Analysing Human Operators and an Automated System in Swabbing Tasks

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Thomas Johnson,* Dr. Simon Watson,* Dr. Clint Sharrad,* and Dr. Thomas Carey †

*The University of Manchester, Oxford Road, Manchester, M13 9PL, thomas.johnson-2@manchester.ac.uk.
†National Nuclear Laboratory, Chadwick House, Birchwood Park, Warrington, Cheshire, WA3 6AE.

INTRODUCTION

In order to safely operate in radioactive environments, routine monitoring and characterisation is required to assess physical, chemical and radiological hazards. Robotic and autonomous systems are increasingly being used for monitoring and characterisation [1], offering increased safety, reductions in operational costs and increased time-efficiency. One task which could benefit from the use of autonomous systems could be sample retrieval through swabbing. This task is often part of characterisation strategies, and some attempts have already been made to use robots in this area [2].

Robotic systems may offer increased swabbing performance when compared to human operators. The retrieval of samples is not perfectly repeatable [3] and so imposes a fundamental limitation on the information that can be obtained through swab sampling. As robots offer greater repeatability than humans, using them may facilitate the reduction of sampling error associated with swabbing. In order to aid the development of these systems, there is a need to develop a greater understanding of the different factors which effect swabbing efficacy and repeatability.

This paper provides a comparison of a human operator (the primary author) and a force-controlled swabbing system in the execution of a single-pass swab test. Swabbing force and mass removal data are presented.

Understanding the effect of swabbing inputs (such as force and swab speed) on pick-up factor will aid the development of automated swabbing systems which will provide greater repeatability in the swabbing process. The tests presented are crucial in identifying the variables in swabbing input which have the largest effect on contaminant removal. While this paper does not quantify the effects of these individual variables, a number of key variables are highlighted in this paper.

METHODOLOGY

To ascertain variables which affect swabbing efficacy and repeatability, a single-pass swab test was conducted ten times for a human operator and a force-controlled swabbing system. A diagram of the swabbing area is shown in Figure 1.

The human operator aimed to produce even force-input through the swabbing motion, maintaining a constant speed and aiming to swab the same area each time. It was not possible to actively control these factors while conducting these tests.

The force-controlled swabbing system used in this paper, first presented in [4], is shown in Figure 2. The system includes a spring-loaded swabbing pad that is compressed to a desired length by the linear actuator. The system provides movement along the swabbing axis by moving the belt-driven stage. The swabbing speed for each test with this system was controlled so that each test would last 10 *s*.

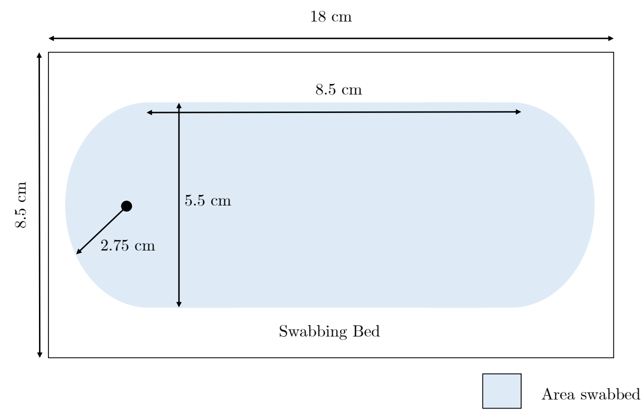


Fig. 1: A diagram of the swabbing area for these single-pass tests.

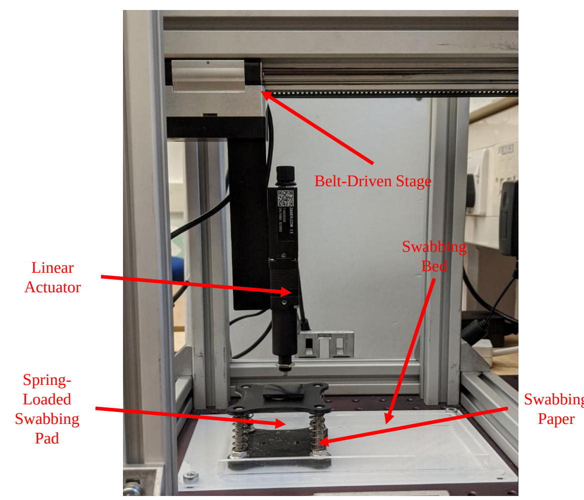


Fig. 2: The force-controlled swabbing system.

