# Proposal for SpotMicro Robotic Dog Project in Egypt

## Executive Summary

This proposal outlines the design, components, and development plan for a SpotMicro-style quadruped robot to be built and tested in Cairo, Egypt. Leveraging the CrealityCloud SpotMicro V4 community model, the robot will feature dynamic walking and balancing via state estimation (ES-EKF), advanced perception using stereo vision and acoustics, onboard AI capabilities (CV, NLP, LLM), and path-planning/person-following using PIR and ultrasonic sensors. All components are sourced from reputable Egyptian suppliers to ensure local availability and cost efficiency, with an estimated total hardware budget of 6,670 EGP. The project aims to integrate cutting-edge AI functionalities, distributed between the microcontroller and a local PC, to achieve intelligent interaction and autonomous navigation.

## 1. Mechanical & Structural Platform

* **Model:** SpotMicro V4 (Community Model from CrealityCloud: https://www.crealitycloud.com/model-detail/spotmicro-robotic-dog-v4)
* **Materials:** PLA and Flexible 3D-printed parts, to be fabricated by a local print shop.
* **Print Settings:**
  + **Printer:** Creality Ender 3
  + **Infill:** 10-20%
  + **Filament Material:** PLA (for rigid parts), Flexible (for feet/grips)
  + **Filament Colors:** White, Black, Gray
* **Actuation:** Twelve high-torque servo motors, with three allocated per leg, providing comprehensive control over the robot's locomotion.
* Project: https://spotmicroai.readthedocs.io/en/latest/

## 2. Electronics & Control

### 2.1 Microcontroller

* **Arduino Nano RP2040 Connect (ABX00053)** - 1,750 EGP
  + **Features:** Onboard Wi-Fi, Bluetooth, IMU (LSM6DSOXTR), microphone, and crypto chip. These integrated features are crucial for connectivity, initial state estimation, and potential audio inputs.
  + **Source:** RAM Electronics
  + **Link:** https://www.ram-e-shop.com/shop/arduino-org-rp2040-arduino-nano-rp2040-connect-with-headers-8395
* **Alternative:** Raspberry Pi Pico RP2040 Connect variant (similar cost and local stock availability).

### 2.2 Servo Actuation

* **MG996R Tower Pro Metal-Gear Servo (×12)** - 210 EGP each (Total: 2,520 EGP)
  + **Specifications:** 11 kg·cm stall torque, 180° range of motion, and a speed of 0.15 s/60°. These robust specifications ensure precise and powerful limb articulation.
  + **Source:** MakerSelectronics
  + **Link:** https://makerselectronics.com/product/mg996r-servo-motor-tower-pro-180-2/
* **PCA9685 16-Channel 12-bit PWM Driver** - 210 EGP
  + **Features:** I²C-controlled, providing 16 Pulse Width Modulation (PWM) channels. This driver enables precise and synchronized control for all twelve servos.
  + **Source:** MakerSelectronics
  + **Link:** https://makerselectronics.com/product/servo-motor-driver-pca9685/

## 3. Sensor Suite & Perception

This comprehensive sensor array will enable the SpotMicro to perceive its environment, localize itself, and interact intelligently.

| **Sensor / Module** | **Model** | **Price (EGP)** | **Function** | **Source (Link)** |
| --- | --- | --- | --- | --- |
| Ultrasonic Distance | HC-SR04 | 60 | Obstacle detection, precise range measurement | MakerSelectronics: https://makerselectronics.com/product/hc-sr04-ultrasonic-sensor-detector/ |
| Passive Infrared (PIR) | HC-SR501 | 50 | Motion detection (for person/object following) | MakerSelectronics: https://makerselectronics.com/product/sr501-pir-sensor/ |
| GPS Positioning | NEO-6M V2 | 450 | Outdoor localization and global positioning | MakerSelectronics: https://makerselectronics.com/product/ublox-hw-539-neo-6m-gps-module/ |
| Stereo Camera Pair (×2) | OV9655 | 350 each | Depth perception, simultaneous localization and mapping (SLAM) | RAM Electronics: https://www.ram-e-shop.com/shop/kit-camera-ov9655-ov9655-camera-module-1-3m-pixels-7976 |
| Acoustic Localization (×3) | MAX4466 Microphone Amplifier | 160 each | Sound-source localization via Time Difference Of Arrival (TDOA) | FUT Electronics: https://store.fut-electronics.com/products/microphone-amplifier-max4466-with-adjustable-gain |
| Sound Sensor | LM393 module | 45 | General sound detection, voice activation | FUT Electronics: https://store.fut-electronics.com/products/sound-sensor-digital |
| Speaker & Amplifier | PAM8403 Amplifier | 35 | Speech output, audio playback | MakerSelectronics: https://makerselectronics.com/product/pam8403-amplifier-with-volume-control/ |
| OLED Display | SSD1306 0.96" 128x64 I2C | 170 | Real-time visual feedback and debugging display | MakerSelectronics: https://makerselectronics.com/product/oled-display-i2c-4-pin-0-96%E2%80%B3-3/ |

