

and

$$f(x)=\frac{1}{\sigma}\left(1+\frac{1}{\alpha}\left(\frac{x-\mu}{\sigma}\right)\right)^{-\alpha-1} \quad (2)$$

respectively. Here, μ, σ, and α are are the location, scale and the shape parameters respectively.

In the extreme value theory literature, the tail index of the GP distribution is given by the reciprocal of the shape parameter, i.e.

$$\gamma=\frac{1}{\alpha}. \quad (3)$$

This quantity determines the tail heaviness of the underlying distribution and other important extreme events estimation depend on this parameter. As a result, the estimation of γ remains a central research area in extreme value analysis (see. e.g., Csörgó and Viharos, 1998; Beirlant et al., 1999; Gomes et al., 2008).

Several methods exist for estimating the parameters of the GP distribution. These include maximum likelihood, elemental percentile and probability weighted moments. In most cases, the maximum likelihood estimation is the standard method for estimating parameters of the generalised Pareto distribution because it has attractive properties such as asymptotic normality, consistency and efficiency. However, it has no explicit expression for the maximum likelihood estimators, and hence, numerical procedures are used to obtain approximate values. In addition, its performance in the case of small samples can be erratic. Therefore, alternative estimators that perform better in terms of the mean squared error (MSE) may be needed in such cases.

The moment and probability weighted moment (PWM), introduced by Hosking and Wallis (1987), are some of the estimators that are usually used in the case of small samples. The PWM has been shown to perform well when $\gamma=[0,1]$ and even better if $\gamma=[0,0.5]$ (de Zea Bermudez and Kotz, 2010). However, these moment-based estimators have their shortfalls too. For example, they do not exist when $\gamma\geq 1$ and estimates obtained from these estimators may be inconsistent with observed data (Beirlant *et al.*, 2004). In view of these difficulties with the estimators mentioned above, the search for better estimators remains an active research area in statistics of extremes.

For example, van Zyl (2015) transformed GP distributed random variables using initial estimates of the GP distribution to Pareto distributed random variables. The aim of this transformation, similar to other transformations used in Statistics, is to improve and stabilise the estimation. Thus, the author investigated whether the transformation leads to improved estimators of the tail index of the GP distribution. Two methods were used for the initial transformation: the Probability Weighted Moments (Hosking and Wallis, 1987) and an empirical Bayes method (Zhang and Stephens, 2009). Thereafter, the resulting Pareto distribution's estimators were fitted using the maximum likelihood method. The maximum likelihood estimator of the Pareto distribution is known to have desirable properties. Firstly, the estimator of the tail index of the Pareto distribution is consistent; its variance is the smallest among all unbiased estimators of the tail index, and hence, it is efficient. Despite these advantages, the poor performance of the maximum likelihood estimator of the tail index has been shown in small samples. Also, the estimator is sensitive to contaminations of the sample (see e.g. Kim *et al.*, 2017; Finkelstein *et al.*, 2006).

This paper makes use of the idea from van Zyl (2015) and transforms the GP distribution to Pareto distribution. However, a pivot-based method is used to estimate the parameters of the resulting Pareto distribution, thereby making use of the attractive properties such as its performance in small samples and its robustness to contamination as enumerated in Kim *et al.* (2017).

The remainder of the paper is organised as follows. Firstly, we present the methods of estimation of the tail index of the GP distribution. Secondly, a simulation study is conducted to assess the performance of the proposed estimators with the existing standard estimators in the literature. In addition, general conclusions from the simulation results are presented. Thirdly, the estimators of the tail index are illustrated with practical data from insurance. Lastly, we present concluding remarks.

Methods of Estimation

In this section, the methods for the estimation of the parameters of the generalised Pareto (GP) distribution are presented. We start with the direct method where the estimation is done from the distribution function of the GP. In the second approach, a transformation of the GP distribution to the Pareto distributed random variables is used to obtain estimates of the parameters.

Direct Methods of Estimation

Several methods have been proposed in the literature for the estimation of the parameters of the GP distribution. The common ones include maximum likelihood, (probability weighted) moment and elemental percentile. In this paper, we consider the maximum likelihood and the probability weighted moments.

The maximum likelihood estimator is obtained through the maximisation of the likelihood function,

$$L(\gamma,\sigma,\mu)=\prod_{i=1}^{n}\frac{1}{\sigma}\left(1+\gamma\left(\frac{x_i-\mu}{\sigma}\right)\right)^{-1/\gamma-1}, \quad (4)$$

obtained from (2) with respect to the parameters γ,σ and μ. However, it is well-known that there is no closed form solution to the likelihood function, (4), and hence, numerical methods are used to obtain approximate solutions (see e.g. Coles, 2001; Beirlant *et al.*, 2004).

Also, Hosking and Wallis (1987) introduced the method of moments (MOM) and the method of probability-weighted moment (PWM) estimators for the GP distribution. The basic idea underlying these methods is that if the population moments exist, then the expression for them can be used to derive estimators of the unknown population moments. A third method based on Bayesian statistics has been studied by Zhang and Stephens (2009).

Estimation via Pareto Transformation

In this section, we introduce the estimation of the parameters of a GP distribution through a transformation to the Pareto distribution. The idea of transformation using estimated parameters is a common practice in statistics. The aims may include stabilising and improving estimation, removing dependence and obtaining a common distribution.

For the three parameter GP distribution (2), van Zyl (2015) considers the transformation

$$y=\frac{\alpha\mu}{\sigma}x+\mu\left(1-\frac{\alpha\mu}{\sigma}\right), \quad (5)$$

and thus, rearranging gives

$$x=\frac{\sigma}{\alpha\mu}y+\mu-\frac{\sigma}{\alpha}. \quad (6)$$

The Jacobian of the transformation is $\sigma/\mu\alpha$, and hence, the density function and the cumulative distribution of the transformed variables are given by

$$f(y)=\frac{\alpha\mu^{\alpha}}{y^{\alpha+1}}, y\geq\mu>0, \alpha>0, \quad (7)$$

and

$$F(y)=1-\left(\frac{y}{\mu}\right)^{-\alpha}, y\geq\mu>0, \alpha>0, \quad (8)$$

respectively.

Once the parameters of the Pareto distribution, (7), have been obtained, any event such as quantiles and exceedance probabilities can be obtained. These estimates can then be transformed back to the original GP distribution using the transformation, (6).

The methods for estimating the parameters of the Pareto distribution will now be presented.

Maximum Likelihood Estimation

From (7), the likelihood function of the Pareto distributed random variables is given by

$$L(\alpha, \mu|y) = \prod_{i=1}^{n} \frac{\alpha\mu^{\alpha}}{y_i^{\alpha+1}}. \qquad (9)$$

Maximisation of the likelihood function (9) (or the log-likelihood function) with respect to the parameters α and μ leads to the maximum likelihood estimators

$$\hat{\alpha} = \frac{n}{\sum_{i=1}^{n} log(y_i/\hat{\mu})} \qquad (10)$$

and

$$\hat{\mu} = y_{1,n}. \qquad (11)$$

Here, $y_{1,n}$ is the minimum value of the Pareto distributed random variable *Y*. The maximum likelihood estimators are the standard method for estimating the parameters of the Pareto distribution. As mentioned earlier, the attractive properties of the maximum likelihood estimators are consistency, asymptotic normality and efficiency. However, it is known to perform poorly in small samples. Secondly, the estimation of the tail index through (10) involves the estimated value of the scale parameter (11). Thus, any error associated with this estimate is passed onto the estimation of the tail index.

Pivotal Quantity

The pivotal quantity idea introduced by Kim *et al.* (2017) is based on the fact that the logarithmic transform of Pareto distributed random variables are exponentially distributed. That is, from (8), we can obtain the following:

$$-log(1 - F(y)) = \alpha \log Y - \alpha \log \mu . \qquad (12)$$

It is easy to show that the left hand side is the distribution of standard exponential random variables with mean 1 and we denote this as Z~exp(1).
Let $Z_{1,n} \le Z_{2,n} \le \dots \le Z_{n,n}$ be the order statistics associated with the random variable Z. Then from (12),

$$Z_{i,n} = \alpha \log Y_{i,n} - \alpha \log \mu, \; i = 1, 2, \dots, n. \qquad (13)$$

Thus, subtracting any order statistics such as $Z_{1,n}$ from $Z_{i,n}, i = 1,2,\dots,n$ eliminates the term $\alpha \log \mu$ in (13):

$$Z_{i,n} - Z_{1,n} = \alpha(\log Y_{i,n} - \log Y_{1,n}). \qquad (14)$$

Since $Z_{i,n}, i = 1,2,\dots,n$ are not observed directly, it is usual to replace them with their with their expected values $E(Z_{i,n}) = \sum_{k=1}^{i}(n-k+1)^{-1}$ and hence, representing $D_{i,n} = Z_{i,n} - Z_{1,n}$ in (14) results in the regression problem,

$$E(D_{i,n}) = \alpha(\log Y_{i,n} - \log Y_{1,n}) + \varepsilon_i, i = 1, \dots, n. \qquad (15)$$

Here, $\varepsilon_i = E(D_{i,n}) - D_{i,n}$ and $E(\varepsilon_i) = 0$. Using the method of least squares on (15) yields the estimator of the slope parameter, α, as

$$\hat{\alpha}_{lsp} = \frac{\sum_{i=2}^{n} E(D_{i,n})(\log Y_{i,n} - \log Y_{1,n})}{\sum_{i=2}^{n} (\log Y_{i,n} - \log Y_{1,n})^2}, \qquad (16)$$

where $E(D_{i,n}) = \sum_{k=2}^{i}(n-k+1)^{-1}$.

In addition, Kim *et al.* (2017) introduced a second estimator based on weighted regression. It can easily be shown that

$$Var(D_{i,n}) = \sum_{k=2}^{i} \frac{1}{(n-k+1)^2}. \qquad (17)$$

Taking the weights $w_i = Var(D_{i,n})^{-1}$, $i = 1,\ldots,n$ yields a weighted version of (16) as

$$\hat{\alpha}_{wls} = \frac{\sum_{i=2}^{n} w_i E(D_{i,n})(\log Y_{i,n} - \log Y_{1,n})}{\sum_{i=2}^{n} w_i (\log Y_{i,n} - \log Y_{1,n})^2}. \quad (18)$$

It can be seen that (18) reduces to (16) if the weights w_i's are equal. In the case of μ, another method is needed to estimate it. Kim *et al.* (2017) proposed using the method of moments estimator

$$\hat{\mu}_p = \left(1 - \frac{1}{n\hat{\alpha}_p}\right) Y_{1,n} \quad (19)$$

where $p \in \{lsp,\ wls\}$ with justification from the reported studies by Lu and Tao (2007). The authors show that the method of moments estimator of μ performs better than the maximum likelihood estimator. The asymptotic properties including consistency of the estimators (16) and (18) have been addressed in Kim *et al.* (2017).

This paper makes use of the transformation of the generalised Pareto distribution to Pareto distributed variables. However, the parameter estimation of the resulting Pareto distribution is obtained using the pivotal-based methods of Kim *et al.* (2017) outlined above.

Simulation Study

The performance of the existing estimators and the proposed estimator of the tail index of the GP distribution is compared in this section using a simulation study. The simulation design and the results as well as the accompanying discussions are presented in the subsections that follow.

