Design, Construction and Testing of a Microcontroller based Robotic Arm for Spray Painting

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Abstract— Robots can be used in painting operations like many other automated jobs. It can also perform welding, drilling, grinding, carrying operation, and various industrial process with the integration of proper tools with its arm. Robots are used widely in industrially developed countries to perform many operations of their industrial processes. Though the application of robots is limited in our country, the implementation has been initiated with the recent trend of moving forward to the automated industry.

In this research work, a robotic arm has been designed and constructed for painting work using a microcontroller. Here for the automation an ATMEGA8 microcontroller is focused and used. The project is divided into four parts. The first part is concerned with the hardware development of the robotic arm by all electronics components connected via the circuit design. The second part is based on software programming to operate the arm. The third part is to arrange a motor, microcontroller, and other components accompanied by the machine design. And finally is to operate a solenoid valve to control the air delivered to the spray gun to do paintwork. It also includes developing a control circuit and control program which will lead the arm to the required position where we need to paint.

Index Terms— Micro-controller-based robotic arm, painting technology, painting robots, robotic arm design, robotic arm construction, robotic arm testing, robot in painting industry, robotics, spray painting robotic arm.

1. INTRODUCTION

When it is talked about the robot, it was a science fiction of the old era and off-shoot of scientific research. There are so many developments and upgrades in preparing robots such as various sensors are added that send signals to processors that process the function commands for Robots. Robotic arms are user friendly and perform as per it is programmed and precisely as compared to other machinery maintaining equipment. Robots are developed with many advanced techniques these days with artificial intelligence control and machine learning tools. The robotic system is equipped with industry for many purposes and performs tasks that are very precise in manufacturing and measurements.

As the field of robotics is developing there is a different branch for learning and research that is known by the Technology of Robotics that deals with the design, industrial application, and research over it. The important areas of robotics are:

(a) Health Care: Advanced robotics has the ability to improve a wide variety of health care practices. Robotics like Prosthesis, Exoskeletons, Telecherics, Locomotive devices has created a powerful and positive impact in modern medical technology.

(b) Manufacturing Industry: To perform repetitive, monotonous, or intricate tasks as well as to generate maximum productivity utilizing minimum production cost robotics are using in modern industry.

(c) Agriculture: GPS-guided self-operating tractors is a revolution in modern robotic. Automated robots are also introducing in the operations like pruning, thinning, mowing and spraying.

(d) Military: To ensure safety, modern robotics like drones are using incredibly [1].

From the requirement of the industry, a robotic arm is developed that is controlled by various controllers that are programmed to perform the particular required task. This arm can move it forward, backward, rotational, or in front directions with the help of joints in the part. This is in the frame of the kinematic chain that is being controlled by controllers. With the help of a microcontroller, these three directional movements are controlled. Using a Microcontroller makes the implementation more cost-effective and simple and it’s easy to accomplish comparatively. The microcontroller uses a computer program to perform the desired operation [2].

The project work includes the design, construction, control of a microcontroller-based robotic arm.

Reasons for using a robotic arm:

The accuracy and unlimited working capacity of the robotic arm introduced it into industrial functioning especially for those tasks that humans can’t perform by their hands. It pulls up a heavy load that saves human labor. It can carry an object in the required place in a precise manner which is quite unexpected from humans. It can receive orders instantly. It is preferable for repetitive work. It can apply to mass production. It is independent of adverse weather [3].

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2. Classification of Robot

Schilling, R.J, listed that robot can have classified [5]:

1. On the basis of the coordinate system:
   a) Cylindrical robot.
   b) Spherical robot.
   c) Joined arm robot.
   d) Cartesian robot.

2. On the basis of the control method:
   a) Non-servo-controlled robots.
   b) Servo-controlled robots.
   c) Point to point servo-controlled robot.
   d) Continuous path servo-controlled robot.

Basic Elements of robotic arm:

Deb, S.R, suggested the basic elements of the (mechanical specially) robotic arm as [3]

1) Manipulator.
2) Controller.
3) Source of power.

Short descriptions of these elements are given below:

Manipulator:

This is one of the main parts of a robot that can perform a task through a mechanism. The manipulator is the basic part that handles and carries any components or equipment's as human fingers do. It can perform hazardous and monotonous tasks with tireless precisions. It can improve productivity and reduce manufacturing costs. It can perform complex jobs. It can even cope with changing conditions in the work-piece when fitted with sensors and adaptive controls.