## 4. State Estimation & Control

* **State Estimation:** An Extended-State Extended Kalman Filter (ES-EKF) will be employed, fusing data from the onboard IMU, leg odometry, GPS, and stereo-vision SLAM to provide accurate and robust localization and state estimation.
* **Kinematics:** Inverse Kinematics (IK) will be implemented in Python/C++ to generate dynamic and stable gait patterns for walking and maneuvering.
* **Stability Control:** Principles of Zero-Moment Point (ZMP) and feedback control loops will be integrated to ensure the robot maintains balance and stability during locomotion and dynamic interactions.

## 5. AI & High-Level Autonomy

The AI architecture is distributed for optimal performance, leveraging the Arduino Nano RP2040 Connect for real-time, lightweight tasks and a local PC for heavy computational loads.

### On Arduino Nano RP2040 Connect (Lightweight, Real-time Tasks)

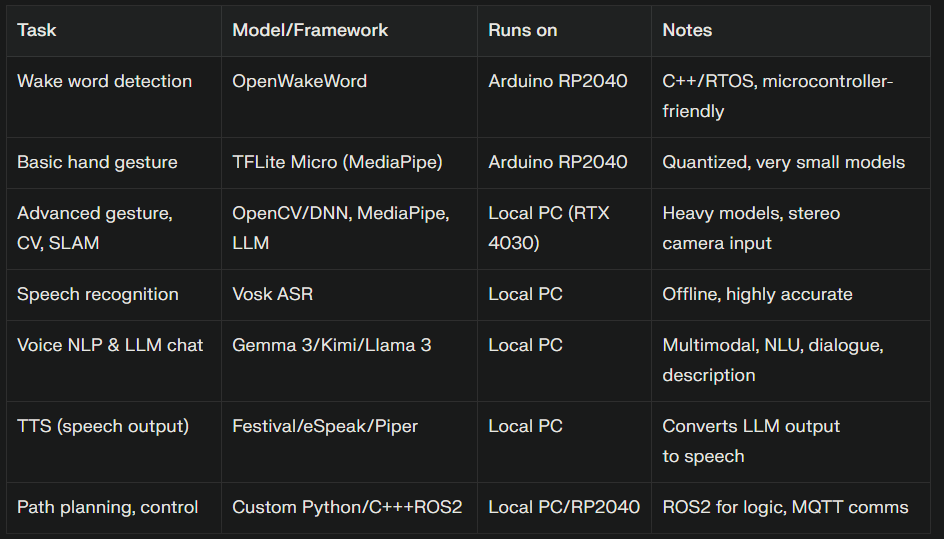
The Arduino Nano RP2040 Connect, with its 264KB SRAM and 16MB external flash, is ideal for critical, low-latency AI functions running on a C++/RTOS stack.

* **Wake Word Detection:**
  + **Model:** OpenWakeWord
  + **GitHub:** https://github.com/dscripka/openWakeWord
  + **Justification:** This model provides C++ examples and is designed for embedded systems. It can be integrated into an RTOS task for an efficient, always-listening capability. Its small footprint (<100KB) and low RAM usage (~50KB) are ideal for the RP2040.
* **Basic Hand Gesture Recognition:**
  + **Model:** Simple MediaPipe Hand Detection (Quantized)
  + **Hugging Face (quantized model reference):** <https://huggingface.co/qualcomm/MediaPipe-Hand-Detection> https://github.com/zmurez/MediaPipePyTorch/
  + **Implementation:** The model will be deployed using the TensorFlow Lite for Microcontrollers C++ library, which is designed for bare-metal and RTOS environments.
  + **Justification:** A quantized TFLite model (approximately 400KB) can run efficiently for basic gestures (e.g., stop, go, follow), enabling immediate physical interaction within the RTOS framework.
* **Sensor Fusion & Low-Level Control:**
  + Processing of IMU data (from onboard LSM6DSOXTR) managed by a dedicated RTOS task.
  + Basic Passive Infrared (PIR) motion detection handled with interrupt-driven C++ routines.
  + Direct servo control via the PCA9685 driver, managed by a high-priority control task.
  + A C++ MQTT client library will be used for efficient, non-blocking communication with the PC.
* **Audio Preprocessing:**
  + Collection of microphone data and basic filtering performed in a dedicated C++ audio processing task.
  + Audio buffering for wake word detection managed within the RTOS to prevent data loss.

