

A Vine-inspired Solution for Enhancing Safety and Efficiency in Broadband Cable Installation

Nathan Rees^{*1,2}, Sarath Kodagoda², Karthick Thiyagarajan², Sangmim Song², Yara Fakoua¹, Damian Sue¹, Chloe Judson¹, Jack Hibbard¹, Jackson Russell², Jiacheng Dong², Ray Owen¹, Eleanor Forwood³, Steve Love³, Catherine Howard³

¹UTS Telecom Research Unit, University of Technology Sydney, Australia

²UTS Robotics Institute, University of Technology Sydney, Australia

³NBN Co Limited, Australia

Abstract

Upgrading broadband networks from copper to fibre is a major focus for many developed countries. Despite their resilience, the underground pipes that house network cables are susceptible to degradation and build-up of foreign material, inhibiting the installation of new cables. The traditional methods for installing new cables remain outdated and inefficient, and can have health and safety implications for the field technicians involved. Our solution, the *Cable Rover*, addresses the urgent need for a safer and faster method of installing new cables by leveraging the adaptive growth capabilities of a vine robot to navigate complex conduit environments. The prototype developed has been tested on numerous occasions in a variety of laboratory and field conditions, with successful results demonstrating the device’s ability to significantly enhance the cable installation process for field technicians.

1 Introduction

1.1 Broadband Network Infrastructure

Broadband networks play a crucial role in delivering consistent, high-speed internet access across diverse geographic contexts, from densely populated urban centres to remote rural communities. In Australia, this responsibility is delivered by NBN Co, which owns and operates the nbn[®] network—a wholesale broadband access network for Australia. To meet growing demand, nbn is phasing out some of its copper-based fixed-line technologies, namely Fibre to the Node (FTTN) and Fibre to the Curb (FTTC). In January 2025, the organisation announced upgrade options for approximately 622,000 end-users still reliant on copper, with over 95% of those



Figure 1: The *Cable Rover* enables safer and more efficient cable installation in telecommunications pipes.

premises having the option to upgrade to full fibre via FTTP [NBN Co, 2025b]. As of July 2025, 12.58 million homes and businesses were able to connect to the nbn access network, and 4.68 million homes and businesses have either upgraded or are eligible to upgrade from FTTN and FTTC copper networks to full fibre [NBN Co, 2025a].

The physical infrastructure that houses fixed-line broadband services predominantly consists of buried pipes, helping to protect existing cables from environmental factors and facilitate the installation of new cables without expensive civil works.

In newer residential developments, referred to as “Greenfields” areas, nbn typically employs polyvinyl chloride (PVC) conduits in three standard sizes, with internal diameters of 104.9 mm (P100), 53.0 mm (P50), and 23.3 mm (P20). In contrast, more established “Brownfields” areas may contain legacy conduit materials such as terracotta, earthenware, or iron, with diameters including 39.65 mm (P35) and 14.65 mm (P10). Conduit runs are generally classified into two categories: network conduits, which connect pits along the street (sometimes extending over 100 m) and typically carry

*Corresponding author: nathan.rees@uts.edu.au

multiple thick cables to service entire neighbourhoods; and lead-in conduits, which run from pits in the street to individual premises and usually carry a single cable over a distance of about 20 m. Network conduits are usually P35 or larger, while lead-in conduits are commonly no larger than P20. Both types of conduit runs may incorporate pre-fabricated 90° bends to navigate around local geographical features and built infrastructure like roads, buildings, and other buried assets.

Environmental factors can significantly impact the structural integrity of buried pipes. Earthworks or natural shifts in soil structure may cause conduit segments to crack or become disjointed, allowing foreign material such as dirt, mud, water, tree roots, or even animals to enter the conduit and cause blockages. Foreign material can also enter from either end of the conduit, further contributing to blockages.

Although nbn specifies a maximum fill ratio of 60% for P20 conduits and 70% for P50 and P100 conduits, pipes in the field may in reality be overfilled, especially in legacy conduits and “Brownfields” areas. Consequently, heavily congested conduits pose challenges for network expansion and new connections due to the space constraints.

1.2 Existing Methods for Cable Installation

For pipe continuity inspection and cable installation, field technicians of broadband service providers worldwide typically use a semi-rigid fibreglass rod. This rod is manually pushed into the conduit in an attempt to reach the exit point, allowing a new cable or drawline to be attached and hauled back through the conduit. Reports from international telecommunications companies document the traditional use of rods for cable hauling and blockage detection within pipe networks [Asumu and Mellis, 1998] [Hayashi *et al.*, 1986] [Davies *et al.*, 2001].

Despite their widespread use, rodding techniques present several limitations. Manual operation of the rod is often inefficient, frequently requiring excessive force to advance. The propelled rod can damage existing cables within the pipe [Griffioen *et al.*, 2002], and when encountering bends, it often becomes stuck as it hits the lips of conduit and bend joints. This impedes forward movement which usually triggers a range of alternative methods including different rod sizes and tips, rodding from the other direction, or flushing the conduit with water. In some instances, field crews may incorrectly assume a blockage, prompting unnecessary excavation at end-user premises or in public spaces such as roads and footpaths.

