Mechatronic Bench Press System

Introduction

The bench press is a fundamental exercise in strength training, widely utilized for developing upper body musculature. Average bench press weight for male lifters in the UK is 98 kg (1RM); female lifters typically lift 51 kg (1RM) [1]. With 10.7 million gym members, the UK's fitness sector has grown significantly, showing a 14% growth rate. Growing public interest in exercise and health is reflected in this expansion. This report explores the design and implementation of an advanced bench press system aimed at enhancing user engagement and performance tracking. The system aims to give real-time feedback by combining accurate force measurement and displacement monitoring technologies, which will enhance user experience and encourage regular gym usage.

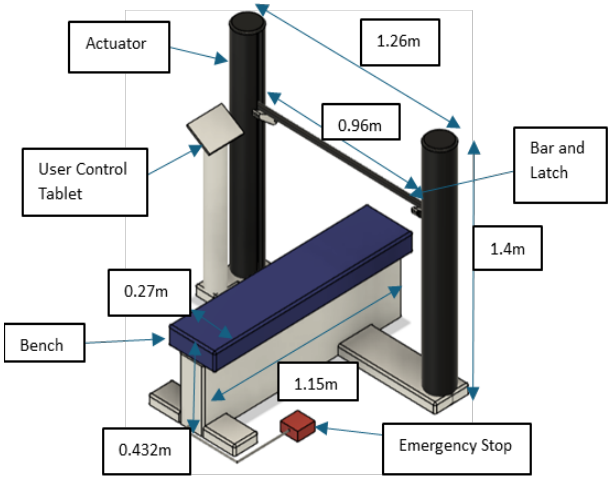
Key Parameters for Outline Design

A load capacity of up to 250 kg to accommodate advanced users, a digital user interface for personalising training regimens and offering performance feedback, and high precision for precise force and motion measurement to guarantee safety and efficacy are the three main parameters identified in the outline design. For repeated gym use, the system also needs sturdy mechanical and electrical parts, as well as a dependable power source to ensure that the actuators and sensors run continuously.

To generate personalised training regimens and ensure that workout plans are based on key factors, the system must be able to record and analyse user data (high priority). It must replace the need for manual weight adjustments by using actuators to simulate load and mimic the operation of fixed weights (high priority). Furthermore, choosing the right sensors and actuators is essential to successfully fulfilling the fundamental sensing and actuation requirements (high priority) [2,5,4].

Design Parameter	Description/Why?
Dimensions of a bench press	Should match the dimensions of a conventional bench press
User Interface	Scan gym membership card to set bench press to your memorized regime (bench press height, fitness regime etc.)
Aesthetics	Should look like a regular bench press to encourage people to use it (not too different from your regular machines so less overwhelming to use)
Data collection	Request your data for the session after it’s complete (email), you can then send it off to a personal trainer if you want
Materials	Should be firm and easy to clean (sweat), yet still comfortable enough to use (leatherette)

Basic Mechanical Arrangement



The system incorporates:

The system is secure while in use thanks to its sturdy steel main frame, which can support up to 300 kg. Under the bar, a 150 kg capacity Loadstar RSB2 compression load cell is positioned to provide precise force readings [5,6,10]. Along the vertical guides, Hall effect sensors—such as the McLaren applied linear model—are incorporated for accurate, non-contact displacement monitoring, improving durability. The barbell's motion is guided by linear ball bearings, which reduce wear and friction over time [7,8,9].

The system has movable hand grip and seat position supports that can be adjusted to suit different grip widths and heights to suit user preferences. Long-lasting dependability in gym settings is ensured by protective polycarbonate enclosures that shield the electrical components from dust, perspiration, and unintentional damage.

Actuator

An electric linear actuator has been selected as it can provide accurate, dependable, and long-lasting motion in demanding gym environments. Furthermore, due to its enclosed design, the actuator ensures long-term dependability and hygiene in high-use environments by shielding internal components from contaminants like sweat, water, and cleaning fluids [3,4].

The two vertical cylinders from the arrangement diagram will be occupied by four screw-driven linear actuators in our mechatronic bench press system (2 on each side). To control the vertical motion of the bench press bar and maintain stability while supporting a maximum weight of 300 kg [2], these actuators are essential. With a length of about 1.26 meters, each actuator fits perfectly inside the structure and works in tandem to distribute the load uniformly. The precise control and responsiveness that these actuators provide through coordinated operation guarantee the system's safety and seamless operation while the user is operating it.