Simulation Design

Samples were generated from the generalised Pareto distribution consisting of three parameters. Three choices of parameter values were assessed: firstly, $\mu = 1$ $\sigma = 1$ and a range of values of $\gamma \in (0,1]$; secondly, $\mu = 1$, $\sigma = 2$ and a range of values of $\gamma \in (0,1]$; and lastly, μ=1, σ=3 and $\gamma \in (0,1]$. The estimators of the tail index, γ, of the GP distribution considered in the study are presented in Table 1.

Table 1: List of estimators of the tail index of the GP distribution

Notation of Estimator	Description
ML	The ML estimator of the tail index of the GPD
T.ML	The ML estimator of the tail index of the GPD based on the transformation to Pareto samples
T.lsp	The pivotal least squares estimator of the tail index of the GPD based on transformed Pareto samples
T.wls	The pivotal weighted least squares estimator the of tail index of the GPD based on transformed Pareto samples

The sample sizes considered were $n = 50$, 200 and 500, and the Monte Carlo simulations were performed $R =$ 5000 times. The performance measures used are the Mean Square Error (MSE) computed as

$$MSE(\hat{\gamma}, \gamma) = \frac{1}{R}\sum_{i=1}^{R}(\hat{\gamma}_i - \gamma)^2 \quad (20)$$

and the bias given by

$$bias(\hat{\gamma}, \gamma) = E(\hat{\gamma}) - \gamma. \quad (21)$$

Simulation Results and Discussion

A sample simulation result arising from the estimation of the tail index, γ, of the GP distribution based on the procedure outlined in Section 3.1 is shown in Table 2. The simulation was carried out for various parameter choices to measure the effect of changing μ and σ. For brevity and ease of presentation, the report is given on $\mu = 1$ and $\gamma = 1$. The reader is referred to Appendix 1 and 2 for results on σ = 2 and σ = 3 respectively. The results were similar for other values of μ, and hence, for ease of presentation, those results were omitted.

The actual numbers for MSE and Bias are given for the ML estimator and the other estimators are expressed as percentages to the standard ML. Thus, the ML estimator is always 100% and a better estimator should have an MSE or a Bias less than 100%.

It was found that for smaller sample sizes, i.e. $n \leq 50$, the proposed estimator, T.wls, is the best in terms of bias and MSE. The other two estimators, T.lsp and T.ML, have mixed results in relation to their performance with that of the ML. However, both record a much smaller bias compared with the ML estimator.

For larger sample sizes, $n \geq 500$ the ML estimator is preferred, as the other estimators do not show much improvement in terms of MSE. This is expected, as the asymptotic properties of maximum likelihood estimation work better for larger sample sizes. Regardless, the proposed estimators, T.lsp and T.wls, record quite a smaller bias compared to the ML estimator. Therefore, these estimators can be considered for estimating the tail index as k increases (i.e. the inclusion of more intermediate order statistics).

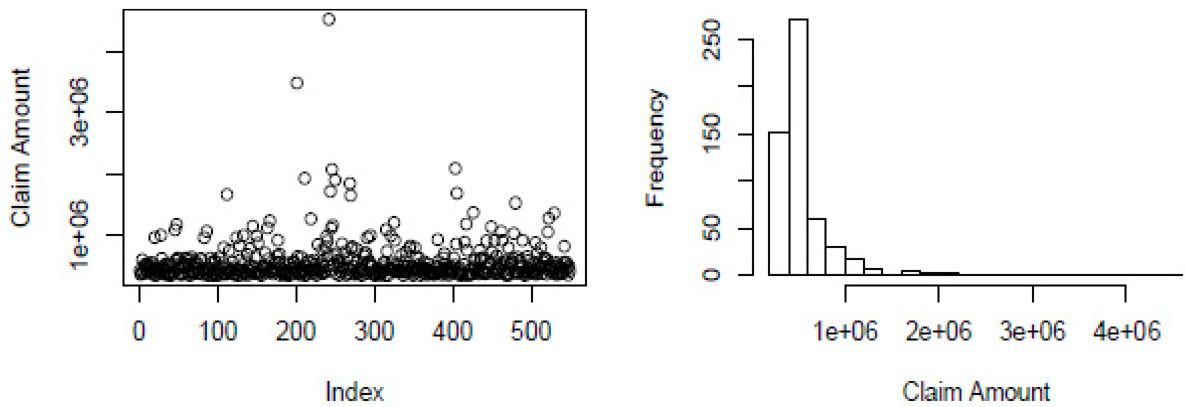
Table 2: Performance of estimators of g of the GPD with $\sigma = 1$ and $\mu = 1$.

	$\mu = 1, \sigma = 1$	MSE				Bias			
n	γ	ML	T.ML	T.lsp	T.wls	ML	T.ML	T.lsp	T.wls
	0.100	0.037	404.4	339.6	70.1	-0.054	-176.1	-149.2	-52.1
50	0.250	0.042	114.0	103.0	60.9	-0.055	-55.5	-55.5	2.9
	0.500	0.050	90.5	92.2	98.4	-0.054	83.0	62.3	60.9
	1.000	0.089	99.9	103.7	103.4	-0.060	100.0	59.9	56.6
	0.100	0.016	252.4	213.2	53.4	-0.032	-260.9	-241.2	-77.8
200	0.250	0.020	84.6	84.6	80.8	-0.027	37.5	28.0	46.3
	0.500	0.028	98.3	100.7	84.8	-0.022	97.3	62.6	51.0
	1.000	0.042	100.0	104.5	109.7	-0.027	99.9	41.7	21.6
	0.100	0.003	90.8	90.1	96.7	-0.006	28.4	25.6	40.6
500	0.250	0.003	99.9	100.3	117.7	-0.007	100.0	84.0	56.9
	0.500	0.005	100.0	101.3	103.5	-0.003	99.9	21.8	-69.1
	1.000	0.008	99.9	102.8	105.2	0.002	99.7	164.9	98.2

Application

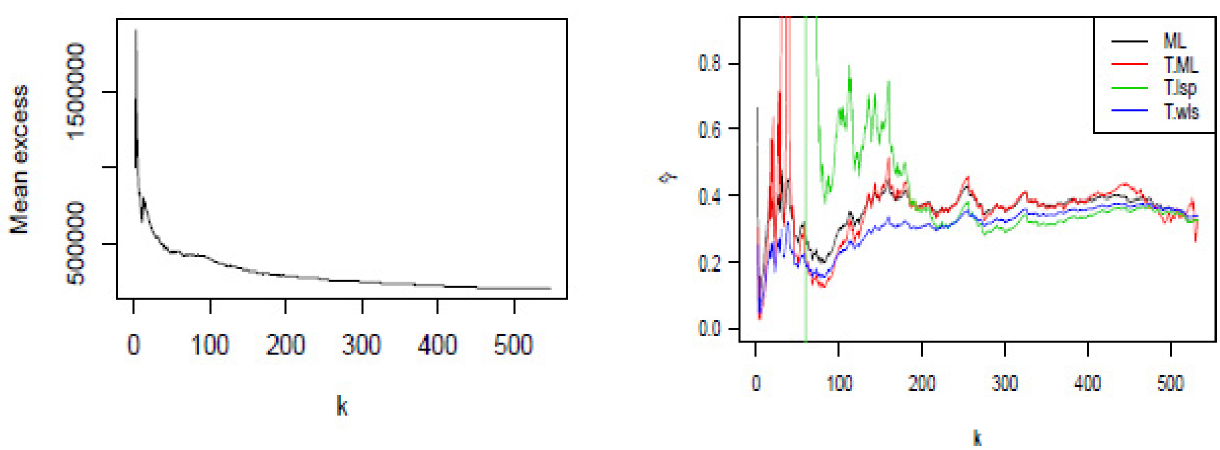
This section illustrates the estimators of the tail index on an insurance dataset. The data is obtained from the SOA Group Medical Insurance Large Claims Database studied by Beirlant *et al.* (2004). The data were obtained from https://lstat.kuleuven.be/Wiley/Data/soa.txt.

The data consist of records of 75788 claim amounts exceeding 25,000 USD over the year 1991. It was extracted from a much larger claims database of over 3 million records over the year 1991-1992 available at http://www.soa.org. In this illustration, we consider claim amounts exceeding 350,000 USD so as to study the extreme tail of the distribution of claim amounts.



(a) (b)

Fig. 1: (a) Plot of claim amount (b) Histogram of claim amount



(a) (b)

Fig. 2: (a) Mean excess plot (b) Estimates of the tail index

Figure 1 shows a scatter plot and histogram of the claim amounts. The histogram is highly skewed to the right. In addition, the increasing behaviour of the mean excess as k decreases as shown in Figure 2(a) indicates that the distribution of the data has a heavier tail than the exponential distribution, and hence, likely to have a positive value of tail index, γ. Therefore, this fits well for the illustration of the proposed estimators. In the case of the ML estimator, it has been illustrated in Beirlant *et al.* (2004) for the SOA data.

Figure 2(b) shows the estimates of the tail index of the distribution for the claim amounts. It can be seen that at $k < 200$, the estimators exhibit large variations, with the exception of T.wls and the ML estimator, which exhibit much stabler conditions. Thus, these two may be considered the best for estimating the tail index. Furthermore, at $k > 200$, all the estimators are near constant. Overall, the T.wls is the most stable for estimating the tail index of large claim amounts in the SOA data. Therefore, T.wls can be considered the most appropriate for the estimation of the tail index in this practical consideration.

Conclusion

This paper introduced a method for estimating the tail index of the generalised Pareto distribution through a transformation to the Pareto distribution and the use of a least squares estimation criterion. Two estimators resulted from this method: an ordinary least squares and a weighted least squares. It was shown through the simulation study that the performance of these estimators is better, or at least at par, in terms of mean square errors and bias with the standard maximum likelihood estimator. The estimators were illustrated using a real data set from the insurance industry. An area for future research is the search for an optimum method for finding the initial estimates of the parameters for the transformation from generalised Pareto to Pareto distributed random variables. In addition, the asymptotic properties of the proposed estimators are a subject for future research. An analytical assessment of the performance of estimators can be done as a follow up to the results.

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Appendix 1: Performance of estimators of g of the GPD with $\mu = 1$ and $\sigma = 2$.

$\mu = 1, \sigma = 2$		MSE				Bias			
n	γ	ML	T.ML	T.lsp	T.wls	ML	T.ML	T.lsp	T.wls
	0.100	0.036	406.8	339.9	65.9	-0.063	-308.4	-284.8	-75.3
50	0.250	0.041	101.9	94.4	64.5	-0.047	-58.6	-60.4	0.9
	0.500	0.056	82.0	84.7	75.2	-0.049	60.0	37.5	42.4
	1.000	0.090	100.0	103.2	100.3	-0.056	99.9	55.0	48.1
	0.100	0.015	272.1	230.6	56.1	-0.030	-261.9	-242.6	-76.6
200	0.250	0.019	86.4	86.2	85.9	-0.024	38.4	27.6	48.8
	0.500	0.025	100.0	100.8	110.9	-0.032	99.9	77.1	65.6
	1.000	0.042	99.9	104.6	153.2	-0.032	99.9	77.1	65.6
	0.100	0.002	91.4	91.6	98.3	0.002	-38.6	-54.0	-31.6
500	0.250	0.003	99.9	100.8	119.9	-0.004	99.9	68.2	31.5
	0.500	0.005	100.0	99.9	137.1	-0.007	100.0	66.4	21.0
	1.000	0.009	100.0	104.8	278.9	-0.001	100.4	-146.2	-313.8

Appendix 2: Performance of estimators of g of the GPD with $\mu = 1$ and $\sigma = 3$.

