CONCEPTUAL DESIGN OF AN ACTIVE AUTOMATIC HEIGHT CONTROL SYSTEM FOR SUGARANE HARVESTING

A Project thesis

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Abstract

Sugarcane is the main source for raw sugar, ethanol fuel worldwide. With an annual global production of about 2 billion tonnes per year and more than 25 million hectares were cultivated in 2011 (FAOSTAT, 2013), it’s considered a vital and valuable cash crop. Any reduction in costs or improvement in ratoon crop health can result in considerable improvement in revenues gains to all sectors involved in the sugarcane related industries. The main objective of this research effort was to increase productivity, enhance efficiency, and decrease losses of sugarcane harvesting process – which is considered the most important process in sugarcane commercial production – by proposing a conceptual design for an automatic system to follow the ground contour and control the height and orientation of the basecutters to stabilize the cutting level and orientation and to avoid cutting under the soil surface. A secondary objective of this research project was to study lodging and its impacts on yields and revenues of the industry. The impacts of field’s unevenness and vibrations on harvesting quality and ratoon crop health were studied and detailed. The available systems to automatically control basecutter height, their sensing techniques, and their actuating means were studied thoroughly. A system of automatic height control was conceptually designed and a model was constructed and tested. The test results showed the potential of applying such system on working harvesters.
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Chapter one: Introduction:
Introduction

1. Sugarcane:

1.1: Sugarcane crop:

Sugarcane is a member of the family Gramineae, tribe Andropogoneae, and is classified in the genus Saccharum. Saccharum originated in the warm temperate to tropical regions of south Asia and Melanesia, and used for sugar production. There are 6 species, all of which are perennial grass. Two of these species occur in the wild state (S. spontaneum L. and S. robustum Brandes & Jesw. Ex Grassl) characterized with heights ranging from 35cm to 10m, thin and hard pithy stalks, low juice & sucrose content, and resistance to diseases. Commercial sugarcane varieties (clones) are complex hybrids involving 2 or more species of Saccharum. The cultivated species are S. officinarum L., S. barberi Jeswiet, S. sinense Roxb. And S. edule Hassk. They have less fiber and higher sucrose content than the two wild species; however, they grow less vigorously and are more susceptible to diseases. S. edule is not grown for sugar but for its edible tassel.

Sugarcane originated from New Guinea and was propagated to China, North Africa, Spain, and North and South America in the 7th and 8th century (Fischer et al., 2008). According to World Crop and Livestock Statistics published by the Food and Agriculture Organization (FAO), world sugarcane growing area increased from 6.3 million hectares in 1950 to 25.4 million hectares in 2011 (FAOSTAT, 2013). Before mechanical harvesting systems were introduced, sugarcane had been harvested manually using various types of hand knives. This conventional harvesting operation still continues in a large scale in developing and underdeveloped countries around the world.

S. officinarum is known as the noble cane because of its thick, juicy stems with high sucrose content. It has stout, jointed, fibrous stalks that are rich in sugar sucrose content, which accumulates in the stalk internodes. The plant is 2 to 6 m and about 5 cm in diameter. The stem grows into cane stalk, which when mature constitutes around 75% of the entire plant. A mature stalk is typically composed of 11-16% fiber, 12-16%soluble sugars, 2-3%nonsugars, and 63-73% water. A sugarcane crop is sensitive to climate, soil type, irrigation, fertilizers, insects, disease control, crop varieties, and the harvest period.

The average yield of cane stalk is 60-70 tonnes per hectare; however these figures can vary between 30 and 180 tonnes per hectare depending on cultivation and crop management. Sugarcane is also used as livestock fodder. Seventy percent of commercial world sugar is produced from sugarcane, while the remaining thirty percent is produced from sugar beet.

Sugarcane can be propagated from true seeds or from cuttings, pieces of stem with auxiliary buds. Each cutting must contain at least one bud. Planting is achieved manually or by mechanical means.
Once planted, a stand can be harvested several times; after each harvest, the cane develops new stalks, called ratoons. Successive harvests give decreasing yield rates; eventually justifying replanting. Two to ten harvests are usually achieved from the same plant, depending on the type of culture. In countries with advanced mechanical agriculture looking for high yield rates on large fields, such as Australia, sugarcane is replanted after two or three harvests to avoid diminishing yields. However, in regions with a more traditional type of agriculture with smaller fields and hand harvesting, such as in some parts of India and Thailand, sugarcane is often harvested up to ten times before replanting.

Sugarcane grows best under warm conditions with high light intensity and fertile soil. It requires a tropical or temperate climate, with a minimum of 60 cm of annual moisture. It’s cultivated in areas with a plentiful supply of water, with a continuous period of more than 6-7 months each year, either from natural rain or through irrigation. The crop cannot tolerate severe frosts. Therefore, most of the world’s production sugarcane production is grown between 22°N and 22°S and some up to 33°N and 33°S. When sugarcane crop is found outside this range it is normally due to unusual climatic conditions in the region.

Sugarcane can be grown on many soils ranging from highly fertile well-drained mollisol (a soil of an order comprising temperate grassland soils with a dark, humus-rich surface layer containing high concentrations of calcium and magnesium, USDA soil taxonomy), through heavy cracking vertisols (a clayey soil with little organic matter that occurs in regions having distinct wet and dry seasons), infertile acidic oxisols (a soil of an order comprising stable, highly weathered, tropical mineral soils with highly oxidized subsurface horizons), peaty histosols (a soil of an order peaty soils, with deep surface layer of purely organic material), to rocky andisols (a black or dark brown soil formed from volcanic material, with an A horizon rich in organic material). Both plentiful sunshine and water supplies increases cane production. This has made Saharan countries with good irrigation facilities some of the highest yielding sugarcane cultivation regions in the world.

Under favorable growth conditions, the bud germinates to produce a primary shoot; subsequently, secondary shoots are developed from basal buds of the primary shoots; the secondary shoots give rise to tertiary shoots and so on, the whole constituting the stool. During the growth cycle, a large number of tillers will die; among those reaching maturity, some may be induced to flower. The final phase in the vegetative life of the stalk is the ripening period, when sucrose will normally accumulate in the stalk. Under commercial cultivation, the stalks are then harvested, and new shoots will arise from the stubble piece, this process being known as ratooning or stubbling.

Temperature is a critical factor limiting sugarcane production. Optimum temperatures for the growing season average 26 - 30°C, sugarcane can survive more extreme temperatures; however death occurs above 60°C and below -11°C.

Air influences sugarcane growth both through its composition and its movement. The water content of air, expressed as relative humidity, affects the incidence of some diseases, and is thought to affect elongation and flooring. Air speed above 40 km/h will cause lodging if cane is tall and the field is wet. Wind speeds above 60 km/h will shred leaves and break tops in rapidly-
growing, tender clones. Speeds over 100 km/h can cause extensive cane breakage even in mature cane, especially if the wind direction is variable.

Either an excess or deficiency of water will affect sugarcane growth and function adversely. Flooding will kill young plants submerged for over a week. A high water table is especially deleterious to stubble during the period following harvest and before regrowth.

