Design and Development of Pneumatic Drug Delivery System

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Abstract: Pneumatic delivery system is a popular system during 19th & 20th century where there was internet to send emails. These systems were used to send files from one department to other department in the office environment. Later these were slowly replaced by fax and email. Now-a-days these are being widely used in hospitals to deliver blood samples or drugs through capsule from one block to other block of the hospital to save time since blood samples and drugs weigh very less. Above being the case, a system was developed where a capsule containing blood samples or drugs of minimum 5kg of weight can be carried using less number of air compressors by creating a smart path. Till now there were systems which were designed for apartments and industries for transportation of products from one location to another location, but the developed system can be implemented in hospitals for drug delivery from one place to other place. The capsules can be built using suction pipes to reduce the cost of the system. Cost of the system can be further greatly reduced by using PVC or acrylic sheets. The system can be made more effective by using smart path which is specially designed to reduce traffic and time delay. The developed system allows the reuse and storage of compressed air in the pipes, so that less number of compressors are being used. The system also allows a unique method of finding the location of the drug in the whole system by Radio-frequency identification (RFID) tags. Finally, the developed system is very useful in hospitals for transporting drugs by reducing the traffic and time delay. Further, the system can be developed such a way that it can be used to deliver the couriers in a faster rate to save time and the cost to deliver product can also be greatly reduced.

Keywords: Pneumatic delivery system, Drug, Hospital, Capsule.

1. Introduction
Pneumatic delivery system is a popular system during 19th & 20th century where there is internet to send emails. So these systems were used to send some files from one department to another department. Later these were slowly replaced by fax and email (6). Now a day’s pneumatic delivery is widely used in hospitals to deliver blood samples from one block of the hospital to other block to save time. Blood samples weigh very less (2). The project proposed includes the development of a pipeline delivery system that can carry a capsule of minimum 5kg weight using less number of air compressors by creating a smart path. The transportation of blood and specimens is the main principal of Pneumatic Tube System (PTS) in hospitals. A PTS provides transportation service for drugs around the hospital campus which is valuable whether or not as a manual operation or mechanically joined to dispensing robots. The specimens and drugs are not only transported by PTS in a hospital (5). These systems can also be used for patient notes, menu cards, prescription requests and plenty of alternative tasks. Where money is accumulated, a Gas Tube System may be a tried methodology of moving it on to a secure location (9). Whether or not the applying may be a multi-checkout grocery store, or one until, an appropriate solution is used to move money firmly, unobtrusively, faithfully and with efficiency. In nearly each sphere of business operations, and even during this age of electronic info, there’s still a demand to maneuver paper.
In producing units, paper documents give careful method directions, in quarries, delivery notes should be transported to the provision workplace (4). Wherever transmission isn't associate possibility, a gas Tube System is that the resolution. Jewellery, Keys, Production Consumables, tiny elements, Dental & Surgical Instruments; the list is endless. For instance, PTS are found inside giant automobile production factories and little jewellers, and in each size of organisation in between. Where tiny parts ought to be transported, a gas Tube System will give the answer (7). In nearly each producing method, there's a demand to move production samples off from the assembly space to a testing facility. Whether or not the sample is plastic chips or cheese, PTS are the foremost economical transportation methodology obtainable for production samples. In food factories, they eliminate the requirement for operatives to enter and leave clean areas. PTS are available for specialised applications like hot or terribly serious samples (3).

Figure 1. Pneumatic Tube Systems for Transportation Requirements across all Industry Sectors.

Figures 1, shows the Gas Tube Systems which provides the solution for various transportation requirements across all industry sectors. The system also increases the security in apartments. Now a day’s strangers are going to the apartments by saying that they are delivery boys and doing illegal activities. This can be eradicated by placing pneumatic delivery system where the delivery boys are allowed only to place the items in the capsule which will be in ground floor under the surveillance of a watch man (1). Few sensors like metal detector detects the items in the capsule if it is a bomb. This system can also reduce the stress of apartment people. In cities, apartments will have at least 10 floors, if anyone forgot their file, mobile or something, then no need to go to 10th floor, he can type a message in a screen which is attached to the capsule and can send the capsule to his flat where a calling bell rings and a notification gets to the mobile then the one who is in the flat can notice it and able to send what he has forgotten (8). In the commercial point of view, it is very cost effective. The whole system can be done at a cost below 10 lakhs for a 10 floors building having 7 flats for each floor.

