International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

EEZYBOT MK1 ROBOTIC MANIPULATOR ARM

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ABSTRACT

Small robotic arms are widely used in education and in light automation to demonstrate how mechanisms, actuators, sensors and control software work together. The EEZYbot MK1 is an open-source, 3D-printable desktop manipulator designed by daGHIZmo in the form of a compact palletising arm. It has three degrees of freedom, a rotating base, a main arm and a forearm, and uses a parallel four-bar linkage so that the forearm and gripper keep their orientation while the arm moves. This project builds and studies the EEZYbot MK1 as a low-cost manipulator for pick-and-place tasks and examines its kinematics, structural strength and positioning performance.

The arm was assembled from the published part geometry, which was checked and adapted in SolidWorks, and the parts were printed in PLA on a fused deposition printer with a 0.2 mm layer height and 30 percent infill. Three MG995 servos drive the base, the main arm and the forearm, and an MG90S micro servo operates the claw gripper. An Arduino Uno generates the motion commands and sends them to a PCA9685 16-channel servo driver powered by a separate 5 V, 5 A supply. A serial command interface allows a target point in Cartesian coordinates to be entered from a computer, and the controller converts it into joint angles.

Forward and inverse kinematics were derived for the arm. Because the four-bar linkage references the forearm angle to the base, the shoulder servo sets the absolute angle of the main arm and the elbow servo sets the absolute angle of the forearm, which simplifies the inverse solution to a planar two-link problem combined with base rotation. With link lengths of 135 mm and 147 mm the computed workspace extends from 75 mm to 245 mm in horizontal reach and from minus 40 mm to 210 mm in height relative to the base plate over a base rotation of 180 degrees. Static finite element analysis of the printed main arm and forearm in ANSYS gave a maximum von Mises stress of 14.8 MPa under the rated payload with a dynamic factor of 2, a factor of safety of 3.4.

The assembled arm was tested in pick-and-place trials with small blocks moved between marked positions on a grid. Over 30 repeated cycles to the same point, the repeatability measured with a dial gauge was within plus or minus 1.2 mm. The mean positioning error over 20 grid points fell from 7.9 mm to 3.6 mm after servo offset calibration. The arm handled a rated payload of 150 g, completed 47 out of 50 pick-and-place trials successfully, a success rate of 94 percent, and took an average of 6.8 seconds per cycle.

Received: 05-10-2026 | Accepted: 08-11-2026 | Published: 17-11-2026

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I. INTRODUCTION

Industrial robots perform welding, painting, machine tending, assembly and palletising in modern factories, but their cost and size make them unsuitable for most classrooms and small workshops. Low-cost desktop manipulators fill this gap. They allow students and small enterprises to learn how a robot arm is designed, how its joints are driven, how a position in space is converted into joint angles and how accuracy is limited by the mechanism and the actuators. Advances in 3D printing and in inexpensive microcontrollers have made it possible to build such arms with parts that cost very little.

The EEZYbot MK1, released as an open design by daGHIZmo, is one of the best-known 3D-printable arms. It is modelled on industrial palletising robots, which use parallel linkages so that the end effector stays level while the arm reaches forward, up and down. The arm has a base that rotates about a vertical axis, a main arm and a forearm driven through a four-bar linkage, and a simple claw gripper. All structural parts can be printed in PLA, and the arm is driven by standard hobby servos, so it is well suited to a mechanical engineering project that combines design, manufacturing and control.

Building such an arm raises several engineering questions. The relationship between servo angles and the gripper position must be derived from the geometry of the linkage, and the inverse relationship must be solved so that a user can command a point rather than individual angles. The printed links must be strong and stiff enough to carry the payload without excessive deflection, and the servos must provide enough torque at the extreme positions of the workspace. The positioning performance of the finished arm must be measured, since hobby servos have dead bands, backlash and offsets that affect accuracy.

This project addresses these questions for the EEZYbot MK1. The parts are checked and adapted in CAD, printed in PLA and assembled with MG995 and MG90S servos, an Arduino Uno and a PCA9685 servo driver. The forward and inverse kinematics of the four-bar arm are derived and used to plot the workspace and to control the arm. The printed links are analysed for static strength in ANSYS, and the complete arm is tested for repeatability, accuracy, payload and pick-and-place success. The aim is to document a reliable, low-cost manipulator that can be reproduced and used for teaching and light automation tasks.

