Building reliable healthcare robots ›

The importance of redundancy systems

Healthcare

WHITEPAPER

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Executive summary

In the rapidly evolving field of healthcare robotics, precision, reliability, and safety are essential. Any failure in a robotic system during medical and paramedical procedures can have serious consequences, making robust redundancy systems critical for medical robots. This whitepaper explores how redundancy plays a key role in ensuring operational safety, particularly in environments where even slight deviations can affect patient outcomes.

Redundancy systems in robotics serve as multiple layers of backup to ensure early detection of potential issues. By incorporating multiple backup systems, such as controllers, and braking mechanisms, redundancy ensures that the robot recognizes potential issues early, stops if necessary, and maintains its intended path. These safety measures improve both reliability and safety, helping healthcare professionals deliver precise and consistent care.

PULSAR, a cutting-edge medical robot, exemplifies this approach by integrating advanced redundancy systems that improve reliability and safety across various applications, from laser dermatology to rehabilitation and diagnostic imaging. By embedding these protections into its core design, PULSAR not only minimizes the risk of errors but also provides healthcare professionals with the confidence to perform tasks with heightened reliability.

As healthcare robotics continues to advance, the importance of redundancy systems will only increase. These systems not only improve the reliability and performance of medical robots but also help healthcare providers achieve better patient outcomes, making them an indispensable part of the future of healthcare.

1. The importance of redundancy in Healthcare Robotics

In healthcare, reliability, and safety are fundamental to ensuring patient well-being and successful outcomes. As robotics technology continues to evolve, it has the potential to revolutionize the way medical tasks are performed, bringing improvements in accuracy, consistency, and overall efficiency. From diagnostic imaging to rehabilitation, robotic systems can offer enhanced precision and control in procedures that are traditionally prone to human error or physical limitations. However, while these advancements bring exciting opportunities, they also introduce the challenge of ensuring system reliability in critical environments. A malfunction during key moments can lead to harm to patients or healthcare providers, making safety a top priority in the design of medical robots.

Redundancy plays a crucial role in addressing these safety concerns. By incorporating multiple layers of backup systems, a robot can detect potential failures before they result in errors. Redundancy not only prevents failures but also enhances the robot's overall reliability, ensuring a consistent performance in healthcare environments. The PULSAR robot exemplifies this principle by embedding comprehensive redundancy into every aspect of its design. From its collision detection mechanisms to its dual controllers and brake systems, PULSAR ensures that if any part of the system experiences a fault, the robot will stop immediately to prevent harm. This approach guarantees that patient and operator safety is never at risk.

2. Understanding the building blocks: Key components of a robot

BizLink PULSAR robotic arm

To fully appreciate how robotic systems function, let's dive into the key components that make up a robot. Each of these components plays a vital role in ensuring precise and safe operation.

Joints

Joints are essential components that enable movement in a robot. They are the movable connections between different segments or links, allowing for rotation and articulation. Joints can have various types of motion, for example, rotational (hinge joints) or translational (sliding joints). The design of joints significantly influences the robot's range of motion and capabilities. For example, a robotic arm may utilize hinge joints for bending and rotating, while a mobile robot might use ball-and-socket joints for multidirectional movements.

Components inside every joint

Actuators:

What they are: Devices that convert electrical energy into mechanical movement.
How they work: Actuators control the motion of the robot's joints, enabling precise positioning and movement. They respond to electrical signals by driving the joints and limbs to perform specific tasks. Common types of actuators include electric motors, which provide controlled rotational or linear movement, and pneumatic actuators, which use compressed air to generate motion.
Gears, as a key component of actuators, play a critical role in the functionality of the joints by adjusting output speed and torque. They allow for precise movements, where depending on the gear ratio, a small turn of the motor translates into a highly controlled, small movement of the joint.

Encoders:

What they are: Devices that measure the position and speed of a robot's joints.
How they work: Encoders provide constant feedback to ensure the robot's movements are accurate.
There are two main types of encoders:
Incremental encoders: These track how far and how quickly a joint moves, but they only measure changes from the last position. This means the robot needs to know its starting position to calculate movement.
Absolute encoders: These give a unique, fixed position for each joint at all times, so the robot always knows exactly where it is, even after being turned off.

