Manufacture and testing of ARGUS: a pole climbing surveillance robot

Willis de Ronde[1*], *Peter* Bosscha[2], *Stephen* Marais[3], *Arnold* Pretorius[4]

[1*] Centre for Robotics and Future Production, CSIR, wderonde@csir.co.za
[2] Centre for Robotics and Future Production, CSIR, pbosscha@csir.co.za
[3] Centre for Robotics and Future Production, CSIR, smarais@csir.co.za
[4] Department of Mechanical Engineering, UCT, arnold.pretorius@uct.ac.za

Abstract. South Africa needs rapidly deployable surveillance in situations such as public marches and periods of unrest. As these events can often last several hours, short-term solutions, such as multi-rotor drones, are generally not feasible. The proposed solution, the Automated Robotic Guardian for Urban Surveillance (ARGUS) platform, is a rapidly deployable pole-climbing robot for surveillance and situational awareness. This paper outlines the system's manufacture, testing, and analysis. The platform was tested under various laboratory and real-world conditions against predefined user specifications. Test results demonstrate that the system can ascend and descend multiple existing pole infrastructures and maintain a hold position without the motors consuming power while on the pole.

1 Introduction and background

This research project aims to design, manufacture, and test a platform that can deploy and traverse up and down existing pole infrastructure to provide ad hoc surveillance ability. The project's first phase, which included the literature review and iterative mechanical design of the robotic platform, was presented in [1]. This paper documents the project's next phase, which comprises the system's manufacture, testing, and analysis of the results. The complete system can be seen in **Fig. 1**, which is attached to a light pole on the CSIR campus. The camera feed from the dashboard is displayed in **Fig. 2**, demonstrating the camera's field of view from the perspective of the proposed system. Having multiple instances of these systems deployed in an emergency situation, combined with the pan-tilt-zoom capability of the cameras, would substantially increase the situational awareness of a given area of interest.

* Corresponding author

Fig. 1. ARGUS platform deployed on a light pole loitering at a height of 4m above the ground.

Fig. 2. Dashboard image from ARGUS camera at minimum zoomed (Left) and maximum zoom (Right).

As described in the preceding paper presented at the 2023 RobMech conference [1], South Africa experiences a significant amount of public unrest due to various factors, including lack of service delivery, labour issues, and political disagreements. It's legally required for organised protests to notify the relevant authority beforehand [2], and the police are tasked with ensuring the safety of protesters, bystanders, and infrastructure. Despite not all protests turning violent, their monitoring is crucial. This need became especially evident during the major '#FeesMustFall' student protests in 2015 and the July insurrection in 2021 affecting KwaZulu-Natal and Gauteng [3], which saw substantial property damage and allegations of police brutality [4]. Protests, often occurring in urban areas, are frequent nationwide, with 1378 public protests recorded in 2020 alone [5].

Over the past few decades, significant research has been devoted to pole-climbing robots, mainly for inspection purposes. This has resulted in various climbing mechanisms, notably wheeled and bio-inspired robots. Wheeled robots either rely on friction [6] or magnetic traction [7], while bio-inspired mechanisms include grippers with segmented joints [8] , soft robotics [9], and quadrupedal designs.

In the 2023 paper [1], a user needs analysis was completed; these needs were then converted to a User Requirement Specification (URS) document to guide the design and development of the robotic system. Inputs into the URS came from existing pole climbing robot research, products, and South African pole infrastructure specifications. The system's key requirements are as follows:

- The system must attach to cylindrical poles with between 65mm and 240mm base diameters.
- The system should accommodate a diameter change on the pole of up to 40%, with a minimum top pole diameter of 50mm and a maximum change of 100mm.
- The system should maintain its position on the pole using minimal to no power.
- The system should operate surveillance equipment for at least 4 hours.
- To allow single-person deployment, the system's weight must not exceed 20kg.