$\mu = 1, \sigma = 3$		MSE				Bias			
n	γ	ML	T.ML	T.lsp	T.wls	ML	T.ML	T.lsp	T.wls
	0.100	0.039	451.8	379.1	73.1	-0.062	-333.7	-308.9	-97.9
50	0.250	0.040	100.8	93.4	65.1	-0.054	-33.0	-34.4	17.2
	0.500	0.053	90.5	92.8	96.7	-0.054	-33.0	-34.4	17.2
	1.000	0.083	99.9	103.3	121.1	-0.049	99.9	50.3	42.7
	0.100	0.015	277.2	235.4	56.1	-0.024	-330.2	-307.8	-112.1
200	0.250	0.020	92.0	89.3	85.9	-0.037	41.8	36.0	58.2
	0.500	0.024	100.0	100.9	97.7	-0.025	99.9	70.3	57.3
	1.000	0.040	100.0	100.9	99.0	-0.031	99.9	52.6	47.0
	0.100	0.003	89.0	88.7	90.7	-0.005	9.5	5.8	48.5
500	0.250	0.003	100.0	100.5	119.9	-0.004	100.0	67.2	3.7
	0.500	0.004	100.0	101.0	160.5	-0.004	100.0	47.1	-25.1
	1.000	0.009	100.0	102.5	261.9	-0.001	99.6	-513.0	-517.6

A Smart Walking Aid for the Visually Impaired: A Case Study of the University of Ghana

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ABSTRACT

Mobility is one of the biggest challenges of the visually impaired and recent studies focusing on how technology can be used to mitigate the effects of this challenge have resulted in the development of smart canes. Current innovations of smart canes include sensors that detect obstacles as well as voice-controlled navigational capabilities. These innovations do not necessarily inform the user of what the potential obstacle is and also require an internet connection for navigation. This paper describes an offline smart cane, called WalkMaTE, with obstacle detection and classification, as well as voice, controlled navigational capabilities. The system is equipped with a pair of ultrasonic sensors placed strategically to detect branches above and obstacles below. Also, an infrared sensor is connected to a vibrating motor which detects nearby gutters and alerts the user(s). The system takes images of the user's surroundings using a Raspberry Pi camera and determines if there are any potential obstacles in the captured image using TensorFlow (an open-source library). To have a sense of where the user is at any point in time, we use a Global Positioning System receiver module to get the coordinates which are then inputted into the navigational system. The destination of the user is provided using speech through a Bluetooth headset with the help of the CMUSphinx speech library. Routing is done with an open-source navigational system called NAVIT. The uniqueness of WalkMaTE is that it works without the use of the internet which is helpful to the visually impaired living in developing countries where the internet is not readily available. The prototype of the smart cane helps the user to get to unknown places on the University of Ghana campus and aids with the identification of obstacles in the path of the visually impaired.

Keywords: navigation; NAVIT; offline smart cane; raspberry pi; TensorFlow; voice control and speech recognition

Introduction

Visual impairment is the loss of vision of a person or a significant limitation of visual capability. Vision is the most essential part of the human physiology as 83% of the information human beings get from the environment is via sight (Agarwal *et al.*, 2017; Aymaz & Cavdar, 2016; Hashino & Ghurchian, 2010; Jose *et al.*, 2016; Kumar *et al.*, 2014). In Ghana, data gathered suggests that there were over 190,000 blind persons in Ghana in 2016 including students of the University of Ghana. The visually impaired can move about with the help of walking aid tools which have evolved from the use of humans as guides to the use of specially trained guide dogs. Through this evolution came the white cane that helps the blind to determine what is in front of them by swinging the stick from side to side. All these tools above have certain limitations. For example, the use of a human guide limits the blind from living independently. Though the introduction of white cane addressed the privacy issue, it still has some drawbacks such as its limited ability to detect objects within the immediate vicinity of the person and cannot determine the type of object for possible maneuvering.

Furthermore, the white cane is unable to detect obstacles such as low hanging branches and in some cases gutters. The latest innovation in walking aids is the smart walking aid where sensors such as infrared and sonar sensors are mounted on walking sticks or bands to detect obstacles. However, there is still the disadvantage of not knowing the type of obstacle. For the blind, navigating to unknown places can be particularly tricky as they are unable to see signboards that would give indications of where they are or how to get to their respective destinations. In the University of Ghana setting, for example, one of the problems highlighted was the problem of not knowing how to get to unknown examination halls without the help of companions who might also be busy during that period. Blind people, therefore, face the risk of getting lost and are restricted to travelling to places they are familiar with.

Traditional white canes are only able to detect objects within the vicinity of the holder giving barely enough time to move away from the obstacle. They do not inform the holder of approaching obstacles such as other people and silent cars and could result in serious injuries. Most smart canes available are developed for countries with readily available internet and thus, are ill-equipped for a developing country such as Ghana where internet connectivity and penetration are not ubiquitous.

The specific objectives of this research work were to design and develop an intelligent walking aid that: (1) determines where a person is and directs the person to their desired destination through speech recognition; (2) detects incoming obstacles as well as low hanging tree branches and with the capability of informing the user the nature of the obstacle for possible avoidance; (3) detects uncovered gutters; and (4) ensures system's possible operation without internet usage.

Review of Existing Works on the Design of a Smart Walking Aid

Jose *et al*. (2016) proposed a scheme that provides a modest budget and efficient navigational aid for the blind. This system consists of a simple walking stick equipped with ultrasonic sensors to give information about the environment such as obstacles, pits, and puddles ahead of the user. This system also has a Global Positioning System (GPS) technology integrated with preprogrammed locations for navigation. The user chooses the destination from a set of locations stored in memory. Also, voice-enabled switching equipment is included. But the system does not provide information on the type of obstacle detected, does not determine the speed of an approaching obstacle, is unable to identify hidden obstacles like downward stairs, and in noisy environments, the user would be unable to hear the voice alerts.

Nada *et al*. (2015) proposed a solution in the form of a walking stick with infrared sensors to detect staircases and a pair of ultrasonic sensors to detect other obstacles in front of the user within the range of 4 meters. Also, a water sensor is used to detect the presence of water. Voice alerts and the vibration motor are activated whenever an obstacle is detected. The system is also equipped with a radio frequency (RF) transmitter and receiver to find the stick if it gets missing. Although speech alerts are given, the type of obstacle is not given.

A lightweight, cheap, user-friendly, fast response and low power consumption, smart stick based on infrared technology has been proposed (Agarwal *et al*., 2017; Jose *et al*., 2016; Nada *et al*., 2015; Sen *et al*., 2018; Tudor *et al*., 2015). The developed systems by all these authors have a pair of infrared sensors strategically placed to detect staircases and other obstacles within a 2-meter range. Infrared sensors are not highly immune to noise; hence the noise could interfere with the reading and corresponding response to detected obstacles for possible avoidance.

Gayathri *et al*. (2014) proposed a system that consists of two units, the sensor unit, and the Global Positioning System (GPS) unit. This system alerts visually impaired people over obstacles, pit, and water and outlines a better navigational tool that consists of sensors that give information about the environment.

The system uses an ultrasonic sensor, a pit sensor, a water sensor, a GPS receiver, a level converter, a driver, a vibrator, a voice synthesizer keypad, a speaker or headphone, a PIC microcontroller, and battery. In this system, the visually impaired person can travel only up to four locations using the stick, and the type of obstacle is not known.

Based on the above review and having identified key weaknesses and strengths, we proposed the design, development and deployment of WalkMaTE, a voice-controlled navigational system with the capability for object detection and obstacle avoidance to aid the visually impaired. The two (2) key features of this system include:

(i) Voice Controlled Navigational System- This is intended to map out the University of Ghana campus using an open-source offline library called NAVIT taking into consideration that the internet in Ghana is not ubiquitous and readily available on demand. Thus, the users would indicate their destinations into the Bluetooth headset. That information is sent to the walking aid through Bluetooth, and the information is converted to text. The software on the stick then gets the location of the person, calculates the distance and direction, and communicates it to the person through the Bluetooth headset, having converted the text to speech.

(ii) Obstacle Detection and Classification- This system makes use of two ultrasonic sensors and a camera on the stick which is needed for communication with the Raspberry Pi. The upper ultrasonic sensor detects objects which are above the user (preferably the upper body part of the user) such as branches from a distance and the lower ultrasonic sensor detects objects which are ahead of the user at a particular distance. When an obstacle is detected, the camera takes an image of that object and sends the image to the Raspberry Pi for recognition and classification using an open-source library called TensorFlow from Google retrained with a database of images from the specified use case (TensorFlow, 2018). The resulting information is converted to speech and communicated through voice to the visually impaired through the Bluetooth headset. Also, there is an infrared sensor which is used for gutter detection. In the presence of a gutter, the vibration motor vibrates to alert the user of possible gutters.

System Design and Methodology

Figure 1 shows the block diagram of the integrated system design with different components and their interactions. The Global Positioning System (GPS), the camera, and the ultrasonic sensors act as inputs to the Raspberry Pi 3 microcontroller. The output of the Raspberry Pi microcontroller is the headset connected via Bluetooth to the walking stick. The infrared sensor act as input to the Arduino, and the output is the vibration motor which aids in obstacle avoidance and alerts.

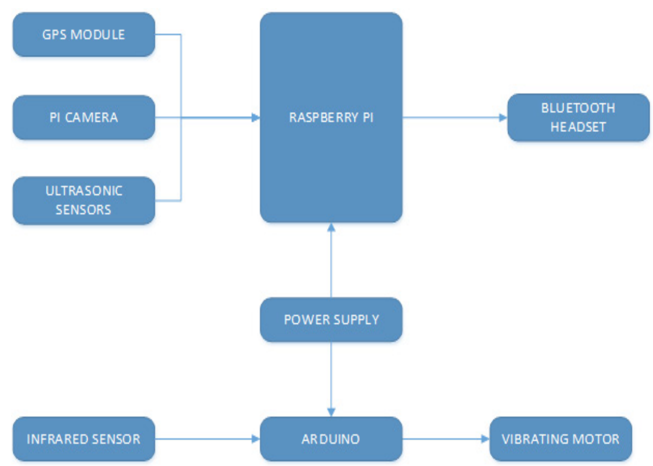


Fig. 1: Block diagram of the integrated system

Obstacle Detection and Classification System

The obstacle detection and classification system are designed by using the ultrasonic sensor, text to speech library (Flite) and TensorFlow. The ultrasonic sensor has a range from 2cm to 400cm and a 15 to 30° measuring angle. Since the ECHO output is 5V and the input pin of the Raspberry Pi GPIO is 3.3V, a voltage divider circuit was used to bring down the voltage to 3.3V. Thus, the voltage divider formula is used.

$$V_{out} = \frac{R_1}{R_1 + R_2} V_{in}$$

The various resistor components for the circuit design were appropriately selected. There were two ultrasonic sensors, one for detecting obstacles like branches and the other for detecting other obstacles like chairs, cars, and so on, hence, the upper and lower ultrasonic sensor. The lower ultrasonic sensor triggered the camera to take a picture. The distance was calculated by the product of the speed of sound and the time it takes for the echo to bounce back divided by two.

