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Multipurpose Agricultural Robot Platform: Conceptual Design of Control System Software for Autonomous Driving and Agricultural Operations Using Programmable Logic Controller

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***Abstract*—**This paper discusses about the conceptual design and development of the control system software using Programmable logic controller (PLC) for autonomous driving and agricultural operations of Multipurpose Agricultural Robot Platform (MARP). Based on given initial conditions by field analysis and desired agricultural operations, the structural design development of MARP is done using modelling and analysis tool. PLC, being robust and easy to use, has been used to design the autonomous control system of robot platform for desired parameters. The robot is capable of performing autonomous driving and three automatic agricultural operations, viz. hilling, mulching, and sowing of seeds in the respective order. The input received from various sensors on the field is later transmitted to the controller via ZigBee network to make the changes in the control program to get desired field output. The research is conducted to provide assistance to farmers by reducing labor hours for agricultural activities by implementing automation. This study will provide an alternative to the existing systems with machineries attached behind tractors and rigorous manual operations on agricultural field at effective cost.

***Keywords*—**Agricultural operations, autonomous driving, MARP, PLC.

I. Introduction

FARMERS are facing a lot of challenges in various agricultural operations like hilling, vinyl mulching, seeding, harvesting, etc. on the agricultural field because of inefficient, unaffordable farm equipment, and unreliable piece of automation in the farm machinery, which can withstand the agricultural environment consisting of uneven, un-predictive piece of land, dust and water, in and off the field [1]. The agricultural sector is experiencing a crisis, and the root cause lies in the lack of cutting edge technology. Here, the cutting edge of the agricultural sector refers to the lack of technological competitiveness [2]. This paper is considering the fact of research and development of the farm robot technology and hence we have developed MARP in our research laboratory. In this paper, we have managed to explain about control system software design and development conceptually using PLC for automatic driving and agricultural operations by MARP. The research and development of MARP is divided in three phases: design phase, control phase, and testing phase. In this paper, we have focused on only control phase of the robot platform with brief introduction of the design phase. The design phase is started from concept design using 3D modelling software followed by production design and development, after structural simulation using analysis software. In control phase, we have focused on autonomous control system simulation of driving and agricultural operations using PLC.

Remote controlled Wireless Sensor Networks (WNSs) is a popular technology in the world containing multifunctional sensors. Sensors networks are preferred over normal sensors [3]. The sensor networks are used to provide inputs which are monitored and transmitted to remote control user, using ZigBee module. This platform is purposely designed for performing mainly three agricultural operations: hilling, mulching, and sowing of garlic seeds (in our research) in respective order. Hilling is the technique in agriculture of piling up soil around the base of a plant. Mulching is a process of applying a layer of plastic sheet (vinyl) on the surface of hill area of the soil. Seeding is the process of sowing seed deep into the soil, as shown in Fig. 1. The agricultural robots are made to operate in the open field and that's why we need to establish basic initial conditions. The average walking speed for pedestrians is 4.11 feet per second, equivalent to 4.5 km/h [4]. To make the robot to be under constant supervision by the operator, the working speed limit is set at 5 km/h.

Fig. 1 Hilling process followed by mulching and seeding

II. Design of MARP

A. Field Analysis

On an average, the ridge (hill of soil) has a height of 200 mm (in some cases it may be a little higher), the distance of the first seed line from the center of the channel where tractors may go,

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is about 300 mm, the space between ridges is approximately 500 mm ~ 600 mm, and finally the working space is about 1500 mm to 1550 mm wide, as shown in Fig. 2.

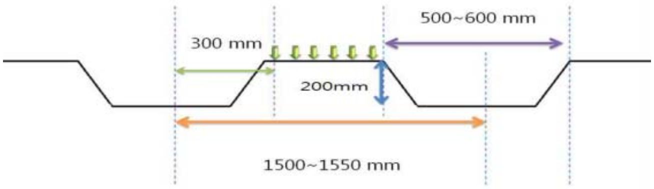

Fig. 2 Height and space between ridges

B. Module Concept

The initial condition of the MARP is that it operates in off road environment at speed of 5 km/h (considering human supervision) with enough power to overcome 30-degree slope. Platform is capable of carrying machinery of up to 300 kg. The complete frame can successfully support 1 ton of overall working platform weight.