Hot winds causing excessive transpiration, may result in leaf burn as well as wilting of tips and margins. Careless harvesting by machine may cause yield reductions in the next crop as uprooting may occur, diminishing the stubble’s vigor.

In-field traffic also imposes stress, since approximately 70% of soil compaction is caused by the first passage of a vehicle. Not only does compaction make root growth difficult, it also reduces water percolation and increases the amount of standing water in the field.

1.2: Sugarcane Lodging:

Lodging is the bending over of the stalks near the ground level due to stem or root failure. Lodging reduces sucrose accumulation in sugarcane (G. Singh et al., 2002); markedly lowers cane juice quality and the effect increases significantly if ratoons are damaged (G. Sayed et al., 1982). Direct losses as a result of lodging in terms of cane and sugar yield may vary depending on timing and extent of lodging and size of the crop (Singh et al., 1999). Indirect losses, such as extra harvesting costs and extraneous matter effects on milling costs can be substantial (Crook et al., 1999; Kent et al., 1999).

In most cases, plants tend to lodge the same way and in the direction of prevailing wind. However, in some cases it may lodge in a random pattern. The effectiveness of any gathering system depends on crop characteristics such as brittleness, degree of lodging and field conditions.

Major factors affecting cane lodging status are soil type, moisture level, crop variety, crop size, planting depth, hill-up and wind. Poor drainage of irrigation water results in uneven crop growth, suckering, lodging, and increased impurities in cane. Excessive nitrogen application can cause lodging. Some diseases and insects like sugarcane grub and pachymetra root rot may cause lodging and tipping of stalks and stools that tear out easily at harvest. Lodged or sprawled crops are harder to harvest, more difficult to gather into the harvester and have more extraneous material than erect crops.

Ripoli et al. (1977, 1983) proposed criteria to classify stalks lodging status (Fig.??), by which stalks were classified into 3 categories:

i. Erect stalks are those which present a degree of alignment with the ground of 60° or higher.

ii. Lodged are those which are found between 30° and 60°.

iii. Recumbent are those which are found less than or equal to 30° of inclination.
Fig. 1.1: Identification of cane lodging level. [Ripolic.C.L.G.Mialhe (1983)]

Fig. 1.2: Lodged and sprawled sugarcane stalks (field no. 457, Sennar Sugar Company).

1.3: Sugarcane harvesting:
Sugarcane is harvested by hand and mechanically. Hand harvesting accounts for more than half of production, and is dominant in developing countries. In hand harvesting, the field is first set on fire. The fire removes dry leaves, and kills insects, snakes and rodents without harming the crop. Burning also helps in concentrating sucrose in stalks but can lead to accelerated rates of deterioration of sucrose content if not processed in a short period. Harvesters then cut the cane just above ground-level using cane knives or machetes.

Hand cutters achieved daily outputs for cutting and loading of 9–12 tonnes in burnt cane and around 6 tonnes in green cane. The advent of mechanical loaders, resulted in a significant improvement in output to about 12–18 tonnes per day in burnt cane.

Manual sugarcane harvesting is a very labor-intensive and laborious activity. Harvest laborers can easily fatigue due to excessive stress on the joints and muscles (Clementson and Hansen, 2008) and are exposed to harmful pests from plantations, creating safety concerns (Carvalho, 2012).

The advent of mechanical harvesting systems frees harvest laborers from the drudgery of field operations. To harvest one hectare of sugarcane, it requires 3.3-4.2 machine-h by mechanical harvesting whereas 850-1000 man-h by manual harvesting (Yadav et al., 2002). Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting (Braunbeck et al., 1999).

Mechanical harvesting uses a sugarcane harvester to cut fibrous tops of stalks, gather and feed stalks into the machine, severe sugarcane at the base of the stool, chop stalks into billets of consistent lengths to facilitate transportation and processing, remove leaves and impurities, blow the trash back to the field and deposit cut billets into transportation vehicles.

Modern harvesters such as Case IH (Austoft), John Deere and Valtra (BE1035e) can harvest up 250 tons of green cane per hour and up 350 tons of burnt cane per hour; however, harvested cane must be processed rapidly.

Once cut, sugarcane begins to lose its sugar content, and damage to cane during mechanical harvesting accelerates this decline. This decline is offset because modern harvesters can complete the harvest much faster than more efficiently than manual harvesting.

Generally, sugarcane harvesters can be categorized into whole stalk harvesters and chopper harvesters. A typical whole stalk harvester system consists of a topper, a base cutter, a feeding mechanism, and a discharging mechanism (fig. 1). The topper is designed to sever cane tops and then discharge the severed tops to the side of harvesting rows.

Topped cane stalks are then cut by the base cutters at about 30 mm above the ground level (Esquivel et al., 2008). The feeding mechanism includes a set of rollers to convey the cane stalks to the discharging mechanism. The discharging mechanism then delivers harvested stalks to either a wagon or onto the field.
The other type of harvester is the chopper harvester. Except for the components of whole stalk harvesters, chopper harvesters include extra components such as chopper and extractors. The functionality of the chopper and extractor are to chop whole stalk into billets and separate leafy materials. In the harvesting process by chopper harvesters, the discharging mechanism is used to deliver the billets to a wagon or a truck.

The field capacity of a sugarcane harvester is determined by the swath width. The cutting head of sugarcane harvesters have been designed to cover one row of canes (single-row) or two rows of canes (double-row) at a time, which causes a substantial variation in swath width. Under the same harvesting conditions and the use of the same harvesting technology, double-row whole stalk harvesters have less operation cost compared to single-row whole stalk harvesters (Salassi and Champagne, 1996).

In the past few decades, the single-row chopper harvester had been widely used for sugarcane harvesting since it is more stable and for high yield variety of sugarcane (Salassi and Champagne, 1998). However, potential for improved harvesting capacity and reduced operating costs have led to a new trend of developing multi-row sugarcane harvesting systems and technologies.

1.4: Farming practices and their impact on harvesting:

I. Green vs. burnt cane harvesting:

Sugarcane can be harvested green or burnt.

Burnt sugarcane harvesting has the advantages of being significantly cheaper than green cane harvesting, easier to perform; especially with large crops, has lower trash and extraneous material content, and better for handling lodged and sprawled crops.

However, burning lowers the quality of raw sugar due to dextrin development as a side effect. Burning accelerates deterioration rates rapidly, significant deterioration can occur within 10 hours after to burning. Burning also removes a valuable organic matter source from the soil thus increasing erosion potential due to low ground cover.

Green cane harvesting significantly reduces cultivation costs. It has greater flexibility in rainy regions where showery conditions are common, or if there is a danger of loss of burnt cane due to deterioration. In lower rainfall regions, there is a moisture conservation benefit, giving better yields reducing irrigation requirements.

However green harvesting has higher cane loss, ranging from five to 20 percent, depending largely on extractor fan speed. It’s more expensive, as cutting rates are 60 to 70 percent of those in burnt cane, and maintenance and fuel costs are higher. Green harvesting also has difficulties in handling high-yielding crops where lodging has occurred. Harvesting capacity in green cane is only 50 to 80 percent of that in burnt cane. However, this depends on crop size, variety, and the severity of lodging.
II. Cultural factors:

i. Farm layout: Improving farm layout increases the productive time for harvesters and reduces the time wasted in turning. Maximizing row length, maintaining shunting tractors and wide smooth headlands all improve farm layout.

ii. Furrowing: that is consistent and matched to the harvester’s base cutter height and angle is vital for reducing stool damage, cane pick-up losses and soil in cane. Hill height and shape will vary depending on cultural practices and agronomic considerations.

