Table of Contents

ABSTRACT

- Compact and efficient readout module based on Xilinx Zynq-7000 FPGA
- Flexible hybrid architecture: Software for complex functions, hardware for low-latency tasks
- Wide CMOS sensor compatibility with power, clock, and operation management
- Synchronized data acquisition using trigger inputs
- Integrated motor control for telescope positioning and automated field scanning
- Dual data paths: Processor processing or direct fiber optic transmission

KEYWORDS

- **Core Technologies:** FPGA-based, Xilinx Zynq, System-on-a-Chip, Programmable logic
- **Data Handling:** Data acquisition, Lossless compression, Low-latency, Synchronization
- **Communication:** White Rabbit (WR), Fiber optic interface, Time-stamping
- **Hardware Components:** CMOS pixel sensors, ARM processor, Motor control
- **Software/Systems:** Linux OS, Space-hardened

INTRODUCTION

- Modern telescopes demand compact, low-power, high-performance electronics for imaging and control.
- Traditional systems are bulky and limited in integration and flexibility.
- Zynq SoC offers a hybrid solution with software programmability and hardware acceleration.
- Enables on-chip sensor control, data acquisition, compression, and transmission.
- This project investigates the architecture, design, and capabilities of Zynq-based modules for astronomical use.

SOCIAL RELEVANCE

- Promotes accessibility in astronomy by enabling cost-effective electronic modules for educational telescopes.
- Supports research institutes and student observatories with low-power, compact modules.
- Aligns with India’s mission of self-reliance in space and defense technologies (e.g., ISRO, DRDO).
- Aids in building smart, autonomous telescopes for remote monitoring and sky surveys.
- Encourages innovation in embedded systems for aerospace and space sciences.

LITERATURE SURVEY AND ANALYSIS

- Low-cost FPGA-based solution with WR synchronization for CTA
- High accuracy timing: ~90 ps resolution
- Efficient data transfer: 905.6 Mb/s throughput
- Dual-core ARM + Linux OS integration for simplified development
- Versatile alternative to existing data acquisition nodes
- Suitable for CTA and other distributed scientific applications

J. Sánchez-Garrido et al., "A White Rabbit-Synchronized Accurate Time-Stamping Solution for the Small-Sized Cameras of the Cherenkov Telescope Array," in IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1-14, 2021, Art no. 2000314, doi: 10.1109/TIM.2020.3013343.

LITERATURE SURVEY AND ANALYSIS

- Xilinx Zynq-based data acquisition system for NASA's EMIT instrument
- Multi-functional capabilities: Data acquisition, cloud-screening, compression, storage, and downlink
- Collaborative development by JPL, Alpha Data, Correct Designs, and Mercury Systems
- Space-hardened embedded System-on-a-Chip design
- Advanced on-board processing: Lossless compression, image co-adding, cloud screening
- Optimized for space missions - enhances data quality and transmission efficiency

D. K. T. Pham et al., "High-Performance Embedded System-on-a-Chip for space imaging spectrometer," 2023 IEEE Aerospace Conference, Big Sky, MT, USA, 2023, pp. 1-10, doi: 10.1109/AERO55745.2023.10115907.

OBJECTIVES AND EXPECTED RESULTS

Objectives:

- Integrate Telescope Functions into a Single Zynq SoC
- Implement Telescope Motion Control
- Enable Camera Integration & Image Capture
- Develop Image Display & User Interface
- Ensure System Stability & Real-Time Performance
- Time Sync & High-Speed Data Handling

Expected Results

- Achieve <1 ns timestamp precision with ~90 ps jitter
- Support event rates up to 7.14 MHz, beyond CTA's needs
- Maintain high-speed data transfer (~905 Mb/s) using FPGA coprocessor
- Ensure stable WR synchronization across devices
- Deliver a compact and scalable time-stamping module for distributed systems

