

Received 22 November 2022, accepted 1 December 2022, date of publication 6 December 2022, date of current version 13 December 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3227068

RESEARCH ARTICLE

Development of Peristaltic Transfer System to Transport Feces in Space: Proposal of Driving Method Using Pressure Difference in Peristaltic Pump

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ABSTRACT We propose a transport system combining peristaltic motion and a negative pressure as a new method of transporting and collecting feces for space toilets. In recent years, for the development of space exploration, the need for a regenerative Environmental Control and Life Support System (ECLSS) to perform manned space exploration for long periods without resource supply has emerged. Currently, human feces is disposed of, but if it can be reused like urine, the performance of the ECLSS can be significantly improved. Existing space toilets do not reuse of feces, and the transfer of feces presents a technical problem. There is no technology that can reliably transport highly viscous solid-liquid mixtures on an intermittent basis. If such technologies are developed, they will be useful for transporting not only feces in space but also chemicals on the ground. Therefore, the authors propose a peristaltic system based on the intestinal tracts of living organisms for the transport of feces in space. Each unit of the system can be actively closed and opened by air pressure. The units are operated in turn to transport feces. The proposed driving method utilizes the pressure difference between the units of a peristaltic pump to increase the transfer rate. A prototype system consisting of three units was developed, and a simulated feces transfer experiment was conducted to validate the proposed method. In the experiment, we compared the conventional peristaltic driving method and the proposed peristaltic driving method, and the results indicated that the proposed method can carry more than twice the amount of simulated feces. Thus, the proposed method is suitable for the transfer of feces in space and can be used to transfer highly viscous solid-liquid mixed fluids under intermittent supply and with little water consumption.

INDEX TERMS Soft robotics, transportation, space robotics, biomimetics, peristaltic movement, pneumatic actuator, space toilet.

I. INTRODUCTION

In recent years, long-duration stays in space have been required for effective utilization of space [1] and exploration of the Moon and Mars [2], [3]. For manned stays in space, environment-controlled life support technologies,

The associate editor coordinating the review of this manuscript and approving it for publication was Giambattista Gruosso¹⁰.

e.g., for oxygen and drinking-water supply [4] and feces disposal [5], necessary for astronauts' activities have been studied for many years. However, for long-term or deep space exploration, challenges remain. For example, a manned space mission to Mars is said to take approximately three years (round trip) [6], and a regenerative Environmental Control and Life Support System (ECLSS) is required for such a long stay without resource supply [7]. The ECLSS regenerates air



FIGURE 1. Overall view of peristaltic transfer system.

and water from carbon dioxide, excrement, and food waste. Focusing on excrement, the International Space Station (ISS) is currently reusing urine. The urine is transported by air suction to a condensate reclamation system [8]. However, the reuse of feces has not been realized. Because feces contains reusable organic matter in addition to water, its reuse is expected to significantly enhance the performance of the ECLSS.

To reuse feces, it is necessary to collect feces and transfer it to condensate reclamation [9] and oxygen production systems. However, in contrast to urine, feces has properties similar to a highly viscous fluid and cannot be transported efficiently by air. In addition, it is difficult to transport and collect feces using gravity, as is the case with ground toilets. Currently, the ISS uses a toilet that turns a fan and sucks feces together with the bag with the flow of air [8]. Although this method can collect feces under microgravity, the transfer distance is relatively short, and the feces is not reused. The feces are sealed in a bag in this method and must be removed from the bag for reuse. As mentioned previously, the transfer of feces is one of the technical challenges for the reuse of feces.

However, several problems occur when existing methods for transporting highly viscous fluids are applied to space. For example, the mohno pump [10] and the screw pump [11] can transfer high-viscosity fluids and liquid mixtures, but they are large and heavy owing to their mechanism of rotating a spiral rigid waiting rod. In addition, layouts other than straight lines are difficult to implement. A tube pump [12] was proposed, but it needs to be filled with incompressible fluid and consumes a large amount of water for transporting feces. These pumps are capable of stable transport when the material to be transported is supplied continuously, but it is difficult to transport materials with an intermittent supply such as feces. Studies have been performed on toilets for use in space, but the reuse of feces was not considered [13], [14].

