0J>e

1 p !A 114 p 40

=$;NO@J8

1998 G/ 2 7n 13 F | Ds=P

9)3X7O8&5f2J 5!3#>pJs9)3X@l96

66241 ?eFb 0jIW

?7$7$$%G!<%?$,F~$C$?$+I&$+$rH=Dj9k!%ad_round_flg $N%/%j%"$r9k!%

```
int get_ad_data(unsigned char n, unsigned short buf[]);
```

AD JQ49$5$1$?%G!<%?$rHCF/$k!%n $O%A%c%s%M%k!$buf[] $O%G!<%?!%

<BAu

%A%c%s%M%k 0 !A 3($^$?$O%A%c%s%M%k 4 !A 7) $r=g$K AD JQ49$9$k%9%-%c%s%b!<%I$rMxMQ 9k!% 4 %A%c%s%M%k=*N;Kh$K3d$j9~$_$,$+$+$j!$%1%8%9%?$K3JG<$5$1$?JQ497k2L$r%a%b %j$KE>Aw9k!%A4 8 %A%c%s%M%k$rJQ49$7=*C?$i!$ad_round_flg $r%;%C%H$9$k!% get_ad_data() 4X?t$G!$%a%b%j$K%P%C%U%!$5$1$?%G!<%?$rFI$_=P$9!%

```
void init_AD(void)
{
    !&!&!&
    inttab[ADI] = (int)ad_finish;    /* 3d$j9~$_%Y%/%?@_Dj */
    !&!&!&
}

static void ad_finish(void)
{
    static char group = 0 ;
    ADCSR &= (~ADST & ~ADF);    /* AD %9%H%C%W */
    if (group == 0) {
        group = 1;
        ad_buf[0] = ((unsigned short) ADDRA) >> 6;
        !&!&!&
        ADCSR |= (GROUP1 | ADST);    /* %0%k!<%W"* 1, AD %9%?!<%H */
    } else {
        group = 0;
        ad_buf[4] = ((unsigned short) ADDRA) >> 6;
        !&!&!&
        ad_round_flg = 1;
        ADCSR &= ~GROUP1;    /* %0%k!<%W"* 0, (AD %9%H%C%W$7$?$^$^) */
    }
}

int new_ad_data(void)
{
    int flg;
    if ((flg = ad_round_flg) == 1) ad_round_flg = 0;
    return flg;
}

int get_ad_data(unsigned char n, unsigned short buf[])
{
    int i;
    if (n >= ad_channels) {
        for (i=0; i<ad_channels; i++) buf[i] = ad_buf[i];
        for ( ; i<n; i++) buf[i] = 0;
    } else {
        for (i=0; i<n; i++) buf[i] = ad_buf[i];
    }
    ADCSR |= ADST;          /* AD %9%?!<%H */
    return i;
}
```

```
int sci_txcount(void);
```

Aw<u?.%P%C%U%!$K;D$C$F$$$k%G!<%?$N%P%$%H?trJV9!%

;HMQNc

%(%3!<%P%C%/$N%W%m%0%i%`!%<u?.$7$?%G!<%?$r$=$N$^$^Aw?.9k!%

```
#include <serial.h>
#define TBUF       64
#define RBUF       128
unsigned char      sci_buf[ TBUF + RBUF ];
const unsigned int sci_bufsize[2] = { TBUF, RBUF };

main()
{
    initSCI0(38400, sci_buf, sci_bufsize);
/*  $^$?$O!$
    initSCI0(38400, NULL, NULL); */

    int_enable();    /* A43d$j9~$_5v2D */

    while(1)
        if (sci0_rxcount() > 0) sci0_putchar(sci0_getchar());
}
```

<BAu

1[byte] <u?.40N;3d$j9~$_!$ 1[byte] Aw?.40N;3d$j9~$_r=l>$lMxMQ$7$F$$$k!%Aw<u?.$=$l$>$l!$FHN)$N%j%s%0%P%C%U%!$r;}$A!$**putchar()**, **puts()** $O!$%P%C%U%!$K%G!<%?$r=q$-9~$_!$**getchar()** $O!$%P%C%U%!$+$i%G!<%?rFI_9~$`!% <u?.%P%C%U%!%U%k$KJC$?;~$O!$<u?.40N;3d$j9~$_$r%^%9%/$7!$<u?.%P%C%U%!$K6u$-$,$G$-$?;~$K%^%9%/$r2r=|9k!%Aw?.40N;3d$j9~$_$OAw?.%P%C%U%!$,6u$N;~$O%^%9%/5l$F$$$k!%Aw?.%P%C%U%!$K%G!<%?$,=q$-9~$^lk$H!$ 1[byte] Aw?.L?Na$r<B9T8e%^%9%/2r=|$5$l!$%P%C%U%!$,6u$KJk$H%^%9%/$5lk!%

A.1.3 AD JQ49%i%$%V%i%j

%=!<%9%U%!%$%k$O!$ ad.c

8 %A%c%s%M%k$"$k 10bit AD JQ494o$rMxMQ$9$k%i%$%V%i%j!%

Reference

```
void init_AD();
```

=i4|2=!% AD JQ49$N%b!<%I@_Dj!$3d$j9~$_4X?t$N@_Dj$JIr9T$&!%

```
int new_ad_data(void);
```

A.1.2 D4JbF14|<0%7%j%"%kDL?.%i%$%V%i%j

%=!<%9%U%!%$%k$O!$ serial.c

2 %A%c%s%M%k$"$k%7%j%"%kDL?.%$%s%?%U%'!<%9 (SCI0, SCI1) $rMxMQ$7$F!$ WS JI$N %7%j%"%k%]!<%H$rDL8FD4JbF14|<0%7%j%"%kDL?.r9k?aN%i%$%V%i%j!% DL?.>r7o$O!$ 8bit, %Q%j%F%#J7, %9%H%C%W%S%C%H 1!%%\!<%l!<%H$O!$ H8 $N%/%m%C%/<~GH?t$,!$ 7.3728[MHz] $^$?$O 14.7456[MHz] $N;~$O!$ 9600 !A 115200[bps] $K@_Dj$G$-$k!% (%O!<%I%&%'%"$N:G9bB.$O!$ 14.7456[MHz] $N;~$K 460800[bps])