After defining the requirements, several concept designs were created through 2D sketches, which were evaluated against the URS, and a best-fit selection was made. Based on the chosen concept, which incorporated a wheeled base robot relying on friction for traction, a detailed design was implemented using computer-aided design (CAD). All requirements and design documentation, CAD files, and documentation packs were managed and coordinated through a Product Lifecycle Management (PLM) system.

2 Methodology

The system was manufactured according to the CAD design presented in [1]. The mechanical structure of the system mainly consists of an aluminium profile and square tubing. Machining was kept to a minimum for the remaining structural parts by using shapes that were cut out of plates using a waterjet, and 3D-printed components from Polyethylene terephthalate glycol (PETG) material where possible. Methodical testing of the sub-systems and the entire robot were completed for overarching performance, and verified against the user requirements. Issues detected during laboratory testing were addressed in design improvements. Real-world tests were conducted once the system performed as expected in the laboratory setting. The project followed a modified V model approach that can be seen in **Fig. 3**. The phase discussed in this paper follows the (green) integration and testing arrow up from the bottom of the V model.

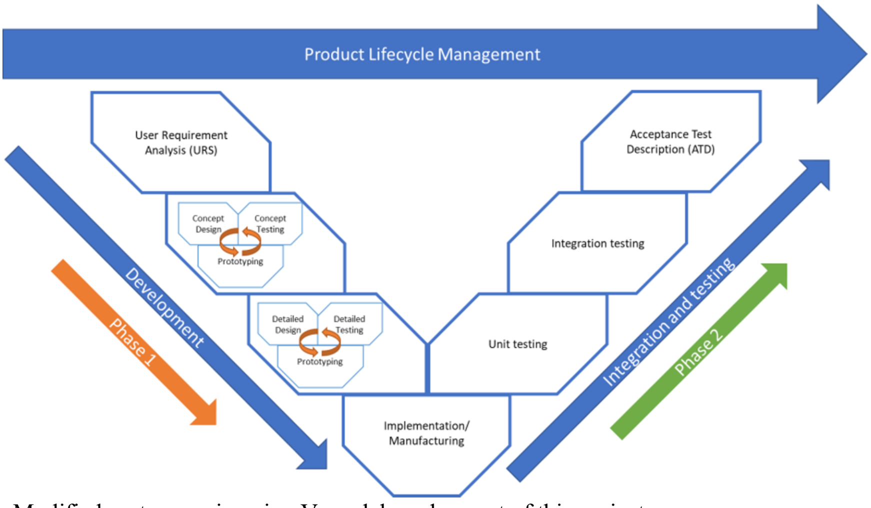

Fig. 3. Modified system engineering V-model used as part of this project.

3 Manufacturing

The system base frame consisted of aluminium extrusions and a welded square tubing top frame. Aluminium was chosen to keep the system weight as low as possible. Supports for the aluminium extrusions frame were made from aluminium sheet metal and bolted onto the frame with t-nuts. The motors were mounted onto the frame using sheet metal brackets. The motor assembly on one side is spring-loaded onto shafts running through linear bearings and has a toggle clamp to pre-tension the system onto the pole. The items bought out were the pillow blocks, linear bearings, shaft couplers, and toggle clamps.

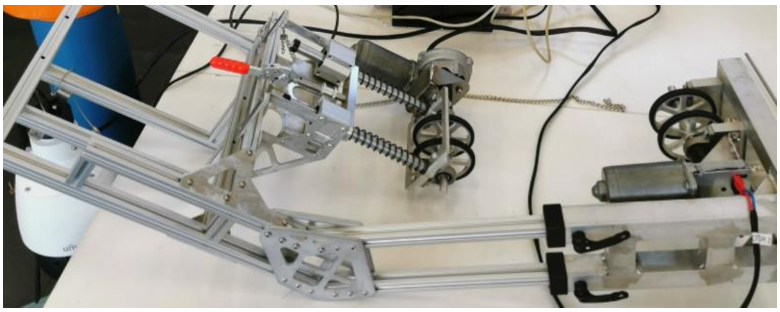

Fig. 4. ARGUS without electronic box mounted.