Heavily congested pipe conditions further increase the likelihood of rods becoming stuck. Even in longer, uncongested network conduit runs exceeding tens of me-

tres, the manual force required to push the rod tends to increase significantly as it gets tangled with cables. The rod may also begin to spiral within the conduit cavity, causing a concertina effect which increases friction and mechanical resistance, demanding greater physical effort from technicians. This not only exacerbates operational delays but also raises health and safety concerns, including incidents where technicians have reported upper body injuries and longer-term body stress injuries. Challenging pipe conditions often necessitate the use of specialist equipment and may require multiple technician visits, prolonging job completion times, increasing costs, and causing frustration for affected end-users.

These limitations underscore the urgent need for more advanced and efficient methodologies for pipe inspection and cable installation within the telecommunications industry. Such approaches should aim to improve operational efficiency, reduce unnecessary costs, and better safeguard the wellbeing of field technicians. Currently, no commercially available products adequately address these limitations. A novel pipe inspection technique for buried broadband infrastructure is explored in our prior work [Rees *et al.*, 2025]. Complementing this innovation, this paper presents the development of a novel tool designed to overcome the limitations of existing rodding methods and enhance the effectiveness of cable installation in buried telecommunications conduits.

2 Related Work

2.1 In-Pipe Robotics

Numerous publications in the literature explore robotic solutions for in-pipe condition assessment and payload transportation. Several wheel-based robotic designs have been proposed [Gunatilake *et al.*, 2021] [Gunatilake *et al.*, 2022a] [Gunatilake *et al.*, 2022b], but their physical dimensions often exceed the constraints of broadband infrastructure. Even when scaled down, these robots struggle to navigate tight bends and vertical segments commonly found in telecommunications pipes. [Kazeminasab and Banks, 2022] present a fast-moving robot equipped with wall-pressing wheel modules that enable vertical climbing. Yet, like other wheeled systems, its locomotion depends on unobstructed contact with the pipe wall—a condition rarely met in buried telecommunications pipes, which are frequently congested with cables and organic debris. [Li *et al.*, 2022] introduce a tracked robot capable of transporting payloads up to 30 kg within 110 mm-diameter pipes, while [Park *et al.*, 2024] demonstrate a robot that can traverse vertical and curved pipes with diameters of 150 mm. Although promising, these designs remain too large for widespread deployment in nbn’s pipe infrastructure. Soft robotic approaches, such as the untethered design proposed by

[Wang *et al.*, 2024], offer potential for navigating smaller-diameter pipes. However, this particular solution lacks the capability to haul cables over long distances, limiting its applicability for installation tasks. [Kodagoda *et al.*, 2024] present a tethered, floatable robot designed for inspecting concrete pipe infrastructure. While effective in large-diameter pipes, its dependence on in-pipe water flow for locomotion renders it unsuitable for broadband pipes, even when miniaturised. The bio-inspired iCrawl robot by [Khan *et al.*, 2020] demonstrates strong adaptability across complex surfaces, a desirable trait for broadband conduit inspection. However, its reliance on electromagnetic feet for crawling on metallic surfaces limits its compatibility with nbn’s predominantly non-metallic conduit assets.

2.2 Vine Robots

In addition to the soft robotics approaches previously discussed, a specific class of soft robots known as “vine robots” has been explored in the literature for navigating challenging environments [Hawkes *et al.*, 2017] [Girerd *et al.*, 2024] [Kübler *et al.*, 2024]. Although existing designs are not tailored for small-diameter pipe applications of lengths upwards of 100 m, they present promising potential for adaptation to the requirements of telecommunications infrastructure.

This study builds upon principles introduced by [Hawkes *et al.*, 2017], which describe a tip-based extension mechanism achieved through the eversion of a thin-walled, inverted vessel when pressurised. By applying this concept to the confined and variable conditions of buried telecommunications pipes, we aimed to address the limitations of traditional cable installation methods.

A key advantage of vine robots is that only the tip moves during growth, resulting in no relative motion between the robot body and its surroundings [Blumenschein *et al.*, 2020]. This characteristic is particularly beneficial in buried telecommunications conduits, where movement while in constant contact with cables, pipe walls, and foreign material can generate friction that impedes mobility. Additionally, vine robots can manoeuvre through spaces narrower than their own body diameter [Blumenschein *et al.*, 2020], enabling navigation around congested cables and partial blockages. Another notable feature is the internal movement of the tubing layer within the outer body, which offers the potential to attach and transport a payload through the robot’s main structure. These principles served as the basis for designing a custom vine robot tailored to telecommunications. The remainder of this paper is structured as follows: we first describe the engineering development of the *Cable Rover* device, followed by a detailed account of the experimental methodology used to validate its performance. We then present results from both lab-based

