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ROS Messages for Nuclear Sensing

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INTRODUCTION

The Robot Operating System (ROS) [1] has become the *de facto* standard middleware for robotics integration of hardware and software. It allows for rapid adoption of sensors such as LiDAR and cameras, with common robot platforms and existing software solutions for high-level robotic features such as path planning and SLAM (Simultaneous Localisation And Mapping). The clear benefit of ROS is the ability to easily upgrade or change components (both hardware and software) to suit the requirements of the user or robot, with manufacturers and the wider community providing the necessary support.

The UK nuclear sector has identified the use of robotics as a vital part of reducing risk and cost for decommissioning of legacy facilities [2, 3], as well as a preference for commercial-off-the-shelf (COTS) systems to further decrease cost and increase technology readiness levels of deployed systems [4]. With the combination of a growing use of robotic systems in the nuclear sector [5] and the prevalence or even legal requirement for ROS integration [6], the specific needs of nuclear sensing must be met by ROS.

Different parts of the ROS system are called nodes, which share information via messages. ROS messages are of a defined structure which allows for both publishing nodes (sending data) and subscribing nodes (receiving data) to both understand the outbound and inbound data streams. These message structures are available for most common robotic sensor types [7], however, there is currently no agreed provision for communicating information based on ionising radiation sensing.

To aid in standardisation of ROS messages for nuclear sensing, therefore promote the use of robotics and adoption of COTS solutions, a workshop was held to solicit opinions and comments from the nuclear robotics community, including researchers, nuclear sector end-users, and instrument manufacturers. This work proposes message structures for radiation detectors based on feedback from participants and precedent set by the ROS community.

Increased instances of robotic inspection of nuclear environments has seen a correlated increase in ROS integrated nuclear sensing [8, 9, 10, 11, 12, 13], enabling users to leverage robot derived data such as SLAM to augment data collection. Furthermore, it can be integrated with autonomous elements to allow for more sophisticated sampling strategies [14, 15]. In almost every instance, each message structure used is based on the specific output of a particular radiation sensor, limiting the potential to change or upgrade a sensor. With the recent prospect of ROS compatible simulated radiation fields for development of robotic systems [16], this will likely decide the message structures developers begin to adopt before deployment into active environments, but therefore dictates what users will demand of instrument manufacturers rather than adopting a broad and fairly agreed upon standard.

Previous work to standardise ROS messages for nuclear instrumentation have been based on existing standards for radiation data [17], however, compared to the findings in this work they require greater bandwidth, carry sometimes superfluous information, and are not always applicable to the scenarios faced by robotics challenges seen by participants. The most obvious is the need for geolocation data in the message structure, whereas activities undertaken at nuclear sites can be GPS-denied either because they are indoors or measurements are specifically not associated with coordinates for security reasons. Though this previous work sensibly aligns itself with an existing standard, and demonstrates concern from the wider nuclear robotics community, it is at odds with the requirements of nuclear instrument users and manufacturers. Where messages must conform to the IEC 63047 standard instruments can publish multiple message types, this work does not wish to replace this existing approach but supplement it.

ROS messages are constructed from basic building blocks of common data types [18]. These include strings, integers, floats, bool, and arrays of basic types. Furthermore, there is the "header" structure which contains time and associated reference frame metadata. Sensor messages include this field and it is expected that nuclear sensors should also adopt this approach. Along side practical reasons for designing messages in a certain manner, the ROS development community, and maintainers at the Open Robotics Foundation recommend conventions and best practices through REP documents (ROS Enhancement Proposal). From these documents, some basic guidelines were established, and in some instances cast serious concerns regarding ROS messages for nuclear detection.

The most impacting REP is in relation to units of measurement, REP-0103 [19]. Units and coordinates are standardised around SI and derived SI units. For radiation measurements, table I outlines SI derived units for radiation related quantities, this includes source activity in decays per second, however, this is usually an inferred metric. All these units can be modified by other SI units, including time and space, to derive other commonly expressed quantities such as Gy/s.

Name	Symbol	Quantity	Equivalent Units
becquerel	Bq	Activity	s^{-1}
gray	Gy	Absorbed dose	$J{\cdot}kg^{-1}$
sievert	Sv	Equivalent dose	$J{\cdot}kg^{-1}$

TABLE I. SI quantities of radiation measurement.