Source of power:

Electricity and hydraulic pressure are the basic power source for robotic arms and the motion that is done with the help of DC servo and stepper motors to move the manipulator. For gripping functions, pneumatic tools are used for power purposes. [6].

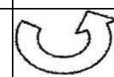
Controller:

The program is used to control its movement. It controls the power supply to the motors. If we need the movement in X-axis it will supply power to the motor which leads to X-axis and also controls the distance need to move [6].

3. Work Envelope Geometries:

The end-effectors is work as a human wrist and it is fitted on a rib. This work envelope is designed such that the locus of focus is in 3-dimensional space covered by the wrist of the robot. This characteristic made it working in all dimensions for an efficient working environment [7].

Table 1: Type of robot joints

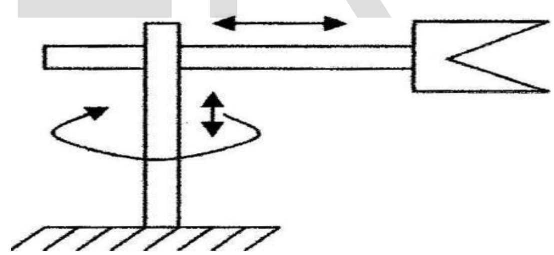
Type	Notation	Symbol	Description
Revolute	R		Rotary motion about an axis
Prismatic	P		Linear motion along an axis

R type robot joints are the most commonly used joints in robotic arms.

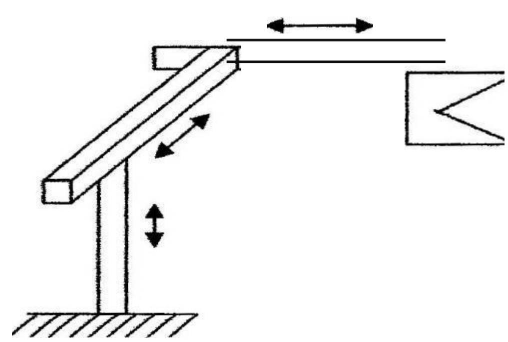
Table 2: Robot work based on major axis

Robot	Axis 1	Axis 2	Axis 3	Total revolute
Cartesian	P	P	P	0
Cylindrical	R	P	P	1
Spherical	R	R	P	2
SCARA	R	R	P	2
Articulated	R	R	R	3

Different types of the robot according to manipulator mechanism were shown in figure 1



a): Cartesian robot



(b): Cylindrical robot

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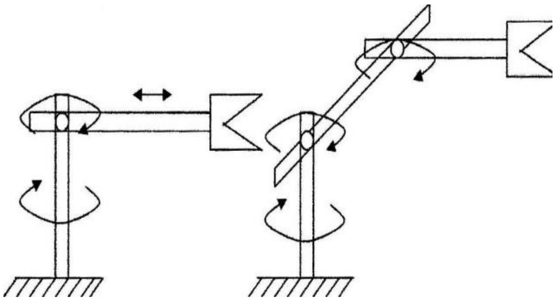

(c): Spherical robot (d): Articulated robot

Figure 1: Different types of the robot according to manipulator mechanism.

Motion control technology:

The two basic types of motion control methods are used in robots.

1. Point to point control method and

2. Continuous path control method.

The primary kind is highlight point movement, where the apparatus moves to an arrangement of discrete focuses in the workspace. The way between the focuses isn't expressly constrained by the client. Point-to-point movement is helpful for tasks, which are discrete in nature.

The other kind of movement is persistent way movement, some of the time called controlled way movement. The end effector will follow as programmed in 3-dimensional space at the required speed. The applications of the point-to-point control method are in welding, pick and drop as well as in loading –unloading whereas the continuous path control method is used where the need of spray painting, arc welding or to stick with glue. Here the end effector must follow a recommended way in three-dimensional space, and the speed of movement along the way may change.

In this project, the Cartesian manipulator was designed which has two degrees of freedom. We also implemented a rotary motion along with these two-degree motions.

Robot specifications:

Having identified how a robot system may be used in a work cell and some of the features and functions that it requires to be useful. Following the specifications that are typically used to describe commercial robots.