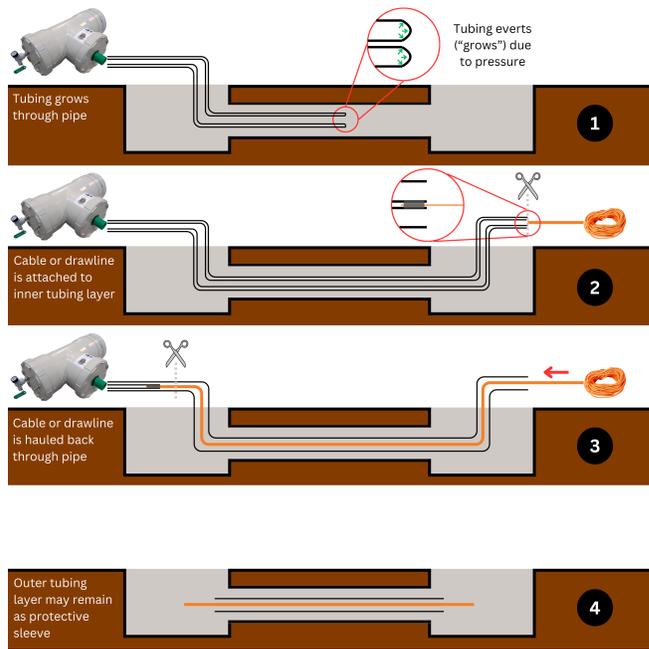


Figure 2: *Cable Rover* deployment process.

experiments and field deployments, and conclude with a summary of our findings and directions for future work.

3 Development of the Cable Rover

Building on the known principles of vine robots, we developed a custom tool named the *Cable Rover* to address the challenges of cable installation in telecommunications pipe networks. The system is designed to operate in two configurations: one for growing (deploying the soft body through the pipe) and one for hauling (retrieving a cable or drawline through the pipe). It comprises four key components: an air compressor, a pressure chamber with interchangeable fittings, a remote monitoring system for real-time performance feedback, and the flexible tubing that forms the evverting body.

As illustrated in Fig. 2, the *Cable Rover* is initially deployed in its growing configuration from a convenient location outside a pit. Once the air compressor is activated, pressure builds within the chamber, causing the flexible tubing to evert and extend forward. The tubing is manually guided into the conduit entry, after which the conduit itself constrains and directs the growth process. When the tubing emerges from the conduit exit, the compressor is turned off and the tubing is cut at its extremity. This allows the user to attach a cable or drawline to the inner tubing layer, switch the system to its hauling configuration, and retrieve the payload back through the conduit. This is achieved by attaching a drill with appropriate socket size onto the backnut fitting on the haul cap. The user can then mechanically wind the

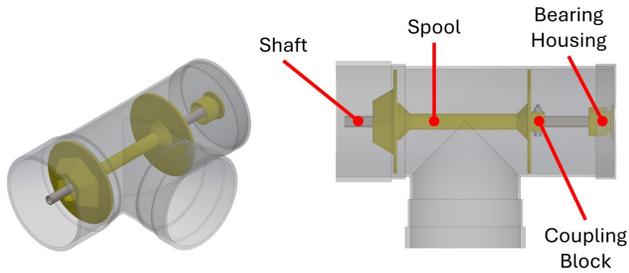


Figure 3: Transparent isometric and top views of pressure chamber with key fittings.

spool such that the tubing (and cable or drawline) is pulled back through the conduit.

3.1 Pressure Chamber and Fittings

To facilitate the growth of the soft tubing, it must be stored within a pressure chamber that enables controlled eversion through an outlet port [Hawkes *et al.*, 2017]. The chamber is constructed from readily available PVC plumbing components to ensure ease of fabrication, cost minimisation, and future scalability. Inside, the tubing is wound onto a spool that spins freely on a steel shaft supported by bearings during the growing configuration, as shown in Fig. 3. The spool, coupling block, and bearing housings are all 3D-printed using polylactic acid (PLA) material.

The chamber design includes three interchangeable end caps: the grow cap, the haul cap, and the outlet cap, as illustrated in Fig. 4. The outlet cap can remain fixed in place to allow the tubing to unspool and pass directly through the outlet port, also 3D-printed in PLA, where it is everted and secured using a custom clamp made from thermoplastic polyurethane (TPU). The grow cap is mounted on the opposite end, allowing the shaft to slide into a second bearing for support during deployment. For retraction, the grow cap is replaced with the haul cap which comprises an additional shaft fitted with backnuts on either end, which interfaces with the spool internally and a drill socket externally. This configuration enables the user to rewind the inner tubing layer back through the outer layer using a handheld drill. The grow cap also integrates a pressure module, which includes a pressure gauge, a safety relief valve set to 15 PSI (≈ 100 kPa), and an air valve for connecting an external air compressor.

3.2 Remote Monitoring System

To support real-time deployment monitoring of the *Cable Rover*, a custom-built remote monitoring system, referred to as the Cable Rover Monitoring System (CRMS), was developed. The CRMS is a compact, Wi-Fi-enabled attachment that provides live feedback on

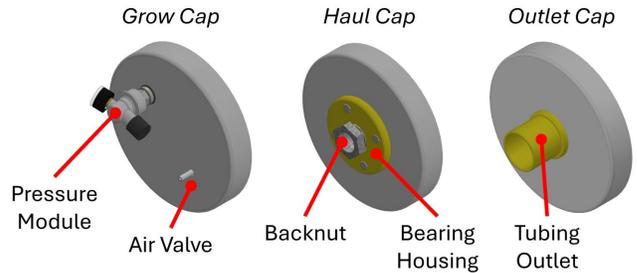


Figure 4: Isometric views of caps with key fittings.

tubing growth metrics, including distance, speed, and internal pressure.