### On PC (Heavy AI Processing)

A local PC will handle computationally intensive AI models, communicating with the Arduino via Wi-Fi and MQTT.

* **Advanced Speech Recognition:**
  + **Model:** Vosk ASR
  + **GitHub:** https://github.com/alphacep/vosk-api
  + **Website:** https://alphacephei.com/vosk/
  + **Justification:** Vosk offers offline, high-accuracy speech-to-text, essential for complex command parsing and understanding. A local Vosk Server (https://github.com/alphacep/vosk-server) can also be run for remote processing.
* **Computer Vision (CV) Pipeline:**
  + **Object Detection:** OpenCV DNN with MobileNet SSD for real-time object detection.
    - **GitHub:** https://github.com/djmv/MobilNet\_SSD\_opencv
    - **Tutorial:** https://ebenezertechs.com/mobilenet-ssd-using-opencv-3-4-1-deep-learning-module-python/
  + **Advanced Hand Tracking:** MediaPipe for detailed hand gesture recognition.
    - **GitHub:** https://github.com/kinivi/hand-gesture-recognition-mediapipe
  + **Face Recognition:** Utilizing pre-trained LBPH (Local Binary Patterns Histograms) models or more advanced FaceNet models for person identification. GItHub https://github.com/otroshi/edgeface
* **Natural Language Processing (NLP) & Language-Based Models (LBM) / Large Language Models (LLM):**
  + **Local LLM:** Leveraging platforms like Ollama with smaller models (e.g., Llama 3.2 (3B)) for conversational AI, enabling the robot to describe its surroundings and engage in dialogue.
  + **Text-to-Speech (TTS):** Using engines like Festival, eSpeak, or Piper TTS for the robot to audibly respond. (https://huggingface.co/neuphonic/neutts-air)
  + **Intent Recognition:** Libraries such as Rasa or spaCy will be used for understanding the user's intent from spoken commands.
* **Path Planning & SLAM:**
  + **Algorithms:** A\* or D\* Lite grid-based planners will be used, generating paths based on a 2D map constructed from SLAM data.
  + **Stereo Vision Processing:** Detailed processing of stereo camera data for robust depth perception and environment mapping.
  + **GPS/IMU Sensor Fusion:** Advanced fusion of GPS and IMU data with stereo vision for enhanced localization.
  + **State Estimation:** The ES-EKF filter will perform the heavy lifting of state estimation on the PC.
* **Training & Optimization:**
  + **Custom Gesture Model Training:** GRLib (https://github.com/mikhail-vlasenko/grlib) will be used for training custom hand gesture models.
  + **Reinforcement Learning (RL):** Platforms like Isaac Gym or OpenAI Spinning Up will be utilized for optimizing the robot's gait and locomotion patterns on a local GPU workstation.



## 6. Software Architecture

* **Firmware:** The microcontroller will run a Real-Time Operating System (RTOS), such as FreeRTOS. All low-level control, real-time sensor interfacing, and basic AI tasks will be implemented in C++.
* **Middleware:** ROS 2 (Robot Operating System 2) will be used on a local PC. ROS 2 will handle inter-process communication, sensor data processing, vision pipelines, and path planning.
  + **MQTT Client for ROS2:** https://github.com/ika-rwth-aachen/mqtt\_client
  + **Arduino MQTT Communication:** https://docs.arduino.cc/tutorials/uno-wifi-rev2/uno-wifi-r2-mqtt-device-to-device
* **Cloud & Tools:**
  + **RIAze:** For reinforcement learning environment setup.
  + **OpenAI Labs API:** For LLM inference, if a cloud-based model is preferred.
  + **Simulation:** Gazebo or PyBullet (pip install pybullet) will be used for developing and testing algorithms in a simulated environment.