$$Distance = \frac{speed \times time}{2}$$

When there was no obstacle detected or the obstacle fell out of range, the ultrasonic continuously detects and senses objects. For the lower ultrasonic sensor, when there was an obstacle, the message "***Obstacle Ahead, watch your steps***" is read out to the hearing of the person before the type of obstacle was read out and vice versa for the upper one. The Obstacle Classification is handled by TensorFlow, which is an open-source software library offered by Google, for numerical computation using data flow graphs. Nodes in the graph represent mathematical operations, while the graph edges represent the multidimensional data arrays (tensors) communicated between them (Tensorflow, 2018). The need to use neural networks for this aspect was because of its ability to learn from the training set without necessarily memorizing the training set, making it biased and not applicable to real-life situations. Using Inception-v3, a pre-trained model, trained by validating against ImageNet – an academic benchmark for computer vision, the transfer learning technique was used to achieve the purpose for the specified use case of the University of Ghana. Modern object recognition models have millions of parameters and can take weeks to train fully. Transfer learning is a technique that circumvents or shortcuts a lot of this work by taking a fully trained model for a set of categories like ImageNet and retrains them from the existing weights for new classes (Demirovic *et al.,* 2018; TensorFlow, 2018). Before training, a set of images was needed to teach the network about the new classes to recognize in the specified use case. Over 3000 images of objects recognized as obstacles were captured and classified to be used. The first phase analyzes all the images supplied and calculates bottleneck values for each of them. Once the bottlenecks are complete, the actual training of the top layer of the network begins. Randomly selected images from a different set are used in the validation after training to prevent the memorization of the dataset and encourage the model to learn and gain the confidence of its prediction over time. Cross-entropy is a loss function which gives a glimpse into how well the learning process is progressing. The objective of the training is to make the loss function as small as possible. As a result of some limitations on the Raspberry Pi, there was the need to optimize the model to run smoothly per the application for the specified use case. The inception model includes a DecodeJpeg operation hence the need for the optimization. The script performs other optimizations that help speed up the model, such as merging explicit batch normalization operations into the convolutional weights to reduce the number of calculations. Hence, by using the optimized graph generated from the optimized tool, the speed was improved for the purpose intended for WalkmaTE. The top five scores with labels were printed out during testing. The topmost label with a probability of 0.5 and above is piped out as speech using ***Flite text-to-speech*** through a Bluetooth headset connected to the Raspberry Pi microcontroller. For example, if a chair is recognized, the resulting speech is "***Approaching a chair***," if the probability is greater than 0.5 but, "Probably approaching a chair," if the probability is less than 0.5. The Pi camera is strategically placed on the walking aid to get a good viewing angle and classify accurately the images it captures if the ultrasonic sensor detects an obstacle based on its calibration. Flite library is embedded into the object recognition and classification to convert the text of classified objects to speech for the blind. Figure 2 shows the flow diagram of the Obstacle Detection and Classification System.

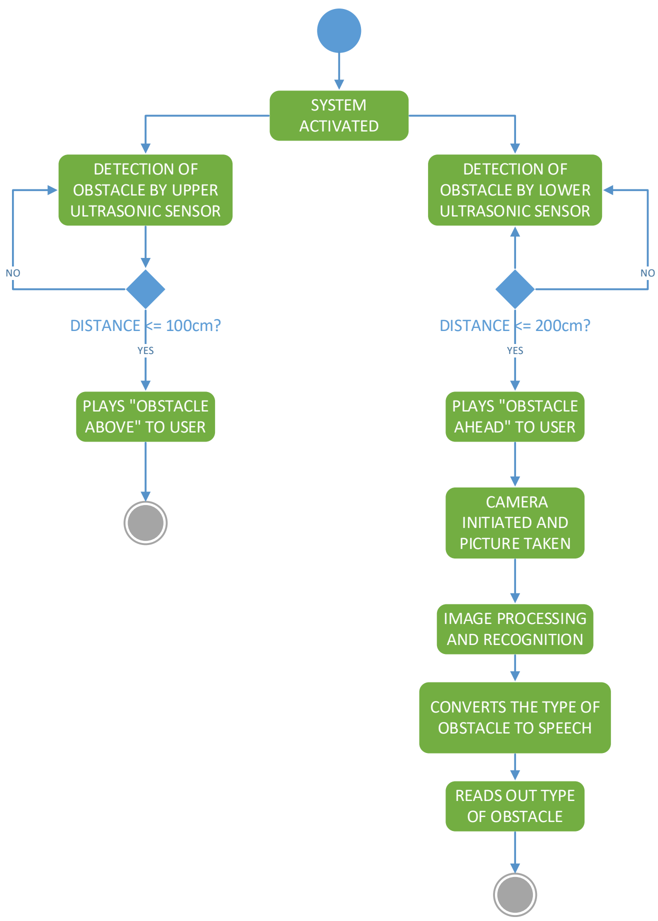


Fig. 2: Flow diagram of Obstacle Detection and Classification System

Voice Control Navigation System

The voice control navigation system involved a turn by turn navigation aid to the visually impaired. It is made up of *Speech-To-Text, Text-To-Speech*, and Maps. CMUSphinx is used for the Speech to Text and to make it more accurate; a grammar model was built. A language model was also required because the pre-trained model was extensive as it contains all English words. A different text-to- speech synthesizer was used for this part, this is known as ***eSpeak*** (Blasch *et al.,* 2015) (Lakdawala *et al.,* 2018; Prakoso *et al.,* 2016; Shivakumaret *et al.,* 2017). For the navigation system, NAVIT (GitHub, 2018; NAVIT, 2018) were used, and the steps used to achieve the smart cane development goals are as follows:

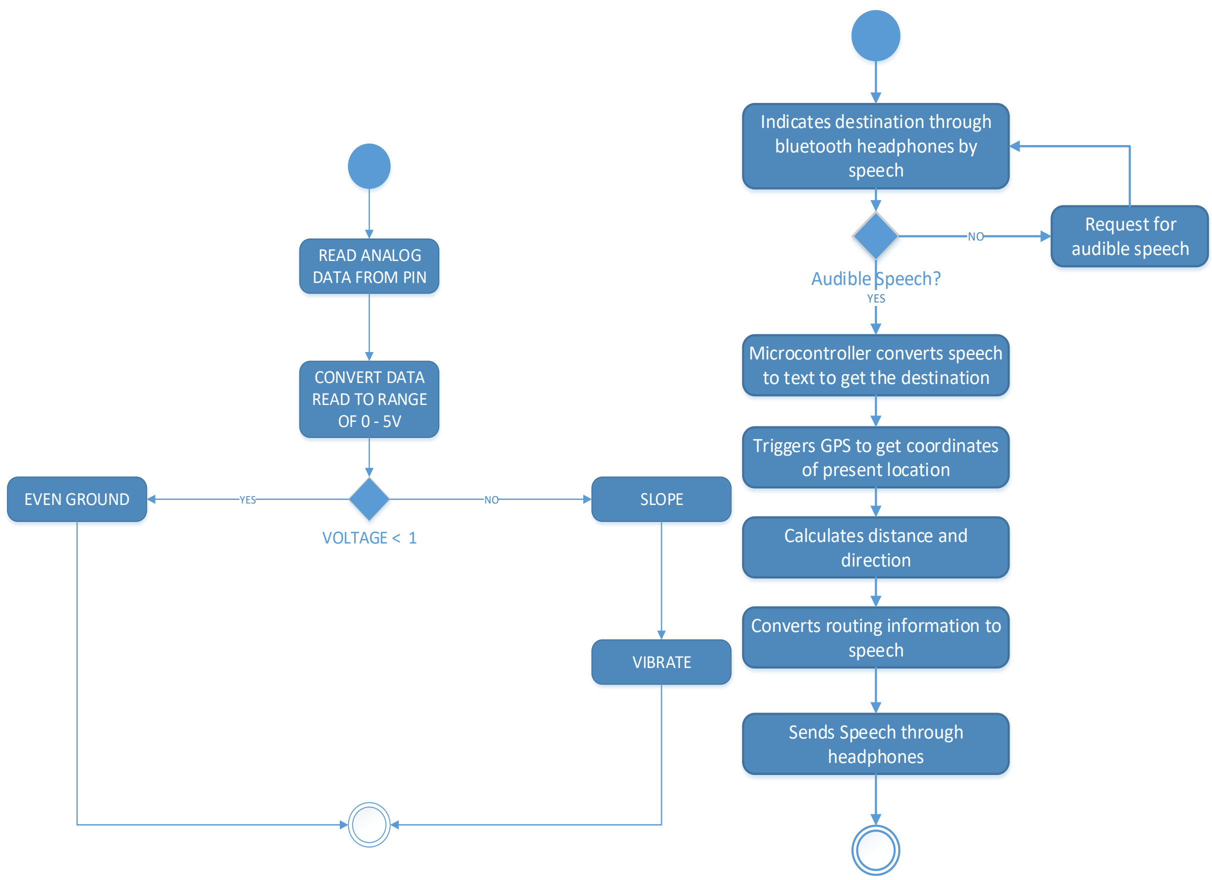
Setting the map - Because the University of Ghana campus so happened to be our case study, the map of the University was downloaded from OpenStreetMaps.

Getting the current location of the user - A GPS module receiver was added to the project to get the current location of the user. The mathematical principle used here is trilateration.

Setting the destination - NAVIT does not come equipped with the ability to set the destination through speech, which is an essential part of the project. With the help of the NAVIT team, an interface was written using the dbus to help communicate to NAVIT through a third-party script. That was done to enable the customization of NAVIT such that voice control could be added to the work as it was not developed for the visually impaired. The extension helps to set destination using bookmarks which are already stored in NAVIT containing the locations of consideration under the desired use case using a Python script.

Routing - The routing takes advantage of NAVIT's turn-by-turn navigation to aid the visually impaired to the desired location. NAVIT makes use of the waypoint technique to connect waypoints along the path from the current location to the desired destination. Waypoints are simply longitudes and latitudes of positions on the surface of the earth. After using the waypoint technique, Dijkstra's algorithm is then used to determine the shortest path from the current location to the destination.

Turn by turn navigation - By making use of a text to speech module called espeak, the system can read out updated turn by turn navigation routes to the user by interfacing with the Bluetooth headset. Figure 3 shows the flow diagram for the Voice Control Navigation System.



(a) (b)

Fig. 3: (a) Flow diagram of Gutter Detection (b) Flow diagram of Voice Control Navigation System

Gutter Detection

The gutter detection involved the Infrared Sensor and the Vibration Motor. The general concept took advantage of the laws of reflection of light. We set the distance of detection of the receiver of the IR to an acceptable distance using the potentiometer. When light bounced off an obstacle within the range, it is assumed to be an even ground. If nothing was sensed, we assume it is just a ditch ahead, and the vibration is sensed by the blind person to take notice of the gutter ahead. The strength of the vibration (PWM) is 80%. Figure 4 shows the flow diagram of the Gutter Detection.

System Hardware Design

Figure 4 shows the front and rear ends of WalkMaTE, and Figure 5 shows the whole circuit design of WalkMaTE.