Reference

0J2<$N4X?tL>Cf$Nsci $N8e$mKK0 $^$?$O1 rD1F SCI0, SCI1 NIAi$N%A%c%s%M%k$rMxMQ9k$+$r;XDj9k!%bAmsN>J}MxMQ9k3H$b2DG=!%

(Nc)init_sci0(); sci1_getchar(); JI

```
void init_sci(unsigned long bps,
              unsigned char *buf,
              const unsigned int bufsize[]);
```

%7%j%"%kDL?.$N=i4|2=!%bps KO%\!<%l!<%HrEO9!%buf KOAw<u?.%P%C%U%!H7$F;H$&%a%b%jNN0hXN%]%$%s%?, bufsize KO%P%C%U%!%5%$%:$NFbLu$r5-=R$7$?const JQ?t$rEO$9!%%G%U%)%k%H$N%P%C%U%!%5%$%:$GNI1l$P!$NULL rEO9!%$=$NB>!$%l%8%9%?$d%P%C%U%!$N=i4|2=!$3d$j9~$_;~$N4X?t$N@_DjJI$r9T$&!%

```
int sci_putchar(char c);
char *sci_puts(char *msg);
```

Aw?.%P%C%U%!$K%G!<%?$r3JG<!%

sci_puts() $O!$NULL $,Mh$k$^$GAw?.%P%C%U%!$K%G!<%?$r3JG<!%

```
int sci_getchar(void);
int sci_getchar_unlock(void);
```

<u?.%P%C%U%!$+$i%G!<%?$r<}G<!%

<u?.%G!<%?$,L5$$>l9g!$sci_getchar() $O 1[byte] <u?.$9k^$G%V%m%C%/$7!$ sci_getchar_unlock() $O!$EOF rJV9!%

```
int _sci_putchar(char c, void (*needed_processes)());
```

sci_putchar() $HF15!G=$@$,!$Aw?.%P%C%U%!%U%k$G%V%m%C%/$7$F$$$k4V$K!$ needed_processes $r<B9T$9$k!%_sci_getchar() $*$h$S_sci_puts() $bF1MM!%

```
int sci_rxcount(void);
```

```
i2c_data_t *i2c_getall(i2c_data_t *data);
```

%G!<%?rFI_9~$‘!%

```
i2c_id_t i2c_get_id(void);
```

<!$Ki2c_getc(); 9k%G!<%?$NAw?.85$NID rJV9!%

```
int i2c_putc(i2c_data_t c, i2c_id_t dest);
int i2c_puts(i2c_data_t *data, int n, i2c_id_t dest);
int i2c_put_pack(i2c_data_t *data, int n, i2c_id_t dest);
```

dest $G;XDj$7$? ID $N%W%m%;%C%5$K%G!<%?$r%^%9%?Aw?.%P%C%U%!$KE>Aw$7!"c rJV9!%$=$N8eprocess_i2c(); $,8F$Pl?;~$K%P%9$,6u$$$F$$$l$P!$%^%9%?Aw?.$r3+;O$7$^$9!%i2c_puts(); $Hi2c_put_pack(); $O!$data $+$i;O$^$kn %P%$%H$N%G!<%?$r%P%C%U%!$KE>Aw$7!"%P%C%U%!$KE>Aw7?%P%$%H?t$rJV7^$9!#i2c_puts(); $O!"B>$N%W%m%;%C%5$HAw?.@h$,=EJC$?;~<u?.$5lk%G!<%?$,:.$6$j9g$&2DG=@-$,$"j^9,!"n $K8BEY$O$"$j$^$;$s!#i2c_put_pack(); $O!"B>$N%W%m%;%C%5$HAw?.@h$,=EJC$?;~$b!"<u?.5l$k%G!<%?$Odata $+$in %P%$%H$OI,$:O"B3$KJj$^$9$,!"n $K8=:_$N%^%9%?Aw?.%P%C%U%!$N6u$-%P%$%H?t0J>e$r;XDj9k3HOG$-$^$;$s (%P%C%U%!KO2?$bE>Aw$5l:!" 0 $,JV$k)!#

```
i2c_msttxbuf_size_t i2c_txcount(void);
i2c_slvrxbuf_size_t i2c_rxcount(void);
i2c_slvtxbuf_size_t i2c_slv_txcount(void);
i2c_mstrxbuf_size_t i2c_mst_rxcount(void);
i2c_msttxpack_size_t i2c_number_of_tpacks(void);
i2c_slvrxpack_size_t i2c_number_of_rpacks(void);
i2c_mstrxpack_size_t i2c_number_of_reqpacks(void);
i2c_mstrxpack_size_t i2c_number_of_satisfied_requests(void);
i2c_slvrxbuf_size_t i2c_stored_amount_of_the_pack(void);
```

```
int i2c_set_slave_transmit_data(i2c_data_t *data, int n, i2c_id_t dest);
```

```
i2c_id_t i2c_get_request_data(i2c_data_t *data);
```

```
int i2c_request_data(int n, i2c_id_t src);
```

```
int i2c_rxbuf_flush(void);
```

```
int i2c_ungetc(i2c_data_t c);
int i2c_unget2bytes(i2c_data_t pre, i2c_data_t prepre);
```

A.1 3F%i%$%V%i%j$N>\@b

A.1.1 I^2C DL?.%i%$%V%i%j

I^2C %P%9$O!$0lDN%P%9$KB??t$N%G%P%$%9$r@\B3$7!$G$0U$N#2DN4V!$$^$?$O!$0l$D$+$i;D$jA4$F (%V%m!<%I%-%c%9%H) $N7A$G!$%7%j%"%kDL?.$G$-$k%W%m%H%3%kG"$k!%

Reference

```
int initI2C(i2c_id_t id, unsigned char *buf, const struct i2c_bufsize *bufsize)
```