Specification	Value	Comments
Actuator Type	Screw Driven Linear Actuator	High precision and load capacity, suitable for controlled and accurate linear motion.
Maximum Stroke Length	1000mm	Adequate for the desired range of motion in the bench press system.
Maximum Speed	0.65m/s	Usually limited speed; would manufacture a one off or implement a pulley system
Max Load Capacity	80kg	Sufficient for lighter-weight applications but may limit heavy-duty usage.
Drive Mechanism	Ball Screw	Ensures smooth, precise motion with high load-carrying capacity.
Motor Type	Electric Servo Motor	Allows fine control of speed, position, and force.
Power Requirements	24V DC	Compatible with standard industrial power supplies.
Ingress Protection	IP65	Dust-tight and protected against water, suitable for gym environments.
Positioning Accuracy	± 0.01 mm	High precision, ensuring repeatable motion ideal for controlled applications.
Operating Temperature	-10°C to +40°C	Suitable for standard industrial environments.
Weight	15kg	Easy to integrate into the bench press frame.
Material	High grade steel	Durable and resistant to corrosion.
Actuation Type	Linear motion	Directly translates rotary motor input into linear output.
Lifecycle	>10,000 cycles	High reliability for prolonged usage in industrial and fitness applications.

Sensors

1.Force Sensor – Compression Load Cell

The force exerted on the bench press bar is measured by the compression load cell. It functions by detecting deformation brought on by the applied load using strain gauges that are fastened to its structure. A Wheatstone bridge circuit transforms the strain gauges' resistance, which is altered by the deformation, into a readable voltage. Accurate load monitoring is made possible by the output signal's direct proportionality to the applied force [6,10]. Reliability is ensured for vigorous gym use by the sensor's robustness and ability to handle loads up to 300 kg.

Specification	Value
Capacity Range	150kg
Accuracy	≤ ±0.03% of Full Scale
Sensitivity	2.0 ± 0.1 mV/V
Zero Output	±1% of Full Scale
Operating Temperature	-20℃ to + 60℃
Input Impedance (Value from Similar sensors)	380 ± 10Ω
Output Impedance (Value from Similar sensors)	350 ± 3Ω
Material	Stainless Steel
Ingress Protection	IP65 (protection from dust and sweat in gym environments)
Dimensions	35mm (diameter) and 12.7mm (height)

Inside the vertical cylinders, there are two integrated compression load cells, one on each side of the bar. To provide precise and real-time feedback, these load cells oversee precisely measuring the force used during the exercise. The load cells, which are positioned directly beneath the ends of the bar, evenly distribute the weight, improving the safety and dependability of the system. To ensure durability under heavy loads, each load cell can handle up to 150% of its rated capacity [5]. Their positioning inside the cylinders shields them from harm while preserving precise force measurement to enable safety features and performance monitoring [5,6].

2.Hall Effect Displacement Sensor

A crucial part of the mechatronic bench press system that allows for accurate displacement measurement is the linear Hall effect sensor. It works by using the Hall effect, which states that when a conductor is exposed to a magnetic field, a voltage is produced perpendicular to the current flow [7]. The sensor provides precise, non-contact position sensing by identifying changes in the magnetic field created by a magnet fastened to the moving barbell. Changes in the strength of the magnetic field as the barbell moves are translated into electrical signals, which enables the system to precisely track repetitions and monitor motion [8]. This sensor has several benefits, including a small size for easy system integration, non-contact operation for longevity and wear resistance, and high precision for identifying even slight positional changes [7,8].

A magnet is fastened to the barbell in the bench press system, and two linear Hall effect sensors are placed at the bench's level and the bar's idle position, respectively. The sensors pick up on variations in the magnetic field as the barbell rises and falls during a workout. Both sensors' combined output signals are used to track repetitions, monitor displacement, and give the user feedback on their form [7]. With its dual-sensor configuration, the system is guaranteed to precisely track the entire range of motion, providing accuracy and dependability when tracking exercise performance.