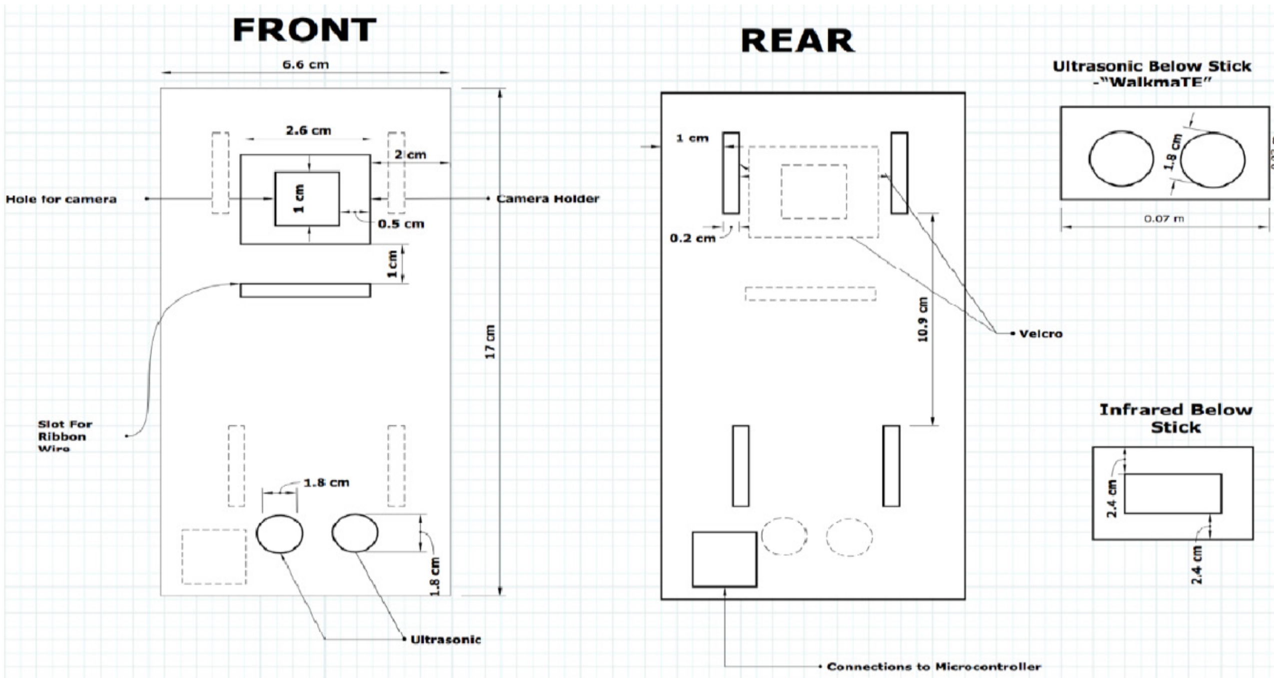


Fig. 4: Front and Rear of WalkMaTE

The circuit design of WalkMaTE in Proteus hardware simulation software.

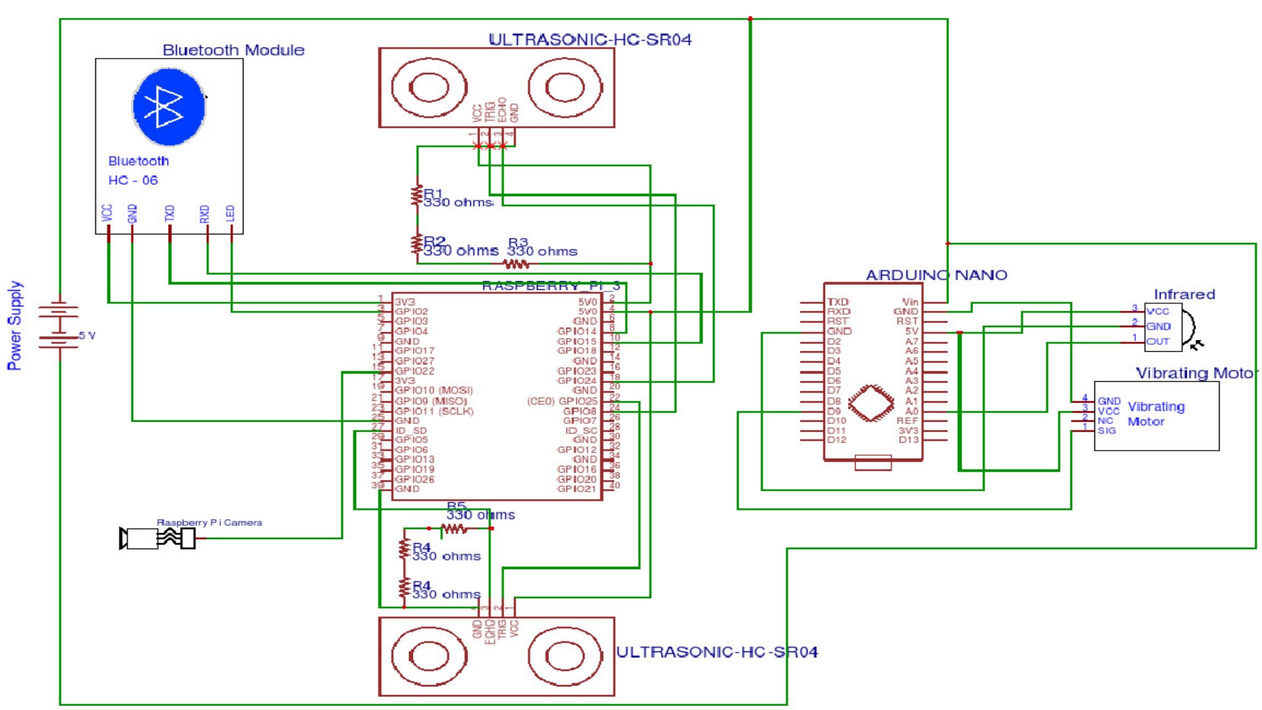


Fig. 5: Circuit diagram developed in Proteus simulation software

System Integration

For the gutter detection, the microcontroller used was the Arduino NANO, and thus there was no need to integrate it with the other parts. It only shared the same power supply with the Raspberry Pi and other components. The Voice-Based Navigation System had the main script that connected all its various parts (i.e., speech to text, text to speech, NAVIT and the GPS). The script for the classification and recognition was written in C++ due to its efficiency and optimization, and that of the ultrasonic sensor was written in Python. Thus, there was a single Python script that connected both scripts for the Obstacle Detection and Classification module. The Obstacle Detection and Classification script is always readily available, but that of the Navigation was only called when the user presses the push-button for navigational information.

Results and Discussion

The results were tested and verified to ensure that the research achieved its stated objectives of providing a smart walking cane for the blind with full navigational capabilities.

Object Detection and Classification

The device was tested in a classroom and room setting. Due to the position of the camera, the system did not always give an accurate instance of what the object was actually in front of the person. It informed the user of the fact that there is an obstacle ahead and based on its classification if the probability was above 0.5 it notified the user of what obstacle was in front of the user. The position of the camera was vital in this aspect of object detection and classification. If the camera is very high, the pictures taken will not correspond to the obstacle in front of the user.

Table 1: Results of object classification and recognition

Actual obstacle	Obstacle detected by system
Monitor	Laptop
Speaker	Speaker
Chair	Chair
Person	Person
Barrel	Dustbin
Bucket	Barrel
Dumb-bells	Dumb-bells

Table 1 shows the results of the Image Classification and Recognition. Due to the picture that was taken by the camera, the obstacle detected might not be the same as the actual obstacle. For instance, the obstacle Barrel was seen as a Dustbin because some of the pictures used to train the classifier have the same features as that of a dustbin. Also, for the Bucket, due to the picture that was taken, there was a barrel in the picture as well as the bucket, and hence the classifier picked the barrel as one with the highest probability.

Table 2: Results of distance covered

No.	Measure Distance (cm)	Sensor Detected Distance (cm)	Error (cm)
1	0	0	0
2	5	4	-1
3	10	8	-2
4	15	14	-1
5	25	23	-2
6	50	49	-1
Average Error			-1.1667

Table 2 shows the difference between the ultrasonic sensor measurement and the actual measurement between the obstacle and the ultrasonic sensor. The average measurement error was 1.1667.

Navigation

Due to the language model and grammar file, the pronunciation of the locations had to be the same as that in the files. Due to this, the system might not respond or pick the first set of words spoken hence a message is repeated for the user to confirm what he or she said. Based on the routing, the user is guided to the destination.

Table 3: Results of speech to text

Location	Number of trials	Breakdown
Engineering	3	'to,' 'engineering.'
NNB	2	'to', 'n', 'n', 'b'
Special needs	3	'to,' 'special,' 'needs.'

Table 3 shows the number of trials the system listens to the user for input and the breakdown of the words for input to the Python script for routing.

Figure 7 shows the navigational system from a source to the destination. After listening to the destination inputted by the user through speech, the system broke the words down and based on its scripts files and bookmarks in NAVIT, the routing part is set, and the description is read out to the user via the Bluetooth Headset.

Overall Hardware Design

Figure 8 shows the overall hardware design of the developed prototype with the various components and where they are placed within the modular hardware design and development of the smart walking cane for the visually impaired and the blind.

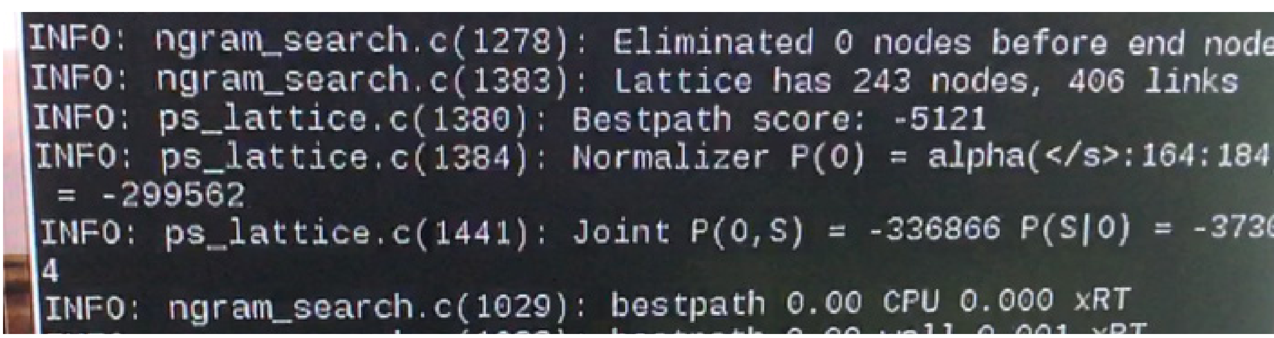
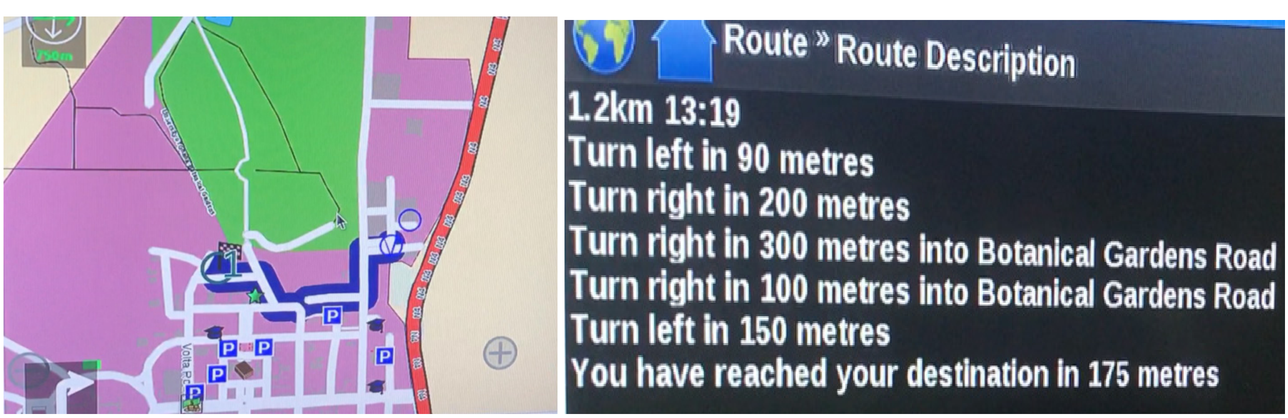


