WORKING NOTE AC92

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A NOVEL REACHING DEVICE

ORIGIN.

I became interested in using "intelligent" robots for rehabilitation purposes around 1986, and in 1987 Shane Clerk began an M.Sc. thesis project on constructing a robotic feeding assistant. (Through no fault of his own, he didn't complete the project.) My intention was to seek means of using comparatively cheap computer intelligence rather than comparatively expensive precision mechanical engineering to solve problems of precise manoeuvring such as are needed for safe operation of machines in the neighbourhood of people with disabilities.

In 1990, Roy Davies discussed with me the possibility of an M.Sc. thesis based on investigating the construction of a mechanical reaching aid which could be used by people in wheelchairs, and in 1991 carried out the investigation[1]. I put forward the suggestion described here early in 1991 as a contribution towards this work.

WHAT IT'S FOR.

It is self-evident that people with limited mobility can benefit greatly from assistance provided by mechanical devices of various forms; the prime example is the wheelchair, now available in many forms from simple manually operated designs to motor-driven versions with elaborate control systems.

Apart from such mobility aids, though, the promise of mechanical assistance has not been borne out in practice. To generalise, as the requirement for more precise control becomes important, machines become less available. In particular, manipulators, designed as more or less limited general-purpose hands, are available, but not widespread. Disabled people can use them, mounted on wheelchairs for example, but they can be clumsy. Specially designed ones exist[2], but they are expensive. That is at least in part because the mechanical components must be rigid to avoid bending and twisting under load. Rigidity also helps to simplify the control problem; while the human operator can control some of the consequences of flexibility, a conventional robot may not have actuators which can counter some possible motions (such as twisting in the arm), and internal vibrations can be serious.

How might one go about designing a cheap but useful device of this sort ? The first task is to decide just what the device is to be able to accomplish; for economy in production, it should be significantly useful to as many people as possible. Roy's requirement was of this type, as it was intended to reach objects in inaccessible places and move them to some standard work station, such as a tray attached to a wheelchair. Many people who use wheelchairs do so because of conditions confined to their legs, and have fully dexterous control of other parts of their bodies; all they need is the means to move objects from awkward places to convenient places, and back again. No very precise or flexible dexterity is required of the device beyond that needed to find a place and pick up an object.

The requirement that the device should be usable with a wheelchair is (obviously enough) not part of the reaching task; a stationary reaching device would be useful for people who spend long periods in bed, or are otherwise immobile. The wheelchair requirement is nevertheless sensible, for two reasons : first, if the device is portable its potential clientele is much enlarged, giving a better chance of economic production; and, second, while a stationary reacher is useful for a stationary person, a mobile reacher is likely to be more useful, as it can fetch and carry from locations around a room – and a device designed for a wheelchair could presumably be provided with an alternative controllable platform. Finally, even without a mobile platform, a portable reacher can be used standing still, while an intrinsically staionary one can't as easily be made to move.

The major design constraint imposed by the wheelchair requirement is that the device must be collapsible to a compact form which is out of the way of the wheelchair occupant when not in use, and doesn't significantly enlarge the wheelchair in any way which would affect mobility.

The device can therefore be succinctly described as a cheap collapsible reacher.

REACHING.

The next step is to specify rather more precisely what I mean by "reaching". So far, I have restricted it to getting things from one place and putting them in another. Tasks requiring any other manipulation of the object reached are not required – so the device need not be able to operate switches or door handles, or poke the fire, or use a watering can to water flowers, etc. Such abilities would be a welcome bonus, but require more complicated control.

In the rest of this section, I discuss some considerations which bear on other aspects of the specification. There is nothing orderly about this discussion; I would prefer a more careful analysis of the problem, but at the moment I don't see how to do it.

Environment.

The device should operate in a normal human environment. This includes the home, shops, office, library, etc. (The home is a special case; if it is the disabled person's own home, it is not unreasonable that it should be modified to suit the person's requirements – so if opening cupboard doors is hard, we can take the doors off, etc. Obviously, modifications cost money, and should be kept to the minimum.)