UNIQUENESS OF THE PROJECT

01. Combines control, imaging, and display on a single Zynq SoC

02. Miniaturized design ideal for portable/remote telescope setups

03. Supports real-time motor control and CMOS image capture

04. Provides HDMI display and user-friendly Linux interface

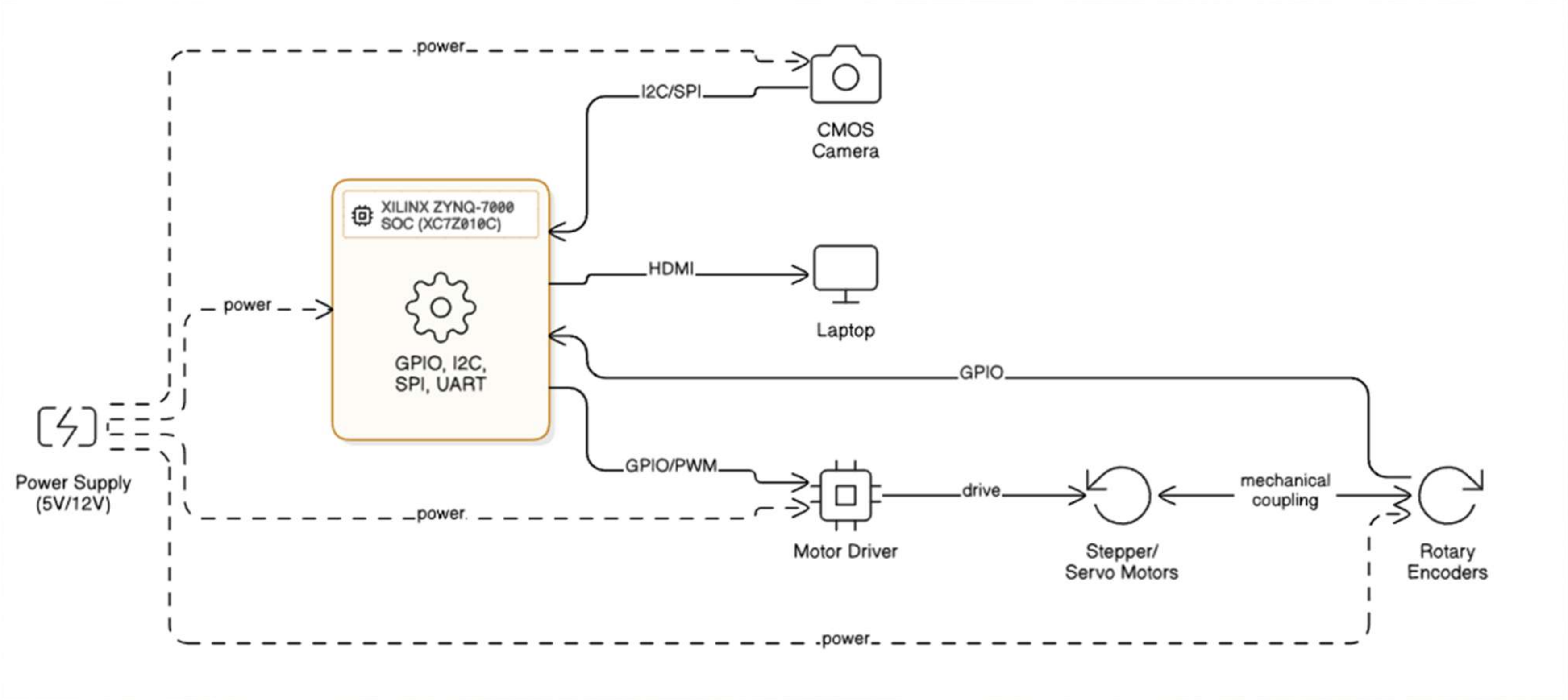
05. Enables Ethernet/USB communication for data transfer/control

06. Cost-effective and customizable for various telescope needs

METHODOLOGY

- Select Zynq-7000 SoC for processing and control
- Design a compact board for camera, motor, and display
- Interface CMOS camera via PL, transfer data to PS
- Implement motor control with encoder feedback
- Display images via HDMI/LCD, with GUI/CLI control
- Run custom Linux for camera, motors, and logging
- Test for image clarity, motor accuracy, and system latency

BLOCK DIAGRAM



PROPOSED TOOLS

Hardware Tools

- Xilinx Zynq-7000 SoC (XC7Z010C)
- CMOS Camera Module (e.g., OV7670)
- Stepper/Servo Motors
- Motor Driver Modules
- Rotary Encoders
- HDMI Display/LCD
- Power Supply unit (5V/12V)
- Peripheral Interfaces

Software Tools

- Vivado Design Suite
- Petalinux/Yocto
- Vitis (or Xilinx SDK)
- Python/C
- Custom GUI/CLI Tools
- Linux Kernel & U-Boot
- OpenCV

PLAN OF ACTION

S. No.	MONTH (2025)	PLANS
1.	July (First half)	Literature survey, Base paper selection
2.	July (Second half)	Project summary
3.	August	Schematic design, Component selection and purchasing
4.	September	PCB +SW development
5.	October	Hardware assembly, Testing
6.	November(First Half)	Prototype completion
7.	November (Second half)	Report Submission

REFERENCES

Base Paper

01. J. Sánchez-Garrido et al., "A White Rabbit-Synchronized Accurate Time-Stamping Solution for the Small-Sized Cameras of the Cherenkov Telescope Array," in IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1-14, 2021, Art no. 2000314, doi: 10.1109/TIM.2020.3013343.

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02. A. B. Yandrapati, V. K. P. R. Singam, B. Namburu, V. Paladugu and T. K. Karakula, "Design of a Smart Embedded Vision System Based on FPGA for Medical Applications," 2023 4th International Conference on Signal Processing and Communication (ICSPC), Coimbatore, India, 2023, pp. 1-5, doi: 10.1109/ICSPC57692.2023.10125679.

Thank you!