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MINI REVIEW

Design of ROSES Application to Endocranial Procedures with AI Help

Guido Danieli[1,2*], Salvatore De Rosa[3], Olindo Di Benedetto[4], Pasquale Francesco Greco[2], Ciro Indolfi[5], Gabriele Larocca[2], Stefano Loizzo[2], Massimo Massetti[6], Emanuele Tinelli[3], Giovanni Tinelli[6], Umberto Sabatini[3], Yamume Tshomba[6]

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Abstract

This article presents the application of the ROSES system in intracranial procedures, integrating artificial intelligence (AI) to enhance precision and safety. The system uses advanced robotic actuators and disposable tools to manage microcatheters and guidewires, enabling efficient stent placement while minimizing contact with aneurysms. By leveraging angiographic data to create 3D vascular models, the AI determines optimal pathways, calculates stent dimensions, and identifies critical curvatures. This approach allows for automated or manual intervention based on procedural requirements, reducing the need for physician presence during high-risk stages. The innovation significantly lowers radiation exposure and improves procedural outcomes in complex intracranial surgeries, offering a promising step toward more autonomous endovascular systems. Importantly, this system reduces the necessity for a doctor to be physically present with the patient, as the AI and robotic components can manage much of the procedure remotely. This advancement could greatly enhance the efficiency and safety of medical procedures.

Key Words: *Robotic-assisted endocranial surgery; Endovascular brain aneurysm treatment; Radiation-free neuro-radiology*

[1]*Department of Mechanical, Energy, and Management Engineering (DIMEG), Calabria University, Rende, Italy*

[2]*Calabrian High Tech (CHT) S.r.L, Rende, Italy*

[3]*Division of Cardiology, Department of Medical and Surgical Sciences, Magna Graecia University, Germaneto, Italy*

[4]*AOU Dulbecco, Catanzaro, Italy*

[5]*Universita Della Calabria, Rende, Italy*

[6]*Universita del Sacro Cuore-Istituto Gemelli, Largo Agostino Gemelli, Rome, Italy*

[*]*Corresponding author: Guido Danieli, Professor, Department of Mechanical, Energy, and Management Engineering (DIMEG), Calabria University, Ponte Bucci Cubo 46C, 87036 Rende, Italy, E-mail: danieli@unical.it*

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Introduction

Minimally invasive surgeries, such as laparoscopy, orthopedic, and spine procedures, have revolutionized patient care by reducing surgical risks, recovery times, and healthcare costs [1-5]. Despite the widespread adoption of robotic systems in these fields [6-10], their application in endovascular procedures remains limited. High costs, technical challenges, and restricted usability often confine their use to specialized systems, such as CorPath by Corindus, which was designed for angioplasty but is presently under modification with the addition of elements by Siemens [11-16], and Robocath [17], which were designed for angioplasty, or the Magellan system by Hansen Medical [18-21], developed for broader endovascular surgeries. These systems primarily function as master-slave devices, requiring constant operator input without leveraging autonomous capabilities.

In endovascular brain procedures, such as aneurysm treatments, the risks are amplified by the need for prolonged radiation exposure during fluoroscopy and the physical demands placed on neuro-radiologists. Protective lead aprons reduce radiation exposure but contribute to chronic spine issues [22-33]. Manual catheter manipulation, often preferred by practitioners for its tactile feedback, offers limited precision in quantitative measurements, such as stenosis length or force applied during catheter advancement. Robotic systems, in contrast, provide measurable feedback and precise control, yet their adoption is hindered by cost and complexity [34,35].

The ROSES system, also initially tested on angioplasty (Figure 1), aims to address these limitations by integrating artificial intelligence (AI) with robotic-assisted technology to perform intracranial interventions. Unlike existing systems, ROSES combine simple, cost-effective disposables with advanced robotic actuators and AI algorithms. This approach minimizes radiation exposure and physical strain on doctors, enabling greater procedural precision and safety. By incorporating AI to map optimal catheter pathways and automate key tasks, the system enhances operator efficiency and reduces the need for direct physical presence during critical stages.

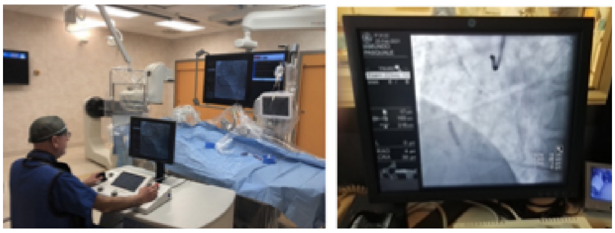

Figure 1) *The angioplasty clinical trials.*

This article focuses on the innovative design of the ROSES system, emphasizing its unique integration of AI for stent placement and aneurysm management. The following sections outline the technical composition of the system, its potential impact on clinical outcomes, and the path toward its implementation in routine medical practice.