I^2C 4XO"$N=i4|2=!%**id** KO<+J,$N ID $rF~$l$k!% ID $O 7bit(0x00 !A 0x7f)!%%/%m%C%/!$ ID!$%b!<%I$N@_Dj!$%P%C%U%!$N=i4|2=!$3d$j9~$_4X?t$N@_DjJI!%**buf** KO%^%9%?!&%9%l!<%V3FAw<u?.%P%C%U%!H7$F;H$&%a%b%jNN0hXN%]%$%s%?, **bufsize** KO%P%C%U%!%5%$%:$NFbLu$r5-=R$7$?9=B$BN!$

```
struct i2c_bufsize {
    i2c_msttxbuf_size_t     mst_txbuf;
    i2c_msttxpack_size_t    mst_tpack;
    i2c_mstrxbuf_size_t     mst_rxbuf;
    i2c_mstrxpack_size_t    mst_rpack;
    i2c_slvtxbuf_size_t     slv_txbuf;
    i2c_slvtxpack_size_t    slv_tpack;
    i2c_slvrxbuf_size_t     slv_rxbuf;
    i2c_slvrxpack_size_t    slv_rpack;
};
```

XN%]%$%s%?$rEO$9!%%G%U%)%k%H$N%P%C%U%!%5%$%:$GNI1l$P!$NULL rEO9!%

```
int process_i2c(void);
```

8=:_$N I^2C $N>u67$KhCFI,MWJ5!G=$r<B9T$9$k4X?t!%
Aw?.%P%C%U%!$K%G!<%?$,$"$l$P%P%9%U%j!<$+%A%'%C%/$7!$%U%j!<JiAw?.$r3+;O$9$k!%%"!<%S%H%l!<%7%g%s!&%(%i!<JI$,5/$3CF$$$l$P!$$=$N=hM}!%=*N;>r7o$r=P9Y$->u67$JiP!$=*N;>r7o$r=P$7%P%9$r2rJ|9kJI!%
%a%$%s%k!<%W$G<~4|E*$K8F$VY-G"$k!%FC$K!$**i2c_putc(); i2c_puts(); i2c_put_pa**
JI$r<B9T$7$?8e$O!$**process_i2c();** $r%3!<%k$7J1lP<B:]$NAw?.$O;O$^$i$J$$!%

```
i2c_data_t i2c_getc(void);
i2c_data_t *i2c_gets(i2c_data_t *data, int n);
```

IUO? **A**

H8 Library

[49] 6b9-J8CK, ?eFb0jIW, 3@FbMNJ?, 0pMU2m9,, 0f>eGn0t. “BNFbLANKh$k?@7P7O$r;}$D%j%b!<%H%V%l%$%s%m%\%C%H$N3+H/”. Bh 15 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, 1997.

[50] INTERLINK ELECTRONICS. “*FSR Integration Guide & Evaluation Parts Catalog*”.

[51] ED5\9,=U, 0pMU2m9,, 0f>eGn0t. “9bJ,;R8|KlNO%;%s%5%G%P%$%9$rMQ$$$?B-Dl%;%s%5rb$DFsB-FsOS%m%\%C%H$N ZMP 8!=P$HB-F’$_F0:nXN1~MQ”. Bh 15 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, pp. 347–348, 1997.

[37] M. Inaba. “Remote-Brained Robotics: Interfacing AI with Real World Behaviors”. In *Proceedings of 1993 International Symposium on Robotics Research*, 1993.

[38] 6b9-J8CK, 0pMU2m9,, 0f>eGn0t. “E,1~9TF05-=RN?aN9=B$A`:n2DG=$JJBNs%W%m%; %9%M%C%H%o!<%/$N<B8=”. F|K\5!3#3X2q%m%\%F%#%/!&%9%a%+%H%m%K%/%99V1i2q‘97 9V 1iO@J8=8, Bh A 4,, pp. 547–548, 1997.

[39] CfB<?NI', ;3:jM'7I. “9TF0$N=E$M9go;M}O@$N8&5f != B?;X%O%s%I$NGD;}F0:n$X $N1~MQ !=”. Bh 14 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 3 4,, pp. 1047–1048, 1996.

[40] Bil Lewis and Daniel J. Berg. “THREADS PRIMER %^%k%A%9%l%C%I%W%m%0%i %_%s%0F~Lg”. Original Edition published by Prentice Hall, Inc. Translated and republished by ASCII Corp., 1996.

[41] Philips. “*The I^2C-bus Specification*”, 1989.

[42] Maja J Mataric, Martin Nilsson, and Kristian T. Simsarian. “Cooperative Multi-Robot Box-Pushing”. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vol. 3, pp. 556–561, 1995.

[43] Duracell Inc., Intel Corp., *et al.* “*Smart Battery Data Specification, Revision 1.0*”, February 1995.

[44] D9:e7{0lO:, 2C2lH~Ao, 0pMU2m9,, 0f>eGn0t. “%j%b!<%H%V%l%$%s%m%\%C%H$K$*$1$k %S%G%*?.9f$X$N%9!<%Q%$%s%]!<%:$rMxMQ$7$?%;%s%5%U%#!<%I%P%C%/”. Bh 13 2sF|K\ %m%\%C%H3X2q3X=Q9V1i2qM=9F=8, pp. 1024–1026, 1995.

[45] 0pMU2m9,, @1LnM35*;R, 0f>eGn0t. “F3EE@-%U%!%V%j%C%/$rMQ$$$?%m%\%C%H%;%s%5 %9!<%D$N3+H/”. Bh 13 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, pp. 947–948, 1995.

[46] 8^==Mr5., 0pMU2m9,, 0f>eGn0t. “35 <+M3EY$rM-$9$k?M4V7?%m%\%C%H$N3+H/”. Bh 12 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, pp. 309–310, 1994.

[47] El5~Bg3X9)3XIt5!3#>pJs9)3X2J. “%^%$%/%m%3%s%T%e!<%?$H%a%+%H%m%K%/%9$N<B 83”, 1993.