A powered wheelchair usually has 12v batteries. Power consumption should obviously be minimised.

The "standard work station" may be a wheelchair tray, or a table top, or workbench, so should be to some degree adjustable. It should be possible to deliver objects to the work station and remove objects therefrom without any unnecessary clutter; in particular, no permanent structure should be needed in the work station.

Objects may be on shelves, on the floor, hanging on hooks, jammed together, supporting each other, interlocked with or inside other objects, etc. I don't expect the device to exhibit human dexterity, so not all problems will necessarily be soluble. Notice that interacting objects can be brought to the work station and disentangled by the person.

Objects may be rigid or floppy or slippery. Some examples : jars of jam; bags of flour, perhaps partly used; books; clothes; teapots; cups of tea; newspapers; ornaments. Weight-lifting and furniture removing are not required. Most objects are likely to have dimensions up to 20cm or 30cm and weights up to 2kg or 3kg.

Objects may be hot. Cooking is an important activity.

Envelope.

The reachable workspace should be comparable to that accessible to most people : from the floor to about 2m in height, 1m sideways, etc. Backward reaching is not required – people can't do it either, and don't usually want to because they can't see what's there.

A rather-larger-than-normal workspace would be of advantage if possible, as it can help to compensate for smaller-than-normal manoeuvrability. On the other hand, a wheelchair can move quite effectively, so extreme range is not a requirement. A good approach is probably to regard the wheelchair as a manoeuvrable, but not freely rotatable, platform; a particular difficulty with a wheelchair is turning in a narrow aisle, as sometimes found in shops and libraries

Speed.

Tasks should be completed at something like ordinary human rates. For a simple local reaching task, in a few seconds; for something more remote or obviously tricky, up to half a minute or so. (Maybe a little longer if it would usually require a ladder or other contrivance.) (The argument that if the device makes it possible for people to do things that would otherwise be impossible then they'll be content to wait a long time doesn't work too well in practice.)

Safety and reliability.

These factors are very important indeed.

Protection against the device's hitting the person in the wheelchair, knocking objects off high shelves, spilling hot liquids, etc. should be provided wherever possible. Failure modes should be identified and made safe. The device should be easy to detach from the wheelchair.

The devices are likely to be used in places where technical assistance is not readily accessible, so should be reliable and easy to repair with a set of standard replacement parts.

PROPOSAL.

A robot is usually heavy, and therefore expensive, because of the difficulty of precisely controlling the position of the end point of a complexly jointed cantilever, and of assuring its stability. If this form of construction is not a requirement, then much lighter and cheaper ways of moving things about are available. In many comparatively stationary machines, objects are moved about efficiently and comparatively simply along paths predefined by mechanical guides of various sorts, such as rails.

The cantilever of a conventional arm robot is used because it will work from a single centre, requiring no other fixed construction cluttering its workspace. It is also an obvious way of working, as most of us are equipped with one at each side of our bodies. At the same time, it isn't the only way to build a robot; Cartesian robots are often constructed as gantries. Analysis of the requirements for the reacher suggests that it may be possible to avoid the cantilever.

The simplifying factor is that, when reaching for an object, it is very probable that the object is initially standing on some fairly rigid support, such as a shelf or the floor. (The device is intended to be used for domestic tasks, which rarely include catching airborne or falling objects, or picking up floating objects.) It would therefore be possible to proceed through these three stages : build a bridge first, move the object along the bridge attached to a mobile transport vehicle, then dismantle the bridge. This is the novel feature of this proposal.

Advantages : the bridge can be supported at both ends, so needn't be nearly so heavy and rigid as a conventional robot. Control needn't be so precise, either – fine adjustment for precise attachment can be done in the transport vehicle, which has a firm base at each end of the travel.

Disadvantages : more parts than a robot ? (though the "arm" itself needs only two joints and a pivot) – the "hand" moves along the arm on some sort of carriage. The mechanism is significantly more complex, and there are more phases to the complete reaching operation.

THE END-EFFECTOR.