For radiation measurements in industry, the adherence to SI units is not strictly followed, mostly due to historical or practical considerations. Units such as Rad or Rem are still in common use, however, conversion to SI counterparts is trivial. More nuanced are units of detector interaction events, typically expressed as counts. These counts may be integrated across energy ranges or be specific to an energy interval in spectroscopy. For simple and sophisticated instruments, counts are still an important metric, and should be included as a metric of radiation intensity. Therefore counts, becquerels, gray and sievert should be supported, and their time resolved counterparts.

A difficult challenge with time resolved quantities is the common practice of reporting dose rates per hour as it is more practical than SI appropriate per second, despite detectors most commonly updating at a rate of once per second. The amount of time humans (or robots) spend in nuclear is normally considered on the time scales of hours whereas periods of seconds have little context, hence the prevalence of non-SI units of time. To conform with SI standards, rates in seconds should be used to communicate information between ROS nodes, however, it is trivial to then convert this to more user friendly units for human-robot interaction.

Though counts are a strictly integer measure, other derived units such as sieverts or rates such as counts/second will most likely be best expressed as a floating point value. This flexibility is preferred, therefore values should be communicated at floating point values (32 or 64 bit) over integer values.

Another convention is the naming of topics (how a node identifies which set of messages to interact with), as common usage is to name the topic something relevant about the source, e.g. camera/right/image and camera/left/image, as a means to easily identify the source and the type of information. This however is only generally recommended and not officially codified within a REP document [20]. For this reason, it was decided not to include additional information in a message structure to indicate other information about the source. Additional information such as serial number, or model can be stored on the ROS parameter server if necessary.

In general, it is better practice to limit data bandwidth requirements for robotic systems [21]. This includes messages communicating radiation information. Smaller, more concise messages are preferred over larger more verbose message structures, particularly if information is redundant or repetitive and can be more appropriately stored on the parameter server. This is demonstrated by the JointState message [7], which has very simple construction of four fields and a header, whereas the manufacturers of the popular dynamixel motor series [22] have 51 fields populated per message in addition to publishing the necessary JointState message. For most users, this additional information is superfluous, wasting bandwidth and memory (if recording data).

RESULTS

The workshop was held virtually on 13th August 2020 via Zoom. Of the 50 total participants, 38 were from UK and international Universities, 9 from industrial users of nuclear robotics, and 3 from nuclear instrument manufacturers. These participants represented a broad range of use cases and needs for robotic systems, from mobile inspection to static waste sorting and nuclear security.

After a brief introduction into ROS, how messages are handled, and the issues of integrating nuclear instruments with ROS, participants were separated into smaller groups to discuss their experience with nuclear robotics, use of cases of nuclear detection, and possible designs of ROS messages. These individual groups then reported on their discussion with the rest of the participants. Their insights and questions were recorded, and these key points form part of the design choices for ROS messages for nuclear instrumentation. A full video recording of the workshop can be found on YouTube [23].

Beyond this workshop, a Slack workspace was initiated to enable more free form discussion between experts and gain feedback on proposed ROS message structures. People were encouraged to join this discussion workshop, and consisted of 11 members from academia and nuclear sector representatives.

The oral feedback from experts in nuclear sensing, operations, and robotics, identified key points which directed what information should be held in a ROS message. Users shared their frustration due to lack of interoperability between sensors and a lack of ROS support in general from manufacturers. It is expected that ROS support should mean plug-and-play instruments and sensors for robotics developers and end-users, however, they may need to then process data further based on analysis approaches chosen.

Sensors and instruments should provide the most fundamental information elements, but can also provide further processed information (for example if part of a integrated product). The workshop and this documents considers what the most fundamental information elements could look like. Inclusion of metadata via a header field was accepted as a method to provide spatiotemporal reference to where and when measurements have been recorded. It was highlighted that other metadata, such as calibration parameters or collimation can be useful in post processing, however, as these are likely time-invariant they can be held on the ROS parameter server or published when updated on a particular topic, rather than constantly published with every message.

Participants highlighted a clear distinction between spectroscopic instruments and non-energy resolved detectors. Electronic personal dosimeters based on solid state or Geiger Muller detector designs are the most commonly used instrument type for "simple" dosimetry, whereas inorganic scintillator or solid state detectors are mostly highlighted by participants for spectroscopy. This anecdotal evidence appears to be representative of devices found in literature [24, 25], for example in the initial response to the events at Fukushima simple personal dosimeters were used [26], whereas spectroscopy can be achieved even for aerial vehicle payloads [27].