II. LITERATURE SURVEY

Research on low-cost robotic manipulators has grown with the availability of desktop 3D printers and open-source electronics. Educational studies report that building and programming a small arm helps students connect the theory of kinematics and dynamics with practical issues such as tolerance, friction and actuator limits. Several open designs have been published, ranging from simple arms with serial joints driven directly by servos to more elaborate arms using belts, gears or stepper motors. Comparisons in the literature show that directly driven servo arms are the cheapest and simplest to build, while stepper and belt designs offer higher accuracy at greater cost and complexity. Arms that use parallel linkages, such as palletising-style designs,

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are described as a useful compromise because the linkage reduces the load on the elbow actuator and keeps the end effector level without an extra wrist joint.

The kinematics of serial and parallel-link manipulators are treated in standard robotics texts using the Denavit-Hartenberg convention and geometric methods. For planar two-link arms the inverse solution can be found in closed form by the law of cosines, giving two solutions for elbow up and elbow down configurations. Studies on palletising robots explain that a parallelogram or four-bar linkage changes this picture, since the actuator that drives the forearm is mounted at the base and the forearm angle becomes an absolute rather than a relative angle. This decoupling simplifies both the inverse kinematics and the control of the end effector orientation. Workspace analysis by sampling joint angles within their limits and plotting the reachable points is widely used to show the usable region of such arms and the effect of joint limits and linkage interference.

Material and structural studies on 3D-printed parts provide guidance for the design of printed robot links. Experimental work on PLA printed by fused deposition shows that tensile strength depends strongly on raster orientation, layer height, infill density and number of perimeters, with parts loaded across the layers being considerably weaker than those loaded along them. Typical reported tensile strengths for PLA lie in the range of 40 to 60 MPa with an elastic modulus of about 3 to 3.5 GPa. Finite element analysis of printed components, using isotropic properties reduced to account for infill and layer bonding, has been used to estimate stress and deflection before printing. Authors recommend generous fillets around pin holes, adequate wall thickness and print orientation that places the main bending stresses along the filament direction.

Actuation and control of hobby-servo arms have been studied with respect to accuracy and repeatability. Standard analogue and digital servos accept a pulse-width command and contain an internal potentiometer for position feedback, but they show dead bands of a few microseconds, gear backlash and offsets between the commanded and actual angle. Studies report that calibrating each servo against a protractor or a reference fixture and storing offset values in the controller can reduce positioning errors substantially. The use of dedicated PWM driver boards with an external power supply is recommended, because driving several high-torque servos from a microcontroller board alone can cause voltage drops, jitter and resets. Smooth interpolation of commanded angles is also reported to reduce overshoot and vibration in light printed arms.

Evaluation methods for small manipulators generally follow the ideas of industrial robot performance testing, with simplified equipment. Reported tests include pose repeatability measured by returning repeatedly to one point and recording the scatter with a dial gauge or camera, pose accuracy measured against a grid of known positions, maximum payload at full reach, cycle time and the success rate of pick-and-place tasks. Published results for servo-driven desktop arms show repeatability in the range of about one to a few millimetres and payloads of a few hundred grams. The present project builds on these studies by combining CAD checking, PLA printing, kinematic modelling, finite element verification and systematic performance testing for the EEZYbot MK1 arm.

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III. SYSTEM ANALYSIS

The EEZYbot MK1 is a three degree of freedom manipulator with a base rotation joint, a shoulder joint driving the main arm and an elbow drive acting on the forearm through a four-bar linkage, plus a claw gripper. The main arm is 135 mm long, the forearm 147 mm, and the shoulder axis is 95 mm above the base plate, which stands on a 50 mm pedestal so that the gripper can reach slightly below it. Because the forearm drive link is referenced to the base, the shoulder servo sets the absolute main arm angle and the elbow servo sets the absolute forearm angle, while a second parallel link keeps the gripper level. The system needs a way to convert a desired gripper point into three servo angles, enough servo torque to hold a 150 g payload at full reach, printed links strong enough for this load, and a controller that moves the servos smoothly. The Arduino Uno computes inverse kinematics, the PCA9685 driver generates the PWM signals for three MG995 servos and one MG90S, and the arm is evaluated for repeatability, accuracy, payload and pick-and-place success.