![Fig.1.3: Furrowing for sugarcane planting.](image)

iii. Row spacing: With row spacing, the most important consideration is consistency. If possible, planting must be controlled using GPS guidance. Row spacing that is not consistent will cause cutting height variation and increase the possibility of the harvester running over stools. This leads to increased soil in cane and stool damage.

iv. Controlled traffic: Controlled traffic is the system of matching row spacing to the track width of the machinery used within the field.

v. Soil compaction: soil compaction increases cultivation costs, machine wear, erosion and run-off. It also causes poor infiltration, slow drainage and reduced aeration which limits root growth, nutrient uptake and crop yield.

vi. Planting depth: Planting depth and furrow height may affect lodging and stool tipping. However, soil type, moisture level, crop variety, crop size and wind all have a large bearing on whether the cane remains upright even with adequate planting depth and furrow.

vii. Fertilizer application: An adequate supply of plant nutrients is an important requirement for a large crop. However, when excessive fertilizer is applied, sugar quality and profitability can be lowered.

viii. Water management: A stressed crop at harvest may have inconsistent CCS and poorer quality sugar. It may also fail to ratoon if damaged at harvest. A pre-harvest irrigation is desirable for cane that is stressed. Under normal growing conditions, a drying off period of 30–60 days, depending on soil type, is recommended to optimize...
CCS. Excessively long drying off periods should be avoided to prevent stress in ratooning cane.

ix. Drainage management: Poor drainage results in uneven crop growth, suckering, lodging, and increased impurities in cane. Wet conditions and lodging cause harvesting difficulties and soil in cane. Good drainage improves soil trafficability and minimizes compaction at harvest. Good surface and subsurface drainage is essential to maintain productivity. Subsurface drainage should keep the water table at least 500 mm below the soil surface.

x. Weed control: It is easier and more cost efficient to control weeds when they are small. Poor vine control makes harvesting difficult. The cleaning system is unable to effectively remove weeds; therefore crops that are excessively weedy will increase EM and decrease sugar quality.

xi. Pest and disease control: Inadequate pest and disease monitoring and control can weaken the crop and lead to increased stool removal, cane loss, EM and reduced sugar yield. Cane grub and Pachymetra root rot damage generally inflate soil in cane supply due to lodged and tipped stools, and stools which tear out easily at harvest. Pest and disease-damaged cane increases levels of dextrin, color and ash in raw sugar and lowers CCS.

III. Crop factors:

i. Varieties: Varieties that are more suited to harvesting are free or loose trashing, have a solid stool with a good root system, and are not excessively brittle or fibrous. Erect varieties can be readily topped to reduce EM and also feed better into the harvester.

ii. Crop class: Older crop classes can be more difficult to harvest. Soil in cane supply tends to increase because older ratoons generally have wider stools, especially in minimum tillage situations. The sticks are thinner in older ratoons and this requires adjustment of fan speed to reduce cane loss.

iii. Crop size: Larger crops are often lodged and may be stool-tipped. Lodged crops are more difficult to harvest, do not feed as well and have higher EM levels than erect crops. If they have fallen in one direction down the row, then cutting one-way is an option to reduce EM, stool damage and cane loss. This, however, will reduce the efficiency of the harvesting operation. Harvester forward speed and pour rate should be adjusted according to crop size to facilitate good ratooning of the block.

1.5: Post-harvest deterioration:

Freshly-cut cane is preferred in sugar industry because sucrose content is highest at harvest and decreases thereafter. Post-harvest deterioration in damaged, stale cane is characterized by a loss of water and an enzyme-mediated inversion of sucrose to reducing sugars. Inversion, which results in less crystallizable sugar and higher molasses production, reduces sugar production and recovery, favors syrup production, but is of no consequence to alcohol production. Inversion may be reduced by shading and wetting cane between harvest and milling; selection of varieties with low inversion is also possible.

Tissue damage may be caused by twisting and cracking of the stem, by the cutting, crushing, and tearing action of mechanical harvesters, by burning to reduce trash, or by freezing (−4°C and below). The degree of deterioration is related to the amount of damage, hand-cut green cane keeping better than machine-cut, burned cane and whole stalk keeping better than chopped-up cane.
After harvest, undamaged cane can show deterioration as inversion within a week, burned cane will show bacterial deterioration in several days and chopped, burned cane in 12 hours. Lightly frosted, standing cane may keep for 2 – 3 months; badly frozen cane may be unfit for processing within 2 weeks.

1.6: Mechanical properties of sugarcane stalks:

The mechanical properties of the plant material significantly influence the performance of the different unit operations in combine harvesters. Hence, studies of these properties were done prior to the design of sugarcane harvesting system. The mechanical properties of sugarcane stalks viz., bending resistance, cutting resistance, penetration resistance and crushing resistance were researched by many researchers over the years. The design of major unit operations such as de-topping, base cutting with de-trashing and conveyance are dependent on the above properties.

Bhaholyotin et al. (1988) reported the hardness, shearing, tension; compression and de-trashing forces play an important role the design of harvesters.

Chattopadhyay and Pandey (1999) conducted the quasi-static tests using a universal testing machine to determine shear, compressive and bending resistance of forage crops.

Miyabe and Abe (1976) conducted tests with forces necessary to remove the leaves of cane sugar, using universal testing machine and observed that the traction force to remove the leaves varies with the position on the stem and the direction of application.

Miyabe and Abe (1979) did tests to determine the resistance for penetration of the stem, bending, cutting and crushing. They concluded that the penetration resistance varies with node position from top to bottom in the range of 300 to 800 kg/cm². They also concluded that the flexural strength and stiffness increases from top to bottom. The crushing strength (80 to 140 kg) increases with the age of the cane and top to bottom.

Miyabe et al. (1979) conducted impact tests verifying that the impact energy varies with location of the nodes, increasing from top to root (2 to 4 kg.m). The results show that the inner tissue of the stem is softer and more elastic in the upper parts of the cane.

Paulo et al. (1979) studied the mechanical properties of the sugarcane by compression test using the universal testing machine and for leaves removal test by friction by a special apparatus designed to allow the registration of the normal and traction force. The sugarcane stalk can resist up to 4.9 Mpa, A normal pressure of 0.8 Mpa which correspond to a friction force of 315 N, is sufficient to remove the leaves independent of its location in the sugarcane stalk.

Qingting et al. (2006) reported that the flexural strength and flexural modulus of basal stalks of sugarcane were 1172 Mpa and 46 Mpa respectively.

Bastian et al. (2014) found that the young’s modulus of the sugarcane stalks is 86 Mpa. The specific cutting resistance varies between 2147.8 and 957.48 KN/m², Penetration resistance
ranged from 29.74 KN/m$^2$ to 56.33 KN/m$^2$ and the crushing force varied from 0.75 KN to 1.53 KN.