On the basis of initial conditions and the concept of the machine, Four-Wheel Driving (4WD) is implemented for our design as it reduces turning radius in comparison to Two-Wheel Driving (2WD). We need small turning radius of the platform as it will save from the destruction of soil hills and planted trees (if any) in the field, also favorable for small agricultural field. The 3D conceptual design model of MARP with attached agricultural machinery is shown in Fig. 3.

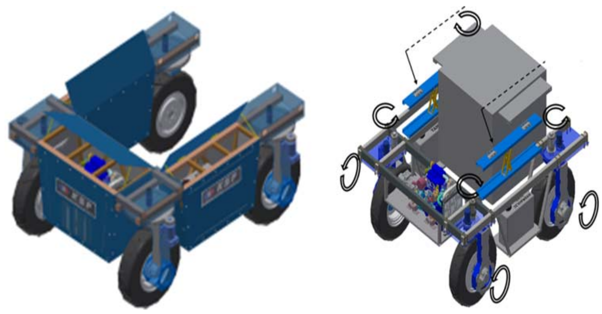

Fig. 3 3D concept design model

III. Algorithm Design

This section explains about the conceptual designing of the algorithm for various modules of MARP autonomous control system.

A. Steering Module

Ackerman steering configuration can give us the relationship between the inner and outer angle and also the turning radius in which our system will steer. By calculating the torque required to steer wheel based on the given conditions, it provides that the hydraulic cylinder providing a torque of 400 N.m will be enough to steer the platform. The steering system algorithm is developed as shown in Fig. 4.

Fig. 4 shows that, once the engine starts, the auxiliary pump will be started and it will transmit the power on either cylinder A port or cylinder B port based on the desired steering direction as per the input sensed by position sensor. In properly working condition, the pump will keep on supplying power to steering system.

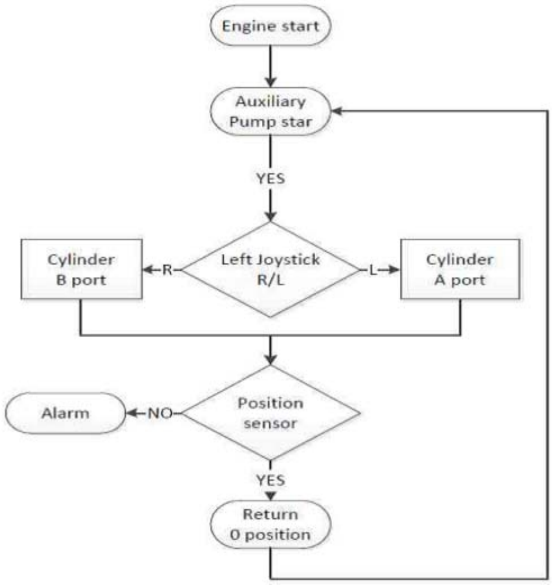

Fig. 4 Steering system flow chart

B. Driving Module

Driving module is the part that delivers all the power onto the tires to overcome the traction from the ground and consequently enhances the performance of the robotic platform. Before sketching our hydraulic system, we must know how much force and torque are necessary. For that, the calculation begins with given conditions: tire of size 15 x 30 cm, operational velocity of 5 km/h, MARP total weight of 1000 kg, static friction of 0.75, kinetic friction of 0.030, time of acceleration is 1.2 s, safety factor of 1.5. The algorithm for driving system is shown in Fig. 5.