Fig. 6: Voice Command for WalkMaTE navigation



(a) (b)

Fig. 7: (a) The path from source to destination on UG Campus (b) Routing Information

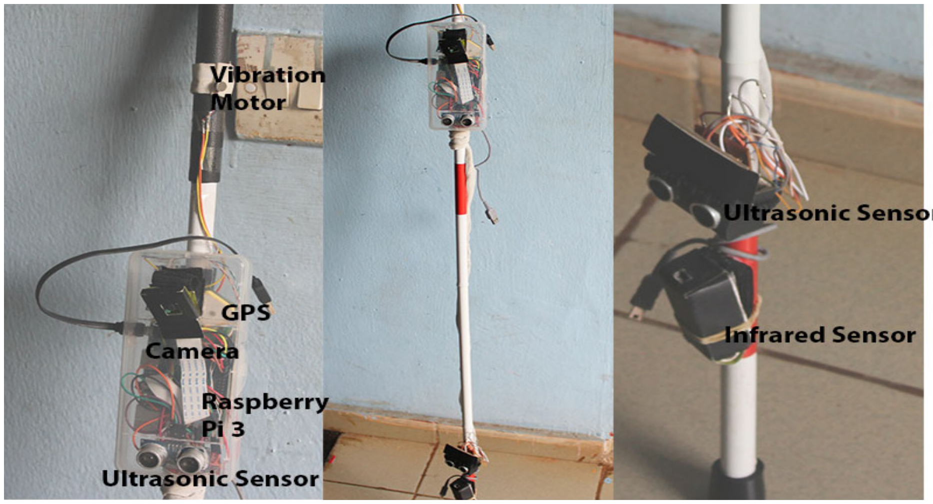


Fig. 8: Overall Hardware Design with integrated software system

Conclusion

The paper presents the design of a hardware prototype of smart walking cane that included the combination of a pair of ultrasonic sensors, an infrared sensor, a global positioning system module, vibration motor, Arduino NANO, Raspberry Pi 3, Raspberry Pi camera for the visually impaired. The two primary objectives of this research paper were to increase mobility and enable an offline navigation system. To improve the movement for the visually impaired, a pair of ultrasonic sensors, a Raspberry Pi camera and the infrared sensor was used. The visually impaired can now identify objects and gutters in their path. Implementation of an offline navigation system enables a visually impaired person to move into unfamiliar places without human guidance, thus, making the visually impaired more independent. The hardware and software part of this project has been integrated to meet all the design requirements.

Given that the system is offline, it is clear that all of the challenges cannot be addressed entirely without significant cooperation and an increase in the speed of the image classification. Adjusting the ultrasonic sensor to detect fast-moving objects and adjusting the infrared sensor to detect staircases are recommended. Also, increasing the grammar file to accommodate more pronunciations of locations will help in directing the person to his or her destination as quickly as possible. As the system uses a power bank to supply power, it is recommended that a backup power supply plan on standby to ensure constant power supply. To improve the performance of the navigational system, a Global System for Mobile Communication (GSM) module can be incorporated to improve indoor navigation.

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Predicting Lecturers Promotional Mobility Using Markov Chain Model

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ABSTRACT

Stochastic mobility models are probabilistic descriptions of how movements take place from one class to another. The main objective of the study was to forecast the number of members of University of Ghana (UG) academic staff in various categories or states of a system. In the literature, a stochastic mobility model for an open system has been developed. This work adopts this preexisting stochastic model to forecast promotion patterns for UG academic staff over specified periods. This is done through the generation of a probability transition matrix for academic staff promotions (open system) from 2001 to 2014. The findings of the study indicate that the total expected size of the university increased steadily over the period under consideration. A member of academic staff recruited to the position of a lecturer who wishes to rise through the ranks and to retire as a professor is likely to spend 27 years in the service (10.3 years as lecturer, another 7.5 years as senior lecturer, 5.6 years as associate professor and 3.6 years as full professor). A member of academic staff of UG recruited into the entry point as a lecturer has a 78.78% chance of becoming a senior lecturer, a 45.56% chance of becoming an associate professor and a 26.51% chance of becoming a full professor.

Keywords: Stochastic mobility model; Probability transition matrix; Markov chain; Open system; Closed system

Introduction

Human societies are often stratified into classes based on demographic variables such as age, sex, income, occupation, social status and place of residence. Members of such societies move from one class to another in what often seems to be a haphazard manner. In a free society a person has some degree of choice about changing his/her job or residence. The essential ingredient of any stochastic model of mobility is thus a probabilistic description of how movement takes place from one class to another. The underlying assumption for the simplest model is that the chance of moving depends only on the present class and not on the past. If movement can be regarded as taking place at discrete points in time, then the appropriate model becomes a simple Markov chain.

In a social system in which our interest is the changing internal structure, it is expedient to assume closeness. A closed social system is one which either no member moves in or out of, or any losses are replaced immediately by identical recruitments. The assumption of a closed system is reasonable for the applications to social class and labour mobility (Gani, 1963).

Nevertheless, there are many systems in which gains and losses are an important feature of the process. One example of a situation in which such a model is appropriate is provided by an educational system. Such a model was first used by Gani (1963) in projecting enrolment and degrees awarded in Australian universities. This model can also be applied promotions in an organization. The model has been applied to the student population of the University of California by Marshell (1973) and by Oliver and his co-workers in several unpublished reports. Musiga *et al.* (2011) modeled the bachelor's degree system using the Markov Chain approach in which the proportions of students who graduate and drop out of the system are separately grouped into double absorbing states. Adeleke *et al.* (2014) used the model to study the pattern of students' enrolment and their academic performance in the Department of Mathematical Sciences (Mathematics Option) at Ekiti State University, Ado – Ekiti, Nigeria. Both Markov's model and the capacity models of Menges and Elstermann (1971) incorporate a Markovian component. Armitage *et al.* (1969) have discussed the applicability of the model in educational planning and Armitage *et al.* (1970) dealt with it in relation to a model of the English Secondary School system. Kamat (1968b ;1968c) proposed a special case of the model suitable for describing the progress of a cohort through the educational system.

The academic staff of the University of Ghana (UG) is categorized into 4 ranks, which are arranged in increasing order of seniority as follows:

(1) Lecturer (*Denoting the first state*)
(2) Senior Lecturer (*Denoting the second state*)
(3) Associate Professor (*Denoting the third state*)
(4) Professor (*Denoting the fourth state*)

Aside these four grades (states), there is an Assistant Lecturer position in the university teacher's ranking. This position is excluded from this paper due to its peculiar terms of engagement. One is appointed to this position for a period (mostly 3 years) within which one is expected to obtain a PhD degree which is the minimum qualification for a lecturer; otherwise one is disengaged. In addition, movement from an Assistant Lecturer position to a Lecturer position is not considered a promotion per the university's terms of reference. Thus, the number of Assistant Lecturers who progress to Lecturer in a particular year are included in the total number of new entrants into Lecturer positions for that year.

Using the model first proposed by Gani (1963), our main interest here was in the number of UG academic staff in various categories or states of the system. These stocks change over time as a result of the operation of transition probabilities of flow between states. The main emphasis was on the stochastic behavior of the stock number and, in particular, on their means and variances.

Method

The number of new lecturers that enter the j^{th} state (status) in year T is denoted by $n_{0j}(T)$, where j = 1, 2, 3, 4. The number of lecturers leaving the university from the i^{th} state in the year T is denoted by $n_{i5}(T)$, where i = 1, 2, 3, 4. The n_{ij}'s $(i = 0, 1, 2, 3, 4$ and $j = 1, 2, 3, 4, 5)$ can be conveniently set in standard matrix form as shown in Table 1 below.

Table 1: Values of n_{ij} for the year *T*

		j				
		1	2	3	4	5
i	1	$n_{11}(T)$	$n_{12}(T)$	$n_{13}(T)$	$n_{14}(T)$	$n_{15}(T)$
	2	$n_{21}(T)$	$n_{22}(T)$	$n_{23}(T)$	$n_{24}(T)$	$n_{25}(T)$
	3	$n_{31}(T)$	$n_{32}(T)$	$n_{33}(T)$	$n_{34}(T)$	$n_{35}(T)$
	4	$n_{41}(T)$	$n_{42}(T)$	$n_{43}(T)$	$n_{44}(T)$	$n_{45}(T)$
	0	$n_{01}(T)$	$n_{02}(T)$	$n_{03}(T)$	$n_{04}(T)$	

Let $n_j(T) = \sum_{i=1}^{4} n_{ij}(T)$ denote the number of university teachers in state (status) j at year T (where T = 0, 1, 2, … and j = 1, 2, 3, 4). The initial state sizes, $n_j(0) = \sum_{i=1}^{4} n_{ij}(T)$ (j = 1, 2, 3, 4), are assumed to be given and we define

$$N(T) = \sum_{j=1}^{4} n_j(T) \tag{1}$$

For $T > 0$ the state (status) sizes are random variables. The expected number, $E\left[n_j(T)\right]$, in state j year T is denoted by $\bar{n}_j(T)$. The number of new entrants into the system in year T is written as $R(T)$, whilst the expected new entrants in year T is denoted by $\bar{R}(T)$.

Let p_{ij} $(j, i = 1, 2, 3, 4)$ be the probability that an individual in state i in a particular year will be found in state j in the following year. Let $\boldsymbol{P}$ denote the matrix with elements $\{p_{ij}\}$

$$\boldsymbol{P} = \begin{pmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{pmatrix}. \tag{2}$$

Since transitions out of the university are possible (open system), $\sum_{j=1}^{4} p_{ij} \le 1$. The probability that an individual in state i in a particular year will be out of the university the following year is given by $p_{i5} = 1 - \sum_{j=1}^{4} p_{ij}$. The proportion of new entrants that enter the j^{th} state is denoted by p_{0j}, where $\sum_{j=1}^{4} p_{0j} = 1$, with expectation $R(T)p_{0j}$ entering the j^{th} state (j = 1, 2, 3, 4). Let $\boldsymbol{Q}$ be the transpose of the transition matrix $\boldsymbol{P}$ (which is sub-stochastic). The one-step transition probabilities, p_{ij} (i = 0, 1, 2, 3, 4 and j = 1, 2, 3, 4, 5), that specify the process can be represented by a matrix $\boldsymbol{M}$ as follows:

Final state

$$\boldsymbol{M} = \text{Initial state} \begin{array}{c} \\ i=1 \\ i=2 \\ i=3 \\ i=4 \\ i=0 \end{array} \begin{pmatrix} j=1 & j=2 & j=3 & j=4 & j=5 \\ p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ p_{01} & p_{02} & p_{03} & p_{04} & \end{pmatrix}, \quad (3)$$