**1.7: Fundamental components of a harvester:**

Technological operations carried out by chopper harvester:

- i. Gathering, raising, and alignment of stalks for optimum feeding into the machine.
- ii. Tops removal.
- iii. Stalks separation from the stool (Base cutting).
- iv. Feeding into the machine.
- v. Chopping into billets of uniform lengths.
- vi. Cleaning and removal of undesired impurities.
- vii. Billets discharge to transportation medium.

![Diagram of a chopper-type sugarcane harvester](https://via.placeholder.com/150)

*Fig. 1.4: Section view of a chopper-type sugarcane harvester (Cameco industries)*

Depending on their relative location of execution on the harvester, these operations may be categorized into 3 main categories:

- i. Frontal (gathering & cutting) components.
- ii. Medial (feeding & processing) components.
- iii. Stern (cleaning & discharging) components.
1) **Gathering and cutting components:** include topper, floating shoes, crop dividers, trimming saws, butt-lifter roller, knockdown roller, finned roller, and base cutters.

a) **Topper:** the primary function of the topper is to remove and eject the leafy top of the cane stalk. Cane is topped at the growing point to remove leaf material because tops comprise 40–45 per cent of total EM. Tops increase EM, depress CCS and reduce sugar quality through increased color, ash and starch. Removing tops reduces the load on the extractors, allowing for improved cleaning, reduced cane loss, and less wear and tear on the machine. Two types exist:

- Drum toppers have a single set of blades and are generally considered the most effective at gathering in the tops. However, the long tops can affect post-harvest operations.

![Fig. 1.5: Drum topper (Case IH 2010).](image)
Shredder toppers have multiple banks of blades to shred the tops more effectively. This provides a more even ground cover for the leaf material and results in a faster rate of trash decomposition. Shredder toppers have higher power consumption, which can impact on machine productivity.
Toppers can rotate either left or right to throw tops away from the standing cane. Strong winds can reduce the ability of the topper to remove the tops and can blow ejected material back into the unharvested field.

b) **Crop dividers:** As the machine moves forward, the cane is guided into the front of the machine and aligned by the crop dividers. The crop dividers consist of a frame attached to each side at the front of the machine by a linkage which carries the gathering spirals, trimming saws and floating shoes. The gathering fronts have either a skid system for height control or, on newer machines, an ‘active’ height control system.

- The crop dividers are connected to the chassis by two parallel linkage arms, to allow the crop dividers to move up and down to follow the row profile and allow the units to be lifted at the end of the crop row.
- A range of systems have been used to help the operator control the height of the crop dividers relative to the soil surface and the machine frame.
- Height control on the crop dividers is important. The tip should typically be operating on the soil surface to ensure proper gathering of the cane stalk. ‘High’ operation of the crop dividers allows lodged cane stalks to then be crushed by the harvester wheels/tracks.

c) **Gathering spirals:** After topping, the gathering spirals make the first contact with the cane crop. The spirals rotate inwards to lift and align the cane for butt-first feeding. The spiral wrap (an upward helix flight) is welded onto the tapered cylinder and is designed to facilitate lifting of the cane.

d) **Trimming saws:** Under conditions of large lodged crops, or where the crop has a poor root system, the use of trimming saws can be the most practical method to assist the feed of cane into the machine. The saws prevent bridging of the cane stalks between the counter-rotating spirals, and the development of bundles of cane, which will cause feeding problems. Manufacturers offer either fixed position or retractable systems. The latter allows the saws to be lowered into an operating position as required, however they do not interfere with the flow of the cane when not needed.

e) **Floating shoes:** Floating shoes pivot on the bottom of the crop dividers to follow the ground contour and help gather stalks that have fallen into the interspace. Correct set-up of the floating shoes essential; as they may grade significant amounts of soil into the basecutters and cane bundle.
f) **Knockdown roller:** The knockdown roller positions the top of the cane stalks away from the harvester to achieve butt-first feeding and helps to align the stalk along the row. The knockdown roller assists front-end feeding in lodged or sprawled crops but does much less feeding in erect crops.

g) **Finned roller:** In most harvesters, a second roller is mounted just in front of and above the basecutters. This roller aims to control the flow of material across the basecutters. On some machines, this roller is fitted with ‘shark fins’ to help with aligning and feeding material between the basecutter legs.
Fig. 1.10: Spiral wound knockdown roller and standard finned roller.

h) Basecutters: The basecutters sever the cane stalk at ground level and help feed the stalk, butt-first, into the feed train. Basecutters interact with the soil, the stool and the harvested stalk. They are a source of soil in cane, stool damage and stalk damage which results in reduced billet quality and increased cane loss.

■ Basecutter configuration:

- Almost universally, the basecutter configuration on modern harvesters is the ‘leg box’ configuration, where both basecutter discs are driven from above through legs attached to a gearbox. Basecutter blades are timed through the gearbox to pass under the adjacent disc and not contact the blades attached to the other disc.
An alternative design strategy is to use a gearbox system under the basecutter discs (underslung). While generally offering enhanced feed performance such as a wider flow of cane into the harvester, problems with operational reliability – particularly in wet conditions due to mud build-up which causes friction between the discs and the gearbox – has meant that manufacturers have generally moved away from that system. Underslung basecutters are preferred for when harvesting cane for billet planting, due to reduced damage.
- **Base cutter disks:**
  - Modern basecutters typically hold five blades per disc, although discs with six blade slots are also available and are preferable at current high ground speeds. Manufacturers also supply discs with different diameters, to either increase or decrease the gap between the discs. This can assist in soil rejection.
  - Other options include dished discs, which increase the nominal angle of the blade, and scalloped discs. Scalloped discs can help with soil rejection, but are also useful in rocky conditions.

- **Basecutter rpm and forward speed:**
  - To maintain optimal quality of cut and ratooning, the basecutter rpm should be variable to match harvester forward speed. Basecutters usually have a fixed rotational speed of between 580–650 rpm depending on year and model, which is best-matched to 7 km/h.

- **Basecutter angle:**
  - Leg basecutters are angled forward at 11°–18° (15°–25° for underslung basecutters) to facilitate butt-first feeding. This minimizes dragging of the discs or gearboxes on the cut stubble.
  - The basecutter angle should be adjusted to match hill height and shape and should increase as the hill height increases. A hydraulically adjustable basecutter angle is an advantage as it enables operators to quickly and easily match the basecutter angle to the stool profile at any time.

- **Basecutter height:**
  - Basecutter height is the distance between the tips of the blades and the bottom of the interspace. The harvester operator sets the basecutter height using a sight gauge in the cabin. This system offers no direct feedback to the operator on the appropriateness of the basecutter height to the desired height.

  i) **Butt lifter:** The butt-lifter roller is mounted behind the basecutters guiding cane into the feedtrain butt-first. The butt-lifter tip speed is a compromise between maximizing feed of the machine (by running at the same tip speed as other rollers in the feedtrain) and maximizing soil rejection (by operating at a reduced speed).
2) **Feeding and processing components:** include the roller train and the chopper system.