Brakes:

What they are: Mechanisms that stop the robot's movements when necessary and/or maintain the joints in a defined position.
How they work: Brakes ensure the robot can stop safely and precisely. Electromagnetic brakes are used for rapid stopping by using an electric current to create a magnetic field, which engages the brake. Mechanical brakes, often powered by springs, act as a failsafe in case of power loss, locking the joint in place to prevent unintended movement.

Electronic cards:

What they are: Printed circuit boards located at each joint.
How they work: Printed circuit boards (PCBs) located at each joint that handles data processing and control functions. These cards monitor the performance of joint components, manage communication between sensors and actuators, and ensure the smooth execution of the robot's movements.

Components at the foot of the robot

Controllers:

What they are: The central units of the robot that manage movements and system operations.

How they work: Controllers receive input from various sensors and encoders to determine the robot's position and speed. They process this information to calculate the necessary actions required for movement. Controllers also implement algorithms for path planning and motion control, ensuring that the robot navigates its environment effectively while maintaining stability and precision.

Communication systems

What they are: Systems that allow different parts of the robot to communicate and share information.

How they work: Communication systems use various channels and protocols to transmit data between the robot's components, ensuring that sensors, controllers, and actuators work together.

Key communication methods:

Ethernet: A high-speed communication method used for reliable data transfer between components over short to medium distances.

RS485: A standard for long-distance communication that is often used for connecting components that need to communicate over longer distances within a robot.

SPI (Serial Peripheral Interface): A fast, short-distance protocol used for quick data exchange between devices, such as sensors and controllers, within a robot.

3. PULSAR's redundancy architecture

PULSAR's redundancy architecture is built to ensure maximum safety and operational reliability in healthcare environments where precision and safety are particularly critical. The architecture consists of local redundancies (embedded into the joints) and global redundancies (ensuring that all the joints are controlled together, and the user's commands are executed correctly). Together, these redundancies create a fail-safe environment that prevents failures and allows safe system stops when needed.

Local redundancies

Internal collision detection

PULSAR's joints are equipped with a dual-encoder system that continuously monitors joint movement. Each encoder operates independently, providing real-time data that is compared to detect any discrepancies. If one encoder registers movement while the other does not, the system identifies a potential misalignment or obstruction. Additionally, the motor's current consumption is monitored; any abnormal increase in current draw signals resistance, which may indicate a collision. This dual-layer approach ensures immediate detection of internal irregularities and allows the system to stop safely to prevent damage or injury to the patient or operator.

External collision detection

PULSAR can be optionally equipped with external sensors to monitor its surroundings and detect obstacles. This additional safety layer works alongside the internal safety mechanisms, stopping the robot if an external object comes within a defined range, based on the needs of the specific treatment room.

Double joint state verification and local monitoring system

As part of its safety features, PULSAR's dual-encoder system continuously monitors joint position, speed, and acceleration. Any discrepancies trigger an immediate system stop, ensuring movement precision. Moreover, two electronic cards independently monitor the performance of each joint. If either card detects an error, the system halts operations. Both cards can also independently activate the brakes, ensuring a safe stop in case of malfunction.

Double braking system

PULSAR is equipped with two braking systems (an electromagnetic brake and a mechanical brake powered by a spring). Either brake is fully capable of stopping the system on its own, but the dual setup provides an added layer of safety. Both brakes can be triggered independently by the monitoring systems to ensure a safe stop in any emergency situation, offering redundancy in case one brake encounters an issue.

Global redundancies

While local redundancies ensure safety at the joint level, global redundancies provide comprehensive safeguards to maintain the robot's operational integrity and reliability, even when broader system issues arise.