A brief description of the ROSES system

The core of the ROSES system is a gear train composed of three large gears and a rotation frame fixed to the first gear. The second and third gears are hollow and internally toothed. Two shafts fixed to internal planets mesh with the internal toothing of the hollow gears and are hinged to the main gear and the rotating frame. These shafts extend from the “mother gear,” which also holds two bevel gears designed to transmit motion to the disposables. Figure 2 illustrates the initial scheme, using colors to highlight the motion chain, which now begins with motors.

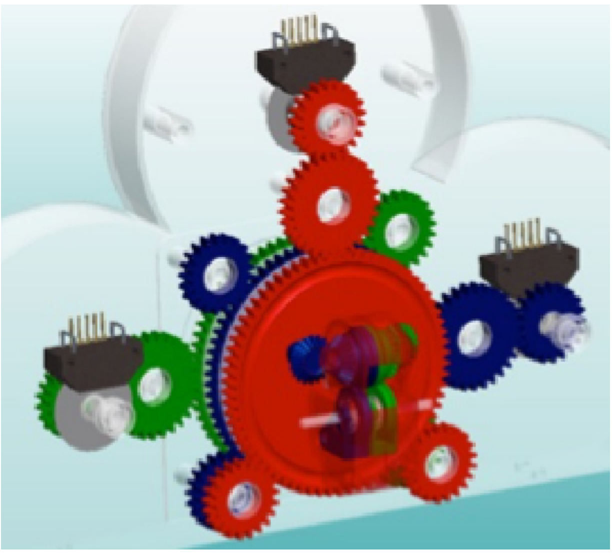

Figure 2) *The basic mechanism of our gear train with three degrees of control.*

This gear train is central to each Robotic Actuator (RA), which may include one or two rotating frames, depending on the task. The RAs are mounted on low-friction slides inclined toward the patient. The proximal RA is secured to another slide with lateral bars that hold the motors, enabling controlled motion between RAs via toothed belts. To prevent the system from falling onto the patient, wires connect it to fixed points, counterbalanced by weights. A force sensor measures the residual g-component of the rail's load. If resistance is encountered, such as from the catheter meeting an obstruction the system detects it through changes in weight distribution, flagging potential dangers (Figure 3).

Figure 3) *The new cart under construction.*

The first RA is primarily dedicated to introducing the initial catheter, working in tandem with the second RA, which holds the hemostatic valve and introductory catheter on a rotating plate. During this phase, the second RA moves toward the first RA, while the internal planet gear handles the guide wire. After catheter introduction, the gear train shifts focus to the main procedure. Various disposables have been designed for ROSES, including a nearly universal disposable initially created for angioplasty but adaptable for brain applications. Figure 4 highlights the disposable's spring-loaded frame, which adjusts to different catheter or guide wire sizes.

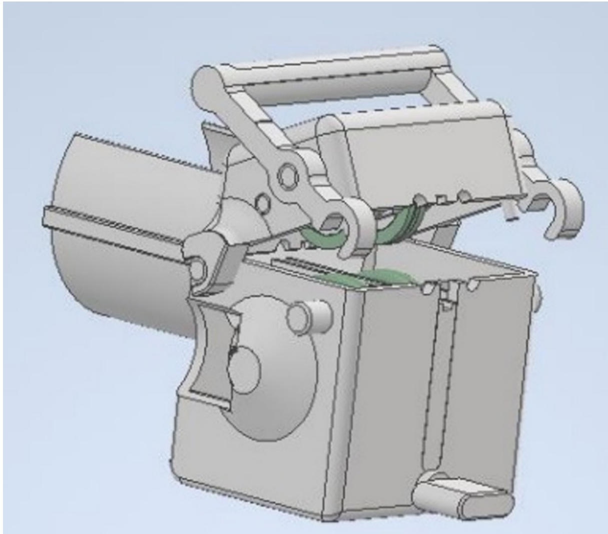

Figure 4) *The new almost universal disposable initially designed for angioplasty.*

For brain procedures, a specially designed catheter with a 4 mm turning radius navigates sharp arterial bends. Available in three sizes for guide wires of 0.017", 0.021", and 0.027", the catheter integrates two lumens: one for the guide wire and brain stent, and another for a nylon wire. Wedge-shaped cuts along the nylon wire create flexibility for precise control. The catheter's curvature mechanism is attached to the third RA's rotating frame, enabling fine-tuned adjustments during insertion. As far as the direction in which the catheter turns, it is known since rotations are controlled counting steps from a reference position. The hemostasis valve prevents blood leakage and ensures proper contrast liquid delivery into the intracranial circulation (Figure 5).