   A. **Roller train:** The function of the roller train is to accept cane as it is being severed by the basecutters and deliver it to the chopper box in a consistent manner.
Fig. 1.14: Schematic diagram of a roller train.

* Roller train speed is varied to control the length of billets. The control either accelerates or slows the rotational speed of the rollers relative to the tip speed of the choppers. While this does vary billet length, it also reduces billet quality and increases losses per cut.

* Rubber-coated rollers provide a soft feed and are aimed at producing high-quality billets with sound eyes for planting.

B. The chopper system: The system consists of two parallel cylinders fitted with replaceable cutting blades along the length of the cylinder. The system has an aggressive feeding action. 12-inch and 15-inch drum centers with four, five, or six blades per drum are available.

* Since the early 1980s, the rotary chopper has been the preferred concept for billeting cane in modern chopper harvesters. There has been considerable evolution and development of the concept.
* Since the early 1980s, the rotary chopper has been the preferred concept for billeting cane in modern chopper harvesters. There has been considerable evolution and development of the concept.
* The first major development was the offset blades to give a ‘shovel/hoe’ effect. The most recent development was the differential chop, where the two chopper drums are of slightly different diameter and the blades are also offset from the centerline of the shaft. This has become the default standard.
Initially, chopper harvesters were designed to produce a billet length of about 300 mm. This was seen as a good compromise between the requirement for load density with burned cane, and the losses and deterioration associated with billeted rather than whole-stalk cane.

With the reduction in cut-to-crush times, and the impact of factors such as higher trash levels associated with green cane harvesting, there has been a consistent move to shorten billet lengths.

Billet quality quickly reduces as blade sharpness deteriorates (Figure). Sharpness of the chopper blade and correct overlap is essential for chopping green leaf and trash, and minimizing recycling of billets. Keep the blades as sharp as possible with a minimum knife overlap.

Fig. 1.15: Rotary chopper configurations (Hocking and Davis 1999).

Fig. 1.16: Effect of blunt chopper blades on cane and juice loss (Norris et al. 1999).
3) **The cleaning and discharging components:** include the primary and secondary extractors and the elevator.

I. **The primary extractor:** The primary extractor is located behind and above the chopper box and works to clean the cane as it is ejected from the chopper box.

![Image of the primary extractor](image1)

**Fig. 1.17:** The primary extractor (Case IH 2010).

- The extractor fan holds four curved blades. These are designed as a compromise between the efficiency of a more complex blade and the cost of regularly replacing blades operating in a highly abrasive situation.

![Image of primary extractor blades](image2)

**Fig. 1.18:** Primary extractor blades (Case IH 2010).

- The hub is driven by a vertical shaft, which has minimal impedance on air and trash flow. Older machines have the hub driven by a horizontal arm, which impedes the flow of air and cane.
- The deflector plate controls the trajectory of the cane from the chopper relative to the extractor fan. The deflector plate needs to be set so that the flow of cane is parallel and close to the fan, but is never into the fan. Deflector plate height depends on pour rate.

II. **Elevator:** The elevator accepts cane as it falls from the primary extraction chamber and delivers it into a trailer. They swing from side to side to allow delivery on either side.

III. **Secondary extractor:** The secondary extractor is mounted on top of the elevator. It’s smaller than the primary extractor with 3 blades. It’s used as a final up of the cane rather than for major trash extraction.
Fig. 1.20: Secondary extractor (Case IH 2010).

Fig. 1.21: Secondary extractor blades (Case IH 2010).
1.8: Harvester ownership and operational costs:

Sugarcane harvesters are used only in the harvesting season which is 5 months long (3600 hours) on three shifts per day system (8 h each including 2h for maintenance ~ 2700 effective working time).

All expenses are calculated on Sudanese Piasters. All conversions are based on the Central Bank of Sudan (CBOS) exchange prices.

Timeliness costs were not calculated due to insufficient data.

Ownership costs:

Ownership costs include depreciation of the machine, profitability on the investment and cost of taxes, insurance and housing of the machine.

The first cost of the harvester was found to be 4,193,511.82 SDG (2015 model) with a depreciation rate of 20% and life expectancy of 5 years.

The prevailing interest rate in Sudan (MURABAHA) in the period from 2003 to 2015 based on data from the CBOF was found to be 11.7%.

The capital recovery factor was found using interpolation from the data of Iowa state university’s extension PM 710 having a value of (0.2752).

Depreciation was calculated using sum-of-years-digits model.

The salvage value after the end of expected life was found to 223653.96 SDG.

Capital recovery = (total depreciation * capital recovery factor) + (S.V. * interest rate)
Capital recovery = (3354809.46*0.2752)+(223653.96*.117) = 1021371.74 SDG/year
Capital recovery (/2700) = 378.28 SDG/hour

Taxes, Insurance and housing (TIH) cost are much smaller than depreciation and interest.

A cost estimate equal to 2% of the purchase price is often used.

TIH = 0.02*4,193,511.82 = 83,870.24 SDG/year
= 83,870.24/2700 = 31.06 SDG/hour

Total ownership costs = 1105241.94 SDG/year = 409.34 SDG/hour
Operating costs:

Also called variable costs, include repairs and maintenance, fuel, lubrication, and operators labor.

Maintenance and labor expenses were calculated based on the data from Sennar sugar factory, one of the Sudanese sugar company factories.

In 2015/2016 season the factory owned ten harvesters operated by fifteen drivers on three shifts per day (8 h each).

Total maintenance expenses on the season were found to be 132,499.83 € (CBOS exchange price = 6.9115 SDG/€) ~ (915,722.575 SDG).

Total cost hour = 915,722.575/2700 = 339.156 SDG/hour

Cost for single harvester = 33.91 SDG/hour

Labor costs were calculated based on the Sudanese Sugar Company wages system for 2015/2016 season.

Wage = 345 + 120 + 110 + 75 + 50 + 200 = 900 SDG (fixed salary + allowances + fixed bonus)

SSC awards its workers with a 2 hours per shift bonus system (dependent on shift time, holidays shifts have higher bonuses).

Mean monthly harvester driver salary = 1362.416 SDG/month

To each harvester driver the factory employs two shunting tractor’s drivers.

Tractor drivers’ wages differ from harvester driver by about -50 SDG.

Mean monthly tractor driver salary = 1312.416 SDG/month

Total labor cost = 3987.25 SP/month = 7.38 SDG/hour

Fuel expenses were obtained from Sennar company fuel administration.

Total fuel consumption of all harvesters throughout the season: 955,232 Litter

Fuel price is 3.445 SDG per Litter.

Total cost = 3,290,774.24 SDG.

Total hourly fuel costs = 1218.805 SDG/hour.

Fuel cost per hour for a single harvester = 121.88 SDG/hour.

Hydraulic oil data (EP100) obtained from Sennar factory workshop.

Barrel contains an average of 202 Litters.
Barrel price is: 2200 SDG/barrel.

Total season consumption was recorded to be 310 barrels.

Total consumption: 62620 Litter.

Total cost = 682,000 SDG ~ 10.891 SDG/lt.

Average oil consumption = 62620/2700 = 23.19 lit/hour.

Average oil consumption for a single harvester = 2.319 lit/hour.