Force data is collected using a linearised capacitive force sensor (SingleTact CS8-100N). The position of these sensors beneath the swab was not fixed for these experiments. Pick-up factors were determined by measuring masses using a mass balance (OHAUS Adventurer AX-224). Whatman 41 filter papers (Ashless, 55mm circles) are used in swabbing experiments. The simulated contaminant for these experiments is sand (50-70 mesh particle size, Sigma-Aldrich 274739).

Swabbing forces were collected during experiments using the capacitive force sensors, with swabs being weighed before and after swabbing to determine pick-up rates. For all of these experiments, sand was deposited loosely on the surface and then shook to homogenise the spatial distribution.

RESULTS AND ANALYSIS

The mass pick-up data, shown in Figure 3, demonstrates that the force-controlled swabbing system provided much greater repeatability in these experiments. While the human operator achieved a standard deviation of $\sigma = 13.1$ %, the force-controlled swabbing system achieved a much lower value of $\sigma = 3.7$ %. These results are consistent with previous work [4].

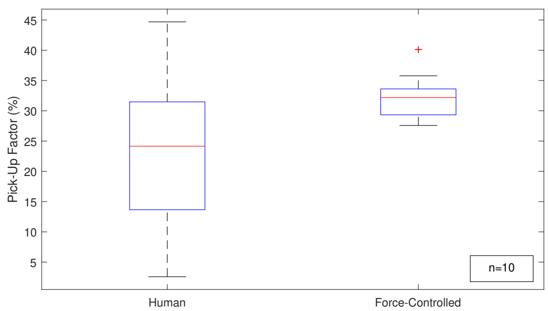


Fig. 3: A comparison of the pick-up factors achieved through human and force-controlled swabbing.

The force sensor data collected can be analysed alongside this pick-up data to provide some insight on to the important variables to control during swabbing. Table I shows a selection of metrics collected in these experiments.

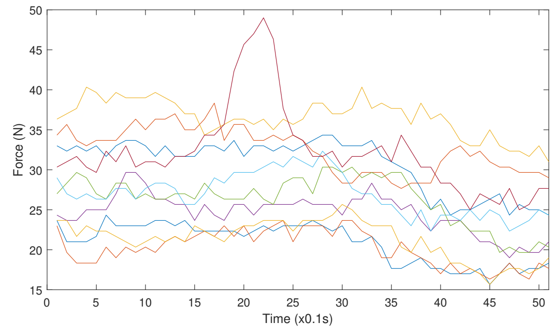
The automated swabbing system offers much greater repeatability in swab time (and consequently swab speed) which may be a contributor to the greater performance in swabbing tests. Aside from this metric, the values in Table I do not clearly demonstrate a large difference in performance.

TABLE I: Performance metrics from swabbing experiments.

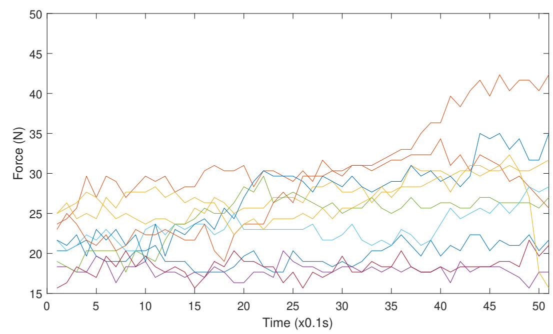
	Human	Swabbing System
Mean Swabbing Force (N)	24.2	29.3
σ_F (N)	3.5	4.3
Mean Swab Time (s)	9.5	10.0
σ_T (s)	2.3	0.0
Pick-Up Factor (%)	23.0	32.4
σ_{PUF} (%)	13.1	3.7

Surprisingly the standard deviation in swabbing force for the human operator was lower than the value for the swabbing system. This seemingly counter-intuitive result is better explained with the information from Figure 4.