The castings of the final wheels were done by 3D printing one-time-use moulds of the wheels. The mould consisted of two parts. The base part housed the aluminium rim and the gap where the polyurethane would be poured to create the tyre and a top piece that stopped the polyurethane from running over the rim's centre. A release agent is sprayed over the moulds to ease the removal of the part after casting. An abrasion-resistant polyurethane rubber casting material, which consists of a two-part mixture, was used. This material was chosen for its shore hardness and ability to cast at room temperature with minimal shrinkage and no degassing is needed. After casting, the parts were left to cure for 24 hours, then removed from the moulds, and post-curing was performed by placing the wheels in an oven at 65°C for 6 hours. The moulds, rim and casting material can be seen in **Fig. 5**.

Fig. 5. Polyurethane wheel casting.

4 Results

Where possible, sub-systems were assembled and tested. Two of the key sub-system tests completed were on the adjustable arms for base diameter changes and on the passive spring adjustment for change over the length of the pole. The adjustable arms need to handle the maximum normal force that the system will exert on the wheels, but they also need to be adjustable without the need for tools. The chosen solution used a bicycle seat quick-release lever that attaches to a T nut in the aluminium extrusion; when the cam lever is locked down, it pulls the T nut against the extrusion, locking the system in place. The mechanism was locked in place, and a pull scale was used to test if it would stay in place with the maximum force applied. The passive adjustment system worked by spring-loading the wheels onto linear bearings with a toggle clamp to engage the initial tension onto the pole. The system was tested to see if all mechanisms could move and function as expected. The two sub-assemblies can be seen in **Fig. 6**.

Fig. 6. Testing setup for adjustable arm concept (Left) and passive spring adjustment sub-assembly (Right).

During initial system testing, the off-the-shelf wheels failed when used on thinner poles. The lateral component of the normal force acting on the wheels increases as the diameter of the pole decreases. The lateral forces exceeded the force that the plastic rims could sustain, resulting in the spokes of the rim breaking, as can be seen in the bottom left image in **Fig. 7**. The rims were then replaced with custom aluminium rims using the same rubber treads from the previous wheels. While testing the new wheels, failure and slipping of the tyres was experienced, and it was decided to cast polyurethane tyres onto the aluminium rims. The newly custom-made wheels functioned much better, improving the robot's traction. The different wheel iterations can be seen in **Fig. 7**.

Fig. 7. Off-the-shelf plastic rim with stretch fit rubber tyre (Left column), aluminium rim with stretch fit rubber tyre (Middle column), and aluminium rim with polyurethane cast tyre (Right column).

Once the system was operating as expected, testing against the user requirements could commence. **Fig. 8** shows one of the test setups used in a laboratory environment, and **Fig. 9** shows example results from driving up and down the test pole. The test pole had a constant diameter and was attached to a base to provide stability. Markings were added to the pole at fixed increments so that experimental results from the encoders could be verified against the video data of the test.