The expected values $\bar{n}_j(T+1)$ satisfy the recurrent relations

$$\bar{n}_j(T+1) = \sum_{i=1}^{4} p_{ij}\bar{n}_i(T) + R(T+1)p_{0j},$$

which can be expressed as

$$\bar{\boldsymbol{n}}(T+1) = \boldsymbol{Q}\bar{\boldsymbol{n}}(T) + R(T+1)\boldsymbol{p}_0, \quad (4)$$

where $\bar{\boldsymbol{n}}(T) = (\bar{n}_1(T), \bar{n}_2(T), \bar{n}_3(T), \bar{n}_4(T))'$ and $\boldsymbol{p}_0 = (p_{01}, p_{02}, p_{03}, p_{04})'$. Substituting $\bar{\boldsymbol{n}}(T) = \boldsymbol{Q}\bar{\boldsymbol{n}}(T-1) + R(T)\boldsymbol{p}_0$

into (4), we have

$$\begin{aligned} \bar{\boldsymbol{n}}(T+1) &= \boldsymbol{Q}[\boldsymbol{Q}\bar{\boldsymbol{n}}(T-1) + R(T)\boldsymbol{p}_0] + R(T+1)\boldsymbol{p}_0 \quad (5) \\ &= \boldsymbol{Q}^2\bar{\boldsymbol{n}}(T-1) + R(T)\boldsymbol{Q}\boldsymbol{p}_0 + R(T+1)\boldsymbol{p}_0 \end{aligned}$$

Proceeding in this manner, we can write

$$\bar{\boldsymbol{n}}(T+1) = \boldsymbol{Q}^{T+1}\bar{\boldsymbol{n}}(0) + \sum_{t=0}^{T} R(T+1-t)\boldsymbol{Q}^t\boldsymbol{p}_0$$

$$\bar{\boldsymbol{n}}(T) = \boldsymbol{Q}^{T}\bar{\boldsymbol{n}}(0) + \sum_{t=0}^{T-1} R(T-t)\boldsymbol{Q}^t\boldsymbol{p}_0 \quad (6)$$

If $R(T)$ has a suitable mathematical form it may be possible to sum the matrix series appearing in (6) and so obtain the solution in closed form. This is the case if $R(T)$ is constant for all T or more generally if $R(T) = R.x^T$ (R > 0, x > 0, T ³ 1). In this case (6) becomes;

$$\begin{aligned} \bar{\boldsymbol{n}}(T) &= \boldsymbol{Q}^{T}\bar{\boldsymbol{n}}(0) + \sum_{t=0}^{T-1} Rx^{T-t}\boldsymbol{Q}^t\boldsymbol{p}_0 \\ &= \boldsymbol{Q}^{T}\bar{\boldsymbol{n}}(0) + Rx^T\left(\sum_{t=0}^{T-1} x^{-t}\boldsymbol{Q}^t\right)\boldsymbol{p}_0 \quad (7) \end{aligned}$$

The sum $\sum_{t=0}^{T-1} x^{-t}\boldsymbol{Q}^t$ is a geometric series of first term $x^{-0}\boldsymbol{Q}^0 = \boldsymbol{J}$ $x^{-0}\boldsymbol{Q}^0 = \boldsymbol{Q}^0 = \boldsymbol{J}$(the unit matrix) with the common ratio $x^{-1}\boldsymbol{Q}$. The sum of the first T terms of the sequence is given by

$$\sum_{t=0}^{T-1} x^{-t}\,\boldsymbol{Q}^t = (\boldsymbol{J} - x^{-1}\boldsymbol{Q})^{-1}(\boldsymbol{J} - x^{-T}\boldsymbol{Q}^T) = x(x.\boldsymbol{J} - x^{-1}\boldsymbol{Q})^{-1}(\boldsymbol{J} - x^{-T}\boldsymbol{Q}^T)$$

$$Rx^T\left(\sum_{t=0}^{T-1} x^{-t}\,\boldsymbol{Q}^t\right)\boldsymbol{p}_0 = Rx(x.\boldsymbol{J} - \boldsymbol{Q})^{-1}(x^T\boldsymbol{J} - \boldsymbol{Q}^T)\boldsymbol{p}_0$$

Hence

$$\bar{\boldsymbol{n}}(\boldsymbol{T}) = \boldsymbol{Q}^T\bar{\boldsymbol{n}}(0) + Rx(x.\boldsymbol{J} - \boldsymbol{Q})^{-1}(x^T\boldsymbol{J} - \boldsymbol{Q}^T)\boldsymbol{p}_0 \quad (8)$$

Consider the random variables $X_{ii}^{(r)}$, defined as

$$X_{ij}^{(r)} = \begin{cases} 1, & \text{if an entrant to grade } i \text{ is in grade } j \text{ after } r \text{ units} \\ 0, & \text{otherwise} \end{cases}$$

where i, j = 1, 2, 3, 4 and r = 0,1, 2, … . If a person is recruited into the university in state i, the total time spent by such an individual in state j is

$$X_{ij} = \sum_{r=0}^{\infty} X_{ij}^{(r)} \quad (i, j = 1, 2, 3, 4)$$

(Note that $X_{ij}^{(0)} = 0$ if j ¹ i and = 1 otherwise). The expected length of time he will spend in state j is

$$E(X_{ij}) = \sum_{r=0}^{\infty} E\left(X_{ij}^{(r)}\right) \quad (9)$$

It is well known from the general theory of Markov chains that (Stone, 1972)

$$P\left(X_{ij}^{(r)} = 1\right) = p_{ij}^{(r)},$$

where $p_{ij}^{(r)}$ is the $(i, j)^{th}$ element of $\boldsymbol{P}^r$. Hence $E\left(X_{ij}^{(r)}\right) = p_{ij}^{(r)}$ and therefore

$$E(X_{ij}) = \sum_{r=0}^{\infty} p_{ij}^{(r)} \quad (10)$$

If we introduce the matrix $\boldsymbol{X} = \left\{X_{ij}\right\}$, then (10) yields

$$E(\boldsymbol{X}) = \sum_{r=0}^{\infty} \boldsymbol{P}^{(r)} = \sum_{r=0}^{\infty} \boldsymbol{P}^{r} = \boldsymbol{I} + \boldsymbol{P} + \boldsymbol{P}^2 + \ldots = (\boldsymbol{I} - \boldsymbol{P})^{-1}. \quad (11)$$

The expected stay of an entrant into grade i in the whole system is

$$E(X_i) = \sum_{j=1}^{k} E(X_{ij}) = d_i \quad (12)$$

Let π_{ij} denote the probability that an entrant into state i spends some time in state j before leaving. If μ_{ij} is the $(i, j)^{th}$ element of $(\boldsymbol{I} - \boldsymbol{P})^{-1}$ then

$$\mu_{ij} = \pi_{ij}\mu_{jj} + (1-\pi_{ij}) \times 0,$$

$$\text{or } \pi_{ij} = \frac{\mu_{ij}}{\mu_{jj}}, \quad (i, j = 1, 2, 3, 4) \quad (13)$$

The diagonal elements of $\left\{\pi_{ij}\right\}$ must obviously be unity; the off-diagonal elements give the chance of reaching the grade corresponding to the column, given that we enter that corresponding to the row.

Results

Table 2 shows the mobility of academic staff at the UG from 2009 to 2014. The individual elements of the j^{th} column for each year shows how the total number of lecturers in the j^{th} state is divided among the various states (status) from which they are moving.

Table 2: Values of n_{ij} from 2009 to 2014

2009

i \ J	1	2	3	4	5
1	317	19			11
2		193	9		13
3			110	3	8
4				59	5
0	48	9	0	1	

2010

i \ j	1	2	3	4	5
1	374	22			3
2		205	13		8
3			115	10	1
4				63	3
0	39	4	0	3	

2011

i \ J	1	2	3	4	5
1	335	31			5
2		184	9		8
3			120	2	6
4				67	6
0	73	8	2	3	

2012

i \ j	1	2	3	4	5
1	343	26			5
2		184	13		7
3			125	7	2
4				68	4
0	60	6	4	0	

2013

i \ J	1	2	3	4	5
1	306	32			9
2		172	21		6
3			136	10	4
4				72	3
0	88	6	2	0	

2014

i \ j	1	2	3	4	5
1	307	37			12
2		158	9		12
3			151	7	7
4				66	10
0	75	3	1	6	
Total	382	198	161	79	820

The values of n_{ij} (i = 0, 1, 2, 3, 4 and j = 1, 2, 3, 4, 5) for the year 2014 are taken to be the initial values at T = 0. In the year 2014, it can be seen that out of the total number of academic staff who were Lecturers in the previous year, 37 were promoted to Senior Lecturers $(n_{12}(0) = 37)$, 12 left the university $(n_{15}(0) = 12)$, whilst 307 maintained the position of Lecturer $(n_{11}(0) = 307)$. The total number of academic staff recruited in 2014 was 85, of which 75 where Lecturers, 3 Senior Lecturers, 1 Associate Professor and 6 Professors. The initial number of teachers $n_j(0)$ at the j^{th} state is given by

$$n_j(0) = n_{1j}(0) + n_{2j}(0) + n_{3j}(0) + n_{4j}(0) + n_{0j}(0) \quad (14)$$

Thus, $n_1(0) = 382$, $n_2(0) = 198$, $n_3(0) = 161$ and $n_4(0) = 79$, which are the total numbers of Lecturers, Senior Lecturers, Associate Professors and Professors, respectively, in the year 2014. Thus, the total number of academic staff in the year 2014 is given by

$$N(0) = n_1(0) + n_2(0) + n_3(0) + n_4(0) = 820.$$

The one-step transition probabilities, p_{ij} $(i = 0, 1, 2, 3, 4 \text{ and } j = 1, 2, 3, 4, 5)$, that specify the process can be represented by a matrix $\boldsymbol{M}$ as follows:

$$\boldsymbol{M} = \begin{array}{c} \\ i=1 \\ i=2 \\ i=3 \\ i=4 \\ i=0 \end{array} \begin{array}{ccccc} j=1 & j=2 & j=3 & j=4 & j=5 \\ 0.9034 & 0.0761 & 0 & 0 & 0.0205 \\ 0 & 0.8954 & 0.0605 & 0 & 0.0441 \\ 0 & 0 & 0.9187 & 0.0473 & 0.0340 \\ 0 & 0 & 0 & 0.9272 & 0.0728 \\ 0.8685 & 0.0816 & 0.0204 & 0.0295 & \end{array} \quad (15)$$

(Rows: Initial state; columns: Final state.)

Note: $\sum_{j=1}^{4} p_{0j} = 1$ and $\sum_{j=1}^{5} p_{ij} = 1.$ The sub-stochastic transition matrix $\boldsymbol{P}$ is given by

$$\boldsymbol{P} = \begin{array}{c} \\ i=1 \\ i=2 \\ i=3 \\ i=4 \end{array} \begin{array}{cccc} j=1 & j=2 & j=3 & j=4 \\ 0.9034 & 0.0761 & 0 & 0 \\ 0 & 0.8954 & 0.0605 & 0 \\ 0 & 0 & 0.9187 & 0.0473 \\ 0 & 0 & 0 & 0.9272 \end{array} \quad (16)$$

In the UG, advancement of academic staff through the hierarchy (i.e. from lecturer through to the position of professor) is mainly one step (level) for any period as in most management hierarchies. This explains why in the transition matrix $\boldsymbol{P}$ of Equation (16), the values of the p_{ij}'s are zero ($p_{ij} = 0$) for $j = i + 1$. Since transitions within a hierarchy are to a higher grade only, $p_{ij} = 0$, for $j < i$. The transition matrix $\boldsymbol{P}$ shows much bigger values for the diagonal elements. This is because very few academic staff get promoted to the next rank, while the majority remain at the same rank. This reflects the kind of conditions usually found in a typical management hierarchy. In the promotion of students in an educational system, where very few repeat a class, the diagonal elements would tend to be much smaller.