[48] 3t<02q<R F|N)%^%$%3%s%7%9%F%` 5;=Q%I%-%e%a%s%H%;%s%?. “H8/3397 %7%j!< %:,h8/3337 %7%j!<%:, H8/3334YF-ZTAT™ %O!<%I%&%'%"%^%K%e%"%k”. 3t<02q <R F|N)@=:n=j H>F3BN;v6HIt, Bh 1 HG, 1994.

[25] K. Salisbury, W. Townsend, B. Eberman, and D. DiPietro. “Preliminary Design of a Whole-Arm Manipulation System (WAMS)”. In *Proc. of the IEEE International Conference on Robotics and Automation*, 1988.

[26] CfB<?NI', D%6G5#, 5HK\7x0l. “%Q%o!<%0%i%9%WH=$N%m%P%9%H@-$NI>2AK!”. F|K\%m%\%C%H3X2q;o, Vol. 13, No. 6, pp. 866–874, 1995.

[27] 9bLn@/@2, 1JEgMxL@, 4X7<L@. “;X$NJ"$KhkJ*BN$NGD0.$HA`jN1?F03X”. F|K\%m%\%C%H3X2q;o, Vol. 14, No. 1, pp. 83–90, 1996.

[28] Matthew T. Mason. “Mechanics and Planning of Manipulator Pushing Operations”. *The International Journal of Robotics Research*, Vol. 5, No. 3, pp. 53–71, 1986.

[29] Bt:jD>G7, 0f>eGn0t. “B?;X%O%s%IKh$kJ*BN$NE>$,$7A`:n”. F|K\%m%\%C%H3X2q;o, Vol. 9, No. 5, pp. 560–571, 1991.

[30] Aj;39/F;, 0pMU2m9,, 0f>eGn0t. “%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%s$N8&5f!'A`:n7ABV$NJ,N`$H%T%\%C%HA`:n$N<B8=”. F|K\%m%\%C%H3X2q;o, Vol. 14, No. 1, pp. 114–121, 1996.

[31] Rodney A. Brooks. “A Robot that Walks; Emergent Behaviors from a Carefully Evolved Network”. In *Proc. of the IEEE International Conference on Robotics and Automation*, 1989.

[32] Rodney A. Brooks. “A Robust Layered Control System For A Mobile Robot”. *IEEE Journal of Robotics and Automation*, Vol. RA-2, No. 1, pp. 14–23, 1986.

[33] CfB<?NI', ;3:jM'7I, NkLZM:0l. “H?<M9TF0$NAH9g$;Kh$k%m%\%C%H%O%s%I$N@)8f”. F|K\5!3#3X2q%m%\%F%#%/!&%9%a%+%H%m%K%/%99V1i2q'95 9V1iO@J8=8, Bh B 4,, pp. 1166–1169, 1.

[34] 2,E/;q, 0pMU2m9,, 0f>eGn0t. “BeNet: <+N'%m%\%C%H$N>pJs%7%9%F%`5-=R$N$?$a$NJBNs>pJs=hM}%b%G%k”. F|K\%m%\%C%H3X2q;o, Vol. 15, No. 6, pp. 878–885, 1997.

[35] J. H. Connell. “SSS: A Hybrid Architecture Applied to Robot Navigation”. In *Proc. of the IEEE International Conference on Robotics and Automation*, pp. 2719–2723, 1992.

[36] R. Peter Bonasso and David Kortenkamp. “Characterizing an Architecture for Intelligent, Reactive Agents”. In *AAAI Spring Symposium on Lessons Learned from Implemented Software Architectures for Physical Agents*, 1995.

[12] 9b@>=_IW. “%R%e!<%^%s!&%3%_%e%K%1!<%7%g%s$r;X8~$7$?%R%e!<%^%N%$%I%m%\%C%H”. F|K\%m%\%C%H3X2q;o, Vol. 15, No. 7, pp. 971–974, 1997.

[13] 9-@%???M, C]CfF), 8^L#MN, >._7?.L@. “?M4V7?%m%\%C%H”. F|K\%m%\%C%H3X2q;o, Vol. 15, No. 7, pp. 983–985, 1997.

[14] 2CF#0lO:. “%j%j%9%\%C%H!=@83h;Y1g%m%\%C%H!=$N9=A[”. F|K\%m%\%C%H3X2q;o, Vol. 11, No. 5, pp. 614–617, 1993.

[15] John M. Hollerbach and Stephen C. Jacobsen. “Anthropomorphic Robots and Human Interactions”. In *First International Symposium on Humanoid Robots (HURO'96)*, pp. 83–91, 1996.

[16] CfEg@iL@, J?0f?-I'. “<BMQH7FN%"%_%e!<%:%a%s%H%m%\%C%H$N<B8=”. Bh 14 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 3 4,, pp. 1169–1170, 1996.

[17] Masahiro Fujita and Koji Kageyama. “An Open Architecture for Robot Entertainment”. In *Proceedings of the First International Conference on Autonomous Agents*, pp. 435–442, 1997.

[18] >>86?N. “%3%s%T%e!<%?%A%'%9$,@$3&%A%c%s%T%*%srGKk”. In **Bit**, Bh 29 4,, pp. 21–24. 6&N)=PHG, 1997.

[19] ?9ED<wO:, NkLZM:0lO:, @n:j5#I', ?{Ln =E<y. “?M4V6&B8%m%\%C%H%^%K%T%e%l!<%?$N>WFM0BA4@_7W$H@)8f”. F|K\%m%\%C%H3X2q;o, Vol. 16, No. 1, pp. 102–109, 1998.

[20] Masayuki Inaba, Fumio Kanehiro, Satoshi Kagami, and Hirochika Inoue. “Two-Armed Bipedal Robot that can Walk, Roll Over and Stand up”. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vol. 3, pp. 297–302, 1995.

[21] 6b9-J8CK, 0pMU2m9,, 0f>eGn0t. “E]lF$b5/$->e$,$k3HNG$-$k?M4V7?%m%\%C%H”. Bh 13 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 1 4,, pp. 195–196, 1995.

[22] 6b9-J8CK, 0pMU2m9,, 0f>eGn0t. “?M4V7?%m%\%C%H$NA4?H9TF0$HF0:n@)8f”. Bh#12s%m%\%F%#%/%9%7%s%]%8%"M=9F=8, pp. 11–16, 1996.