Oil costs = 10.891*2.319 = 25.256 SDG/hour.

Total costs = 409.34 + 33.91 + 7.38 + 121.88 + 25.256 = 597.766 SDG/hour.
2: Problem statement:

Sugarcane must be cut at about 30 mm above the ground level (Esquivel et al., 2008). Improper cutting height results in problems and deficiencies in all sectors associated with commercial sugarcane production.

Sugarcane harvester height control has always been an exhausting and timely-consuming necessity due to the fact that in most harvesters – modern and outdated – the cutting mechanism is situated directly below the operator. Consequently, height control depends only on operator’s intuition and judgment without any visual inference.

Experienced operators tend to conduct a trial and error process to adjust the height to a proper value by harvesting a pre-determined test length of row and then adjusting height accordingly. Most manufacturers provide means for automatically adjusting and maintaining height of cut at a preset value.

It should be noted that the effects of insufficient height control detailed below, including estimates of additional expenses from dirt of sugar supply are based on extrapolation of old data and assume reductions in dirt levels will provide proportional decreases in operating costs. These assumptions may not be completely valid but they do give some indication of the magnitude of the problem.

2.1: Impacts of insufficient height control on sugarcane industry:

I. Effects on the farming sector:

The harvesting process can cause problems if stalks are cut too high or too low with respect to ground level.

When stalks are cut too high, they may shatter introducing diseases into the plant sometimes even causing death of the plant resulting in loss of production in the subsequent years. On the other hand, the stool, or the root system may be damaged leading to similar results. In either case, instead of being able to achieve multiple ratoons from the same plant, earlier replanting may be required.

Losses of revenue are also incurred due to amounts of millable cane left on the field when cutting too high, or due to reduction of commercial cane sugar (CCS) level associated with increased percentage of dirt in the harvested sugar cane when cut too low.

II. Effects on the harvesting sector:

The power of modern sugarcane harvesters makes it possible to well below ground level with no noticeable effect on speed, or other indicators on the harvester. However there is a down side to cutting below ground surface due to the increased wear and tear on the machinery, particularly the base cutter blades. Unnecessarily loading the machine also increases operating costs through extra fuel and oil consumption.
Fig. 1.22: Sectional view of sugarcane harvester (Blackburn, 1984).
Anecdotal evidence show that in almost all sugarcane production areas worldwide, mills only process freshly cut cane purchased from farmers; mills don’t plant and cultivate the crop to process it. Hence, farmers hire contractors to cut their cane and transport it to the mill site. Most sugarcane farmers request that the contractors cut their cane below ground level to presumably give them the best return on their crops.

The cost savings estimated by Neves et al for the reduced wear on the base-cutter blades was US$4400 per season of two hundred days. This figure assumes that the harvester operates for 24 hours per day. Amending this to eighteen hours per day over a one hundred and fifty days season, operator could expect savings of about US$3300 per season by using a moderately effective base cutter height control system.

Automatic control of the base-cutter height should lead to reduced wear for the cutting blades and less maintenance and running costs for the harvester; given that farmers and operators are convinced of the benefits of proper height setting.

III. Effects on the refining sector:

With global production up to 1.8 billion tons of sugarcane per year (FAO, 2015), even a small reduction in milling costs will translate into significant savings to the sugarcane industry. In Australia, Mason and Garson in 1986 performed an investigation into the extra costs associated
with the milling of sugarcane contaminated with extraneous matter. It was concluded that the cost to the sugar industry was $0.62 per ton of sugarcane to maintain the milling facilities due to the extraneous matter. Assuming the inflation has increased at a rate of three percent over the past thirty years, the cost today should be approximately $1.5 per ton for maintenance of the mill.

Assuming the current average amount of soil in harvested sugarcane is around 1.7 percent; as was estimated by Mason and Garson in their investigation, it can be estimated that by reducing this level to around 0.5 percent by optimizing the cutting height, a total savings of approximately $1.05 per ton to the sugar milling industry could be expected. This figure corresponds to an estimated total global reduction in running costs of sugarcane mills of up $1.26 billion each year.

These figures based only on the maintenance costs to the milling sector. In practice, in addition to these costs, there is extra expenditure associated with the transportation of the material to and from the mill, reduced sugar quality and quantity, and extra wear on milling facilities. These factors mean that the actual costs to the milling sector are much greater than those estimated above.
3: Research Objectives:

The primary objective of this research project is to study the impacts of field unevenness due to deficiencies in leveling and tillage preparation operations in sugarcane harvesting and purpose a mechanism to maintain a predetermined reference height and correct orientation errors. A secondary aim is to facilitate harvesting lodged and sprawled sugarcane stalks to reduce losses, increase productivity and enhance efficiency.

The detailed objectives include:

1. Study the impacts of field evenness and vibrations on harvesting quality and ratoon crop health.
2. Study the available purposed solutions and the machineries implementing these solutions.
3. Purpose a mechanism to measure and respond to height and orientation errors.
4. Study lodging in sugarcane stalks and its impacts on harvesting process.
5. Propose solutions to reduce losses, increase productivity and enhance harvesting process efficiency.
Chapter Two: literature review:
Research on the topics of cutting height sensing, height control of sugarcane harvesters' base cutters, and cutting quality has been intensive since the adoption of mechanical harvesters for harvesting sugarcane due to their impacts on revenues gained on investment and quality of next ratoon shooting from the plant being handled.

**Cutting quality:**

Cutting quality on stalks and stools is critically important to reduce cane (juice) loss and to avoid the possibility of reduction in ratoon (the shoot of new sugarcane plant). Therefore, a good cane cutter should produce a smooth cut surface with minimal splits or cracks in addition to minimizing cutting force and cutting energy consumption. Researchers conducted a series of studies to investigate how dynamic and geometric parameters of the system affect cutting quality.

Gupta and Oduori (1992) studied the effect of blade cutting velocity on cutting quality through a series of lab-based cutting tests. It was found that the rotating base cutter would tear the cane stalk from the root rather than cutting it if the velocity is less than 13.8 m/s (Gupta and Oduori, 1992). Later, Liu et al. (2007b) conducted similar lab-based cutting tests and also concluded that there is a minimum blade velocity requirement for good cutting quality. The threshold value estimated by Liu et al. (2007b) was 22.0 m/s compared to 13.8 m/s by Gupta and Oduori (1992). These two studies estimated different minimum blade velocities probably because of different cutter parameters used in those studies. In Gupta and Oduori’s study, the oblique angle and tilt angle were set to 35° and 27°, respectively, based on their first-stage testing results (Gupta and Oduori, 1992) whereas in Liu’s study, the oblique angle and tilt angle were set as 0° and 8°, respectively.

There are other system/cutting parameters impacting stalk cutting quality. Liu et al. (2007c) carried out a series of lab-based cutting test for analyzing the sensitivity of stalk cutting quality to system parameters. In these trials, they investigated the effects of blade cutting velocity, relative position between the base cutter centerline (i.e. direction of travel) and stalk (row) centerline, and machine forward speed on stubble damage rate. The sensitivity analysis showed that blade cutting velocity has the most significant impact on stubble cutting quality (Liu et al., 2007c).