Therefore, the authors focused on the peristaltic movement of the intestinal tract of an organism as a transfer method [15]. The intestine transfers food masses by contracting and relaxing the muscles on the wall and by transmitting the opening and closing motions in the transfer direction. We believe that this motion makes it possible to transfer a mixed flow of air, solids, and liquids even in a micro-gravity environment. In previous research, a peristaltic pump was used to vertically transfer highly viscous fluids [16] and solid–liquid mixed fluids [17] against gravity. Therefore, we consider that it is possible to transport and collect feces even under microgravity conditions. However, because the systems examined in these studies were not designed for use in space, design and control methods assuming weightlessness have not been established, and transfer in cases of intermittent supply has been difficult. In addition, water is required for the transfer of solids. In previous studies, water was added to dry sediment to increase the fluidity of the contents [18]. This method consumes less water than transport via flow but is less desirable in a resource-constrained environment.

We propose a peristaltic system for transporting feces in space. Fig. 1 shows a conceptual drawing of the proposed system. Each unit can be actively closed and opened by changing the air pressure. By operating each unit in turn, the feces is transferred. The proposed driving method utilizes the pressure difference in the peristaltic pump to increase the transfer rate. A prototype machine consisting of three units was constructed. Finally, the effectiveness of the proposed method was experimentally confirmed. There has been no established method for transporting highly viscous fluids in a microgravity environment. This research is a cornerstone of the future space development field because transportation in a microgravity environment is one of the important factors in the space development field.

The main contributions of this study are as follows:

- A new method for transporting excrement using peristaltic motion was developed, which can be used under microgravity conditions. In contrast to the existing method, the proposed method can be used to transfer highly viscous solid–liquid mixed fluids under intermittent supply; furthermore, it consumes less water.
- We proposed a drive control system that utilizes the pressure difference inside the peristaltic pump and used it to increase the transfer efficiency of the pump.

II. DESIGN

A. MECHANISM OF PERISTALSIS IN INTESTINAL TRACTS OF ORGANISMS

The intestinal tract of an organism consists of two types of muscle layers, i.e., circular muscle and longitudinal muscle, which perform contraction and relaxation movements. Fig. 2(a) shows an overview of the transfer. In the intestine, the circular muscle contracts upon contact with the food mass and pushes the food mass out. After contraction, the circular muscle relaxes and returns to its original state. By repeating this action, the intestine continuously transports the food mass with a weak force.

B. EXISTING PERISTALTIC TRANSFER SYSTEMS AND FECAL TRANSFER CHALLENGES

An existing transfer system using peristaltic motion can continuously transfer highly viscous fluids, solid–liquid mixtures, and sediment. However, this system is not suitable for intermittent transport, because the transfer rate of each unit of the system is low; thus, materials accumulate in the unit.



FIGURE 2. (a) Mechanism of peristalsis in the intestines of living organisms. (b) Proposed peristaltic transfer system. (c) Appearance and cross-sectional view of a tank for feces. (d) External and cross-sectional views of the peristaltic pump unit. (e) Existing cylindrical inner rubber tube (right side) and the proposed gouge-shaped inner rubber tube (left side). (f) Existing peristaltic patterns. (g) Proposed peristaltic movement pattern utilizing a negative pressure.

Thus, continuous transport is assumed, where the items to be transferred are constantly replenished.

Therefore, it is necessary to improve the equipment and driving method for increasing the transfer rate for intermittent transfer, e.g., in the case of feces.

C. PROPOSED SYSTEM

We propose the following two methods to solve the aforementioned problems.

1) PERISTALTIC TRANSFER DEVICE USING GOUGE-TYPE INNER RUBBER TUBE

Fig. 2(b) shows the developed peristaltic transfer system. The device consists of a feces tank, several peristaltic pumps, and a collection tank. The peristaltic pump unit and the feces tank are composed of acrylic pipes, rubber tubes, and flanges (Figs. 2(c) and (d)). The inner diameter of the peristaltic pump unit and the fecal tank are dimensioned according to the average feces size. When compressed air is applied to the chamber between the inner rubber tube and the acrylic

pipe, the inner rubber tube expands, closing the inside of the pipe. The authors developed a gouge-type inner rubber tube in addition to the cylindrical inner rubber tube used in previous studies (left side of Fig. 2(e)). Compared with the conventional cylindrical inner rubber tube (right side of Fig. 2(e)), the developed inner rubber tube has four corners that are gouged out. Compared with the conventional cylindrical inner rubber tube (right side of Fig. 2(e)), the rubber tube with gouged corners is expected to reduce the dead space when the unit is closed, increasing the feces transfer rate. The feces in the feces tank is transferred to the peristaltic pump, and the feces is transferred to the collection tank in the peristaltic motion pattern, as shown in Fig. 2(f).

