factors may interfere with the signal strength of an analogue transmission. Try listening to a distant radio station and notice how the reception varies according to the time of day and the weather conditions. The same sort of problems can affect robot communications.

Digital methods can have problems as well, especially when interference causes bits to be missed out or inserted where they shouldn't be. To avoid this, messages to the robot are often repeated, with the robot acting only after it has received an identical message several times.

FEEDBACK SYSTEMS

A more sophisticated technique is to use a 'loop' system, in which the robot provides feedback to the transmitter concerning the signal it has just received. This could be regarded as a dialogue between the transmitter and the robot. For example, the transmitter might say 'move forward' and, having received this message, the robot says 'did you say move forward?', to which the transmitter replies 'yes', and the robot then moves forward. This can help to avoid serious mistakes if the robot is handling nuclear waste or is about to step into a crater on the Moon.

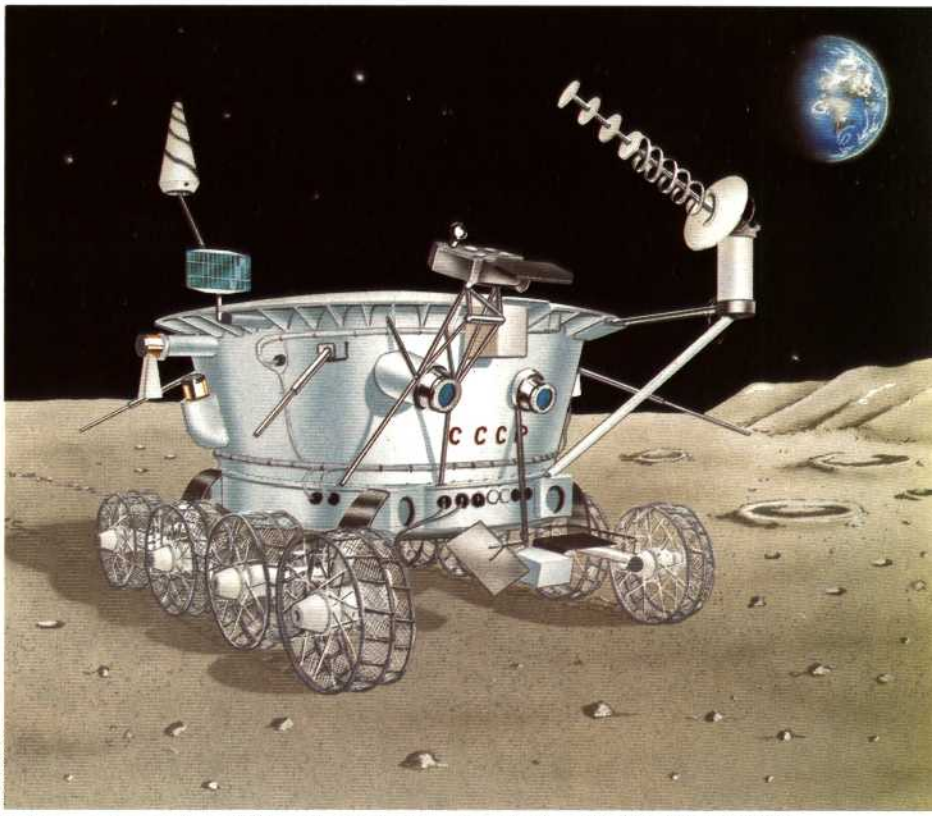
The same general techniques can be applied to other means of remote control. For instance, some robots can be controlled via infrared emitters of the sort used in remote control devices for television sets. Or they might be controlled by ultrasonic sound, rather like a dog whistle, or by audible sound of a distinctive nature, such as a series of hand claps. Whichever method is used, the underlying techniques of passing the message and making sure that the robot has received it remain the same.

If the human operator is fairly near the robot it may not be necessary to use such sophisticated techniques —the commands to the robot could be transmitted through a connecting wire. There is also the possibility of using more than one wire, which is equivalent to having several channels on a radio controlled aeroplane. But, in the case of the robot, the extra wires are usually used to provide parallel instead of serial communication (a string of bits is sent out in parallel along all the wires rather than as a series of pulses along one wire). This allows faster communications with the robot. Perhaps even more important is the fact that most computers have a parallel port on them. This provides a convenient way of communicating instructions to the robot from a computer keyboard.

If the robot movement is to be controlled by a human operator sitting at a computer keyboard, and the operator can see the robot, then there is little difference in principle between controlling the robot via a human operator and controlling the robot via a computer. This is because, like the radio controlled aeroplane, the operator can always see what the robot is doing and can correct any errors immediately. But if the robot is some distance away (on the Moon for instance, or even in the next room), or if the robot is to be controlled via a program within the computer rather than by real-time keyboard commands, then the robot must be slightly more intelligent.

Essentially what is needed is some form of feedback. This is a process that enables the system to adjust what it is doing by reference to what it has done already and to what it should be doing. For instance, if you want a robot to travel three feet across the floor and you are controlling it directly, you can start it moving, judge its progress, and stop it when it has gone three feet. This is because you have visual feedback on the robot — you can see how far it has gone, how far you want it go, and you can correct its actions accordingly.

In the absence of human sensory feedback, the robot has to provide some of its own if it is to move accurately. The line-following robot uses feedback from the line it is following on the ground and, equally, the computer-controlled robot must use some feedback if it is to travel exactly three feet forwards. One of the most commonly used methods of providing the necessary feedback is a *shaft encoder* — a circular disc attached to the main axles of the robot's wheels, which gives a very precise measure of how far they have rotated. So, if the computer sends instructions to the robot to move forward three feet, the robot can start moving and, at the same time, monitor the signals coming from its shaft encoders to see how far the robot has moved. If the robot has to go further it can carry on moving. When it gets there it can stop, and if it should happen to overshoot its mark then it can always back up by the correct amount calculated from the information sent from the shaft encoders.



STEVE CROSS

A Giant Leap For Robotkind
The USSR's Lunokhod 1 was landed on the Moon in 1970 to collect information about the nature of the surface and the atmosphere. It was not a true robot — being controlled by radio from Earth — but its indifference to lunar conditions enabled the spacecraft to carry a larger scientific payload than would have been possible with human passengers and their elaborate life-support systems.

Like all remote-controlled objects in space, Lunokhod suffered from the three-second lag between its transmitting information to Earth and receiving a control signal in reply