The system is powered by a Beetle ESP32-C6 microcontroller, chosen for its small form factor and wireless capabilities. Tubing growth is measured using an IR break beam sensor mounted inside the CRMS housing, which detects pre-marked intervals on the tubing. Pressure readings are captured using a BMP180 digital pressure sensor, and battery status is indicated via onboard LEDs. All components are mounted on a custom perf-board and housed within a 3D-printed PLA enclosure that sits inside the pressure chamber’s outlet cap to read the tubing as it exits the outlet.

Users interact with the CRMS via a smartphone-accessible web interface, hosted locally on the device. Upon powering the unit, users connect to the CRMS Wi-Fi network and access the interface through a browser or NFC scan. The interface provides controls to start, pause, and reset monitoring sessions, as well as view live metrics such as pressure, tubing speed, elapsed time, and total distance everted. A settings page allows users to calibrate ambient pressure, enable sound alerts for pressure thresholds, and adjust tubing mark spacing.

The CRMS is designed for ease of use in the field. It automatically enters sleep mode after 30 minutes of inactivity and can be recharged via USB-C. During de-



Figure 5: The remote monitoring system displays readings in real-time on the web-app user interface.

ployment, the system enables technicians to monitor performance without manual intervention, improving accuracy and reducing the likelihood of over-pressurisation or mismeasurement. While the current prototype uses off-the-shelf components, the design is modular and can be adapted for future PCB integration or enclosure refinement.

3.3 Flexible Tubing

Most vine robots utilise low-density polyethylene (LDPE) to form the main flexible body tube [Coad *et al.*, 2020]. Although LDPE is appealing due to its availability and partial recyclability, initial prototyping revealed drawbacks for our application, most notably its tendency to rip or tear in the harsh conditions of pit and pipe infrastructure.

As a result, we investigated alternative tubing materials to identify a more durable solution. [Blumenschein *et al.*, 2020] explore a range of potentially suitable alternatives, while [Naclerio and Hawkes, 2020] demonstrate the viability of coated ripstop nylon as a tubing material. Based on these findings, lengths of this nylon tubing up to approximately 7 m were fabricated in the laboratory using an impulse heat sealing machine to bond the polyurethane (PU) coating.

Lab and field testing showed a significant increase in robustness, allowing the same tubing to be reused multiple times without failure. However, the manual fabrication process proved tedious and prone to defects, often resulting in imperfect seals and leakage. Additionally, the material is not commercially available in tubing form, but rather as flat sheets, necessitating the manual fabrication process described above.

Consequently, this material was abandoned, and the *Cable Rover* now uses recyclable LDPE as its flexible tubing. For deployments involving the CRMS, LDPE tubing with solid black markings at regular, predetermined intervals is used to enable accurate growth sensing. LDPE tubing is available in various flat widths and thickness gauges, some of which were explored during experimentation.

4 Experimental Methodology

Controlled laboratory experiments were conducted to evaluate the performance of the *Cable Rover*'s growth under various pipe conditions. All tests were performed using a 6 m-long P50 conduit laid in a straight configuration without bends to isolate the effects of internal congestion and blockages. The chamber was pressurised using an Ozito handheld air compressor with a flow-rate of 12 L/min.

Tests were conducted using two sizes of LDPE tubing; flat width of 60 mm and 75 mm, both with a thickness of 75 microns. To simulate cable congestion, up

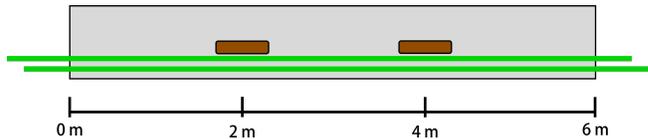


Figure 6: Laboratory experimental setup. Cutaway view of P50 conduit, showing two cables and two blockages.

to two 10 mm-diameter telecommunications cables were used in some tests. Up to two identical partial blockages were also introduced using plastic bags filled with dirt, each taking up approximately 15% of the conduit's cross-sectional area and placed at 2 m and 4 m from the start of the conduit, as seen in Fig. 6. These blockages were designed to mimic common in-field obstructions.

The *Cable Rover* was set up in its growing configuration. As the air compressor was turned on and the tubing began to evert, it was manually guided into the conduit. Data was collected regarding the pressure inside the chamber, growth distance, and time. The tubing was considered to have successfully traversed the conduit when it emerged from the conduit exit. Test conditions varied across three main categories: no congestion (baseline tests with no cables or blockages), cable congestion (tests with one or two cables pre-installed in the conduit), and partial blockage congestion (tests with one or two artificial blockages placed at 2 m and 4 m).