(NOTE : this section was added in 2006, when the reappearance of the diagram reproduced below drew my attention once again to the problem. I have not changed the 1995 material.)

The end-effector of the device is attached to the transport vehicle, and is responsible for loading the object onto the vehicle, and for unloading it at the destination. The destination itself is interesting; a second special feature of this machine is that the intention is not simply to move objects from one arbitrary location to another; it is to move objects between one arbitrary location, and one comparatively fixed location – the operator's work space. While the arbitrary location is essentially undefined, the fixed location can be designed as part of the system, which is – at least potentially – a simplifying feature.

The common end-effector for a conventional robot is some form of gripper, but an instrument which could effectively grip all the sorts of object which I have listed would perhaps be difficult to design and almost certainly expensive to construct. The objects have different surface characteristics, floppiness, consistency, etc. On the other hand, they all have a common feature : they can all stand on flat surfaces. An end-effector constructed as a flat platform with a dragger-on and pusher-off is therefore a possibility. This fits in well with the bridge notion : to retrieve (for example) and object, you manoeuvre the arm so that the distant platform is resting on the source surface, then use the machinery to convey the object from the surface onto the platform, which is at the operator's work space.

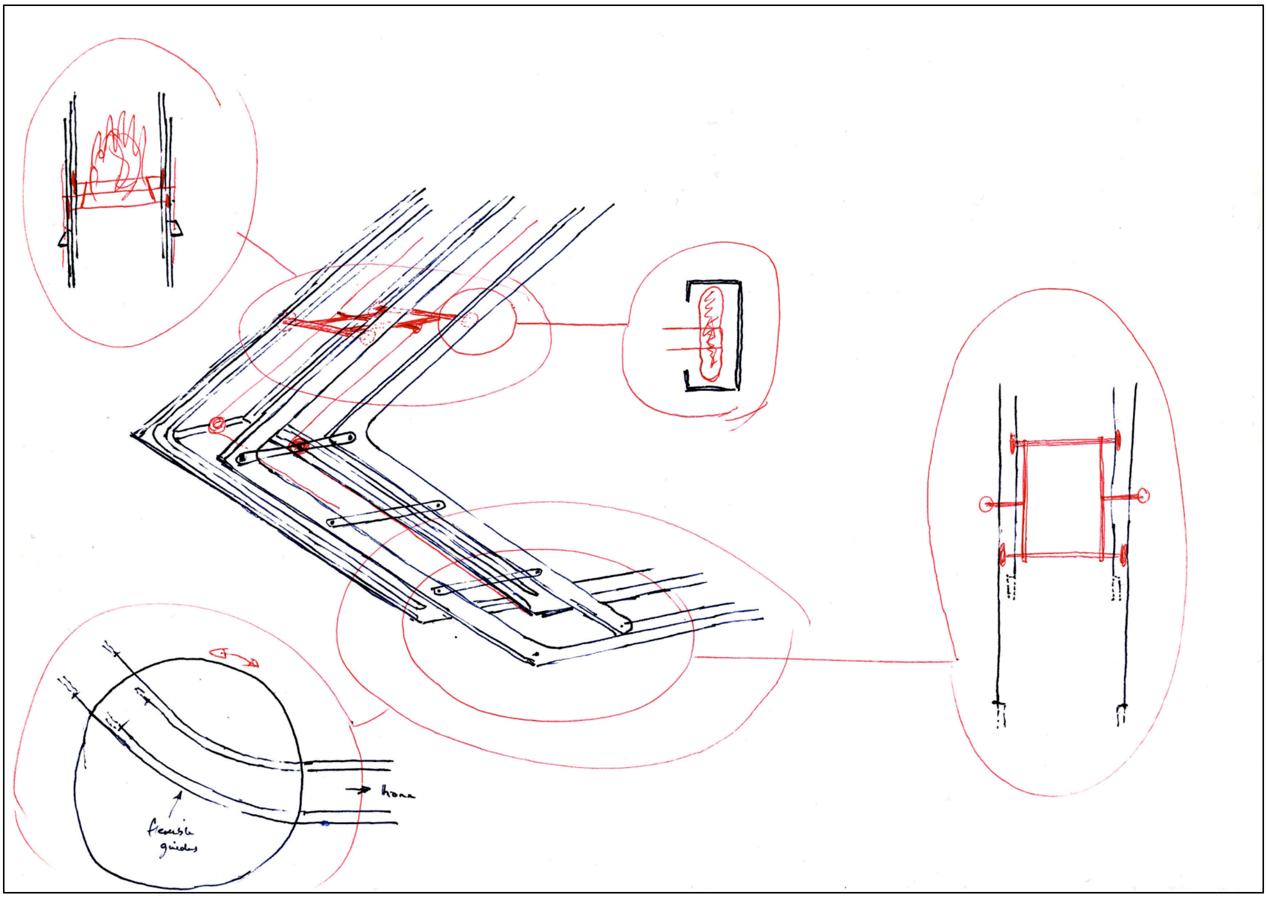
Such an instrument is a minimal end-effector, but might cover a wide range of possible object configurations satisfactorily. More ingenuity might be necessary to devise a means for removing (or replacing) objects such as closely packed books, or others in which there are local constraints on motion or accessibility.