Messages should distinguish between radiation types based on the sensitivity or discrimination of a detector. Radiation type has consequences not only for health physics in dosimetry calculations, but for autonomous activities where scale length and impact may influence robot responses. For example a robot may need to avoid gamma or neutron radiation sources due to risk of electronic component failure compared to non-penetrating alpha sources. Furthermore, different sensor technologies are sensitive to different radiation types, and that may be discriminated into separate species or a sensor simply reports gross values from multiple radiation types. There is necessity to declare which radiation types are being reported but also to declare where there may be ambiguity.

Finally, there are other useful information types that often accompany radiation detectors such as threshold alarms, which should be included along side dose information. Minimum and maximum values are a commonly reported value by consumer dosimeter units, however, this could be represented using the same message types but with a different topic name, e.g. /radiation_sensor_topic/data, /radiation_sensor_topic/min, /radiation_sensor_topic/max.

As a result of discourse with nuclear sensing and robotics experts, four different message types are proposed, covering: counts/dose accumulated over a period of time, count rate or dose rate over a period of time, alarm/threshold alerts, spectroscopic information. These messages may be subject to change, and are therefore not explicitly described here. Users wishing to access or implement these ROS messages can retrieve the latest version from the appropriate GitHub repository [28].

CONCLUSIONS

This work presents proposed message structures to convey ionising radiation information in ROS. These designs were constructed based on feedback of workshop participants, consisting of 50 researchers, industrial end-users, and instrument manufacturers. Four message types have been devised, covering accumulated dose, dose rate, alarms and spectroscopy, with flexibility to cover all radiation types and common SI units. A ROS package containing the messages are made freely available. The message structures form the basis of a community wide effort to standardise information exchange between nuclear sensing and other nodes in a robotic platform, and the community is encouraged to adopt these structures when integrating current and future instruments for nuclear inspection. The community is further encouraged to engage in suggesting improvements and use cases to better suit all users.

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REFERENCES

1. M. QUIGLEY, K. CONLEY, B. GERKEY, J. FAUST, T. FOOTE, J. LEIBS, R. WHEELER, and A. Y. NG, “ROS: an open-source Robot Operating System,” in “ICRA workshop on open source software,” Kobe, Japan (2009), vol. 3, p. 5.
2. NUCLEAR DECOMMISSIONING AUTHORITY, “NDA 5-year R&D Plan 2019 to 2024,” (2019).
3. NUCLEAR DECOMMISSIONING AUTHORITY, *Strategy effective from March 2021*, Dandy Booksellers Ltd, London (2020).
4. R. SMITH, E. CUCCO, and C. FAIRBAIRN, “Robotic Development for the Nuclear Environment: Challenges and Strategy,” *Robotics*, **9**, *4*, 94 (Nov. 2020).
5. I. TSITSIMPELIS, C. J. TAYLOR, B. LENNOX, and M. J. JOYCE, “A review of ground-based robotic systems for the characterization of nuclear environments,” *Progress in Nuclear Energy*, **111**, 109–124 (Mar. 2019).
6. F. E. SCHNEIDER, J. WELLE, D. WILDERMUTH, and M. DUCKE, “Unmanned multi-robot CBRNE reconnaissance with mobile manipulation System description and technical validation,” in “Proceedings of the 13th International Carpathian Control Conference (ICCC),” IEEE (May 2012).
7. T. FOOTE, “sensor_msgs - ROS Wiki,” `http://wiki.ros.org/sensor_msgs` (2014).
8. I. TSITSIMPELIS, A. WEST, M. LICATA, M. D. ASPINALL, A. JAZBEC, L. SNOJ, P. A. MARTIN, B. LENNOX, and M. J. JOYCE, “Simultaneous, Robot-Compatible γ-Ray Spectroscopy and Imaging of an Operating Nuclear Reactor,” *IEEE Sensors Journal*, **21**, *4*, 5434–5443 (Feb. 2021).
9. R. GUZMAN, R. NAVARRO, J. FERRE, and M. MORENO, “RESCUER: Development of a Modular Chemical, Biological, Radiological, and Nuclear Robot for Intervention, Sampling, and Situation Awareness,” *Journal of Field Robotics*, **33**, *7*, 931–945 (Jun. 2015).
10. A. WEST, I. TSITSIMPELIS, M. LICATA, A. JAZBEC, L. SNOJ, M. J. JOYCE, and B. LENNOX, “Use of Gaussian process regression for radiation mapping of a nuclear reactor with a mobile robot,” *Scientific Reports*, **11**, *1* (jul 2021).
11. R. B. ANDERSON, M. PRYOR, and S. LANDSBERGER, “Mobile Robotic Radiation Surveying Using Recursive Bayesian Estimation,” in “2019 IEEE 15th International Conference on Automation Science and Engineering (CASE),” IEEE (Aug. 2019).
12. R. MCDOUGALL, S. B. NOKLEBY, and E. WALLER, “Probabilistic-Based Robotic Radiation Mapping Using Sparse Data,” *Journal of Nuclear Engineering and Radiation Science*, **4**, *2* (Mar. 2018).
13. K. VETTER, R. BARNOWSKI, J. W. CATES, A. HAEFNER, T. H. JOSHI, R. PAVLOVSKY, and B. J. QUITER, “Advances in Nuclear Radiation Sensing: Enabling 3-D Gamma-Ray Vision,” *Sensors*, **19**, *11*, 2541 (06 2019).
14. M. BUDD, B. LACERDA, P. DUCKWORTH, A. WEST, B. LENNOX, and N. HAWES, “Markov Decision Processes with Unknown State Feature Values for Safe Exploration using Gaussian Processes,” in “2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),” IEEE (Oct. 2020).
15. K. GROVES, E. HERNANDEZ, A. WEST, T. WRIGHT, and B. LENNOX, “Robotic Exploration of an Unknown Nuclear Environment Using Radiation Informed Autonomous Navigation,” *Robotics*, **10**, *2*, 78 (May 2021).
16. T. WRIGHT, A. WEST, M. LICATA, N. HAWES, and B. LENNOX, “Simulating Ionising Radiation in Gazebo for Robotic Nuclear Inspection Challenges,” *Robotics*, **10**, *3*, 86 (Jul. 2021).
17. E. C. J. R. CENTRE., *Performance of the IEC 63047 demonstration device: ERNCIP thematic group radiological and nuclear threats to critical infrastructure.*, Publications Office (2019).