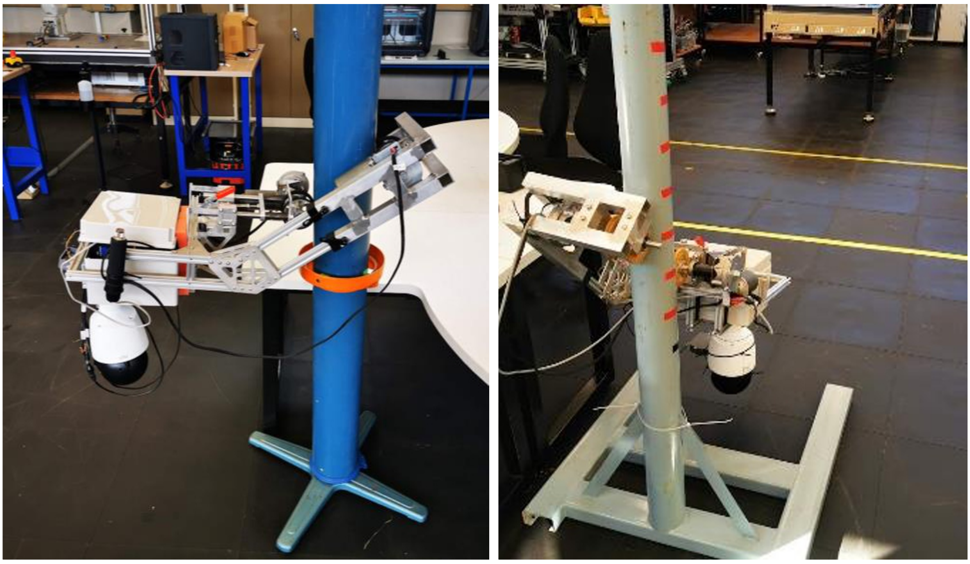

Fig. 8. Images of ARGUS during separate ascents as part of the laboratory tests.

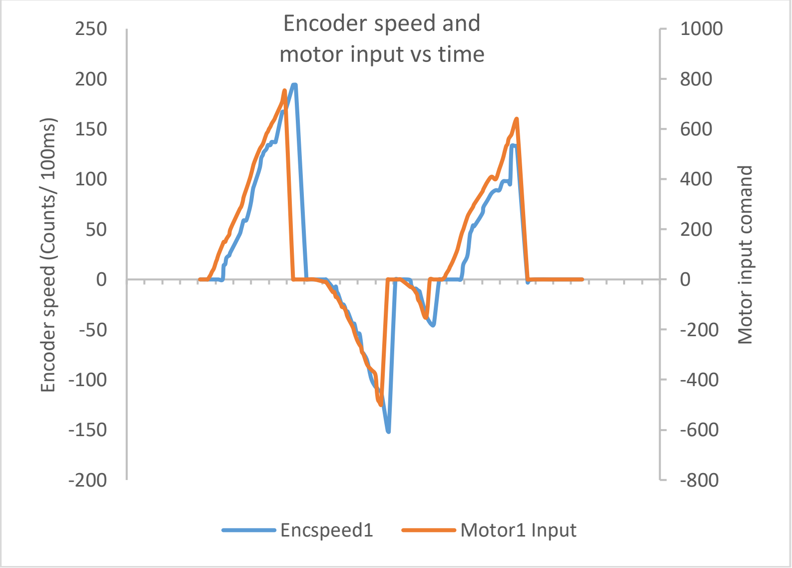

Fig. 9. Graph of ARGUS' motor commands and measured speed during laboratory testing.

The testing showed that the system could attach to poles with base diameters between 63mm and 231mm and ascend to a height of 4 meters on a tapered pole, traversing over small obstacles up to 12mm and adjusting for changes in diameter over the pole's length. ARGUS was able to achieve a climbing speed of 0.12m/s and an operational battery life of over 14 hours. Physical testing was only performed to a maximum base diameter of 231mm, as a pole with a larger diameter was not available. However, the design of the adjustable gap between the wheel pairs allows for a pole diameter of distance of up to 240mm, achieving the requirement. While driving up the tapered pole with base diameter of 231mm a change in diameter of 85mm was experienced and successfully ascended the pole. This diameter change equates to a 37% reduction in diameter and narrowly misses the 40% requirement. Thus, a laboratory test was done where the adjustable arms of the system were set for a pole with a 167mm base diameter, which was then attached to the 100mm test pole. As the system still had the required traction, it proves that up to 40% change in diameter can be handled by the system. Photos of the system attached to the minimum and maximum pole sizes tested can be seen in **Fig. 10**.