2. Design and Fabrication

Design of Pneumatic Drug Delivery System starts with the design of simple and most effective drive system which is a very important part as it has to carry the drugs in hospitals from one location to other. The proposed project starts with the selection of air compressors depending upon the load and stations followed by the selection of pipe material, capsule material and its fabrication. Further, the fabrication of the shifter will be done and the required motor, sensors and electronic controllers are selected and finally ends with programming the smart path according to the position of stations.

Figure 2. Design Methodology for the Project.

Figure 2, gives a brief idea about the design methodology of Pneumatic Drug Delivery System. It starts with the pay load calculations and ends with the error rectification and minimization.
Figure 3, shows the CAD model of Pneumatic Drug Delivery System designed using Autodesk Inventor.

There are following technical components needed to be studied:

2.1. Air Compressor
Air compressor is the main part in the project as it supplies compressed air, which is fuel to the capsule to carry objects from one place to other place. Air compressor should be chosen according to the weight of the capsule that to be transported. Pressure (mainly continuous pressure), Cubic Feet per Minute (CFM) should be considered mainly in choosing an air compressor. Let us consider, a capsule weighing 5 kg, then the pressure of the compressor should be more than 5 kgf/cm², and the CFM is very important to choose because it tells that how fast will a compressor fill the pipe of volume $\pi r^2 x$ with compressed air when the capsule moves a distance ‘$x$’. According to the practical results, for an air compressor to push the capsule of weight 1.5 kg in a 110 mm diameter pipe of length 30 meters, the compressor should have 7 kgf/cm² and 33 CFM. Capsule takes a minute to travel that distance. Figure 4, shows the single stage air compressor used for these results which can maintain 5 kgf/cm² continuous pressure.

Figure 4. Single Stage Air Compressor.

2.2. Pipes
The pipes should be chosen such that it should withstand to the pressure used in the system. For a capsule of weight 1.5 kg, PVC pipe of 6 kg pressure can be used or acrylic pipes of 6 kg pressure. The advantage of using acrylic is that, as it is transparent, the movement and position of capsule can be
monitored from outside without using GPS. But the cost of acrylic pipe is very high. It costs 2000 rupees per metre which makes us to go with GPS by using other non-transparent & cheaper pipes. PVC pipes with 6kg pressure can be used, but PVC pipes are available with only 45 and 90 degrees in the market in which 15 to 25 degrees’ bend pipes are required at the turning of each floor of an apartment. Also PVC pipes are not cheaper, it costs 1000 rupees per metre. If we go with glass fibre which costs only 300 rupees per metre and also required bends are available, it weighs 5kg per metre and it also brittle in nature. So it is better to use suction pipes which costs only 300 rupees per metre, flexible and also weighs less. Figure 5, shows the suction pipes which are connected at the ground floor for maintain pressure difference by exposing to atmosphere whenever needed.

2.3. Shifter

At the edge of each floor, a decision has to be made to send the capsule to the above floor or to the same floor and accordingly path has to prepared for the capsule to move forward. So this operation will be done by the shifter. Figure 6, shows the shifter which is used to send the capsule to the required floor or room. Shifter splits a single path into two paths. It is a rectangular shaped box containing threaded pipe connectors and a rotating plate on other end. The rotating plate rotates according to the floor that capsule has to move. A motor of 0.5 HP, 1440 RPM, 2.47 Torque, so that it can efficiently rotate the plate. An angled suction pipe is connected between the two ends.

