Project Idea Description: Modular, Sustainable, and Contextually Appropriate Prosthetic Hand Platform

1. Contextual Problem Statement and Justification

The need for an affordable, high-functioning upper limb prosthesis in India is severe and critically underserved. Epidemiological data confirms that the target demographic is predominantly young, economically impoverished, rural males engaged in manual and agricultural labor, where trauma from machinery is the leading cause of amputation (70.3%). Current solutions fail because they are either economically unattainable (myoelectric models at 90,000 Rupees to 42 lakh Rupees) or functionally inadequate or uncomfortable (body-powered devices). The high cost and complexity of commercial prostheses, coupled with their sensitivity to the dust, moisture, and mechanical stress of the typical rural environment, lead to alarmingly low adoption (40% fitment rate) and high abandonment rates. Our solution addresses this by defining **functionality** not merely as dexterity, but as sustained **durability and local maintainability** within the user's harsh life context. The goal is to break the vicious cycle of poverty and disability by providing a viable tool for regaining economic independence.

2. Architectural Blueprint: The Three-Tiered Control System

The core innovation is a platform architecture that separates the robust, FDM-printed mechanical hand from the control interface. This modularity allows for mass customization and a phased upgrade path, ensuring that a functional, motorized hand is accessible to all income levels and physiological conditions.

Tier 1: Ultra-Low-Cost Push-Button Control

a. **Mechanism:** Simplest, most reliable, and lowest-cost entry point. Control is achieved via one or two robust, tactile push-buttons integrated into the socket or a simple wrist strap.

b. **Functionality:** A single press of the button initiates a pre-programmed **Close** sequence for the hand, driven by the onboard servo motor. A subsequent press triggers the **Open** sequence. This binary control is managed by a low-power microcontroller (for example, ESP32 or Arduino Nano).

c. **Rationale:** This tier provides an immediate, motorized functional improvement over a passive hand at minimal cost. It is a critical option for users with severe nerve damage or insufficient residual muscle mass for myoelectric control.

Tier 2: Intermediate Body-Actuated Switch Control (Hybrid System)

a. **Mechanism:** Blending the advantages of mechanical and electronic control. A simplified, non-load-bearing harness and single cable are used to actuate a small, internal electronic micro-switch (not to pull the tendons).

b. **Functionality:** A gross body movement (for example, shoulder forward flexion or abduction) pulls the cable just enough to momentarily close the micro-switch, sending a signal to the microcontroller to power the hand to close. Releasing the movement signals the hand to open.

c. **Rationale:** This offers an intuitive control scheme, retaining the user's innate sense of proprioceptive feedback from the cable tension, while offloading the physically demanding task of generating high grip force to the electric motor. It is highly robust against environmental factors as it avoids external EMG sensors.

Tier 3: Advanced Low-Cost Myoelectric (EMG) Control

a. **Mechanism:** Integration of low-cost, open-source-friendly surface **EMG sensors** (such as the MyoWare or similar DIY circuits) positioned over the residual flexor and extensor muscles.

b. **Functionality:** The microcontroller reads the amplified analog EMG signal. Control can be implemented via a simple **On-Off Threshold** (signal above threshold closes hand; below opens hand) or, more advanced, **Proportional Control**, where the speed and force of the grip are proportional to the intensity of the muscle contraction, allowing for nuanced, natural-feeling control.

c. **Rationale:** This provides the most intuitive user experience at a fraction of the cost of commercial systems, utilizing readily available electronic components and open-source control algorithms to manage complexity.

3. Actuation and Power Transmission System

The mechanical heart of the device is designed for high efficiency, compactness, and strength.

a. **Actuators:** Standard, readily available hobby-grade DC **Servo Motors** (for example, TowerPro MG995 for main actuation) are used due to their ubiquitous presence and low cost (94 Rupees to 350 Rupees per unit in India). They are directly controlled by PWM signals from the microcontroller.

b. **Torque Amplification:** To achieve a target pinch force of 8 Newton-meters required for manipulating tools and heavy objects, a high-ratio **Worm Gearbox** mechanism is integrated into the 3D-printed palm housing. The worm gear provides the necessary torque increase and offers the critical benefit of being **self-locking**. Once the hand grips an object, the gear mechanism holds the position without requiring continuous power draw from the motor, drastically conserving battery life and ensuring a secure hold.

c. **Underactuated Tendon System:** To minimize cost, weight, and component count, the hand utilizes an **underactuated mechanism** where a single primary motor drives the four fingers via high-strength braided fishing line (tendons) routed through internal channels. This configuration allows the fingers to naturally flex and conform to irregularly shaped objects in an **adaptive grasp** pattern, maximizing contact and security. Elastic TPU components or cords provide the passive return (opening) force.

4. Fabrication, Materials, and Ergonomics

a. **Decentralized Fabrication:** All structural components are fabricated using **Fused Deposition Modelling (FDM) 3D printing**, enabling cheap, rapid, and decentralized production in local maker spaces, directly addressing the geographic access chasm.

b. **Hybrid Material Strategy:** The components use a combination of low-cost materials: **Polylactic Acid (PLA)** for the rigid structural parts (palm, socket, phalanges) due to its strength and ease of printing, and **Thermoplastic Polyurethane (TPU)** for the compliant fingertips, palm pads, and integrated hinges. TPU offers high friction for superior grip and durability against abrasion.

c. **Anthropometric Design:** A major factor in rejection is poor fit. The device is parametrically designed using **India-specific anthropometric data** for hand lengths, breadths, and finger dimensions (for example, male mean hand length is approximately 192 point 8 millimeters, female is approximately 169 point 6 millimeters), ensuring that the final print is perfectly scaled to the user's anatomy based on simple caliper measurements.

5. Cost Validation and Sustainability (Design for Maintainability)

The project is grounded in verifiable affordability. Our preliminary Bill of Materials (BOM) for the Tier 1 Push-Button Control model totals approximately **4,199 Rupees** in retail component costs, achieving a 95% cost reduction compared to commercial myoelectric devices.

Sustainability is guaranteed through **Design for Maintainability (DfM)** principles:

a. **Modularity:** The hand is structured as easily separable modules (fingers, actuation block, control module). If a finger is damaged, only that part needs re-printing (material cost of a few Rupees), maximizing uptime and minimizing repair cost.

b. **Standardization:** Exclusive use of **Commercial-Off-The-Shelf (COTS)** components (standard servo motors, metric fasteners, common microcontrollers) ensures local sourcing of spare parts, eliminating dependency on proprietary supply chains and vendor lock-in.

c. **Open-Source Model:** All CAD files, code, and documentation will be released under a permissive license, encouraging global and local iteration, community support, and the establishment of local repair and fitting networks by NGOs and local entrepreneurs.

This holistic approach transforms the project from a one-off device into a sustainable, scalable platform, providing enduring functional value to a critically underserved population.