The following equations can be used to calculate the expected growth rate of the LDPE tubing in uncongested conduit conditions. It is important to remember that the conduits into which the *Cable Rover* will be deployed are constrained environments, meaning the real-world growth rates will likely be impacted based on the varying degree of constraint in each unique situation.

$$V_L = \frac{FW^2 l}{1000 \pi} \quad (1)$$

$$V_{L,1m} = \frac{FW^2}{1000 \pi} \quad (2)$$

Using (1) we can calculate the volume V_L in litres of a given length of tubing l , based on its flat width FW in millimetres. To determine the volume in litres of a 1 m length of tubing, we can use (2).

$$v = \frac{Q}{60 V_{L,1m}} \quad (3)$$

$$v = \frac{1000 \pi}{60} \frac{Q}{FW^2} \quad (4)$$

Using (3) we can calculate the growth rate v in metres per second, based on the volume per metre $V_{L,1m}$ of a given tubing and flow rate Q in litres per minute of the air compressor being used. Combining all variables, we

Tubing Flat Width (mm)	Air Compressor Flow Rate (L/min)	Growth Rate (m/s)	Time to Grow 10m (min:sec)
60	10	0.145	1:09
	12 (Ozito)	0.175	0:57
	20	0.291	0:34
	30	0.436	0:23
	40	0.582	0:17
75	10	0.093	1:47
	12 (Ozito)	0.112	1:30
	20	0.186	0:54
	30	0.279	0:36
	40	0.372	0:27

Table 1: LDPE tubing growth rates calculated based on common handheld air compressor flow rates.

can use (4) to easily determine the growth rate of a given tubing flat width.

Table 1 presents calculated growth rates based on flow rates of air compressors commonly found on the market, including the Ozito air compressor used when conducting lab experiments. We sought to validate these calculations as part of the experimental methodology.

5 Results

5.1 Baseline Performance

Baseline tests were conducted using the laboratory P50 conduit with no cables or blockages to evaluate the pressure and growth characteristics of the *Cable Rover* with two tubing sizes: 60 mm and 75 mm flat width LDPE. Figure 7 shows the pressure profiles over four tests; each tubing size deployed in the conduit with no congestion (baseline test, denoted by the blue traces), as well as the maximum tested congestion of two cables and two partial blockages (denoted by the green traces) over the 6 m deployment distance. The naming convention is as follows: *tubing size–number of cables–number of blockages*. The results of each test are captured in Table 2.

The 60 mm tubing’s baseline profile exhibited a gradual pressure increase to approximately 6.6 kPa within the first 1.6 m, where the pressure remained stable for the remainder of the conduit. In contrast, the 75 mm tubing showed a steeper initial pressure rise, reaching 5.0 kPa by 1.0 m, and continued to fluctuate, peaking at 6.2 kPa at 2.5 m. This indicates that while the larger tubing doesn’t necessarily require more pressure to maintain eversion, the pressure instability may lead to unpredictable growth patterns. This is likely due to its greater internal volume and surface contact area with the environment.

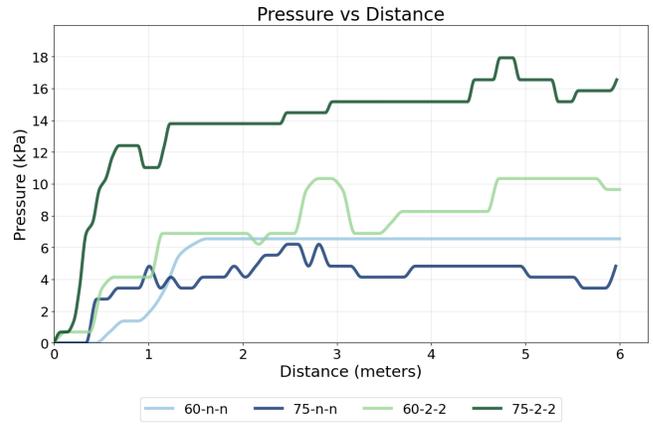


Figure 7: Pressure vs. distance for 60 mm and 75 mm tubing across baseline (blue) and highest congestion (green) tests.

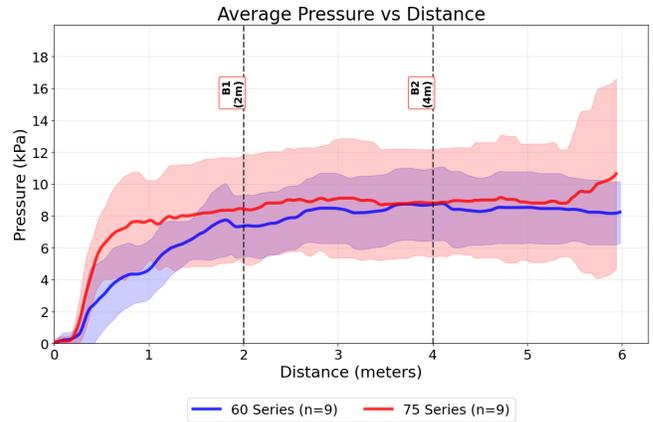


Figure 8: Average pressure vs. distance for 60 mm and 75 mm tubing across all test conditions. Shaded regions represent pressure variance across trials.