2.4. Capsule

Capsule is a vehicle which is made of PVC or acrylic pipe and uses compressed air as fuel to transport the objects from one end of pipe to the other end. Capsule length and diameter should be chosen according to the objects that is to be sent. While choosing the dimensions of the capsule, angle of the pipe at turnings should also be considered such that it won’t get stuck at the turnings. Capsule should be designed in such a way that friction between the pipe and capsule should be less. The capsule which is used practically is a closed PVC pipe of length 45 cm and 75 mm diameter. To reduce the friction, two sand papers are wrapped at the edges. As capsule travels at high speed, due to impulse, the objects in the capsule can be damaged. So the internal part of the capsule should be cushioned. Figure 7, shows the capsule used to transport the objects from one end to other end of the pipe.
2.5. Sensors and Control System

Sensors are so useful for sending feedback to the main system. A sensor will be placed at the receiver of every room such that, when the capsule reaches the receiver of a room, sensor senses the capsule and sends the feedback to the main system, so that the system can allow another capsule to have its path. Without sensor it can’t be estimated if the capsule reached the destination or not. Sensors also useful for finding the location of a capsule in the whole system. Figure 8, shows the RFID tags which can be used as sensors for finding the location of the capsule, as the transponder in the capsule will be detected by the nearest tag and sends feedback to the main system, so that the exact location of the capsule can be detected.

The final fabricated model of the system is as shown in the below figure 9, it consists of a shifter, capsule and a suction pipe for the delivery of blood samples or drugs.

![Fabricated Model of the System](image)

Figure 9. Fabricated Model of the System.

3. Construction and Working

For the transportation of blood samples or drugs through capsule from ground floor (G) of an hospital to any floor fastly, a smart and effective path is required such that traffic can be reduced greatly. Due to smart path, capsule can be transported with no delay. Delay’s due to simultaneous transportation of two capsules can be eradicated. From figure 10, we can observe that there are four rooms, four shifters. Let us assume that a delivery boy wants to send blood samples or drugs to room (R1) which was ordered by them. Now the delivery boy places the product in the capsule and type’s the room number, immediately after typing the room number shifter (S1) connects the pipes (P11) and (P13), shifter (S2) connects the pipes (P23) and (P21), door one will be opened and the small pipe (AP2) exposes to the atmospheric pressure. So that the capsule reaches room (R1) from ground floor. After the capsule reaching the room (R1); shifters, pipes, doors will get back to its normal positions. Let us consider a person who lives in room (R1) wants to send blood samples or drugs to room (R4). Then door three gets opened, shifter (S1) connects pipes (P11) and (P13), shifter (S2) connects pipes (P23) and (P21), small pipe (AP2) exposes to the atmosphere, so that capsule will be moving in the way to ground floor. When it crosses shifter (S2), shifter (S1) gets back to its original position and shifter (S2) will connect pipes (P13) and (P12), shifter (S3) will connect pipes (P33) and (P31) such that the capsule enters the door three and reaches room (R3). In this way smart path helps in fast transportation of capsule by using less number of compressors and re-using pressure.
Figure 10. Path Algorithm (Smart Path).

Figure 11 shows the path algorithm for the transportation of blood samples or drugs in hospitals from one location to other.

| FROM | TO  | AP1 | AP2   | S1   | S2   | S3   | S4   |
|------|-----|-----|-------|------|------|------|------|
| 1    | G   | R1  | CLOSE | OPEN | P11→P13 | P23→P21 |
| 2    | G   | R2  | CLOSE | OPEN | P11→P13 | P23→P21 |
| 3    | G   | R3  | CLOSE | OPEN | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 4    | G   | R4  | CLOSE | OPEN | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 1    | R1  | G   | OPEN  | CLOSE | P13→P11 | P21→P23 |
| 2    | R1  | R2  | CLOSE | OPEN | P11→P13 | P23→P21 |
| 3    | R1  | R3  | OPEN  | CLOSE | P13→P11 | P21→P23 |
| 4    | R1  | R4  | OPEN  | CLOSE | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 1    | R2  | R1  | OPEN  | CLOSE | P11→P13 | P23→P21 |
| 2    | R2  | G   | OPEN  | CLOSE | P11→P13 | P23→P21 |
| 3    | R2  | R3  | OPEN  | CLOSE | P11→P13 | P23→P21 | P31→P33 | P41→P43 |
| 4    | R2  | R4  | OPEN  | CLOSE | P11→P13 | P23→P21 | P31→P33 | P41→P43 |
| 1    | R3  | R1  | CLOSE | OPEN  | P11→P12 | P21→P22 | P31→P33 | P41→P43 |
| 2    | R3  | R2  | OPEN  | CLOSE | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 3    | R3  | G   | OPEN  | CLOSE | P11→P13 | P23→P21 | P31→P33 | P41→P43 |
| 4    | R3  | R4  | OPEN  | CLOSE | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 1    | R4  | R1  | OPEN  | CLOSE | P11→P13 | P23→P21 |
| 2    | R4  | R2  | OPEN  | CLOSE | P11→P12 | P22→P21 | P31→P33 | P41→P43 |
| 3    | R4  | R3  | OPEN  | CLOSE | P11→P13 | P23→P21 | P31→P33 | P41→P43 |
| 4    | R4  | G   | OPEN  | CLOSE | P11→P13 | P23→P21 | P31→P33 | P41→P43 |