The individual elements in the rows of $(\boldsymbol{I} - \boldsymbol{P})^{-1}$ show how the total expected length of service of an entrant is divided among the various states, where $\boldsymbol{I}$ is a 4 ´ 4 identity matrix.

$$(\boldsymbol{I} - \boldsymbol{P})^{-1} = \begin{array}{ccccc} j=1 & j=2 & j=3 & j=4 & \textbf{Row total} \\ 10.3520 & 7.5314 & 5.6045 & 3.6414 & 27.1293 \\ 0 & 9.5602 & 7.1143 & 4.6223 & 21.2969 \\ 0 & 0 & 12.3001 & 7.9917 & 20.2918 \\ 0 & 0 & 0 & 13.7363 & 13.7363 \end{array} \quad (17)$$

For instance, a member of academic staff of UG is expected to spend 10.3 years in the first state (as a lecturer). After transition to the next state (as a Senior Lecturer) he is expected to spend 7.5 years in that state, 5.6 years in the third state as an Associate Professor and finally 3.6 years in the fourth state as a Professor. If an academic is recruited to join the second grade (state 2) as a Senior Lecturer, the pattern then changes. This is evidenced in the second row of equation (17). The average time he spends in state 2 is 9.6 years. He is then expected to spend 7.1 years and 4.6 years in the third and the fourth states respectively. This reflects the fact that the individual was not recruited through the first grade. A recruit who enters at state 2 is expected to spend 4.6 years in state 4.

The expected length of service of an entrant into the 1st state (Lecturer) = 27.1 years

The expected length of service of a recruit into the 2nd state (Senior Lecturer) = 21.3 years

The expected length of service of a recruit into the 3rd state (Associate Professor) = 20.3 years

The expected length of service of a recruit into the 4th state (Professor) = 13.7 years.

Thus to obtain the matrix π of probabilities $\{\pi_{ij}\}$ we must divide the elements in each column of $(\boldsymbol{I}-\boldsymbol{P})^{-1}$ by the diagonal elements of that column. Therefore

$$\boldsymbol{\pi} = \begin{pmatrix} 1 & 0.7878 & 0.4556 & 0.2651 \\ 0 & 1 & 0.5784 & 0.3365 \\ 0 & 0 & 1 & 0.5818 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \quad (18)$$

The diagonal elements of equation (18) must obviously be unity. This means, there is a certain probability that an academic staff will remain in his grade (status). A member of academic staff of UG recruited to enter the first state as a lecturer has a 78.78% chance of becoming a senior lecturer, a 45.56% chance of becoming an associate professor and a 26.51% chance of becoming a full professor.

It can be seen from Table 2 that the average number of teachers recruited each year into the University of Ghana is $R = 74$. Let $\boldsymbol{Q}$ be the transpose of the transition probability matrix $\boldsymbol{P}$ (which is sub-stochastic) so that

$$\boldsymbol{Q} = \begin{pmatrix} 0.9034 & 0 & 0 & 0 \\ 0.0761 & 0.8954 & 0 & 0 \\ 0 & 0.0605 & 0.9187 & 0 \\ 0 & 0 & 0.0473 & 0.9272 \end{pmatrix} \quad (19)$$

From Table 2

$$\bar{\boldsymbol{n}}(0) = \begin{pmatrix} 382 & 198 & 161 & 79 \end{pmatrix}' \text{ and}$$
$$\boldsymbol{p}_0 = \begin{pmatrix} 0.8685 & 0.0816 & 0.0204 & 0.0295 \end{pmatrix}'$$

The expected total number of academic staff after T years is $\bar{n}(T)$ and is given by (Bartholomew, 1973)

$$\bar{\boldsymbol{n}}(T) = \boldsymbol{Q}^T \bar{\boldsymbol{n}}(0) + R(\boldsymbol{I}-\boldsymbol{Q})^{-1}(\boldsymbol{I}-\boldsymbol{Q}^T)\boldsymbol{p}_0 \quad (20)$$

We find that

$$(\boldsymbol{I}-\boldsymbol{Q})^{-1} = \begin{pmatrix} 10.3520 & 0 & 0 & 0 \\ 7.5314 & 9.5602 & 0 & 0 \\ 5.6045 & 7.1143 & 12.3001 & 0 \\ 3.6414 & 4.6224 & 7.9917 & 13.7363 \end{pmatrix}$$

Thus, from the model, the distribution of the total number of university teachers after 1 year (i.e. 2015) is given by the vector

$$\bar{\boldsymbol{n}}(1) = \boldsymbol{Q}\bar{\boldsymbol{n}}(0) + R(\boldsymbol{I}-\boldsymbol{Q})^{-1}(\boldsymbol{I}-\boldsymbol{Q})\boldsymbol{p}_0$$

which gives $\bar{\boldsymbol{n}}(1) = (409,\ 212,\ 161,\ 83)'$. The set of entries in the vector $\bar{\boldsymbol{n}}(1)$ gives the estimated number of academic staff in the various ranks in 2015. Based on Equation (20), the estimated grade sizes from 2015 to 2025 are computed and the results are given in Table 3. The expected size of the academic staff at UG in each category shows a steady increase over the period.

Table 3: Expected number of lecturers from 2015– 2025

Rank	Years										
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Lecturer	409	434	456	477	495	511	526	540	552	563	573
Senior Lecturer	212	257	285	310	331	251	369	385	400	412	425
Associate Professor	161	211	236	256	273	289	304	316	328	338	347
Professor	83	120	141	158	172	186	198	209	219	227	236
Total	865	1022	1118	1201	1271	1237	1397	1450	1499	1540	1581

Table 4: The expected mobility in 2017

		j				
		1	2	3	4	5
i	1	413	24			10
	2		280	16		14
	3			238	8	9
	4				148	11
	0	64	6	2	2	

The expected mobility for 2017 is as given in Table 4. The individual elements of the j^{th} column of Table 4 show how the total expected number of academic staff in the j^{th} state is divided among the various states where they are moving from. The number of new entrants into the first and second states as lecturers and senior lecturers for 2017 were 64 and 6, respectively, whilst 2 members of staff were expected to be recruited to enter into each of the remaining higher grades (i.e. associate professor and professor). The number of teachers expected to be promoted from the first grade to the second (i.e. from the position of lecturer to senior lecturer) was 24 whilst 16 were expected to be promoted from senior lecturer to associate professor. The total number of teachers expected to leave the university in 2017 was 44. The values in the 5^{th} column show how these 44 teachers who were expected to leave the university in 2017 were divided among the various states from which they were resigning. For example, 10 teachers were expected to exit from the position of lecturer whilst in the same year 9 associate professors were expected to leave. The diagonal elements in Table 4 give the number of teachers in state *i* in the year 2016 who were expected to remain in the same state in 2017, where $i = 1, 2, 3, 4$. For instance, the expected number of senior lecturers in 2017 who were still senior lecturers in 2017 was found to be 280.

Table 5: Total staff strength as at 2017

Rank	Total
Lecturer	472
Senior Lecturer	321
Associate Professor	130
Professor	81
Grand Total	1004

Ghana adopted a national policy which controlled public service recruitments in 2015 and 2016. Most public institutions were not allowed to recruit staff. This affected the University academic staff enrolment. The total academic staff strength of UG as at the end of the 2016/2017 academic year is given in Table 5. The study therefore cannot use the 2017 actual staff strength to validate the predicted stock of the university academic staff in Table 3.

Figure 1.0 is a graph of the expected and actual number of academic staff based on rank for 2017.

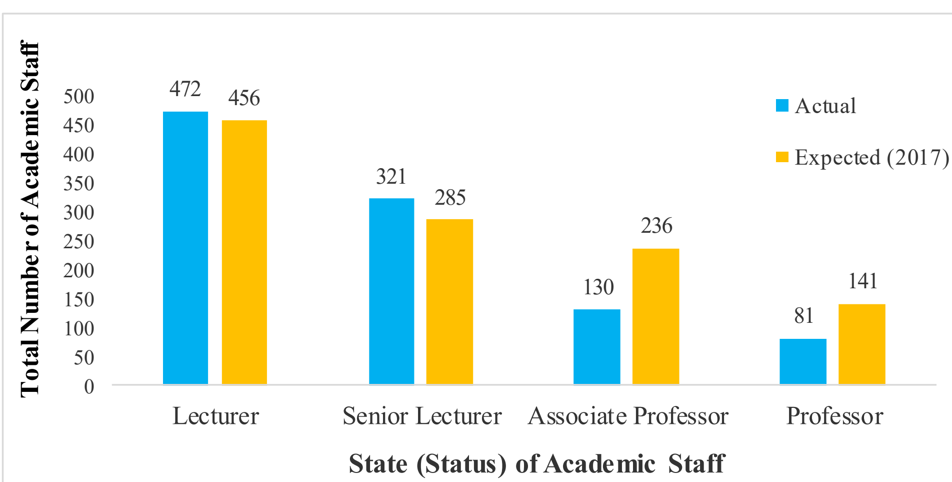

Fig. 1.0: Expected and Actual Distributions of Academic Staff based on rank for 2017.

Conclusion and Recommendation

The study predicted the expected number of academic staff of University of Ghana at specified periods and the respective transitions based on promotions and exits. The study found that a member of academic staff of UG recruited to enter the first state as a lecturer has a 78.78% chance of becoming a senior lecturer, a 45.56% chance of becoming an associate professor and a 26.51% chance of becoming a full professor. The total expected size of the university teachers increased steadily through the period under consideration (2001 to 2015). The expected number of professors decreased gradually over the period (2001 to 2015) while the number of lecturers and senior lecturers grew steadily within the same period.

It is recommended that the academic staff of the university of Ghana increase efforts toward promotion.

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- PNG (suitable for images)
- BMP (suitable for images)
- CDX (ChemDraw - suitable for molecular structures)

Figure size and resolution

Figures are resized during publication detailed below.

Figures on the web:

- width of 600 pixels (standard), 1200 pixels (high resolution).

Figures in the final PDF version:

- width of 85 mm for half page width figure
- width of 170 mm for full page width figure
- maximum height of 225 mm for figure and legend
- image resolution of approximately 300 dpi (dots per inch) at the final size

Figures should be designed such that all information, including text, is legible at these dimensions. All lines should be wider than 0.25 pt when constrained to standard figure widths. All fonts must be embedded.

Preparing Tables

When preparing Tables, please follow the formatting instructions below.

- Tables should be numbered and cited in the text in sequence using Arabic numerals (i.e. Table 1, Table 2 etc.).
- Larger datasets, or tables too wide for A4 or Letter landscape page can be uploaded as additional files.
- Table titles (max 15 words) should be included above the table, and legends (max 150 words) should be included underneath the table.
- Tables should not be embedded as figures or spreadsheet files, but should be formatted using
- 'Table object' function in your word processing program.
- Tables should NOT be submitted as figures but should be included in the main manuscript file
- Colour and shading may not be used in tables. Parts of the table can be highlighted using superscript, numbering, lettering, symbols or bold text, the meaning of which should be explained in a table legend.
- Commas should not be used to indicate numerical values.