2) DRIVE CONTROL USING PRESSURE

DIFFERENCE INSIDE PUMP

For increasing the transfer rate, we propose a method that involves applying a negative pressure to the peristaltic transfer device and exploiting the pressure difference inside the pump. The transition of the pressurization pattern utilizing



FIGURE 3. (a) Approximate model of Existing peristaltic motion. (b) Approximate model of proposed peristaltic motion utilizing a negative pressure.

the pressure difference inside the pump is shown in Fig. 2(g). When a negative pressure is applied to a unit, the inner rubber tube expands outward, which generates a pressure difference between adjacent units and a force that pulls the material to be transported in the transport direction. This air flow is expected to increase the transfer rate. (pull refers to the action of a unit pulling in its contents from one previous unit) transported in the transport direction. This air flow is expected to increase the transfer rate.

D. APPROXIMATE MODEL

The approximate model was used to compare the existing peristaltic driving method with the negative-pressure driving method using the pressure difference inside the pump. Consider the case of a device with one tank and three units (Fig. 3). In the peristaltic motion, the feces in the tank is pushed out by applying air pressure. Assuming that the feces is always ejected at a constant rate with respect to the contents, mass of contents in the *i*th unit in cycle *j* is m_{ij} , and the transfer rate is *r*. The transfer mass s_{ij} is given as follows:

$$s_{ij} = rm_{ij}.\tag{1}$$

Similarly, if the content mass of the tank is m_{tj} and the transfer rate of the tank is r_t , the transfer mass s_{tj} is given by the following equation:

$$s_{tj} = r_t m_{tj}.$$
 (2)

Therefore, when the machine is driven for one cycle from phase 1 to phase 6, the transfer mass S_j is expressed

as follows:

$$S_j = r_t r^3 m_{tj} + r^3 m_{1j} + r^2 m_{2j} + r m_{3j}.$$
 (3)

Next, we consider a method that utilizes the internal pressure difference of the pump. First, for phase 3 to phase 4 and phase 5 to phase 6, the amount to be transferred is the content multiplied by the transfer rate, as in normal peristalsis. In phase 2 to phase 3, the third unit is always closed so that no gas enters or exits, and the pressure inside the unit decreases when the unit is opened. When the unit opens, the pressure in the unit decreases. This draws the feces and air in the tank into the unit. Assuming that the pressure inside the unit is P_1 , the atmospheric pressure is P_0 , the volume of the unit in the closed state is V_0 , the volume in the open state is V_1 , and the inside of the tank is almost filled with feces, the following equation holds:

$$P_1 = \frac{P_0 V_0}{V_1}.$$
 (4)

However, the pressure applied to the feces in the tank increases owing to the blockage of the tank. If the elasticity of rubber is ignored, the pressure is equal to the supply pressure P_{in} to the tank. Here, $P_{in} \ll P_1$ causes the pressure in the unit to decrease to a larger extent than the pressure at the left end of the tank, and a force is generated to pull the feces into the unit. Because it is difficult to accurately model the behavior of the feces at this time, if the increase in the transfer rate due to the pressure difference is r'_t , the transfer mass s'_{tj} can be



FIGURE 4. (a) Experimental environment for transfer using a peristaltic pump with a cylindrical inner rubber tube. (b) Experimental environment for transfer using a peristaltic pump with a gouged inner rubber tube. (c) Before and after transfer using a peristaltic pump with a cylindrical inner rubber tube. (d) Before and after transfer using a peristaltic pump with a gouged inner rubber tube. (e) Transfer rates for the cylindrical and gouge-shaped inner rubber tubes.

TABLE 1. The powder and liquid components.

	Rate of inclusion (%)
Miso (soybeen paste)	50.0
Water	42.7
xanthan gum	5.0
olive oil	2.3

expressed as follows:

$$s'_{ti} = (r_t + r'_t)m_{ti}.$$
 (5)

In phase 4 to phase 5, the pressure in the pump increases owing to the blockage of the second unit. If the rubber elasticity is ignored, the pressure received by the feces at this time is P_{in} . Therefore, when $P_{in} > P_0$, the feces is ejected by the pressure as soon as unit 3 is opened. Because this behavior is difficult to model accurately, let the increase in the transfer rate be r'; then, the transfer quantity s'_{ij} can be expressed as follows:

$$s'_{ij} = (r + r') m_{ij}.$$
 (6)

From the above, the transfer quantity in one cycle (S'_j) is given by the following equation.