Fig. 10. ARGUS attached to a pole with a small base diameter of 63mm (Left) and ARGUS attached to a pole with a large diameter of 231mm (Right).

ARGUS uses two non-backdrivable worm gear motors to drive up and down the pole. As a result, the motors are able to hold the wheels in position without using power, thereby achieving one of the key user requirements. The system could traverse over small obstacles, up to 12mm, such as weld seams and joints but could not overcome large access panels up to 40mm. This issue can be improved by increasing the diameter of the wheels on the system. The video feed to the dashboard over Wi-Fi worked sufficiently well up to a tested distance of 113m, beyond which operation and control of the system started to give issues due to delays in the video feed and commands from the base station to the robot. The access point used for the system can be fitted with a variety of antennas, and a higher gain antenna can be connected to extend the range to the desired 200m. The system's weight was slightly over the desired 20kg, with a total system weight of 21kg, including the camera payload. The weight was deemed acceptable for the system's operation and deployment by a single operator. However, there are a few places, such as the aluminium square tubing, motor selection and battery sizing, where weight optimisation could happen. Testing and verification of all the user requirements can be seen in the summary tables below (**Table 1** and **Table 2**).

Table 1. ARGUS test results.

Test description	Requirement	Achieved/ Not Achieved	Test results
Attach to cylindrical poles with specific base diameters	65mm-240mm	Achieved	63mm-231mm/240mm
Attach to multiple material poles	Metal, fibreglass, and wooden poles, excluding wet gum poles	Achieved	Metal, plastic, fibreglass, and wooden poles, excluding wet gum poles
Traverse over obstacles	40mm protrusion from the diameter of the pole.	Not achieved	12mm protrusion (Weld seam and other small obstacles)
Handle changes in diameter.	100mm or 40% diameter change over the length of the pole	Achieved	85mm (37% reduction in base diameter) tapered pole. 67mm (40%) pre-set on laboratory pole
Climb up to a minimum of 4m from ground level	4m	Achieved	4m
Ascend and measure speed	Reach a height of 4 meters in under 60s ≈ 0.067m/s	Achieved	Max speed of 0.12m/s achieved. As the max speed far exceed the required speed it is assumed the system would reach 4m in under 60s
Attach a payload (including camera)	Payload capacity of 4kg	Achieved	4kg
Loiter in position and measure motor power draw	Motors use no power to loiter	Achieved	Motors use no power to loiter
Run surveillance equipment and measure power draw	4hours of running ≈ 2.75A	Achieved	0.733A ≈ 14hours
Store onboard video	24 hours' worth of video	Achieved	256GB Micro SD should be able to record approximately 8 days of video
Wireless connectivity range	200m	Not achieved	113m
The system must be able to re-deploy within 8 hours	Charge in less than 8 hours	Achieved	01:32
The system should be lightweight.	20kg	Not achieved	21kg

The use of cam levers to lock the adjustable arm and a toggle clamp for the pre-tensioning means no external tooling is used to attach the system to a pole. The system was remotely controlled by means of bidirectional Wi-Fi from a laptop displaying the control dashboard, as can be seen in **Fig. 11**. The dashboard can display information about the system, such as battery voltage, height, motor speed command, and encoder counts.

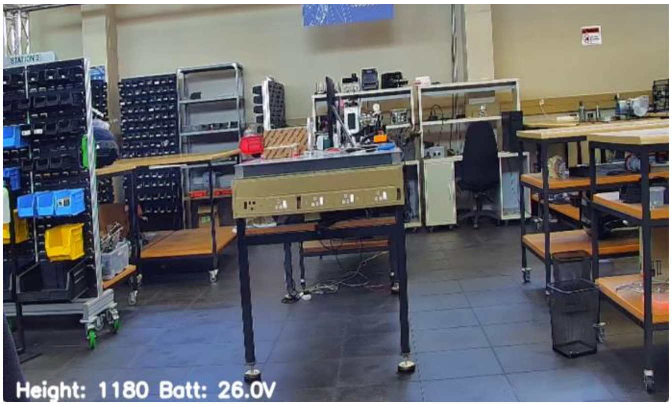

Fig. 11. ARGUS control dashboard with video feed during laboratory testing.