Rotor specifications with characteristics are its maximum speed in particular cycle timing in Kg, reach & strokes that are in mm/sec, tool orientations are measures in mm and degree of repeatability.

4. DESIGN & CONSTRUCTION

Construction of the robotic arm:

The schematic view of the manipulator was shown in figure 2. The description of various parts and manufacturing procedure was as below:

At first, the upper box of size 16 cm ×8 cm ×10 cm with a 4 mm thickness was constructed. The box was consist of two channels section and two plates.

The two plates were jointed with bolts with the channels. The channels and plates were made by casting. Then the surfaces were finished by file.

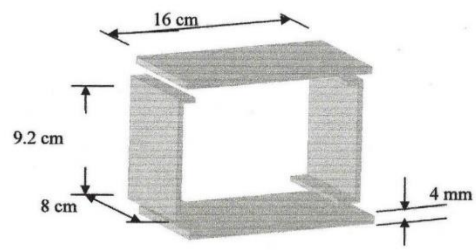

Figure 2: Schematic view of the upper box.

Then the horizontal shaft of mild steel of 6 mm diameter was made from an MS rod by turning in the lathe. In the shaft, there were collars to resist the movement of bearings and gears.

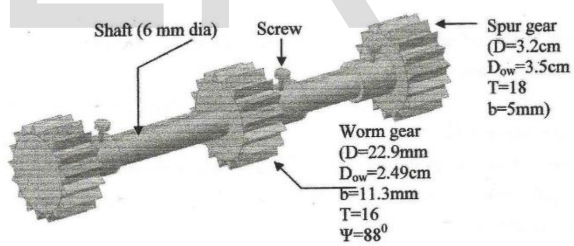

Figure 3: Schematic view of the horizontal shaft with spur and worm gear

Two spur gears and one worm gear were made. Two spur gears were placed at the two ends of the horizontal shaft of the upper box. The worm gear was placed at the middle of the shaft. Both the spur gears and the worm gear had some extended portions. In these extended portions screw is fitted to fix the gears with the shaft. Inside the box, two bearings and bearing housings are placed. The housings are placed with bolts with the box.

The vertical shaft with the worm was then made. The worn was fixed with the shaft with bolts. The shaft was fitted with the box with two bearings and bearing housings. The worm was placed in such a way that it meshed with the worm gear on the horizontal shaft.

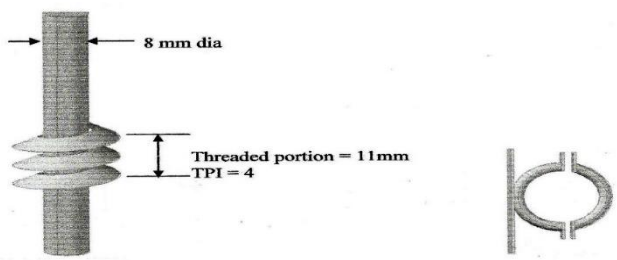

Figure 4: Schematic view of the worm and Schematic view of spray gun holder

The Spray gun holder was constructed from the GI flat bar. Two bars were bent and one bar was flat. One of the bent bars was welded with the flat bar and the other was free. The bent bars consisted of holes at their ends by which the two bent bars were jointed with nut- bolts. The holder was placed between the bent bars.

The motor was fitted on the opposite side of the box where the spray gun holder was placed. On the motor shaft and the extended portion of the vertical shaft, the pulley was placed. A rubber belt was mounted on both pulleys. When the motor shaft rotates, the pulley rotates the pulley of the vertical and then the shaft rotates. The worm rotates the worm gear. The worm gear rotates the shaft in which two spur gears were mounted.

The spur gears meshed with the racks. The upper and lower movement of the upper box maintained by the rotation of the spur gears on the racks.

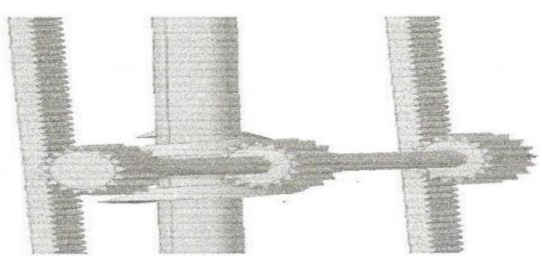

Figure 5: Schematic view of rack and gear arrangement

The racks were placed on the lower box. The lower box was also made with two channels and two flat plates.