$$S'_{j} = (r_{t} + r'_{t}) (r + r') r^{2} m_{tj} + (r + r') r^{2} m_{1j} + (r + r') r m_{2j} + r m_{3j}$$
(7)

Therefore, the amount transferred per cycle (dS), which is increased by exploiting the pressure difference, can be expressed as follows:

$$dS = \left(r_t r' + rr'_t + r'r'_t\right) r^2 m_{tj} + r'r^2 m_{1j} + r'r m_{2j}.$$
 (8)

III. EXPERIMENTS TO COMPARE TRANSFER RATES OF INDIVIDUAL UNITS WITH DIFFERENT RUBBER TUBES

Simulated feces transfer experiments were performed using the developed peristaltic pump unit.

A. PURPOSE

The transfer of simulated feces by a peristaltic pump using the proposed gouge-type inner rubber tube and a conventional cylindrical inner rubber tube was evaluated experimentally, and the transfer performance was compared.

B. EXPERIMENT SUMMARY

The experimental environment is shown in Figs. 4(a) and (b). The simulated feces was fed into the peristaltic pump placed vertically, and compressed air was applied by an air compressor to the apparatus through a pressure-reducing valve. When a gouge-type inner rubber tube was used, a negative pressure was applied to the unit before feeding the simulated feces, and the rubber tube was opened, as shown in Fig. 4(b). If the mass of simulated feces fed into the unit is M_0 [g] and the mass of simulated feces left in the unit after transfer is M [g], the transfer rate R [%] can be expressed as follows:

$$R = \frac{M_0 - M}{M_0} \times 100.$$
(9)

This experiment was performed using a cylindrical inner rubber tube and a gouge-type inner rubber tube, twice each. When the applied pressure of compressed air to the pump unit exceeds 70 kPa, the inside of the pipe is not blocked any further. For this reason, the applied pressure was set to 70 kPa and the application time to 3 seconds. (The pipe is completely occluded within 2 seconds after application.) The mass of simulated feces was 50 g. The composition of the simulated feces is presented in Table 1; This simulated feces has properties similar to an average human feces, such as viscosity and stickiness to the wall surface. The actual feces vary from person to person and have viscosities ranging from low to high, but this is not considered in this study.

C. EXPERIMENT RESULTS AND DISCUSSION

Figs. 4(c) and (d) show the state of transfer for the peristaltic pump unit using two types of inner rubber tubes.



Confirm that the feees has been transported to the collection bag. (c)

FIGURE 5. (a) Experimental environment for the simulated feces transfer experiments using the developed peristaltic transfer system. (b) Transfer rates in the simulated feces transfer experiments using the developed peristaltic transfer system under different conditions. (c) Transfer of simulated feces in each phase of the simulated feces transfer experiment using the developed peristaltic transfer system.

The average transfer rates are shown in Fig. 4(e). The transfer rates of the cylindrical and gouge-type inner rubber tubes were 73.2 % and 87.2 %, respectively; thus, the transfer rate of the gouge-type inner rubber tube was 14.0 % higher. This may be because for the gouge-type inner rubber tube, there was less extra space after the unit was closed.

IV. EXPERIMENTS FOR EVALUATING TRANSFER RATE OF PROPOSED PERISTALTIC TRANSFER SYSTEM

Simulated feces transfer experiments were performed using the developed peristaltic transfer system.

A. PURPOSE

A peristaltic transfer system consisting of three peristaltic pumps and a feces tank was used to conduct a simulated feces transfer experiment. In the experiment, we compared the transfer performance between the cases of a positive pressure and a negative pressure.

B. EXPERIMENT SUMMARY

The experimental environment is shown in Fig. 5(a). In this experiment, three peristaltic pumps were connected to a feces

tank, and a collection tank was attached to the end of the peristaltic pump. Simulated feces and water were fed into the tank. The compressed air from the air compressor was provided by a pressure-reducing valve. A vacuum generator (Nihon Pisco Corporation, VUH05-66J) was used to generate the negative pressure. A positive pressure of 70 kPa and a negative pressure of -70 kPa were applied, and the application intervals were set at 2 s. The transitions of the patterns of applied pressure are shown in Figs. 2(f) and (g). The pattern without a negative pressure mimics the peristalsis of the intestine; the simulated feces was moved only by the pushing force of the tube. In contrast, in the case where a negative pressure was generated in the unit, the simulated feces was transferred by the pulling force in addition to the pushing force of the tube. The higher the value of applied pressure, the greater the degree of blockage in the tube by the rubber tube, and the greater the pushing force on the object being transfered. In addition, the greater the difference in applied pressure between positive and negative pressure, the greater the force to pull in the material to be transfered. However since the amount of deformation of the rubber tube does not change even when pressure is applied above 70 kPa, the

transfer rate is not considered to increase. Therefore, 70 kPa was used in this experiment. The contents were transferred from the tank to a collection bag attached to the end of the unit, and the transfer performance was evaluated with regard to the following three transfer rates.