Growth rate calculations based on (3) predicted higher rates for the 60 mm tubing under ideal conditions. Experimental results confirmed this trend, with the 60 mm tubing achieving an average growth rate of 0.148 m/s compared to 0.119 m/s for the 75 mm tubing. These findings validate the theoretical model and highlight the trade-off between tubing size and pressure efficiency in uncongested environments.

5.2 Effects of Congestion

Figure 8 presents the average pressure profiles for both tubing sizes across all test conditions. The shaded regions represent the pressure variance, defined as one standard deviation from the mean, indicating the degree of fluctuation across different congestion scenarios. Vertical markers at 2 m and 4 m correspond to the locations of artificial blockages.

For the 60 mm tubing, congestion resulted in moderate increases in pressure and slight reductions in growth rate. The most congested configuration (two cables and two partial blockages) showed a peak pressure of 10.3 kPa and an average of 7.3 kPa, with a corresponding growth rate of 0.128 m/s. Compared to the baseline (5.4 kPa average, 0.148 m/s), this represents a 35% increase in average pressure and a 13.5% decrease in growth rate. The pressure profile remained relatively stable across the conduit length, with variance increasing slightly near the blockage locations, suggesting localised resistance and variability in tubing behaviour under congestion.

The 75 mm tubing was more sensitive to congestion. Under full congestion, peak pressure reached 17.9 kPa and average pressure rose to 13.7 kPa, with a growth rate dropping to 0.068 m/s, a 234% increase in average pressure and a 43% decrease in growth rate compared to the baseline (4.1 kPa average, 0.119 m/s). The pressure trace showed a more pronounced rise and greater variance near the blockage locations, indicating increased resistance and inconsistency in eversion performance under constrained conditions.

Qualitatively, the 60 mm tubing demonstrated greater resilience in navigating congested conduits, maintaining more consistent pressure and growth performance. It required less manual intervention and exhibited fewer stalls. In contrast, the 75 mm tubing, while capable of completing the traversal, showed higher pressure demands and more frequent interruptions, suggesting reduced adaptability in the presence of obstructions.

5.3 Field Deployments and Learnings

A series of field trials were conducted with nbn field technicians and engineers to evaluate the performance, robustness, and usability of the *Cable Rover* prototype. These trials spanned a variety of conduit sizes (P35, P50, P100) and environmental conditions across both active “Brownfields” and “Greenfields” areas, with examples illustrated in Fig. 9.

One of the most successful deployments occurred in Lindfield, NSW, where the *Cable Rover* traversed a 62 m P50 conduit containing two cables. Despite muddy and waterlogged conditions, the system reached the target pit in just 16 minutes. The tubing displaced a significant volume of water during inflation, and by the time it emerged at the exit pit, it was fully submerged (Fig. 10b). A drawline was then attached and hauled back using a drill and haul cap, demonstrating the system’s effectiveness in long-distance hauling and resilience in wet environments.

However, a subsequent deployment at the same site into a shorter 28 m P50 conduit revealed limitations. Reused tubing failed to reach the target pit, likely due to punctures or tears that prevented proper inflation.

Tubing Flat Width (mm)	Cables Present	Blockages Present	Pressure (kPa)		Growth Rate (m/s)
			Max	Avg	
60	None	None	6.6	5.4	0.148
		1	13.8	9.9	0.130
		2	9.7	6.9	0.126
	1	None	6.9	4.8	0.137
		1	11.7	6.7	0.121
		2	7.6	5.5	0.120
	2	None	7.6	5.9	0.121
		1	13.8	9.9	0.130
		2	10.3	7.3	0.128
75	None	None	6.2	4.1	0.119
		1	6.9	6.0	0.130
		2	8.3	6.6	0.094
	1	None	6.9	5.9	0.091
		1	13.8	8.9	0.104
		2	9.7	7.6	0.115
	2	None	6.9	6.0	0.092
		1	27.6	15.9	0.085
		2	17.9	13.7	0.068

Table 2: Pressure measurements and growth rates during *Cable Rover* deployment across various pipe configurations.

During retrieval, the LDPE tubing snapped under excessive force, possibly caused by bunching or a blockage. This highlighted the risks associated with reusing tubing and the importance of assessing tubing integrity before redeployment.

At another site in Lindfield, the *Cable Rover* successfully traversed a 52 m P50 conduit in 11 minutes. In contrast, an attempt to deploy the same 60 mm flat-width tubing into a congested P35 conduit in nearby Killara failed due to spatial constraints. The tubing could not enter the conduit, underscoring the need to match tubing dimensions to conduit size and cable congestion levels.

Further trials in Albion Park, NSW, introduced a high-flow Milwaukee air compressor with a flow rate of 40 L/min, significantly improving deployment speed. In a P100 conduit with high cable congestion (approximately 50% of the cross-sectional area), the tubing reached 60 m before bursting, likely due to pressure buildup from a substantial blockage. Conversely, a nearby deployment in a less congested P100 conduit was successful, allowing technicians to haul drawline through the conduit, as seen in Fig. 11.