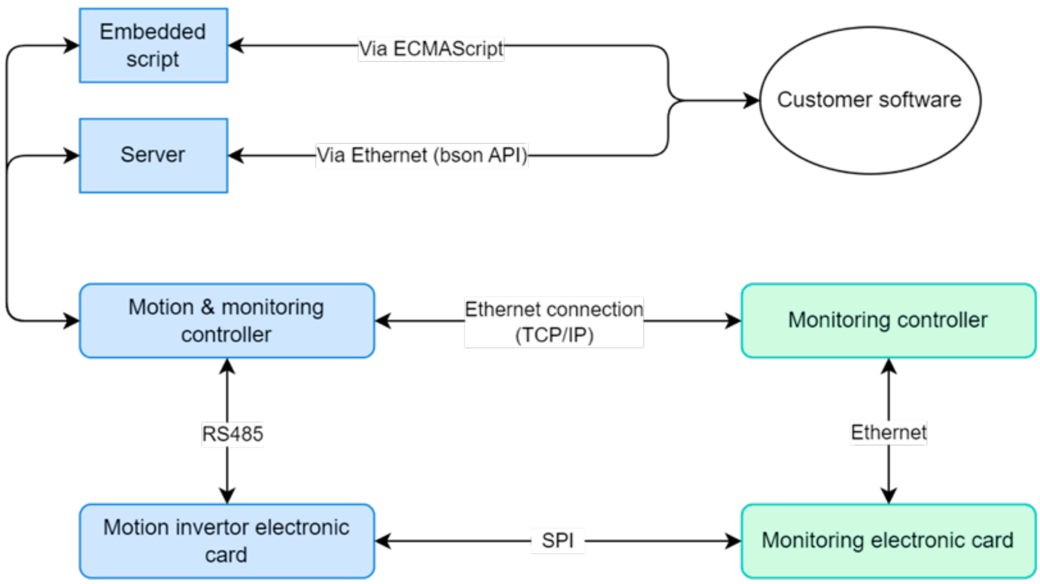
Redundant controllers

The robot has two controllers: one to manage movement and monitor performance, and the other dedicated solely to monitoring. These controllers constantly check each other's outputs to ensure everything is functioning as intended. If any discrepancy arises between the two independent controllers – such as differing commands or outputs – the robot will halt automatically to prevent unintended actions, even if no malfunction is detected. This layer of redundancy ensures that the robot only performs the exact task it's been instructed to do.

Redundant communication systems

PULSAR uses two independent communication channels (Ethernet TCP/IP and RS485) to transmit data between its components and receive commands from the operator's system. The operator's order is sent through both channels to PULSAR's two independent controllers, ensuring redundancy in communication.