[23] >.KsF). “%0%i%9%T%s%0$N?7E83+”. Bh 15 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 3 4,, pp. 909–912, 1997.

[24] >.KsF). “B?;X%O%s%IKh$k<42sE>%W%j%_%F%#%VJ*BNA':n”. F|K\%m%\%C%H3X2q;o, Vol. 14, No. 6, pp. 853–859, 1996.

[1] Ichiro Kato, Sadamu Ohteru, Hiroshi Kobayashi, Katsuhiko Shirai, and Akihiko Uchiyama. “Information-Power Machine with Senses and Limbs(WABOT 1)”. In *First CISM - IFToMM Symposium 5-8 September 1973, on Theory and Practice of Robots and Manipulators*, Vol. 1, pp. 11–24. Springer-Verlag, 1974.

[2] 2CF#01O:$[$+. “80HW3Z4o1iAU%m%\%C%H “WABOT-2””. F|K\%m%\%C%H3X2q;o, Vol. 3, No. 4, pp. 337–338, 1985.

[3] R.A. Brooks and L.A.Stein. “Building Brain for Bodies”. In *Autonomous Robots*, Vol. 1, pp. 7–25, 1994.

[4] 0pMU2m9,, 6b9-J8CK, 0f>eGn0t. “G>$r;}$AJb$+$J$$#2B-#2OS%m%\%C%H$N3+H/”. Bh 11 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, pp. 623–624, 1993.

[5] Kazuo Hirai. “Current and Future Perspective of Honda Humanoid Robot”. In *Proc. of the IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS’97)*, Vol. 2, pp. 500–508, 1997.

[6] 66K\<~;J, @.ED@?G7=u, >.NSE/B’, 9b@>=_IW. “%W%i%C%H%U%)!<%‘H7FN 2 B-Jb9T 7?%R%e!<%^%N%$%I: WABIAN”. Bh 15 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 3 4,, pp. 763–764, 1997.

[7] Karel Čapek. “R.U.R.: %m%C%9%‘$N%f%K%P!<%5%k!&%m%\%C%H”. 4dGHJ88K; @V (32)-774-2. 4dGH=qE9, 1989. @iLn1I0lLu.

[8] ;38}?N0l, 0f>eDgIR, @>LnBg=u, 8<AjZ_, 9b@>=_IW. “;kD03P>pJs<hF@5!9=$rM-$9$k?M 4V7? 2 B- 2 OS%m%\%C%H$NA4BN@_7W”. Bh 14 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 2 4,, pp. 723–724, 1996.

[9] ;38}?N0l, 0f>eDgIR, >>HxLP<y, 9b@>=_IW. “2 B-Jb9T7?%R%e!<%^%N%$%I$K$*$1$kA4?H 6(D47? 2 B-F0Jb9T@)8f”. Bh 15 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 3 4,, pp. 851–852, 1997.

[10] T"5H9/IW, D95WJ]>=I’. “%R%e!<%^%N%$%I!&%$%s%?%i%/%7%g%s8&5f !]?M4V!&%m%\%C %H!&4D6-$N 3 9‘Aj8_:nMQ$NAOH/$K8~$1$F !]”. Bh 14 2sF|K\%m%\%C%H3X2q3X=Q9V1i 2qM=9F=8, Bh 2 4,, pp. 711–712, 1996.

[11] D95WJ]>=I’, T"5H9/IW, @PLJM[0l. “ETL-Humanoid $N%7%9%F%‘@_7W35MW”. Bh 14 2sF|K\%m%\%C%H3X2q3X=Q9V1i2qM=9F=8, Bh 2 4,, pp. 707–708, 1996.

;29MJ88%

F1$8$/Bg3X1!$+$i3N8&5f<<$KF~$j?46/$$Cg4VG7$?!%$^$?!$CN<1$,K-IY$G!$$h$/$o$+ iJ$$$3HrAjCL7^7?!%5HCS7/$O8&5f$rO8$aMM!9$J3HKBP7$F%7%S%"$JG.$$L\ $r;}$A!$$$$m$$$m$H;29M$KJk0U8+$rJ9$/3H$,$G$-$^7?!%$^$?!$$JKh$j4k2h20$G $$$m$$$m$J4k2h$rN)FF$/$lkN$G8&5f$NB)H4$-$KJj$^$7$?!%:d0f7/$O8&5frO8a MM!9J3HKBP7F%/!<%k$JL\$r;}$A!$$$$m$$$m$H;29M$KJk0U8+$rJ9$/3H$,$G$-$^ 7?!%$^$?!Dya@Zj,GwiJ$$$H5$;}$,>hiJ$$I.<T$H$$$D$b0B?446$rM?$($"CF$$ $?$h$&$K;W$$$^$9!%9a;37/$O>o$K7W2h$I$&$j$K8&5f$r?JaF$$$F!$H/I=$JIN=`Hw$bAa $/!$8+=,$&$Y$-$H3m$,$?$/$5s"j^7?!%LnED7/$O$$$D$b;~4VE*M>M5$r;}CF8&5f $r?J$a$F$$$^7?!%$^$?!$8&5f0J30$NLLGb;~4V$r>e<j$K;HCF=<<B7?Bg3X@83hr* $/$C$F$$$k0u>]$,$"$j!$8+=,$$$?$$$H;W$$$^7?!%

M1 $N2,ED7/!$>.@n867/!$1";37/!$@>OF7/!$W"@n7/!$>>LZ7/!$5\K\7/!$H,=E3_7/!$ B4 $NCSED7/!$BgIp5s!$3@Fb7/!$3qBt7/!$Bp4V7/!$J!Eg7/!$Fs0f7/!$;39b7/!$;3K\$5 sO!$$=l>$lK-$+$JH/A[$G8&5f$r?J$a!$I.<T$,65$($ilk3H$bB?$+C?G9!%

I.<TrCH+$/8+<i$C$F2<$5$j!$M&5$$rM?$($F2<5j!$;I7c$rM?$($F2<5C$?B?$/$N @hGZC#!$M'?MC#$K46<U$7$^$9!%