When actively attaching to or detaching from an object, the end-effector is in a stable position, at one or other end of the bridge; it is therefore well placed for more precise manipulations. It is therefore appropriate to do fine adjustment in the end-effector, so that high precision is not essential for the rest of the system.

Many possible refinements come to mind : a television camera might help for objects placed well back from the edge of the shelf, means of selecting objects behind other objects could be useful, etc. At this stage, I am more interested in a minimal device which illustrates the principle than in a luxury version.

AN ATTEMPT.

The closest we got was the incomprehensible diagram below. I present it here as a demonstration of goodwill, and a suggestion of feasibility in principle, not as a serious design proposal.



In accordance with the earlier discussion, it's modelled on an escalator-like[3] mechanism, with a carriage running on front and back "rails". The "rails" must enclose the wheels, as in the central inset, because the wheels must be able to run when the rails are turned over – consider bending the upper part of the arm as illustrated upwards through the vertical and on to a position in line with the lower section.

The rails are offset, with one set of narrower gauge than the other. This ensures that the carriage can remain level both on the horizontal section leading to the home position and on the inclined arm.

The carriage is moved by a chain (or other flexible but near-inextensible pulling device) drive; the chain – but not its return path – is shown in red on the diagram. We chose the chain because we couldn't think of any more plausible alternative. The obvious return path is parallel to, and outside, the forward path.)

The joints are driven by conventional joint motors, which are not shown.

It uses a hinged arm, which works up to a point, but if you bend it to make a peak, as opposed to an elbow as in the illustration, you can't drive the carriage over the peak without putting the longer axle through the narrower rails and the driving chains. (More precisely you can make it work that way, but then it won't make an elbow pointing out. An escalator works because it doesn't matter if the steps turn upside down during the hidden part of their cycle.) That's just about all right if you're careful; you don't need to use the impossible bend except when stowing the bridge after use.

The circular feature at the bottom right is intended to represent a connection between the turntable-mounted bridge and a static guide to a "home" position at the work station. The text reads "flexible guides" and "home".

Much later, Roy began work on a simple end-effector, and constructed an almost-working model. I can find the model, but no documentation. He constructed most of the electronics[1], but the mechanical bits never really got done. His model does not descend from the diagram above; it's a much more conventional gripper on an arm, which could perhaps stand on the carriage. In Roy's defence, his contribution is perhaps the most practical outcome of our discussions.

REFERENCES

1 : Roy Davies : *The development of a robotic reaching aid*, M.Sc. Thesis, Auckland University Computer Science Department, 1992.

2 : H. Kwee, C. Stanger : "The Manus manipulator", *Rehabilitation Robotics Newsletter* **5#2**, 1 ("Spring", 1993)

3 : http://science.howstuffworks.com/escalator1.htm