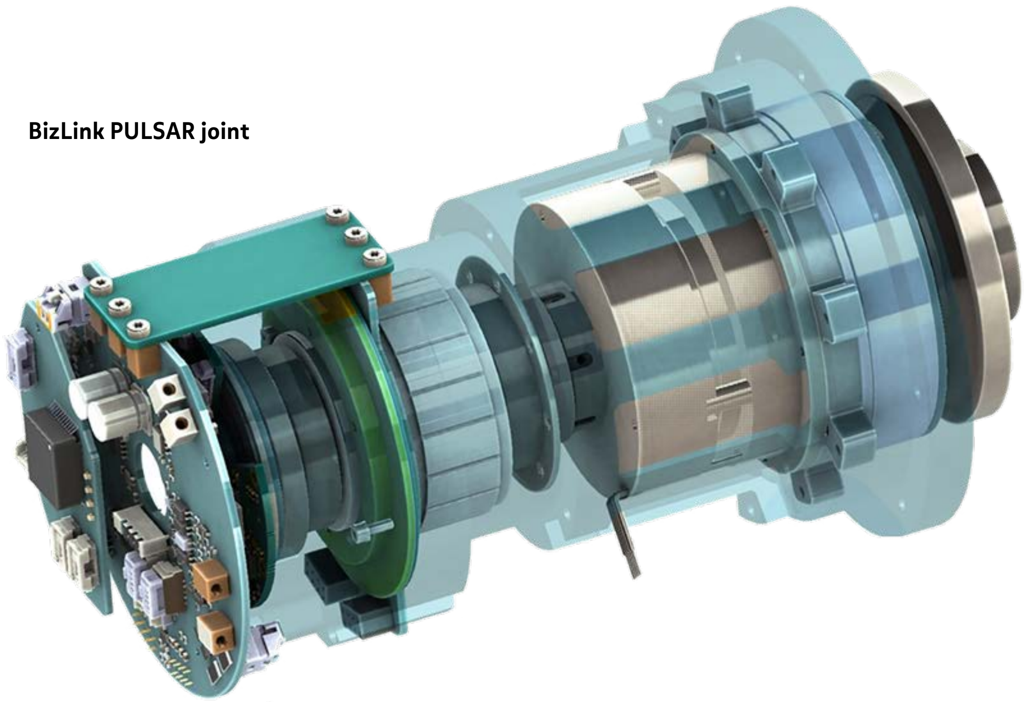
BizLink PULSAR software architecture



Overview of key technical features supporting redundancy

Component	Description	Key benefit
Encoders	Dual encoders (optical and electromagnetic) in each joint for position and speed monitoring.	Ensures continuous real-time monitoring, providing precision and error detection.
Braking systems	Dual brake systems: electromagnetic and mechanical (spring-powered) braking.	Provides immediate stopping in the event of an emergency, ensuring safety even if one system encounters an issue.
Controllers	Redundant controllers: one for motion and one for monitoring.	Ensures continuous supervision of operations, maintaining reliability in the event of a failure.
Electronic cards	Two electronic cards per joint for independent monitoring and control.	Provides independent control of the components, ensuring system shutdown if any potential issues arise.
Current measurement	Monitors motor current to detect any abnormal resistance or overload, signaling potential collisions.	Prevents damage or misalignment by detecting resistance and stopping the system when necessary.
Communication systems	Dual communication channels (Ethernet TCP/IP and RS485).	Maintains reliable communication between components, preventing single points of failure.
External collision sensors (optional)	Sensors to monitor the robot's surroundings for potential obstacles.	Provides an additional layer of safety by stopping the robot when external objects are detected.

BizLink PULSAR joint



In summary, by integrating both local and global redundancies, PULSAR's architecture ensures reliable performance and continuous safety. This robust design not only minimizes risks but also enhances reliability, enabling healthcare providers to deliver better outcomes with confidence.

4. How redundancy improves path reliability

A robot's redundancy systems acts as a safety net that ensures it stays precisely on course, providing essential support to the operator throughout each task. These built-in mechanisms allow even the smallest deviation to be detected early, enabling the operator to maintain precise control and reliability in the robot's movements. Additionally, redundancy systems guarantee that the robot performs exactly as instructed, aligning every movement with the operator's intended task and reinforcing reliability in demanding healthcare environments.

Catching deviations in real-time
Think of the robot's dual encoders as two sets of eyes constantly watching every movement it makes. If even the slightest deviation occurs, the system detects it instantly.

Stopping before going off track
When a deviation is detected between the two controllers, the robot's redundancy systems intervene immediately (everything halts). This stop prevents the robot from continuing on an incorrect trajectory. By pausing, recalibrating, and then resuming, the robot minimizes any risk of errors, ensuring reliable movements throughout the procedure.

Example: Laser dermatology
Imagine a laser dermatology procedure, where the robot is assisting a physician in treating delicate areas of a patient's skin. Precision is essential, as even a slight misalignment could cause the laser to miss its target, potentially leading to unintended laser exposure or skin damage. Mid-procedure, the robot detects a minor issue with its arm movement. Before the physician even notices, the robot's redundancy systems spring into action—halting the laser's movement instantly to prevent any harm.

The system pauses, allowing the physician to assess the situation and recalibrate the robot's positioning. Once everything is realigned, the procedure continues with full precision. By catching the issue before it becomes a problem, the robot ensures that the procedure remains both safe and accurate, ultimately increasing the physician's and patient's confidence in the system's reliability.

5. Regulations and their relevance to PULSAR

In the field of medical robotics, adherence to standards and regulations is not merely a formality but a cornerstone of trust, reliability, and safety. These standards ensure that devices meet rigorous requirements to protect patients, operators, and the broader healthcare system. PULSAR has been designed with these principles in mind, embedding compliance with key international and regional standards at its core.