18. M. QUIGLEY, “std_msgs - ROS Wiki,” `http://wiki.ros.org/std_msgs` (2017).
19. T. FOOTE and M. PURVIS, “REP 103 – Standard Units of Measure and Coordinate Conventions,” `https://ros.org/reps/rep-0103.html` (2014).
20. OPEN ROBOTICS FOUNDATION, “Best Practices - ROS Wiki,” `http://wiki.ros.org/BestPractices` (2021).
21. OPEN ROBOTICS FOUNDATION, “ROS/-Patterns/Communication - ROS Wiki,” `https://wiki.ros.org/ROS/Patterns/Communication` (2014).
22. D. LIM, “dynamixel_workbench_msgs/XH Documentation,” `http://docs.ros.org/en/noetic/api/dynamixel_workbench_msgs/html/msg/XH.html` (2018).
23. RAIN HUB, “RAIN Webinar 13th Aug 2020: UK-RAS ROS Nuclear Sensing Workshop,” `https://youtu.be/rdy53jwjKZA` (2020).
24. L. MARQUES, A. VALE, and P. VAZ, “State-of-the-Art Mobile Radiation Detection Systems for Different Scenarios,” *Sensors*, **21**, *4*, 1051 (Feb. 2021).
25. D. CONNOR, P. G. MARTIN, and T. B. SCOTT, “Airborne radiation mapping: overview and application of current and future aerial systems,” *International Journal of Remote Sensing*, **37**, *24*, 5953–5987 (11 2016).
26. K. NAGATANI, S. KIRIBAYASHI, Y. OKADA, S. TADOKORO, T. NISHIMURA, T. YOSHIDA, E. KOYANAGI, and Y. HADA, “Redesign of rescue mobile robot Quince,” in “2011 IEEE International Symposium on Safety, Security, and Rescue Robotics,” IEEE (Nov. 2011).
27. P. MARTIN, J. MOORE, J. FARDOULIS, O. PAYTON, and T. SCOTT, “Radiological Assessment on Interest Areas on the Sellafield Nuclear Site via Unmanned Aerial Vehicle,” *Remote Sensing*, **8**, *11*, 913 (Nov. 2016).
28. A. WEST, “ROS Radiation Messages,” `https://github.com/EEEManchester/radiation_msgs` (2021).