:G8e$KI.<T$N8&5f@83h$r;Y$(F/l?N>?F$H!$L@k/3Z$7$$;0?M$NKeC#$K46<U7^ $9!%

#1#9#9#8G/#27n ?eFb 0jIW

K\8&5f$OEl5~Bg3X5!3#>pJs9)3X2J0f>eGn0t65<x!$0pMU2m9,=u65<x$N8f;XF3NbHG9TJol^7?!%

0f>e65<xKO!$8&5f$KBP7F1T$$;XE&$d0U8+$r$$$?$@$-HF$bJY6/$KJj$^$7$?!%$^$?!$8&5f0J30$N<R2q@-$J$I?M4VE*$JLLGb$4;XF3D:$-$^$7$?!%

0pMU=u65<xKO!$%j%b!<%H%V%l%$%s%m%\%C%H$K?@7P7O$rAH$_9~$`$H$$$&=U%W%m%8%’%/%H (1996 G/) $K;22C$5$;$F$$$?$@$-!$Bg3X1!$+$i8&5f<<$KF~$C$?I.<T$,8&5f$K%9%`!<%:$KF~$C$F$$$1kh$&9M$($F$$$?$@$-$^$7$?!%$^$?!$I.<T$,8&5f$NJ}8~@-$d?J$aJ}$KG:$s$G$$$k;~$K!$?F?HKJCF=u8@$r2<$5$$$^7?!%

6aLn=u<jKO!$Hf3SE*?H6a$J8&5f<T$N@hGZ$H7F%m%\%C%H8&5f$N@$3&JIKD$$$F$$$m$$$m$H65$($F$$$?$@$-$^$7$?!%

$^$?F#ED5;41!$8MDM5;41!$@iBe1dHk=q!$Bg_7Hk=q$K$O8&5f$r?Jak$?$a$NMM!9$J;vL3=hM}r7$FD:$$$?$*$+2G!$=gD4$K8&5f$r?J$ak3H,G-$^$7$?!%

2C2lH~5s$OI.<T$,8&5f<<$KG[B0$5l?P+jN3m$+$i!$1&$b:8bo$+$i$LI.<T$KHF$b?F@Z$K8&5f<<$N4D6-$d%j%b!<%H%V%l%$%s%0%k!<%W$N>u67JI$r65$($F2<$5$$$^7?!%>>K\$5sO>o$K8&5f$KBP7F87$7$/HjAHsG$$$F!$8+=,$oJ1lP$H46$8$F$$$^7?!%6b9-5s$O!$8&5fd=$NB>$N3HKD$$$F%/!<%k$JL\$G8+$?K\<AE*$J3H$r$$$m$$$m8+$;$F$/$@$5$$$$^7?!%$9$4$/@E$+$J?M$@JH$$$&Bh0l0u>]G7$?$,!$D9Eh$5sO8&5fKD$$$F?<$/FM$C9~s@<ALdr7$F2<$5CF!$8&5fFbMF$r@0M}9kNKHF$b;29M$KJj$^$7$?!%0pM8$5sO!$3X@8$N8&5f2qG"$k HUROBINT $K0l=o$K;22C7?$j!$%$%.%j%9?M$NM’?M$r>R2p$7$F$$$?$@$$$?jH!$I.<T$KBP7FNI$$;I7cKJk3Hr0l=oK7$?$H$$$&0u>]$,$"j^$9!%D9:d$5sN%^%$%Z!<%9$GCe!9$H8&5f$r?JaF$$$/MM;R$OA"$^7/;W$$$^$9!%$^$?!$8&5fFbMF$bHs>o$K6=L#?<$$$bNGHF$b;I7c$r<u1^7?!%

<FED5sKO=$;N 1 G/$N;~$K%Q%i%0%i%$%@!<$d%F%K%9$J$IM7$S$KM6$C$F$$$?$@$-$^$7$?!%$^$?!$!VG>$N7W;;M}O@!W$NNX9V$N;~$dM7SK9TC?H-Kb!$$$$m$$$m$HI.<T$N8&5fNOCrJ9$$$F$$$?$@$-=u8@$r$$$?$@$-$^$7$?!%M7$sGb8&5f7FbHFb%Q%o%U%k$J?M$G!$I.<T$NL\;X$9?MJ*A|$H6a$$$H3m$,$"j^7?!%2,5sKO!$<g$K%a!<%k$G%m%\%C%H%7%9%F%`$N8&5f$N8=>u$dI.<T$N9M$(J}KBP7$F0U8+$d=u8@$r$$$?$@$-$^$7$?!%

ED5\7/HO$:$CHNYNC<KvKJBs$G$$$F!$8&5f$NOC!&%9%]!<%D$NOC!&M7$SNOCJ$I$$$m$$$mHOCr7^7?!%%P%i%s%9$N8&5f$r7F$$$k$@$1$"$C$F!$8&5fH=$NB>$N3H$r%P%i%s%9NI$/3J7F$$$?$H$$$&0u>]G9!%$^$?!$I.<T$N$"$^jK$/$@iJ$$%.%c%0Kb!CH+$/%D%C%3%_$rF~lF$/$@$5$$$$^7?!%@1Ln5s$O8&5f$r7C$+$j?Jak$+$?oi!$J7O05$$$rOB$^$92qOC$HB)H4$-$N5!2q$rDs0F7F$/$@$5$$$^7?!%FC$K!$I.<T$,3X2q$dBg3X1!Gn;N2aDxF~;n$GH/I=$r9kH-$KI.<T$ND>A0$KH/I=$9k3H,B?$/!$>l$NJ7O05$$$,OBs@H3mGI.<T$NH/I=$r7^$($k3H$,$G$-$^7?!%>.20Gw7/$OI.<T$H

<U<–

$^$?!$3X=,5!G=$rAH$_9~$‘3H$,M-8z$@$H9M$($k!%$3lK$O!$<!Nh$&$J;0<oN‘$NOHAH$r9M$($k!%