All external components and enclosures have at least an IP44 rating, and any cables passing through the main enclosure utilise grommets or glands. The system did not undergo any further ingress protection testing.

Table 2. ARGUS requirements verification.

URS	Requirement	Achieved/ Not Achieved
5	No external tooling needed to attach to the pole	Achieved
6	Be deployed by a trained operator under 10min	Achieved
7	Remotely controllable	Achieved
14	Have ingress protection of at least IP44	Achieved
15	Supply DC power and communication interfaces to the payload.	Achieved
16	Have bidirectional wireless connectivity	Achieved
17	Has sufficient bandwidth to stream 1080p video and control the robot.	Achieved
19	Have rechargeable batteries.	Achieved
21	Verify that the system has attachment points for payloads.	Achieved
22	Can alert the operator when the power is low	Achieved

5 Conclusion

ARGUS was shown to be a viable solution to the need for rapidly deployable surveillance, which was adjudged against predefined user requirements. The results show that the system can function both in laboratory and real-world conditions and is adaptable to a range of operating conditions, such as pole material and diameter. The system is able to give the operator situational awareness by ascending at least 4 meters on existing pole infrastructure while traversing small obstacles and adjusting for changes in diameter over the pole's length. The system is also able to maintain a loiter on the pole without consuming power. Future work will investigate optimising the system design, such as weight reduction and improvements to the wheel design to be able to handle larger obstacles, as well as adding machine learning to the video data collected.

References

1. W. de Ronde, P. Bosscha, S. Marais and A. Pretorius, "ARGUS: a pole climbing surveillance robot," in *RAPDASA-RobMech-PRASA-AMI Conference*, Pretoria, 2023.
2. "REGULATION OF GATHERINGS ACT 205 OF 1993".
3. F. Makonye, "Interrogating the July 2021 Looting, Burning and Violence in South Africa: Case of KwaZulu-Natal (KZN)," *African Journal of Peace and Conflicts Studies,* vol. **11**, pp. 55-66, (2022).
4. A. Faull, "Editorial," *Crime Quarterly,* No. **58**, pp. 3-8, (2016).
5. "Public protest and violence stats," (24 05 2022). [Online]. Available: https://issafrica.org/crimehub/maps/public-protest-and-violence-stats..
6. A. Baghani, M. Ahmadabadi and A. Harati, "Kinematics modeling of a wheel-based Pole Climbing Robot (UT-PCR)," in *IEEE International Conference on Robotics and Automation*, (2005).
7. M. Erbil, S. Prior, M. Karamanoglu, S. Odedra, C. Barlow, J. Bell and M. Brazinskas, "Design and development of a pole climbing surveillance robot," in *New Zealand Rapid Product Development Conference*, (2011).
8. Y. Guan, L. Jiang, H. Zhu, X. Zhou, C. Cai, W. Wu, Z. Li, H. Zhang and X. Zhang, "Climbot: A Modular Bio-inspired Biped Climbing Robot," in *International Conference onIntelligent Robots and Systems*, (2011).
9. M. Q. Y. G. Y. Z. H. L. Z. Su, "Climbot-Ω: A Soft Robot with Novel Grippers and Rigid-compliantly Constrained Body for Climbing on Various Poles," in *International Conference on Intelligent Robots and Systems*, Prague, (2021).
10. M. N. Ahmadabadi, H. Moradi, A. Sadeghi, A. Madani and M. Farahnak, "The evolution of UT pole climbing robots," in *1st International Conference on Applied Robotics for the Power Industry*, Montreal, (2010).