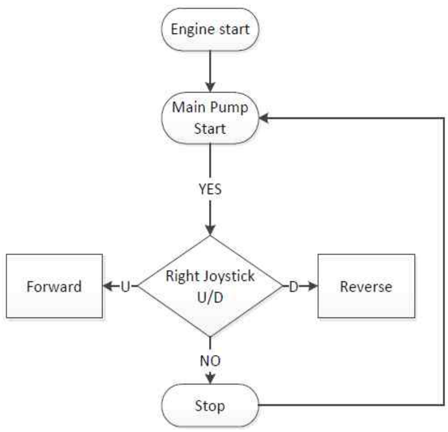

Fig. 5 Driving system flow chart

As soon as the engine starts, the pump will start giving ample power to avoid traction of the tire with the ground for driving in forward or reverse direction.

C. Machinery Module for Agricultural Operations

MARP has to perform hilling, mulching, and seeding operations for which the respective machines have been attached and are adjustable according to the field conditions. The lifting system has been attached with the frame actuated by the hydraulic cylinder to lift all the three machines. The algorithm for the operation of lifting system is shown in Fig. 6.

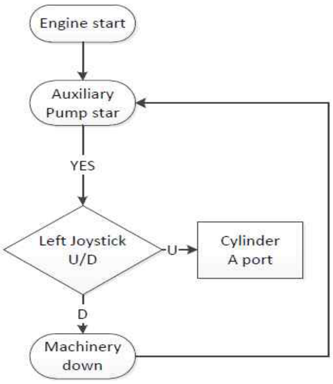

Fig. 6 Machine lifting system flow chart

D.Hydraulic System

The hydraulic system has been used broadly to deliver the power to the system. The hydraulic circuit of MARP as modelled using software is shown in Fig. 7.

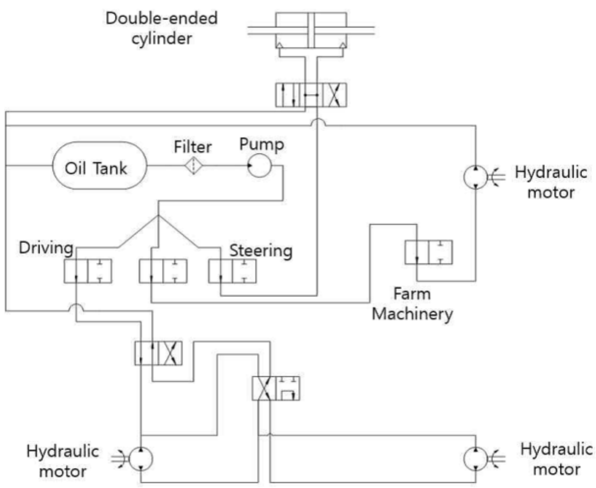

Fig. 7 Hydraulic circuit of the agricultural platform

E. Electronic System

PLC is a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic operations in order to control machines and processes [5].

In the MARP, for control system simulation, the PLC GLOFA G7M architecture, as shown in Fig. 8, is preferred over any microprocessor for the following reasons: a) Standard and simple programming languages as LD (Ladder Diagram) and SFC (Sequential Function Chart); b) Device useable in industrial and hazardous environment; c) Modular extensions available to increase inputs and outputs. The basic electronic controller elements are transmitter, receiver, controller, and the actuators.

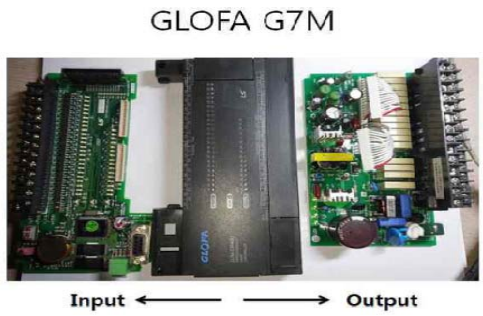

Fig. 8 GLOFA G7M

IV. Results and Discussion

A. Control System Simulation

The programming environment tool provides programming and debugging environment to PLC. The program has been developed using the ladder logic being quite sequential, simple, and favorable to run for complex operations. Methodology of steering control system is as explained in Fig. 9. The controller receives the input signals from sensors and sends the command to the hydraulic guidance module that actuates the four solenoids with an electrical signal. The solenoids command the actuation of the four proportional valves. Each of the four valves has two ways to determine the direction of the movement of the wheel. The opening of the valves releases the fluid that carries out the linear movement of the hydraulic cylinders. The coupled system of racks and pinions, connected to the hydraulic cylinders, transforms the linear motion into radial motion of the wheels.