Existing System

In conventional practice, simple pick-and-place operations in laboratories and small workshops are either done by hand or by industrial robot arms that cost several lakh rupees and require trained staff, guarded cells and special power supplies. Such robots are rarely available to undergraduate students, who therefore learn manipulator kinematics only from textbooks and numerical exercises. Many low-cost educational arms that are available commercially are sold as closed kits with fixed software, so the student cannot see or change the kinematic model, and their links are often thin acrylic plates that flex under load. Hobby builds of printed arms usually drive each servo directly by entering angles by trial and error, without a kinematic model, structural check or calibration, so the gripper rarely reaches the intended point and the arm drifts when loaded. Testing of accuracy and repeatability is seldom carried out, and the performance of such arms remains undocumented.

Disadvantages of Existing System

- Industrial robot arms are too costly for most classrooms and small workshops.
- Closed educational kits hide the kinematic model and control software.
- Thin acrylic links bend noticeably under even small payloads.
- Servo angles are often set by trial and error instead of inverse kinematics.
- Printed parts are seldom checked for stress and deflection before use.
- Servos powered from the microcontroller board cause jitter and resets.
- Servo offsets and dead bands are not calibrated, reducing accuracy.
- Repeatability, accuracy and payload are rarely measured or recorded.
- Direct serial arms need an extra wrist joint to keep the gripper level.
- Students get little hands-on experience linking design, manufacture and control.

Proposed System

The proposed system is a complete, documented build of the EEZYbot MK1 palletising-style arm with a kinematic controller and measured performance. The

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published part geometry is checked in SolidWorks for clearances at the pin joints and servo horns, and the main arm and forearm are given larger fillets around the pin holes. All parts are printed in PLA with a 0.2 mm layer height, 30 percent infill and three perimeters, oriented so that bending stresses act along the filament. Three MG995 servos drive the base, shoulder and elbow, and an MG90S operates the claw. An Arduino Uno receives target coordinates over a serial link, solves the inverse kinematics of the four-bar arm in closed form, applies per-servo calibration offsets and joint limits, and interpolates the motion before sending commands to a PCA9685 PWM driver powered by an independent 5 V, 5 A supply. The links are verified by static FEA in ANSYS, and the arm is evaluated through repeatability, accuracy, payload and pick-and-place trials.

Advantages of Proposed System

- The arm is built from inexpensive PLA parts and standard hobby servos.
- The four-bar linkage keeps the gripper level without an extra wrist servo.
- Closed-form inverse kinematics lets the user command a point instead of angles.
- The workspace is mapped in advance, so unreachable targets are rejected.
- Printed links are checked by FEA before printing and loading.
- A separate servo driver and supply remove jitter and controller resets.
- Per-servo calibration offsets reduce the mean positioning error.
- Repeatability, accuracy, payload and cycle time are measured and recorded.
- Open design files and code allow the arm to be reproduced and modified.
- The project links mechanism design, manufacturing and control in one system.

IV. METHODOLOGY

The work followed a sequence of design, manufacture, modelling and testing steps. First, the EEZYbot MK1 part files were imported into SolidWorks, assembled with mates and checked for interference over the full range of joint motion, and the pin hole regions of the main arm and forearm were reinforced. Second, the parts were printed in PLA, about 210 g of filament over 18 hours, and assembled with M3 and M4 pins, bearings for the base and the four servos. Third, the forward kinematics were written from the link geometry, giving the gripper position from the base angle and the absolute shoulder and forearm angles, and the inverse kinematics were solved with the base angle from atan2 and the arm angles from the law of cosines in the vertical plane. Fourth, the workspace was plotted by sampling joint angles within their limits. Fifth, static FEA of the links under 150 g payload with a dynamic factor of 2 was carried out in ANSYS. Finally, the servos were calibrated and repeatability, accuracy, payload and pick-and-place trials were conducted.