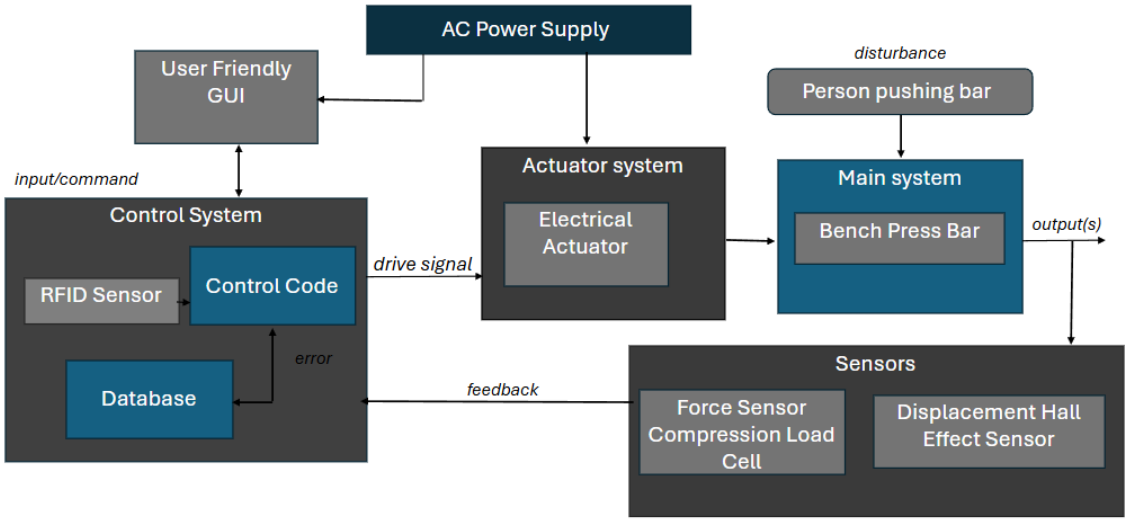
Specification	**Value**
Type of Sensor	Linear Hall Effect Sensor
Measurement Range	29.4mm displacement
Sensitivity	2.5 mV/Gauss (minimum)
Accuracy	±1% of Full Scale
Resolution	0.01 mm
Operating Voltage	8.5 V DC
Output Type	Analog Output 0.1V and 4.9V
Operating Temperature Range (Value from similar sensors)	-40°C to +125°C
Mounting Configuration	Head on to the magnet, maintaining a fixed gap
Durability	Resistant to mechanical wear due to non-contact operation

3.RFID reader

Specification	Value
Operating Frequency	13.65 MHz
Protocols Supported	ISO/IEC 14443 Type A
Read/Write Range	1-5 cm
Interface	SPI (Serial Peripheral Interface)
Power Supply	3.3V
Current Consumption	13-26mA (active), 10µA (standby)
Operating Temperature Range	-20°C to +70°C
Data Transfer Rate	Up to 848 kbps

For a smooth and customised exercise experience, the RFID reader identifies users and stores information about their prior sessions in the system's database. To identify nearby gym cards, the RFID reader first emits an electromagnetic field. A unique user ID is transmitted back to the reader by the gym card's embedded tag in response to the card entering this field. After gathering this information, the reader transmits it to the control system, which interprets it to retrieve the user's exercise history and modify the session as necessary [9]. The system can offer customised training programs while keeping precise records of each user's progress thanks to this effective and user-friendly mechanism.

Control Scheme Structure



The mechatronic bench press system's control scheme combines cutting-edge parts to provide accuracy, safety, and a smooth user experience. Users are authenticated and their customised exercise data is retrieved from the database using an RFID sensor and an intuitive graphical user interface. The actuator system, which uses an electrical actuator to power the bench press bar, is controlled by this data. Real-time feedback on load and motion is provided by sensors, such as linear Hall effect sensors and a compression load cell, which enables the system to make quick adjustments. By tracking bar displacement, keeping an eye on user-applied force, and taking into consideration outside variables like manual force on the bar, this integrated design guarantees seamless operation while preserving durability and safety [5,7,8].

Three essential feedback loops are used by the system to guarantee accurate and secure operation. By using the compression load cell to measure user-applied force, the Force Feedback Loop compares it to the limits of the training regime and modifies the actuator force as necessary. To guarantee controlled motion and appropriate safety stops, the Position Feedback Loop uses Hall effect sensors to measure bar displacement and compares it with pre-established motion profiles. The Safety Loop keeps an eye out for overloads or emergencies, and if any are found, the actuator system instantly stops working. The system guarantees seamless operation, accurate repetition tracking, and prompt error handling for a safe and effective workout experience through a structured control process that includes user authentication via RFID and GUI as well as dynamic force and position adjustments during workouts.

Conclusion

A strong and useful design for the mechatronic bench press system is presented in this report, taking into account important specifications and implementing changes in response to comments. Before prototyping, the design is validated through extensive testing and simulation. The system promises to provide an enhanced and secure gym experience by utilising cutting-edge sensing and actuation technologies.

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