Following these joint trials with UTS researchers and nbn personnel, five *Cable Rover* prototypes were distributed to nbn field technicians across New South Wales, Queensland, and Victoria for use in active jobs over a three-month period. One notable success occurred in Victoria, where technicians faced a short 5 m con-



Figure 9: Examples of deployments in active nbn conduits of size (a) P100, and (b) P50.

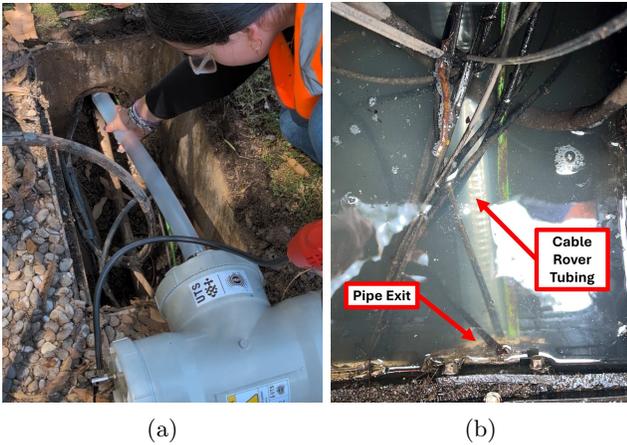


Figure 10: The *Cable Rover* successfully grew through (a) P100 earthenware conduits, and (b) waterlogged P50 conduits and pits.

duit with two bends forming a “U-bend”. Initial rodding methods failed and would have triggered the need to source specialised equipment, but the *Cable Rover* enabled rapid deployment and drawline hauling. Another job in New South Wales involved a 92 m P100 conduit that previously required specialised equipment and significant manual effort. The *Cable Rover* traversed the conduit in minutes, substantially reducing technician strain and improving operational efficiency.

Technician feedback across trials indicated that while the *Cable Rover* was less preferred for simple jobs due to setup time, it consistently outperformed manual rodding in complex scenarios involving long runs, bends, or partial blockages. Its air-powered deployment and drill-assisted hauling reduced physical strain and demonstrated clear operational advantages in challenging environments.



Figure 11: Field technicians successfully hauled drawline through conduits.

6 Conclusion and Future Work

This paper presented the development and evaluation of the *Cable Rover*—a vine robot-inspired tool designed to improve cable installation in underground broadband conduits. By addressing the limitations of traditional rodding methods, the *Cable Rover* offers a safer, more efficient alternative for field technicians working in complex and congested pipe environments.

We reviewed existing technologies in in-pipe robotics and soft robotic systems, identifying vine robots as a promising foundation for our design. Building on these principles, we developed a modular system comprising a pressure chamber, flexible tubing, and a remote monitoring system. Laboratory experiments validated the theoretical growth models and demonstrated the system’s adaptability across varying congestion levels. Field deployments further confirmed the *Cable Rover*’s robustness and usability, with successful traversals in conduits up to 92 m long under challenging conditions.

Future work will focus on transforming the *Cable Rover* into a fully autonomous robotic platform. This includes integrating sensing capabilities, such as tip-mounted sensors or embedded modules, to enable real-time perception of internal conduit conditions. Techniques like acoustic reflectometry may be incorporated to enhance blockage detection, classification, and localisation. These advancements will support the development of a comprehensive mapping and inspection tool, empowering broadband service providers to perform installations and diagnostics with greater precision, safety, and efficiency.

References

- [Asumu and Mellis, 1998] D. E. Asumu and J. Mellis. Performance in Planning — Smart Systems for the Access Network. *BT Technology Journal*, 16(4):138–151, 1998.
- [Blumenschein *et al.*, 2020] Laura H. Blumenschein, Margaret M. Coad, David A. Haggerty, Allison M.