SYSTEM ARCHITECTURE

The architecture of the system is a mechatronic chain from the user command to the gripper, with a calibration and feedback path. The Command Layer is a serial terminal on a computer through which the operator enters a target point in x, y and z coordinates or selects a stored pick-and-place sequence. The Control Layer is the Arduino Uno, which runs the workspace check, the closed-form inverse kinematics

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solver, the calibration table of servo offsets and joint limits, and a trajectory interpolator that divides each move into small steps. The Drive Layer is the PCA9685 16-channel PWM driver with its own 5 V, 5 A supply, which generates the pulse signals for the servos. The Actuation Layer consists of the three MG995 servos for base, shoulder and elbow and the MG90S gripper servo. The Mechanism Layer is the printed PLA structure, with the rotating base, main arm, forearm, four-bar drive link and parallel link that keeps the claw level. Measured positions from dial gauge and grid trials are fed back to update the calibration table.

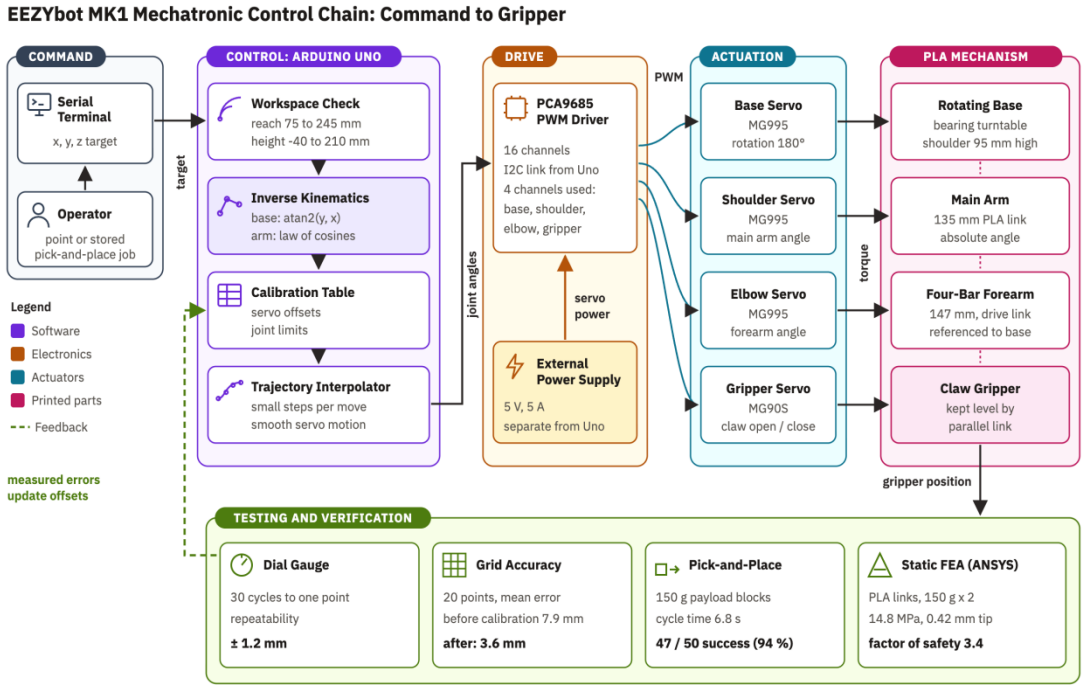


Fig. 1 System Architecture

V. RESULT AND OUTPUT

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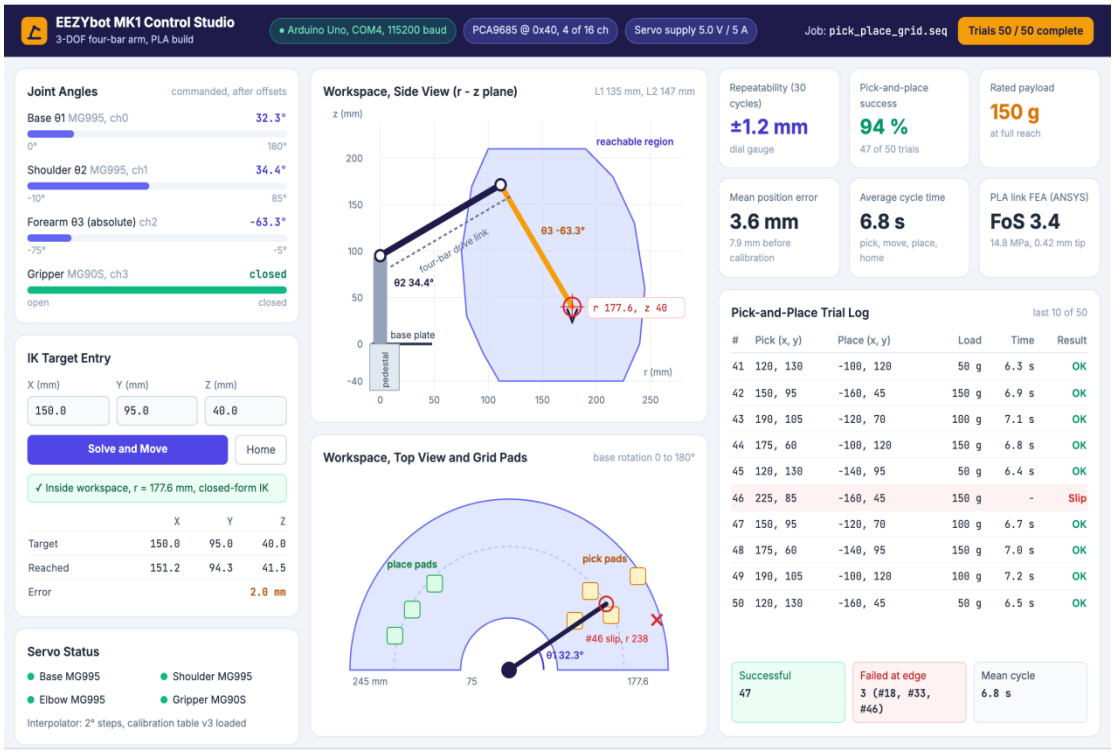


Fig. 2 Result and Output Screen

VI. CONCLUSION

This project built and studied the EEZYbot MK1, an open-source 3D-printed palletising-style robotic arm, as a low-cost manipulator for light pick-and-place work. The parts were checked and reinforced in SolidWorks, printed in PLA and assembled with three MG995 servos, an MG90S gripper servo, an Arduino Uno and a PCA9685 servo driver on a separate supply. The finished arm weighs about 520 g including servos and can be reproduced with commonly available equipment.