- <+N’5!G=%b%8%e!<%k$N3X=, <+N’5!G=$NI>2A4X?t (Nc$($P%P%i%s%9$,J]$F$F$$$kEY9gJI) $r:n$j!$$=NCMr9b$/$9kh$&$K!$6/2=3X=,$JIrMQ$$$F2<0L%b%8%e!<%k$NF~=PNO$NJQ99$d%Q%i%a!<%?$ND4@0$r9T$&!%

- Dj7?F0:n$N3X=, $"$kDj7?$NF0:n!&9TF0$NC#@.EY$d8zN($r<($9I>2A4X?t$r:n$j!$$=NCMr9b$/$9kh$&$J2<0L%b%8%e!<%k$NAH9g$;$r;n9T:x8m$Khj3X=,9k!%bAms!$3F%b%8%e!<%kFb$N%Q%i%a!<%?$bJQF0$5$;$J$,$i9T$&!%6qBNE*$K$O!$Nc$($P!X0\F0!Y$H$$$&Dj7?F0:n$NC#@.EY$d8zN($r<($9I>2A4X?t$r!$“0\F0NL” $d “0\F0NL / %(%M%k%.>CHq” JIH7$F!$0\F0$H$$$&9TF0$r9T$&;~$K$$$D$b!$>/7:$D%Q%i%a!<%?$rJQ2=5;I>2A4X?tNCMr5a$a!$$=l,9b$/$J$kJ}8~$K%Q%i%a!<%?$rD4@0$9kJIH$$$&3H$r<($9!%

- >pF07O (9T$-1d$Sk?aN5!9=) @8J*$N>pF0$O4pK\E*$K!X2w!Y$+!XIT2w!YG"$j!$$3lO:,K\E*KO!$!X@8B8!Y$r4p=‘H7$?FbItI>2A$G$"$k!%3l$r%m%\%C%H$N%7%9%F%‘Kb1~MQ9k$H!$Nc$($P!Bg-$J=PNO$r=P7F$$$k;~$O!XIT2w!Y$G$"$kH+!$%(%M%k%.!<$rJd=<9k;~$O!X2w!Y$G$"$k$H$$$C$?I>2A$r9T$&>pF07O!$$$$o$P>pF0I>2A4p=‘$r;}$?$;kH$$$&3HKJ$k!%

  %m%\%C%H$NMM!9$J%;%s%5F~NOKBP7$F!$$=l>$l>pF0I>2A4p=‘$rM?$(!$8=:_$N%;%s%5F~NO>pJs$,JkY/!X2w!YKJkh$&$K9TF0$rD4@a$9$kOHAH!$$9Jo$A>pF07O$r%m%\%C%H%7%9%F%‘$K:N$jF~lk!%

3liNOHAH$NF3F~$Khj!$2r@OE*$K:FqrH<$&$h$&$J<+N’5!G=$r!$<B8=9k3H$,$G$-$k2DG=@-$,$"$k!%

:#8e$O!$0J>eNh$&$J2]Bj$N2r7h$K8~$1!$$5iK8&5f$r?J$a$F$$$/3H$,5a$ail$F$$$k!%

7.1 7kO@

K\8&5fGO!$>-MhIa5Z!&H/E8$9kG$"$m$&?M4V7?%m%\%C%H$N:#8e$N8&5f$K$*$$$F!$A4?H$rMxMQ7?J*BNA`:n$,=EMW$J2]Bj$G$"$k$3$H$r;XE&$7!$?M4V7?%m%\%C%H$,A4?H$GJ*BNA`:n$r9T$&3HNG$-$k%7%9%F%`$r9=C[$9kH$$$&J}?K$G!$0J2<N3Hr9TC?!%

Bh 2>O!V?M4V7?%m%\%C%HK*1kJ*BNA`:n!W$G$O!$$3$l$^$G$NJ*BNA`:n$r9T$&%m%\%C%HHNN`;wE@$H?M4V7?%m%\%C%H$KFCM-$JE@$r@0M}$7!$?M4V7?%m%\%C%H$OJ*BN$rA`:n7D$D%P%i%s%9$JIK$b5$$rG[iJ1lPJiJ$$$E@JI$N2]Bj$r5s2?!%

Bh 3>O!V?M4V7?%m%\%C%H%7%9%F%`$N9=@.K!!W$G$O!$J#;(@-$r;}$D?M4V7?%m%\%C%H$K$*$$$F$O!$<+N'7O$r4^$`OHAH$r;}$D3H$,Hs>o$K=EMWG"k3Hr;XE&7?!%$=$7$F!$JBNs$N<+N'5!G=%b%8%e!<%k72$+iJ$k<+N'7O$r9=@.$7!$<+N'7O$r2<0LAX$K;}$DFsAX9=B$$r!LCNJ*BN$NA`:n$J$I$rA4?H$rMxMQ$7$F9T$&?M4V7?%m%\%C%H$N%7%9%F%`$H7FDs0F7?!%

Bh 4>O!V<+N'7O$r2<0LAX$K;}$DG>%7%9%F%`$N3+H/!WGO!$<+N'7O$NOHAH$N<BAu$K$D$$$F=R$Y!$<+N'5!G=%b%8%e!<%k$r3+H/4D6-$N9=C[KD$$$F=R$Y!$$=lKH<$$LdBjHJ$k%O!<%I%&%'%"$H%=%U%H%&%'%"$N%$%s%?%U%'!<%9$N3+H/$K$D$$$F=RY?!%

Bh 5>O!VBNFb LAN $r;}$D?M4V7?%m%\%C%H$N3+H/!W$G$O!$B?<+M3EY!&B?%;%s%5$r;}$D?M4V7?%m%\%C%H "Haru" $r3+H/$7!$$=li$rBNFb?@7P7O$rDL7F%j%b!<%H$N<+N'7O$H@\B3$7!$<+N'7O$N%=%U%H%&%'%"$r%o!<%/%9%F!<%7%g%s>e$G3+H/$9k3Hr2DG=K7$?!%