- 1. Transfer rate from the tank to the bag
- 2. Transfer rate from the tank to the unit
- 3. Transfer rate of simulated feces and water to the bag in the unit

If the mass of simulated feces and water to be fed into the feces tank is M_0 [g], the mass of simulated feces and water transferred to the collection tank is M_1 [g], and the mass of simulated feces and water remaining in the unit after transfer is M_2 [g], the transfer rates R_1 [%], R_2 [%], and R_3 [%] (corresponding to cases 1, 2, and 3 above, respectively) can be expressed by (10)–(12).

$$R_1 = \frac{M_1}{M_0} \times 100$$
 (10)

$$R_2 = \frac{M_1 + M_2}{M_0} \times 100 \tag{11}$$

$$R_3 = \frac{M_1}{M_1 + M_2} \times 100 \tag{12}$$

The simulated feces used in the experiment was identical to that used in the experiments of Section III. The weights of simulated feces and water were 108.1 and 27.1 g, respectively. The water addition rate was 20% of the total weight of the simulated feces and water. The experiment was conducted under different conditions, three times each. The conditions were as follows. "Existing peristalsis" refers to the existing drive system shown in Fig. 2(f), and "proposed peristalsis" refers to the proposed drive system utilizing a negative pressure, which is shown in Fig. 2(g).

Condition 1: Use of cylindrical inner rubber tube, existing peristalsis

Condition 2: Use of gouge-type inner rubber tube, existing peristalsis

Condition 3: Use of gouge-type inner rubber tube, proposed peristalsis

In addition, t-test was used for all data.

C. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 5(b) shows the average transfer rate in the experiment under each condition. Fig. 5(c) shows the transfer rate of the simulated feces in each cycle for the peristaltic transfer system.

1) COMPARISON BETWEEN CONDITIONS 1 AND 2

Conditions 1 and 2 were compared to evaluate the difference in the transfer rate between the cylindrical and gouge-type inner rubber tubes used in the peristaltic transfer system. Compared with Condition 1, the transfer rate R_2 was almost identical for Condition 2, and the transfer rate R_3 was 36.1% higher. As described in Section III, the gouge-type inner rubber tube has a higher transfer rate than the cylindrical inner rubber tube, corresponding to a smaller amount of simulated feces remaining in the unit. In addition, R_1 , which represents the transfer performance of the whole system, was higher for Condition 2. There was a significant difference between condition 1 and condition 2 (p < 0.05). As shown in Fig. 5(c), the amount of simulated feces transported to the collection tank in one cycle was larger for Condition 2 than for Condition 1.

2) COMPARISON BETWEEN CONDITIONS 2 AND 3

Conditions 2 and 3 were compared to evaluate the difference in the transfer rate between the cases with and without the use of a negative pressure. Compared with Condition 2, the transfer rates R₂ and R₃ were 46.6% and 19.2% higher, respectively, for Condition 3. This is because the negative pressure caused the force to pull the simulated feces from the tank and the unit. In particular, the transfer rate from the tank to the unit (R_2) exceeded 90%, suggesting that the proposed method using a negative pressure is effective for transferring simulated feces from the tank and that R_1 , which represents the transfer performance of the system, was also higher for Condition 3. There was a significant difference between condition 2 and condition 3 (p < 0.05). As shown in Fig. 5(c), the amount of simulated feces transported to the collection tank in one cycle was larger for Condition 3 than for Condition 2.

3) COMPARISON BETWEEN EXPERIMENTAL AND THEORETICAL VALUES

The theoretical values of the transfer rate for each condition are shown in Fig. 5(b). The theoretical values were calculated based on the approximate model described in Section D of Chapter 2. The transfer rate r was set from the experimental values in Chapter 3, 0.732 in conditions 1, and 0.872 in conditions 2 and 3. The transfer ratio of the tank rt is set to 0.15. r' and rt', the increase ratio in the transfer rate when negative pressure is applied, were both set to 0.3. rt, r', and rt' were decided by trial and error for setting the calculated value as close to the experimental value in the total transfer rate R_1 .