- Okamura, and Elliot W. Hawkes. Design, Modeling, Control, and Application of Everting Vine Robots. *Frontiers in Robotics and AI*, 7, 11 2020.
- [Coad *et al.*, 2020] Margaret M. Coad, Laura H. Blumenschein, Sadie Cutler, Javier A. Reyna Zepeda, Nicholas D. Naclerio, Haitham El-Hussieny, Usman Mehmood, Jee-Hwan Ryu, Elliot W. Hawkes, and Allison M. Okamura. Vine Robots. *IEEE Robotics & Automation Magazine*, 27(3):120–132, 9 2020.
- [Davies *et al.*, 2001] Martin Davies, Chris Esbester, Ralph Sutehall, Phil Barker, and Dave Bastin. Advances in Blown Cable Technology: The Development and Life Cycle Analysis of a High Density Optical Fibre Cable. Technical report, 2001.
- [Girerd *et al.*, 2024] Cédric Girerd, Anna Alvarez, Elliot W. Hawkes, and Tania K. Morimoto. Material Scrunching Enables Working Channels in Miniaturized Vine-Inspired Robots. *IEEE Transactions on Robotics*, 40:2166–2180, 2024.
- [Griffioen *et al.*, 2002] Willem Griffioen, W Greven, and T Pothof. A New Fiber Optic Life for Old Ducts. 2002.
- [Gunatilake *et al.*, 2021] Amal Gunatilake, Lasitha Piyathilaka, Antony Tran, Vinoth Kumar Vishwanathan, Karthick Thiyagarajan, and Sarath Kodagoda. Stereo Vision Combined With Laser Profiling for Mapping of Pipeline Internal Defects. *IEEE Sensors Journal*, 21(10):11926–11934, 5 2021.
- [Gunatilake *et al.*, 2022a] Amal Gunatilake, Sarath Kodagoda, and Karthick Thiyagarajan. A Novel UHF-RFID Dual Antenna Signals Combined With Gaussian Process and Particle Filter for In-Pipe Robot Localization. *IEEE Robotics and Automation Letters*, 7(3):6005–6011, 7 2022.
- [Gunatilake *et al.*, 2022b] Amal Gunatilake, Sarath Kodagoda, and Karthick Thiyagarajan. Battery-Free UHF-RFID Sensors-Based SLAM for In-Pipe Robot Perception. *IEEE Sensors Journal*, 22(20):20019–20026, 10 2022.
- [Hawkes *et al.*, 2017] Elliot W. Hawkes, Laura H. Blumenschein, Joseph D. Greer, and Allison M. Okamura. A soft robot that navigates its environment through growth. *Science Robotics*, 2(8), 7 2017.
- [Hayashi *et al.*, 1986] F. Hayashi, Y. Yuki, and T. Watanabe. Optical Fiber Cable Installation Techniques. *IEEE Journal on Selected Areas in Communications*, 4(5):661–668, 8 1986.
- [Kazeminasab and Banks, 2022] Saber Kazeminasab and M. Katherine Banks. SmartCrawler: A Size-Adaptable In-Pipe Wireless Robotic System with Two-Phase Motion Control Algorithm in Water Distribution Systems. *Sensors*, 22(24):9666, 12 2022.
- [Khan *et al.*, 2020] Muhammad Bilal Khan, Thirawat Chuthong, Cao Danh Do, Mathias Thor, Peter Billeschou, Jorgen Christian Larsen, and Poramate Manoonpong. ICrawl: An Inchworm-Inspired Crawling Robot. *IEEE Access*, 8:200655–200668, 2020.
- [Kodagoda *et al.*, 2024] Sarath Kodagoda, Vinoth Kumar Viswanathan, Karthick Thiyagarajan, Antony Tran, Sathira Wickramanayake, Steve Barclay, and Dammika Vitanage. Robotics and Sensing for Condition Assessment of Wastewater Pipes. In *Infrastructure Robotics*, pages 243–261. Wiley, 1 2024.
- [Kübler *et al.*, 2024] Alexander M. Kübler, Cosima du Pasquier, Andrew Low, Betim Djambazi, Nicolas Aymon, Julian Förster, Nathaniel Agharese, Roland Siegwart, and Allison M. Okamura. A Comparison of Pneumatic Actuators for Soft Growing Vine Robots. *Soft Robotics*, 5 2024.
- [Li *et al.*, 2022] Jie Li, Feng Huang, Chunlei Tu, Mengqian Tian, and Xingsong Wang. Elastic Obstacle-Surmounting Pipeline-Climbing Robot with Composite Wheels. *Machines*, 10(10):874, 9 2022.
- [Naclerio and Hawkes, 2020] Nicholas D. Naclerio and Elliot W. Hawkes. Simple, Low-Hysteresis, Foldable, Fabric Pneumatic Artificial Muscle. *IEEE Robotics and Automation Letters*, 5(2):3406–3413, 4 2020.
- [NBN Co, 2025a] NBN Co. How we’re tracking: July 2025. 7 2025.
- [NBN Co, 2025b] NBN Co. NBN Co announces upgrades for remaining homes and businesses on Fibre to the Node, 1 2025.
- [Park *et al.*, 2024] Jeongyeol Park, Tuan Luong, and Hyungpil Moon. Development of a Wheel-Type In-Pipe Robot Using Continuously Variable Transmission Mechanisms for Pipeline Inspection. *Biomimetics*, 9(2):113, 2 2024.
- [Rees *et al.*, 2025] Nathan Rees, Sarath Kodagoda, Damian Sue, Yara Fakoua, Ray Owen, Eleanor Forwood, Steve Love, and Catherine Howard. A Novel Deep Learning Approach for Non-Invasive Condition Assessment of Broadband Pipes. In *2025 IEEE 20th Conference on Industrial Electronics and Applications (ICIEA)*, pages 1–6. IEEE, 8 2025.
- [Wang *et al.*, 2024] Wenbiao Wang, Xin Wang, Gang Zheng, Rui Chen, Zean Yuan, Jincheng Huang, Ke Wu, and GuanJun Bao. A Modular Soft Pipe-Climbing Robot With High Maneuverability. *IEEE/ASME Transactions on Mechatronics*, 29(6):4734–4743, 12 2024.