The kinematic study showed that the four-bar linkage makes the shoulder and forearm servo angles absolute angles, which reduces the inverse kinematics to a closed-form planar solution combined with base rotation. With link lengths of 135 mm and 147 mm the workspace covers a horizontal reach of 75 mm to 245 mm and a height range of minus 40 mm to 210 mm relative to the base plate over 180 degrees of base rotation, and the controller rejects targets outside this region. Static FEA of the PLA links under 150 g payload with a dynamic factor of 2 gave a maximum stress of 14.8 MPa, a factor of safety of 3.4 and a tip deflection of 0.42 mm.

Performance tests confirmed that the arm is suitable for its intended tasks. Repeatability over 30 cycles was within plus or minus 1.2 mm, and the mean positioning error over 20 grid points dropped from 7.9 mm to 3.6 mm after servo calibration. The arm carried a rated payload of 150 g, completed 47 of 50 pick-and-place trials, a success rate of 94 percent, and had an average cycle time of 6.8 seconds. The three failures occurred at the edge of the reach, where servo torque margin and link deflection were greatest.

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The remaining errors come mainly from servo dead band, gear backlash and the absence of external position feedback. Future work can add magnetic encoders at the joints for closed-loop control, cubic trajectory planning for smoother motion, a camera with simple colour detection to locate objects automatically, and printing of the main links in PETG or carbon-filled nylon to raise the payload. These improvements would make the arm a more capable platform for teaching robotics and for small automation tasks.

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