## 7. Development Timeline & Milestones

This project is estimated to take approximately 20 hours.

| **Phase** | **Duration** | **Deliverables** |
| --- | --- | --- |
| Mechanical Design & 3D Printing | 2 hours | Printed leg & body parts, assembly of mechanical structure |
| Electronics Integration | 2 hours | Board mounting, wiring harness, initial power-on tests, basic connectivity |
| Firmware & IK Implementation | 3 hours | Stable walking demonstration with basic Inverse Kinematics |
| Perception & State Estimation | 4 hours | Stereo SLAM implementation, ES-EKF localization for environment mapping |
| AI Features & Autonomy | 5 hours | Object detection, command following, LLM-driven descriptive capabilities |
| System Testing & Optimization | 4 hours | Robust walking, refined feature integration, overall system performance tuning |

## 8. Budget Summary (EGP)

| **Component Category** | **Quantity** | **Unit Price (EGP)** | **Total Cost (EGP)** |
| --- | --- | --- | --- |
| Arduino Nano RP2040 Connect | 1 | 1,750 | 1,750 |
| MG996R Metal-Gear Servos | 12 | 210 | 2,520 |
| PCA9685 16-ch PWM Driver | 1 | 210 | 210 |
| HC-SR04 Ultrasonic Sensor | 1 | 60 | 60 |
| HC-SR05 PIR Sensor | 1 | 50 | 50 |
| NEO-6M GPS Module | 1 | 450 | 450 |
| OV9655 Camera Modules | 2 | 350 | 700 |
| MAX4466 Microphones | 3 | 160 | 480 |
| LM393 Sound Sensor | 1 | 45 | 45 |
| PAM8403 Audio Amplifier | 1 | 35 | 35 |
| SSD1306 OLED Display | 1 | 170 | 170 |
| 12V Battery Pack (e.g., 7000mAh Li-ion) | 1 | 1,200 (IDK) | ~ |
| Miscellaneous (wiring, connectors, etc.) | - | - | ~ |
| **Grand Total** |  |  | **6,670 EGP** |

## 9. Conclusion

This project presents a robust and innovative approach to building an autonomous SpotMicro-style robot in Egypt, leveraging locally available components, open-source hardware and software, and advanced estimation and AI techniques. The estimated budget of 6,670 EGP covers all necessary hardware and materials, with a weak development roadmap leading to a fully functional prototype capable of dynamic walking, advanced perception, and intelligent interaction.

## 10. Appendix: Research & References

### AI & Machine Learning

* **Hand Gesture Recognition**
  + MediaPipe Hand Gesture Recognition: https://github.com/kinivi/hand-gesture-recognition-mediapipe
  + GRLib - Comprehensive Gesture Library: https://github.com/mikhail-vlasenko/grlib
  + Real-time Hand Tracking with Flask: https://github.com/KelvinPuyam/Hand-Gesture-Recognition
  + Google AI MediaPipe Solutions: https://ai.google.dev/edge/mediapipe/solutions/vision/gesture\_recognizer
* **Wake Word Detection**
  + OpenWakeWord (Primary): https://github.com/dscripka/openWakeWord
  + Picovoice Porcupine Engine: https://github.com/Picovoice/porcupine
  + Snowboy (Legacy): https://github.com/Kitt-AI/snowboy
* **Computer Vision & Object Detection**
  + DNN Object Detection Framework: https://github.com/TheNsBhasin/DNN\_Object\_Detection
  + OpenCV with MobileNet SSD: https://github.com/djmv/MobilNet\_SSD\_opencv
  + OV9655 Camera Datasheet: https://blog.arducam.com/downloads/modules/OV9655/ov9655\_full.pdf

### Hardware & Components

* **Alternative Suppliers (Egypt)**
  + Maker Electronics: https://makerselectronics.com
  + Most Electronic: https://mostelectronic.com
  + Micro Ohm: https://microohm-eg.com
  + DIY Electronics Egypt: https://diyelectronicsegypt.com/
* **Component Datasheets & Information**
  + MAX4466 Amplifier: https://www.analog.com/en/products/max4466.html
  + PAM8403 Amplifier: https://www.mouser.com/datasheet/2/115/PAM8403-247318.pdf
  + LM393 Sound Sensor: https://www.circuits-diy.com/lm393-sound-sensor-module/

### 3D Models & Mechanical

* **HC-SR04 Ultrasonic Sensor Mounts:**
  + https://www.printables.com/model/777360-hc-sr04-ultrasonic-sensor-holder/related
  + https://www.printables.com/model/102887-hc-sr04-case
* **HC-SR501 PIR Sensor Case:**
  + https://www.printables.com/model/728270-hc-sr501-pir-sensor-box/collections

### General Resources

* **YouTube Tutorials:**
  + SpotMicro on uneven terrain: https://www.youtube.com/watch?v=rifzrq5KiEs
  + SpotMicro ESP32 Control: https://www.youtube.com/watch?v=GDnmAI\_7lOk