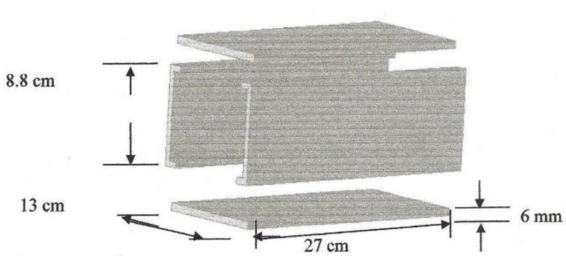

Figure 6: Schematic view of the lower box

Four reinforces were used which have threads at the two ends. These were attached to the box with bolts. Each reinforcement consists of two bearings that act as wheels.

These bearings move on the grooves of the mild steel bars. Four bars were used. Two bars on the upper portion and two bars on the lower portion of the lower box.

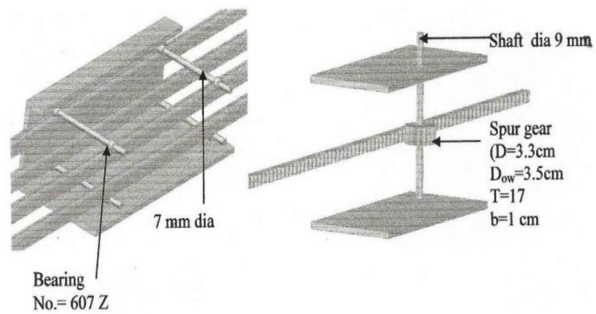

Figure 7: Reinforces and Rack and gear arrangement in the lower box

A vertical shaft consist of a spur gear was placed in the lower box. The spur gear meshes with the horizontal rack. When the shaft rotates, the spur gear rotates on the rack. As the rack and other bars that have grooves were fixed with the wood plates, the box moves on the right side and left side. Some parts were not made as like as design value. There were some causes.

Table 3: Causes for designing parts

Name of the parts	Design value	Constructed value	Cause
Spur gear in the lower box	T=35	T=17	1. Difficulty to make 35 teeth with available module 2. To reduce the cost of
Worm in worm gearing in a vertical shaft in the upper box	Pa=2mm L =2mm	Pa=6.35mm L =6.35mm	Difficult to make

5. PROGRAM AND CONTROL OF ROBOTIC ARM

It consists of two major parts

i) To make a suitable electronic circuit, this will fix the rotational direction of the motor.

ii) To develop a program, this will control the circuit by fixing its direction and duration.

Control Circuit:

Here we use C programming to give the necessary command for the automation of the robotic arm. The program is then loaded into the microcontroller and the hardware using the microcontroller according to the circuit design. The hardware is then set up with the construction according to the design along with the motor. The main task is to control the motors of the robotic arm with the hardware to perform the required operation. There are several languages available to target microcontrollers. Here in this project, the program is made using C language. Then this is converted into machine language by creating a hex file using software called AVR programming. This is a simple program where we make only six signals to go at a given time interval to secure the forward and reverse motion of the three motors.

Components of Control Circuit:

This circuit consists of:

1. 12volt Relay - 1 pcs
2. Arduino UNO - 1pcs
3. LM7805 - 1 pcs
4. LED RED - 1 pcs
5. Capacitor 1000uF, 25volt - 1pcs
6. Capacitor 10uF, 25volt - 1pcs
7. Transformer 12-0-12 volt, - 1pcs
8. Diode 1N4007 - 8 pcs
9. on/ off switch - 2 pcs
10. Plastic connector - 6 pcs
11. Vero board – 2 pcs
12. AC Cord - 1pcs
13. Heat sink - 4 pcs
14. Good wire - 2 meters
15. L298 Motor Driver

Construction of Control Circuit:

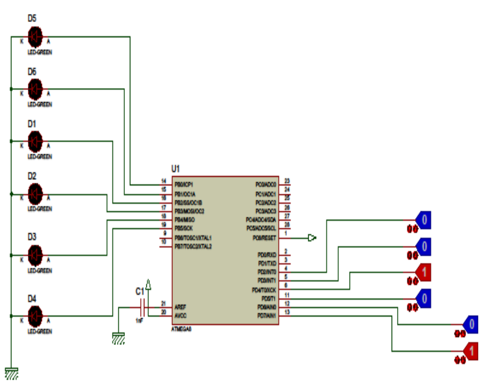

Fig. 8: Schematic diagram of the circuit

Microcontroller Program:

Microcontroller programming is generally used in robotic arms due to its compactness available on-chip controller and give befit to avoid haziness of heavy controllers prepared by hardware.