Liu et al. (2007a) compared the stalk damage rates caused by one-blade and two-blade cutting. It was concluded that the two-blade cutting process has lower stubble damage rate than one-blade cutting (Liu et al., 2007a). The reason is that the maximum cutting force required during one-blade cutting is bigger than the maximum cutting force required during two-blade cutting, thus one-blade cutting has a greater probability of stalk cutting failure (split or crack) (Liu et al., 2007a).

Yang et al. (2007) conducted relevant field tests to examine of influence of various field factors (unevenness) and machine structure factors (natural frequency) on stubble damage rate. They found that the cutting head movement frequency and amplitude, determined by field conditions and system structure characteristics, have notable influence on stubble damage rate (Yang et al., 2007). Decreasing stubble damage rate requires decreased frequency and amplitude of cutting head movement. This study suggested that cutting head movement could be controlled by modifying configurations of cutting head structure and leveling crop field. Similar to cutting force, the shape of blade is also an important factor affecting cane cutting quality. Mello and Harris (2000) compared the performance of cutting blades with serrated
edges and smooth edges in terms of sugar loss and stalk damage. Although serrated blades had better cutting quality (smaller cracks and splits in stool and stalk) than smooth blades, the sugar loss was greater because the roughness of serrated blade surface removed more sugar cells (Mello and Harris, 2000).

To minimize the negative effect on sugar loss, Mello and Harris (2000) suggested that serrated-edge blades could be fabricated into curved shape to add some level of slicing into the impact cutting process of straight serrated blades. Later, Mello and Harris (2003) investigated the effect of serrated-edge cutter parameters on base cutting damage rate. They used factorial experiment that involved two kinds of blades (forward and backward curved; fig. 10) and two pitches of serration (3 and 7 mm). It was concluded that the forward blade with 3 mm pitch has low stubble damage rate (Mello and Harris, 2003), which showed a potential of using curved serrated-edge blades for a practical and economical solution to improve cutting quality during sugarcane harvesting.

![Fig.2.1: Backward-curved serrated blades (left) & forward-curved serrated blades (Mello and Harris, 2003).](image-url)
Sensing techniques:
There have been a number of proposals over the past thirty years of methods to measure and control the base cutter height on mechanical harvesters. It appears that most of these approaches have had limited success due to the difficult measurement environments involved.

From a control point of view, it’s highly desirable to measure the ground height in front of the basecutter so that the basecutter height can be adjusted to suit the required ground height profile. However, when sensing the height in front of the basecutter, a sensor has to contend with the presence of the sugarcane. The sugarcane stalk or leaf can obscure a sensor’s “view” of the soil or may cause error and even damage to the sensor.

Measuring ground height behind the basecutter has the advantage that most of the sugarcane has been removed and the sensor will have a clearer view of the soil. However, when measuring behind the basecutter, the passing of the basecutter nearly always disturbs the soil making it near impossible to get an accurate reading of the ground level. Furthermore, the lag between cutting the sugarcane and measuring the actual ground height means that the control system is continuously trying to “catch up” and hence will not perform as well as a predictive-type system.

There are two distinct classes that have been tested for basecutter height control. One style of device that has been tried in many different forms can be broadly termed a “mechanical contact sensor”. This type uses a skid or a wheel to gauge ground height [9]. Formerly, this type has proven to be impractical in high-tonnage cane crops and suffers from fouling by the sugarcane, leaf matter and mud that can be found around the basecutter region on the harvester. This flaw was due to the outdated ‘short and open’ design of crop dividers on sugarcane harvesters.
Fig.2.3: Case Austoft A8800 showing new design of crop dividers (Case IH 2014).
The other style of ground level contact detection sensor can be broadly labeled as a “non-contact sensor”. This type of sensor attempts to determine the position of the soil by detecting changes in a field or a travelling wave that interacts with the surroundings. Some sensors of this type include ultrasonic sensors that measure delays of a sound wave or radar sensors that detects variations in the travelling electromagnetic wave.

The main advantage of the non-contact type sensors is that the measurement device does not disturb the ground level and there is less chance of fouling, as the sensor does not physically contact the soil or the crop. For similar reasons, non-contact sensors also tend requires less maintenance to ensure reliable operation. However, this type of sensor is still under development & research and has not been utilized by the industry yet.

2.1: Mechanical contact sensors:

Mechanical contact sensors use angle sensors other techniques to measure distance or angle created by the mechanical sensing device to calculate the location of the ground.

Neves et al. (2001) proposed a system that uses a floating base cutter configuration with a raised dome hubcap below the basecutter to raise the basecutter height when the ground level increases. The system consists of articulated arm joins the basecutter components (motor,
gearbox, discs and blades) to the machine structure. These articulated arms allow the basecutter to move back-and-up or forward-and-down simultaneously. They used two springs to balance the weight of the equipment and reduce the pressure between the height control hubcap and the soil.

![Diagram of floating basecutter](image)

Fig. 2.5: Schematic representation of floating basecutter (Neves et al. 2001).

Test results by Neves et al. show that the floating basecutter configuration performs better than the fixed basecutter with less trash and extraneous material level delivered to the mills, less amount of stubble pulled out of the soil, and less visible infield losses.

Neves et al. research has shown that using of an automated control system would improve the efficiency of the harvesting process. If the basecutter height is maintained at close to the top of the row, then extraneous matter included in the harvested sugarcane could be halved resulting in significant cost savings.

2.2: Hydraulic pressure sensors:

This technique involves monitoring the pressure across the hydraulically driven basecutter motor. In theory, the pressure should vary as the basecutter starts to cut more deeply into the more dense soil. However, more recent studies have shown that the basecutter pressure does not vary in a predictable manner. In particular, the basecutter pressure was found to vary non-linearly with both the cutting height and the harvester’s travel speed, making it difficult to use the method with any confidence.
2.3: Ultrasonic sensors:

In this type of sensor, an ultrasonic signal is transmitted and subsequently reflected by the ground. The time difference between sending a signal and receiving the reflection is used to determine the distance that the signal traveled; the ground height. The sugarcane research institution (SRI) of Australia has been investigating the use of ultrasonic sensors for basecutter height control for many years. Their investigations have shown that if the sugarcane is cut green or partially burnt, the trash surrounding the stool often blocks the ultrasonic signal. Hence, using ultrasonic sensors would only be feasible if the sensors were located behind the basecutter – where they are not blocked by trash – which is not the optimal option.

2.4: Microwave sensors:

Microwave electromagnetic sensors can penetrate through most non-conducting materials to differing degrees. Thus, using a microwave sensor in height control of basecutter seems to be an attractive concept as such a device may be suitable for positioning in front of the basecutters. There have been previous investigations into the feasibility of using microwave radar technology for ground height measurement applications. Shin et al. (1991) has investigated using a dual-frequency radar measurement technique at a frequency of around 1 GHz. However, their work was all conducted in the laboratory and no conclusive results were obtained.

Luke (2006) has conducted field experiments to test the feasibility of using microwave ground height detection system for automatic height control of basecutters. His results showed that the type of measurement technique was suitable for use on sugarcane harvesters. He suggested that this measurement technique needs more development to be practically utilized on harvesters.