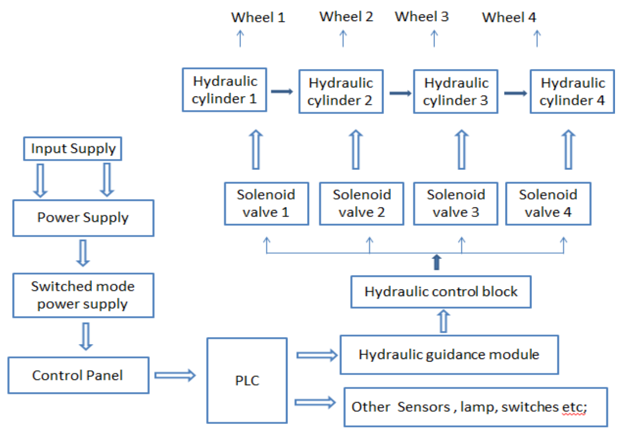

Fig. 9 Block diagram of methodology of control system for steering

Methodology for performing agricultural operations is shown in Fig. 10. The PLC used, is to control the agricultural operations based on the inputs sensed by the sensors. It basically consists of three parts: input section, output section and processing section. The sensor will provide the input signals to the input section of the PLC, and the output of the input section will be given to the processing section of the PLC. The signals are received from the ZigBee module which can be sent to PC by using RS-232 interface.

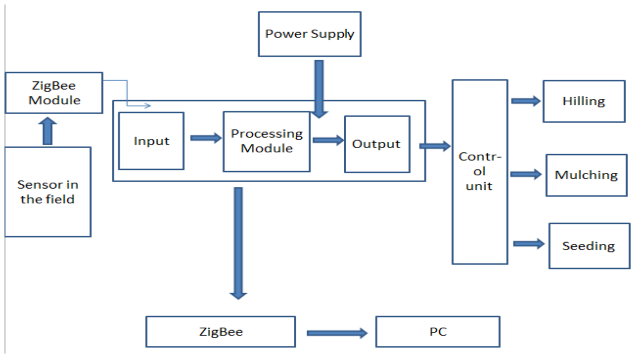

Fig. 10 Block diagram of methodology for performing agricultural operations

In hilling operation, the depth of hill is sensed by ultrasonic sensor which sends signal to ZigBee at the control house. The important task of the PLC here is to control the motor which rotates hill machine blades continuously at certain rpm and stops rotation of the hill blades as soon as the seeding machine attached at the last position stops working.

In mulching operation, the vinyl sheet is coated over the hills, which is attached at second position in the sequence of operation. This machine will start with the commutation of motor attached with hilling machine. The signal for the proper vinyl mulching over the hills is sensed by photoelectric sensors attached to the roller of the machine, which basically adjusts the position of the machine over hills, so that the vinyl is mulched accurately. Once the position is set, it will give signal to PLC, in turn, PLC turns ON the mulching machine motor. It also stops when the seeding machine stops working.