Different complexities are solved by using compilers and easy-to-change commands as per requirements of functionality due to its machine code memories.

There are two variants of programming in microcontrollers that make it easy for developer controls. There is no limit to programming and only needs to modify a few codes for upgrading the system as there are RAM and ROM that available with the coder.

Various adjustments may be available where the ROM is gotten to as an outside contraption instead of as inside memory, in any case, these are getting dynamically extraordinary in view of the no matter how you look at its availability of unassuming microcontroller engineers [3].

The main program is given below:

```
#include <Stepper.h>
const byte LimitH=A0;
const byte LimitV=A1;
const byte LimitC=A2;
const byte RelayPin=A3;
const byte PlaneSurface=A4;
const byte CircularSurface=A3;
const int stepsPerRev = 200;
const int steperSpeed = 30;
Stepper stepperH(stepsPerRev, 2,3,4,5); //Horizontal Stepper
stepperV(stepsPerRev, 6,7,8,9); //Vertical Stepper
stepperC(stepsPerRev, 10,11,12,13); //Circular
void setup()
{
pinMode(LimitH,INPUT);
pinMode(LimitV,INPUT);
pinMode(LimitC,INPUT);
pinMode(RelayPin,INPUT); pinMode(PlaneSurface,INPUT);
pinMode(CircularSurface,INPUT);
//pull up digitalWrite(LimitH,HIGH);
digitalWrite(LimitV,HIGH); digitalWrite(LimitC,HIGH);
digitalWrite(PlaneSurface,HIGH);
digitalWrite(CircularSurface,HIGH);
stepperCir.setSpeed(steperSpeed);
stepperVer.setSpeed(steperSpeed);
stepperHor.setSpeed(steperSpeed);
}
void loop()
{
if(!digitalRead(CircularSurface) ||
!digitalRead(PlaneSurface))
digitalWrite(RelayPin,HIGH);
else digitalWrite(RelayPin,LOW);
if(!digitalRead(CircularSurface))
{
```

```
stepperCir.step(100); stepperVer.step(100); stepperCir.step(-
100); stepperVer.step(100);
}
if(!digitalRead(PlaneSurface))
{
stepperHor.step(-800); stepperVer.step(100);
stepperHor.step(800); stepperVer.step(100);
}
}
```

Control Program:

A control program is necessary to control the movement of the box in the X, Y-axis and in rotational movement in a close loop i.e. each motor will rotate in both directions, so it helps forward and backward movement of the object using just one motor. Here program should control the following feature

a) Which motor will rotate i.e. will it move in the X-axis or Y-axis.

b) Giving the rotational direction of the motor i.e. clockwise or anticlockwise.

c) Distance control of the motor i.e. how long the motor will rotate to reach its desired position.

For the accomplishment of these features, we develop a program that will take three inputs. These are

a) "+" or "-"which will define the rotational direction (clockwise or anticlockwise)

b) "M1" or "M2" or "M3" which will define which motor will rotate.

c) Distance will define how far the box or base will go or rotate.

In our program, we have two types of program input. These are

Command control:

In this type of control system, we input rotational direction (clockwise & anticlockwise), the direction of motion (X-axis & Y-axis) & distance (how far the object will go).

Manual control:

This is an advanced type of control system which is specially designed for this robotic bed. Here we use switches on the microcontroller circuit board to operate manually. The individual switches lead the respective motor to run in the required direction & run to how long does it go. So with this program, we can control a complete and satisfactory movement of the bed.