2.5: other sensors:

Other types of sensors were proposed and tested. One example for such sensors is nuclear sensor. The radioactive decay of a nuclear material can be measured through virtually any material, including metals. The main advantage of a nuclear sensor is that the radioactive particles will penetrate virtually any material, making this type of sensor suitable in even the most difficult measurement applications. However, there are always health and safety concerns when using a radioactive material that would make this sensing technique a last resort if not totally precluded.
Chapter Three: Concept Development:
As the objectives of this research effort states, a conceptual design of an automatic height control system is proposed. The concept design focuses simplicity of design and use, cost efficiency, removability, use of components readily-available in the market, ease of manufacture, and ease of maintenance. This research also aims to treat with cutting level orientation variations and machine vibrations resulting from uneven ground profiles due to improper soil preparation operations or due improper water management in fields.

The system proposed consists of two interconnecting sub-systems; the sensing mechanism and the height control mechanism. The concepts investigated in each subsystem shall be detailed in the following paragraphs.

3.1: The height sensing component:

Height sensing is of primary importance for controlling the height of cutting in sugarcane harvesters. Many measurement techniques were investigated over the years. Some of the techniques studied by researchers have shown promise for utilization in harvesters. Other techniques were found to be impractical at the time of conducting the experiments, such as the mechanical contact sensors and the ultrasonic sensors. These sensors are excluded due to their tendency to be blocked or fouled by dense cane crops. Dense cane crops can damage the sensor or result in permanent malfunction or error in the reading, if for example, trash entered between the rings of the springs in the floating basecutter configuration proposed by Neves et al.
In this project, the height sensing component is proposed to utilize a removable mechanical contact height sensor. The sensor consists of a wheel-and-suspension mechanism that can be attached to the sugarcane combine harvester. The sensor is to be attached inside the harvester's floating shoes outer walls, where the floating shoes' safety locks are fixed during maintenance operations.
Fig. 3.2: Safety locks with shear pins (Austoft A8000 manual).

Fig. 3.2: Floating shoes’ safety locks attachment location (Case IH Austoft A8000).
An oleo strut suspension mechanism shall be utilized in the concept. An oleo strut is a pneumatic air-oil hydraulic shock absorber used on the landing gear of most large aircrafts and many smaller one. Oleo strut suspension mechanisms have the ability to cushion the impacts and dampen vertical oscillations; that’s why they are preferred for applications where vibrations are not acceptable. Oleo struts are utilized in this concept to cushion large impact forces encountered in the tough working environments that this system was designed to contend with.

Two oleo struts shall be used to measure height of ground level and orientation. Oleo struts consists of two telescopic cylinders supported by torque arms with a metering orifice in between the cylinders. The wheel axle is attached to the inner cylinder (piston). The outer cylinder is attached to the machine frame. The cavity between the two cylinders is filled with gas (usually nitrogen, sometimes air) and oil (usually hydraulic fluid), and is divided into two small chambers that communicate a small orifice. The mechanism is to be equipped with a pressure sensing mechanism at the servicing valve to measure hydraulic fluid pressure, which is then used to measure height of floating shoes. The height of the floating shoes is used to determine height of the harvester and the orientation of the ground profile.

The oleo strut concept of operation is that when pressure is induced on the wheel axle, the piston slides up. The movement of the piston compresses the gas, which acts as a spring, and forces oil through the orifice, which acts as a damper.
Fig. 3.3: Sectional views of an oleo strut mechanism.
Fig. 3.4: A depiction showing Oleo strut operation concept.
3.2: The height control component:

For active control of height and orientation correction in the harvester, a floating basecutter mechanism is proposed. The mechanism is to be actuated by four synchronized hydraulic axial cylinders that shall be attached under the basecutter to adjust and correct height and orientation errors.
Fig. 3.6: Side view of height control component.
Fig. 3.7: Side view of fixed basecutter configuration on Austoft A8000 sugarcane harvester (Case IH).
Chapter four: model Development:
A model was constructed to mimic and demonstrate the construction and operation of the concept on the harvester with more focus dedicated to the cutting mechanism. Ultrasonic sensors were used instead of wheel-mechanical-contact sensors for simplicity of design and for the model to be cost-effective.

The model was designed to be as simple and as economical as possible; using used toys’ parts, metal plates, and steel pipes available in the market. The model consists of: main chassis, main wheels, frontal section components (horizontal articulation axle & wheels), base cutter, stepper motors, ultrasonic sensors, a microprocessor, and connecting wires.

A special removable testing path was designed to demonstrate the concept of operation of the automatic height control system. The path was constructed using cardboard sheets and a paste of paper, glue, and gypsum. The path consists of variable slopes and tough terrains to simulate the working environment that the automatic cutting height control system was proposed to contend with.

Many concepts were examined for height and orientation sensing on the model including using a gyroscope and accelerometer configuration (technically known as the inertial measurement unit; which may include other components as well), strain gages, and ultrasonic sensors.

Ultrasonic sensors were used in front of the horizontal articulation axle to measure height. The data from the ultrasonic is to be analyzed by the microprocessor to acquire real-time readings of orientation and elevation variations. Ultrasonic sensors were chosen for their accuracy, simplicity of installation, and fairly reasonable price.

Three sets of wheels were used on this model; two sets are the regular support and propulsion components on the sugarcane harvesters. The third set was added in front of the horizontal articulation axle to follow the ground contour. The ultrasonic sensors are fixed behind the third wheel set.

Weights were added above the frontal section; in front of the articulation axle to magnify momentum on the frontal section, thus overcoming the axle’s reluctance to rotate. Counter weights were added to overcome the added momentum.

The propulsion mechanism on this concept was ignored due to budget limitations; the concept shall be pulled or pushed manually.

A cutting height range between (10 – 50 mm.) is proposed in this model. Cutting height to be maintained in the experiment is at (30 mm.). A visual reference cutting level is introduced.
Fig. 4.1: Model schematic drawing.
Fig. 4.2: A photograph of the model before wiring.
Fig. 4.3: Finished model before decoration.
Fig. 4.4: Electronic circuit of the model.
Fig. 4.5: Sample of readings.
Chapter five: conclusions:
Conclusions:

The research successfully satisfied its aims. The impacts of field’s unevenness and vibrations on harvesting quality and ratoon crop health were studied and detailed. The available systems to automatically control basecutter height, their sensing techniques, and their actuating means were studied thoroughly. A system of automatic height control was conceptually designed and a model was constructed and tested. The test results showed the potential of applying such system on working harvesters. Lodging was researched and studied both on field and from research papers. However, influencing factors of lodging could not be determined.

Recommendations and future work:

To avoid drawbacks of improper cutting stated on this research:

1. The ground surface must be leveled using high accuracy methods (e.g.: laser leveling).
2. Experienced operators must be hired – even for extraordinarily higher wages – whenever possible.
3. Training programs for inexperienced operators and maintenance staff must be given more focus.
4. More research effort must be aimed at lodging and its harmful impacts on the sugar industry.
5. Automatic height control systems available on harvesters must be activated on all working harvesters; even if they result in decreased harvesting rates.
References