ISO 60601: Medical electrical equipment safety
ISO 60601 is a critical standard for medical devices, focusing on electrical safety and essential performance requirements. This norm mandates strict design practices to ensure devices operate safely in clinical environments.

How PULSAR aligns:

- PULSAR incorporates dual controllers and independent braking systems to ensure operational safety, directly addressing ISO 60601's emphasis on fail-safes and risk mitigation.
- The robot's built-in redundancies, including dual encoders and communication channels, further comply with the standard's focus on reliability during critical operations.

IEC 62304: Medical device software life cycle processes
This norm oversees the development of software used in medical devices, emphasizing risk management and validation. It requires manufacturers to build software that can handle unexpected faults without compromising safety.

How PULSAR aligns:

- PULSAR's software architecture is designed with redundancy in mind, enabling the system to detect faults in real time and stop operations if discrepancies arise.
- Regular testing and validation processes ensure that the software meets the performance and safety benchmarks required under IEC 62304.

Quality system regulations
In certain regions, medical devices must comply with the existing Quality System Regulations (for example, FDA in the United States, or CE in Europe). These regulations outline the need for comprehensive design controls, risk management, and validation processes.

How PULSAR aligns:

- PULSAR's robust design process includes detailed validation of its redundancy systems, ensuring that every safety mechanism operates as intended under real-world conditions.

By aligning with these standards, PULSAR demonstrates its commitment to delivering a product that not only meets but exceeds the expectations of safety and reliability in healthcare environments. Each redundant system, whether in its encoders, controllers, or communication channels, has been purposefully designed to comply with the highest norms, ensuring that healthcare providers can trust PULSAR to perform its tasks with precision and consistency.

6. Conclusion

In healthcare robotics, precision and safety are not just priorities—they are requirements. The integration of redundancy systems within a robot provides essential layers of protection, ensuring that any potential errors are detected and mitigated before they can impact the procedure. Throughout this paper, we've demonstrated how redundancy plays a key role in maintaining path reliability, enhancing safety, and supporting healthcare professionals in performing their tasks with confidence.

By incorporating multiple layers of fail-safes, such as dual encoders, redundant controllers, and real-time monitoring, a robot becomes a reliable partner in delivering consistent, precise results. Whether assisting in laser procedures, rehabilitation, or diagnostic imaging, redundancy systems ensure that any deviation from the intended path is caught early, allowing the operator to make informed adjustments and continue with accuracy.

Redundancy goes beyond being a technical specification—it serves as a crucial safety mechanism that enhances the reliability of robots in demanding medical scenarios. PULSAR exemplifies this approach by embedding robust redundancy systems into its design, providing healthcare professionals with a tool to achieve the highest levels of precision and safety. As healthcare robotics continues to advance, the importance of such systems will only grow, offering professionals the confidence they need to embrace these technologies and improve patient outcomes.

About BizLink

BizLink Healthcare is part of BizLink Group. We transform our customers' ideas into innovative solutions that bring their innovations to life. We deliver our expertise through partnership-based collaboration, sustainable performance, and global availability. As system partners, we work closely with our customers in a development-supporting role, creating the best solutions based on custom specifications. Our robotics expertise ensures maximum safety, efficient treatments, and precise patient positioning. Our PULSAR platform allows for customized and modular medical robotics solutions because we believe in adapting the robot to your needs, not the other way around. Our intuitively manageable ORION patient positioning system exemplifies the innovative solutions we provide when we combine our extensive knowledge of medical applications with our decades of industrial robotics experience.

Contact

Nicolas Valbuena
International Sales & Business Development
M +49 (0)1514 380 7748
Nicolas_Valbuena@bizlinktech.com

Vincent Besnard
Project Manager | Robotics Innovation
M +33 (0)6 80 71 33 83
T +33 (0)2 37 91 21 85
Vincent_Besnard@bizlinktech.com

BizLink Robotic Solutions France S.A.S.
5, Avenue Victor Hugo · 28000 Chartres · France · bfr_healthcare@bizlinktech.com · T +33 2373375-00 · Follow us on LinkedIn