Working Principle of the control circuit:

Here microcontroller is loaded with the necessary program that provides six signals at the required time interval. Then the circuit is set by using necessary components. Then from the microcontroller circuit, six output lines are generated and connected in the transistor's baseline. The transistor is occupied with six 6V relays. When there comes a signal from the microcontroller after switching the AC power line then the 6V relay is switched on and consequently the 220V AC coil relay which is connected with this 6V relay becomes switched on and the first motor start to run. As the time interval is assigned in the program this process continues and the required work is performed.

Hardware Development of Control Circuit:

After accomplished, the program is simulated by using Proteus software to check whether it is correct and valid. Then the program is loaded in the ATmega microcontroller by using AVR software. We made the circuit board then along with a microcontroller. The circuit is checked by using LED lights to check whether it works perfectly by connecting the power line. The six 6V relays are connected with the output line from the microcontroller. These relays are further connected with the 220V AC coil relays.

Then the circuit is set up in the robotic bed where the six 220V AC coil relays are connected with the three motors according to the forward and reverse considerations through the 8 pin octal socket. The two motors get power directly from the AC power supply and one is from the DC power supply which switched by the microcontroller signal. It is made in such a way that when a signal comes at the relays respectively one motor is on whether other motors are off. And this running motor is active for the time interval given in the program of the microcontroller. Also, the first three signals are used to switch the three motors to perform the forward work and the last three signals are used to make the motor switch respectively for the reverse work.

The design of the construction:

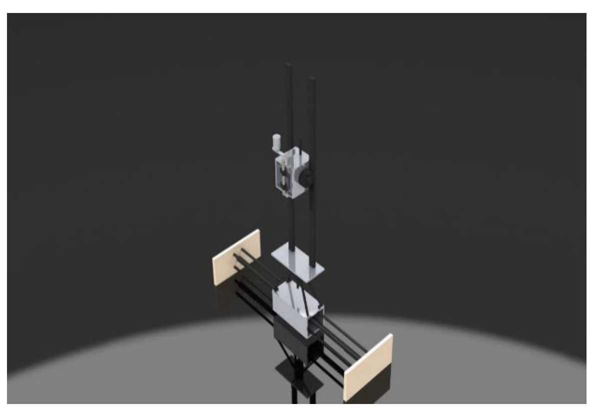

Figure 9: Rendered view of the robotic arm

The photographic view of the robotic arm after completion of construction:

Figure 10: Photographic view of the robotic arm

6. RESULT AND DISCUSSION

Result:

After complicating the design and experimental setup, the spray paint was tested and the following results were found.

a) The construction of our robotic arm is completed.
b) The control circuit is developed for operation.
c) The program is developed.
d) The manipulator can get commands from the computer.
e) It can go to proper positions.
f) After the operation, it can return to its previous position.
g) It can control the air coming from the compressor by a solenoid valve and can spray the paint.
h) The spray painting is done successfully.

Discussion:

In this project work, several types of difficulties aroused. The first problem aroused, during the construction of the worm and worm gear. The designed dimensions of the worm and worm gear were so complicated that it was very difficult to construct. So, suitable dimensions were chosen. Before construction, the chosen dimensions were verified. The upper and lower boxes were constructed with aluminum by casting. As the surfaces were not so finished, so it was very difficult and time-consuming to finish the surfaces. Another problem was aroused in the time of choosing gear to make a couple with the stepper motor. At last, we choose bevel gear to move the arm to the required position. And we have faced a lot of problems to couple the gear with the motor.

7. CONCLUSION AND FUTURE RECOMMENDATION

Conclusion:

The project can be concluded as follows:

i) The robotic arm was designed and constructed for the purpose of spray painting.
ii) The program was developed.
iii) The circuit was designed.
iv) The spray painting was tested.
v) The robotic arm can move in the X, Y-axis and can rotate along an axis satisfactorily.

Future Recommendation:

The robotic arm was designed to move in two dimensions along with 360 rotary motion, which are X, Y-axis, and ɵ degree. It was designed for the purpose of spray painting in the required direction using a microcontroller. But due to being short of the power output of motors and very expensive construction, it can carry any object not more than 10 kg paint in the required direction. Further, it can be used in drilling grinding, welding operation with proper attachment on the bed. Alignments of various parts are very important for proper movement with accuracy. To get the accuracy we have to collect data from the output and analysis it for the proper feedback system. In this manner, we can get a true close loop operation. Separate research work is necessary for the accomplishment of these features.

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