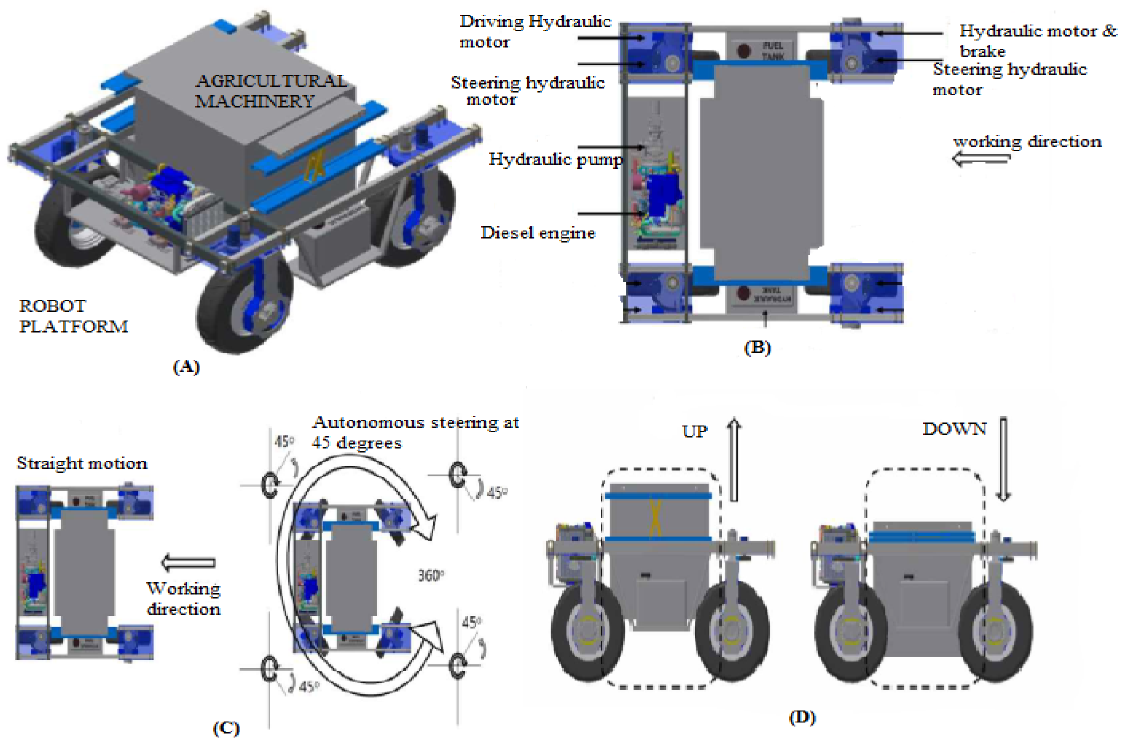

Fig. 11 (a) Machine assembly and operation concept; (b) Hydraulic system configuration concept; (c) Steering system configuration concept; (d) Concept for Lifting system for machinery

In seeding operation, the seeding machine consists of a tray over which the seeds are travelled to the cup shaped blades. The multiple blades are arranged in the several rows throughout the roller of the seeding machine. The sensor is attached with the end of the roller, near the vinyl mulching sheet so that each time when the blades comes closer to the vinyl mulch, the roller stops for a while, whose time period is fixed in PLC timer and sow the seeds in the ground. As soon as the time delay is over, roller again rotates to the next position and so on. The MARP has been developed with the reliable control system software for the complete automation of the driving and agricultural operations as shown in Fig. 11. Fig. 11 (a) is the concept design of complete MARP with attached agricultural machines in the middle of the platform. Fig. 11 (b) is the hydraulic system configuration that includes hydraulic pumps, hydraulic motor for steering and driving, and hoses for the connections according to the hydraulic circuit. Fig. 11 (c) shows the autonomous 4-wheel driving and steering (at 45-degree) system concept, and Fig. 11 (d) shows the automatic hydraulics based lifting system concept to lift and adjust of space between the operating machinery and ground in ON and OFF working condition. This concept of control system software design for autonomous driving and autonomous agricultural operations not only provides the precise autonomous control but also deals with unpredicted environment of agricultural field. It gives the future prospects to researchers to get more advanced solution based on PLC for agriculture in hilly region and outer space. MARP is in its initial stage. Further our research focus will be based on making it compatible to outer space application.

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