Figure 4 shows force measurements (taken with $f = 10\ Hz$) from the middle 5 s of the intended 10s swabbing time. Aside from one large spike in force measurement (caused by an item accidentally being dropped on the desk near to the experiment) the force measurements in Figure 4a give a more consistent force level through swabbing than in Figure 4b. Figure 4 shows that the increased deviation in swabbing force



(a) Force-controlled swabbing



(b) Human swabbing

Fig. 4: Force profiles during the middle 5s of swabbing.

for the autonomous system is in fact due to the wider range of force measurements across all of the tests. This is thought to be due to inconsistencies in the position of the force sensor under the swabbing pad.

Figure 4 highlights differences between automated swabbing and the human operator as well as raising issues that must be addressed in future work:

1. The automated swabbing system provided more consistent swabbing force in individual tests, though there was a large range of forces across different tests. It is yet to be determined whether this is a true reflection of the system behaviour or whether this was caused by the force sensors.

2. The force application measurements were more similar than expected. If these results are a true reflection of the real swabbing inputs, then the force input during swabbing may be less important than assumed [5, 6].

CONCLUSIONS AND FURTHER WORK

The results presented demonstrate the advantages of using force-controlled systems for swabbing. Automated systems, such as the one used in these experiments, offer less variance in swabbing time and provide consistent force application. This has a clear positive impact on the removal of contamination, and it is demonstrated here that swabbing systems can provide much less variance in the removal of contamination. The standard deviation in contaminant mass removal was just $\sigma =$

3.7 % for the swabbing system, while the human operator could only achieve σ = 13.1 %.

Though it is clear that automated swabbing systems can offer more reliable contamination removal, the reasons for this are not entirely known. Existing literature has long thought that variable swabbing forces have a negative impact on the repeatability of pick-up factors [7, 8, 9, 10], however the results in this paper give no strong indication that this is the case.

The clearest differences between the swabbing of a human operator and the swabbing system are the differences in swabbing time and a difference in the way force is applied to the swab. While data from more operators are required before making definitive statements, it seems that human operators struggle to maintain constant swabbing speed and this may be a reason for the decreased repeatability of pick-up factor. It is noteworthy that the way force was applied to the swab in these experiments was different for the different systems. The human applied force only across the three fingers used to hold the swab, and this placement was not possible to be made consistent across trials. The swabbing system was able to apply force evenly across the whole swab and this may have had a positive impact on swabbing efficacy.

It is necessary for future work to determine which swabbing input factors are most important during swabbing, and for work to quantify the impact of these factors.

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REFERENCES

1. 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**, *May 2018*, 109–124 (2019).
2. Y. YUGUCHI, “Remote Control Technology used in the Fukusima Daiichi Nuclear Power Plant (Toyota),” in “Waste Management Symposium 2021,” Phoenix, AZ (2021).
3. C. P. LICHTENWALNER, “Evaluation of wipe sampling procedures and elemental surface contamination,” *American Industrial Hygiene Association Journal*, **53**, *10*, 657–659 (1992).
4. T. JOHNSON, C. SHARRAD, S. WATSON, and T. CAREY, “Investigating the Effect of Force Input on the Pick-Up Factor of Loose Contamination - 21093,” in “Waste Management Symposium,” (2021).
5. D. CRISTINI, B. D. SOUZA, and R. VICENTE, “Wipe Sampling - Review of the Literature,” in “2011 International Nuclear Atlantic Conference,” Belo Horizonte (2011), pp. 24–28.
6. C. CHAVALITNITIKUL and L. LEVIN, “A Laboratory Evaluation of Wipe Testing Based on Lead Oxide Surface Contamination,” *American Industrial Hygiene Association Journal*, **45**, *5*, 311–317 (1984).
7. R. MITCHELL and B. EUTSLER, “A Study of Beryllium Surface Contamination,” in “Surface Contamination,” Tennesse (1964).
8. G. ROYSTER and B. FISH, “Techniques for Assessing Removable Surface Contamination,” Tech. rep., Oak Ridge National Lab, Tenn. (1965).
9. W. SAXBY and J. HOLE, “Practical Aspects of Surface Contamination at AWRE,” in “Surface Contamination,” (1964).
10. J. PRINCE and C. WANG, “A Method for Evaluating Surface Contamination of Soft Beta Emitters,” in “Surface Contamination,” (1968), pp. 179–183.