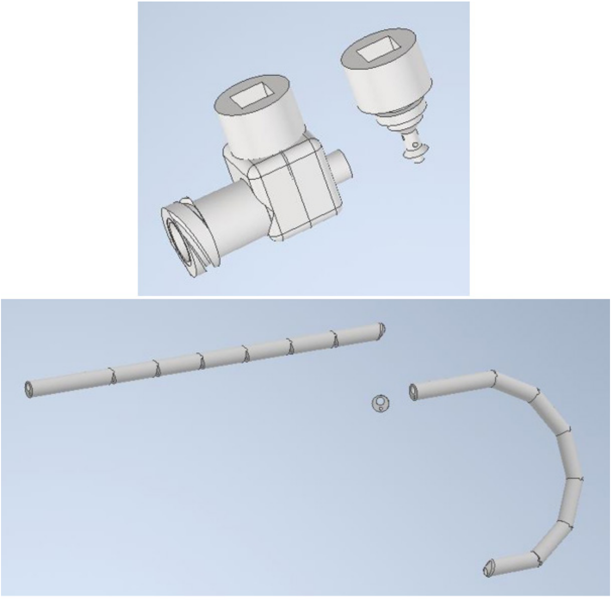

Figure 5) *Catheter with controlled tip curvature for brain procedures on the left the control mechanism containing the drum that pulls the internal wire, on the right, the catheter tip, straight and bent.*

Use of AI to guide the progression of the catheters inside the brain arteries

In procedures such as brain aneurysm treatment, the process begins with the doctor navigating the catheter to the carotid artery. At this point, an initial CT scan of the skull is taken, followed by the injection of contrast fluid for a second scan that visualizes the intracranial vascular system. The operator then marks three key points: the catheter's starting position in the carotid artery, the beginning of the stent's placement, and its intended endpoint.

Using this input, the AI system calculates the optimal path for the catheter by determining the central coordinates of the arterial section within the angiograph's reference system. Starting a few millimeters beyond the initial point, the AI maps a trajectory through successive points until reaching the endpoint. While operators could manually perform these tasks using the angiographer's program, the AI significantly accelerates and automates the process across the entire brain arterial system [36-45].

By analyzing the vascular path, the AI identifies key parameters such as the minimum section, the shortest radius of curvature, and the precise length of the stent required. In cases where a sharp directional change occurs near an aneurysm, the system interpolates additional intermediate points to create a curve compatible with the anatomy of the intracranial circle, ensuring a safe and efficient trajectory.

Figure 6 illustrates the AI's calculated path overlaid on the original angiographic image of the intracranial circle. These visual highlights the precision and adaptability of the AI system in mapping catheter progression.

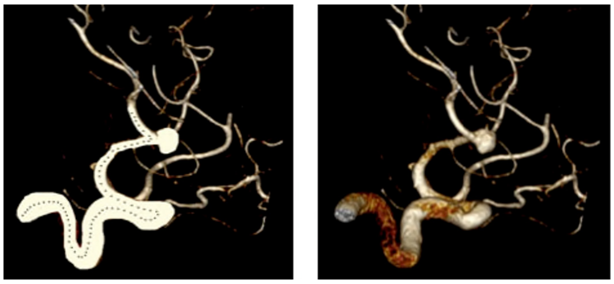

Figure 6) *The AI simulated intervention.*

Once the coordinates of the path are defined, the system advances the micro-guide wire followed by the microcatheter. The system pauses at predefined intervals or when the operator raises concerns about the trajectory. For procedures using the animated catheter, such stops are rarely necessary, as the computed path ensures reliable guidance. This approach offers a stark contrast to traditional manual advancement, which lacks the precision and predictive capabilities of the AI-guided system.

By automating critical steps and providing real-time data, the ROSES system demonstrates a significant advancement in safety and efficiency for intracranial procedures, reducing the reliance on manual intervention while offering a layer of oversight for operators.

Next Steps

We have already collected multiple 3D representations of the endocranial circle from angiographic scans. Using tools like Altair's generative software, we will process these data as previously described. In parallel, the Python program required to control the various procedures often involving three motors operating under separate controllers is in active development. Meanwhile, the physical construction of the robotic actuators is progressing.

Once the system is ready, we will employ the Python library opedSCAD to generate a precise 3D model of the endocranial circle. This model will be used to build a transparent replica, complete with extra stabilizing legs. These features will allow the model to be positioned on a horizontal plane, ensuring that each point corresponds accurately to the angiographic coordinates. To guarantee correct alignment of the system, we will include an initial rigid tube, precisely aligned with the carotid's entry portion, to validate the guide wire tip curvature in a vertical plane. With these elements in place, we can begin in vitro demonstrations to verify the automatic system's functionality. This progression lays the groundwork for eventual in vivo testing [46-52].

Conclusion

With foundational development nearing completion, we are ready to test the ROSES system across various applications. By the end of January, the first complete prototype, integrating both software and hardware, will be finalized and prepared for in vitro trials. Our work has been protected by multiple patent applications, many of which are set for global extension.

In parallel, we are developing a "black box" version of the system, which will encapsulate the technology while safeguarding its proprietary design. This effort ensures that the system's innovative capabilities such as AI-guided catheter navigation akin to following the "small stones" of Tom Thumb can revolutionize intracranial interventions, reducing radiation exposure and enhancing procedural precision.

These steps represent a pivotal moment in advancing automated and AI-integrated solutions for complex endovascular procedures. We are committed to refining and expanding this technology to benefit patients and healthcare providers worldwide.

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