Comparing the experimental and theoretical values, it can be confirmed that the experimental values of the transfer rate R_3 for conditions 1 and 2 are smaller than the theoretical value. This is because the transfer rate is lower than that of a single unit because of the residual simulated feces between the units when multiple units are connected. On the other hand, in Condition 3, when negative pressure is applied, the residual simulated feces between units decreases due to the effect of negative pressure, and the transfer rate approaches the theoretical value. the transfer rate "r" actually depends on the number of units from the entrance. In addition, the transfer rate "r" of each unit includes individual differences. However, since this transfer unit consists of one tank and three pumps, differences in transfer rate "r" is ignored, and the simplified model assumes that all units are the same. In the future, it will be necessary



Negative pressure on some units due to the closure of an adjacent unit.

FIGURE 6. Scene of the transfer in condition 2 of the transfer experiment using the peristaltic transfer system, when a different movement from the assumed drive pattern was confirmed.

to investigate the transfer rate of each unit, perform rigorous simulations, and compare the results with experimental values.

4) EXCEPTIONS IN CONDITIONS 2 AND 3

For the experiment of condition 2, data were intentionally excluded from the average transfer rate graph in Fig. 5(b) because of the different operation from the assumed drive. Fig. 6 shows the transfer rate in this case. Compared with the operation pattern of Fig. 2(f), we observe that the second unit of the transfer unit was closed during Phase 2. Therefore, in the first transfer unit (Fig. 6, red frame), a pressure difference due to the negative pressure was generated, and the resulting force pulled in the simulated feces. Thus, the existing peristalsis method, which should not utilize a negative pressure, exhibit a movement similar to that of the proposed peristalsis method, and a high transfer rate was obtained. The reason for closing the second unit in Phase 2 was that the simulated flight was jammed and it took longer than expected to open. Although there is a possibility that a negative pressure can be utilized by the existing peristalsis method, the proposed peristalsis method is considered to be more suitable for utilizing the negative pressure reliably.

5) CONSIDERATION OF MULTIPLE PERISTALSIS AND MULTIPLE DEFECATION

In this experiment, the peristaltic pattern shown in Figs. 2(f) and (g) is driven for three cycles in one simulated feces transfer. the amount of feces that can be transferred per cycle can be expressed by Equations (3) and (7) of the simplified model, so the transfer rate increases as the number of peristaltic movements increases. However, the proposed method is more efficient than the existing method because the transfer rate per cycle is higher. Therefore, if the device is always moved, the more it is moved, the more simulated fecess can be transferred. In addition, since the proportion

of contents transferred by one unit of the transfer device in one transfer cycle is always constant, the transfer rate will be higher as the original contents increase due to multiple defecation cycles. Future experiments should be conducted to study the details of the actual use of the device in space.

V. CONCLUSION

A peristaltic transfer system was developed for the purpose of developing a space toilet that can transfer feces without gravity and with less water consumption than the conventional system. The transfer performance was compared between a cylindrical rubber tube and a gouge-type inner rubber tube, and the results indicated that the gouge-type inner rubber tube could carry 15.0% more feces (by mass). In addition, the transfer method using a negative pressure was able to carry 50.2% more feces than the pattern without a negative pressure. For the proposed peristaltic transfer system, the transfer rate is much higher than that of conventional transfer systems, but the amount of feces transported from the tank to the unit is not 100% of the total tank contents, and the residual feces in the tank raises concerns. Therefore, in the future, we will improve the system to transfer a larger amount of simulated feces from the tank to the unit. In addition, it is desirable to measure and analyze the pressure inside each unit in order to analyze in detail the mechanism by which the device transfer the contents. Currently, however, it is difficult to measure or simulate the internal pressure without compromising the flexibility of the pump. In the future, we will measure the internal pressure and analyze the pressure difference actually occurring inside the unit. In addition, we intend to conduct evaluation experiments using the developed system under microgravity environment. When this system is actually used in space, the number of units must be increased depending on the required pipe length. As an initial study, the minimum number of units that can utilize negative and positive pressure is being used. In the future, we will examine the difference in transfer rate when the number of units is increased.

ACKNOWLEDGMENT

This study was conducted in collaboration with the Japan Aerospace Exploration (JAXA) as part of the 6th Research Proposal (RFP) of the Space Exploration Innovation Hub.

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