Figure 11. Path Algorithm for the Transportation of Blood Samples or Drugs.
4. Experimental Observations
Practically, three loads of 1 kg, 1.5 kg, 2 kg are taken and respective values of pressure, CFM, pipe
diameter, capsule dimensions, distance moved etc. are shown in the below table.

Table 1. Load of 1 kg.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Pressure of Compressed Air | 6.5 Bar                |
| CFM                        | 33                     |
| Capsule Dimension          | Length = 30 cm, Diameter = 75 mm |
| Speed of the Capsule       | 1 m/s                  |
| Length of the Pipe         | 1 m                    |
| Pipe Diameter              | 110 mm                 |

Table 1 shows that, for a load of 1 kg of drugs or blood samples to be transported at 6.5 bar for a length
of 1 m, the speed of the capsule will be 1 m/s.

Table 2. Load of 1.5 kg.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Pressure of Compressed Air | 7.2 Bar                |
| CFM                        | 33                     |
| Capsule Dimension          | Length = 30 cm, Diameter = 75 mm |
| Speed of the Capsule       | 0.28 m/s               |
| Length of the Pipe         | 1 m                    |
| Pipe Diameter              | 110 mm                 |

Table 2 shows that, for a load of 1.5 kg of drugs or blood samples to be transported at 7.2 bar for a length
of 1 m, the speed of the capsule will be 0.28 m/s.

Table 3. Load of 2 kg.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Pressure of Compressed Air | 8 Bar                  |
| CFM                        | 33                     |
| Capsule Dimension          | Length = 30 cm, Diameter = 75 mm |
| Speed of the Capsule       | 0.5 m/s                |
| Length of the Pipe         | 1 m                    |
| Pipe Diameter              | 110 mm                 |

Table 3 shows that, for a load of 2 kg of drugs or blood samples to be transported at 8 bar for a length
of 1 m, the speed of the capsule will be 0.5 m/s.

Thus observing practical results, it can be concluded that pressure doesn’t alone responsible
for speed of the capsule, but CFM also matters. Every compressor can maintain a 10 bar
pressure, but the compressors vary in CFM which is very important for the speed of the capsule.
5. Conclusion and Future Scope
Till now there were systems which were designed for apartments and industries for transportation of the products, but the developed system can be implemented in hospitals for the delivery of drugs or blood samples from one place to other place. The capsules can be built using suction pipes to reduce the cost of the system. Cost of the system can be further greatly reduced by using PVC or acrylic sheets. The system can be made more effective by using smart path which is specially designed to reduce traffic and time delay. The developed system allows the reuse and storage of compressed air in the pipes, so that less number of compressors are being used. The system also allows a unique method of finding the location of the drug in the whole system by Radio-frequency identification (RFID) tags. Finally, it can be concluded that the developed system is very useful in hospitals for transporting drugs or blood samples by reducing the traffic and time delay in a cost effective manner. Other application that can be found using the system is to send couriers. PTS can be built from one place to another place (example from Mysore to Bangalore) and can send couriers in it weighing 15 kg also. This will become a revolutionary change in the field of logistics. The space beside railway tracks can be used for implementing the above system as most of the places in India has railway connectivity and railway tracks will not have sharp bends, so this space is the perfect space to build the system. The system can be developed such a way that it can be used to deliver the couriers in a faster rate to save time and the cost to deliver product can also be greatly reduced.

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