Bh 6>O!VH?<M7?<+N'%b%8%e!<%krAH_9go;$?J*BNA`:n9TF0$N<B8=!W$G$O!$A4?H$rMxMQ$7$FJ*BNA`:n$r9T$&:]$KI,MWHJ$k<+N'5!G=%b%8%e!<%k$r<BAu$7!$$=li$rE,595/F0!&=*N;$9k3HG!$=ENL$,LCNNJ*BN$NE,1~E*;}$A>e$2F0:n$d!$J*BN$N=EMWJQ2=XNE,@Z$JBP1~F0:n$,<B8=G-k3Hr<($7!$<+N'7O$r2<0LAX$K;}$D%m%\%C%H%7%9%F%`$NM-8z@-$r<($7$?!%

7.2 :#8e$N2]Bj!&E8K>

:#8e$O!$86;OE*$J%7%9%F%`$G$"$k<+N'7O$N>e$K!$$$$+$KE,@Z$JF0:n$r<B8=$9k+$r99$K8&5f$r?J$a$F$$$/I,MW$,$"$k!%Jz$($?>uBV$G$N0\F0$d!$%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%sJI$N!$J*BN$r0\F0$5$;$kF0:n$N<B8=$,K>$^$l$k!%

K\O@J8$G<($7$?$h$&$J!LCNJ*BN$N;}$A>e$2F0:n$K$*$$$F$O!$;}$A>e$2k3HKhjMM!9$J>pJs$,F@il$k!%;}$A>e2?J*BN$N=ENL$O4X@a%H%k%/%;%s%5>pJs$+$i?dDj2DG=G"$k!%7A>u$NM=B,$O@\?(E@$,>/$J$$>l9gOFq7$$$,!$J*BN$N=E?40LCV$N?dDj$O2DG=G"m&!%J*BN$N=ENL!&=E?40LCV$,?dDjG-lP!$$=lr%m%\%C%H$N%b%G%k$KE}9g$7!$$3l^GK8&5f5l$F$$$kJb9T$N%"%k%4%j%:%`$rMxMQ9k3HKhCF!$Jb9T$r9T$&$3Hb2DG=G"kH9M$($ilk!%

Bh **7** >O

7kO@$H:#8e$N2]Bj!&E8K>

0J>eKh$j!$=ENL$,L$CN$NJ*BN$rJz$(>e$2$kF0:nCf$K!$JBNs$K<B9T5l$F$$$k<+N'5!G=%b%8%e!<%k$,M-8z$K:nMQ7F$$$k3H$,$o$+$k!%

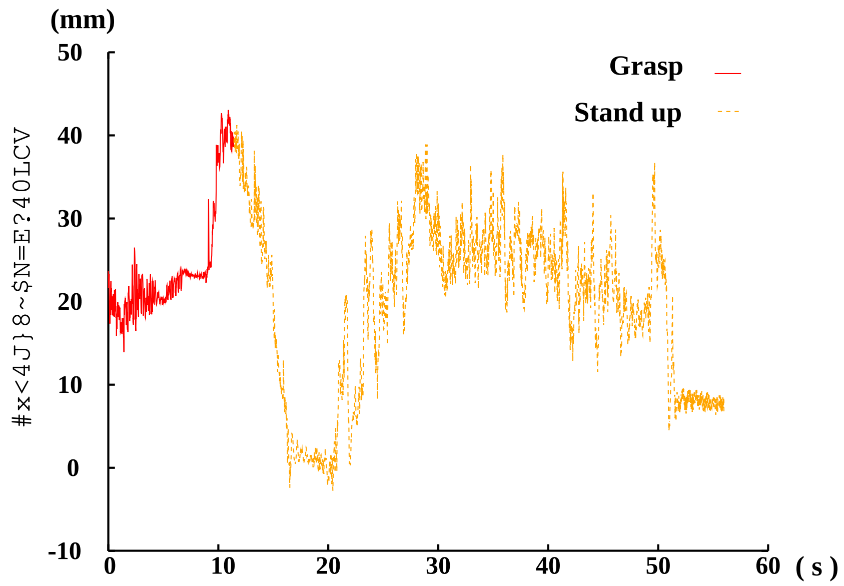


Fig. 6.14 =ENLJ*rJz(>e2k<B83Cf$NB-N"H?NOCf?4$N50@W (1&B-)
The locus of the center point of force at sole (right leg)

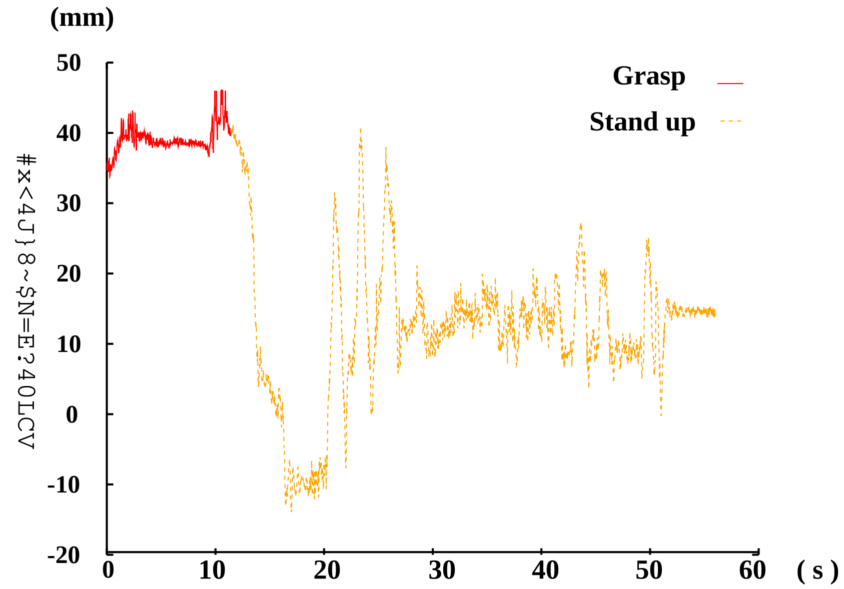


Fig. 6.15 =ENLJ*rJz(>e2k<B83Cf$NB-N"H?NOCf?4$N50@W (:8B-)
The locus of the center point of force at sole (left leg)

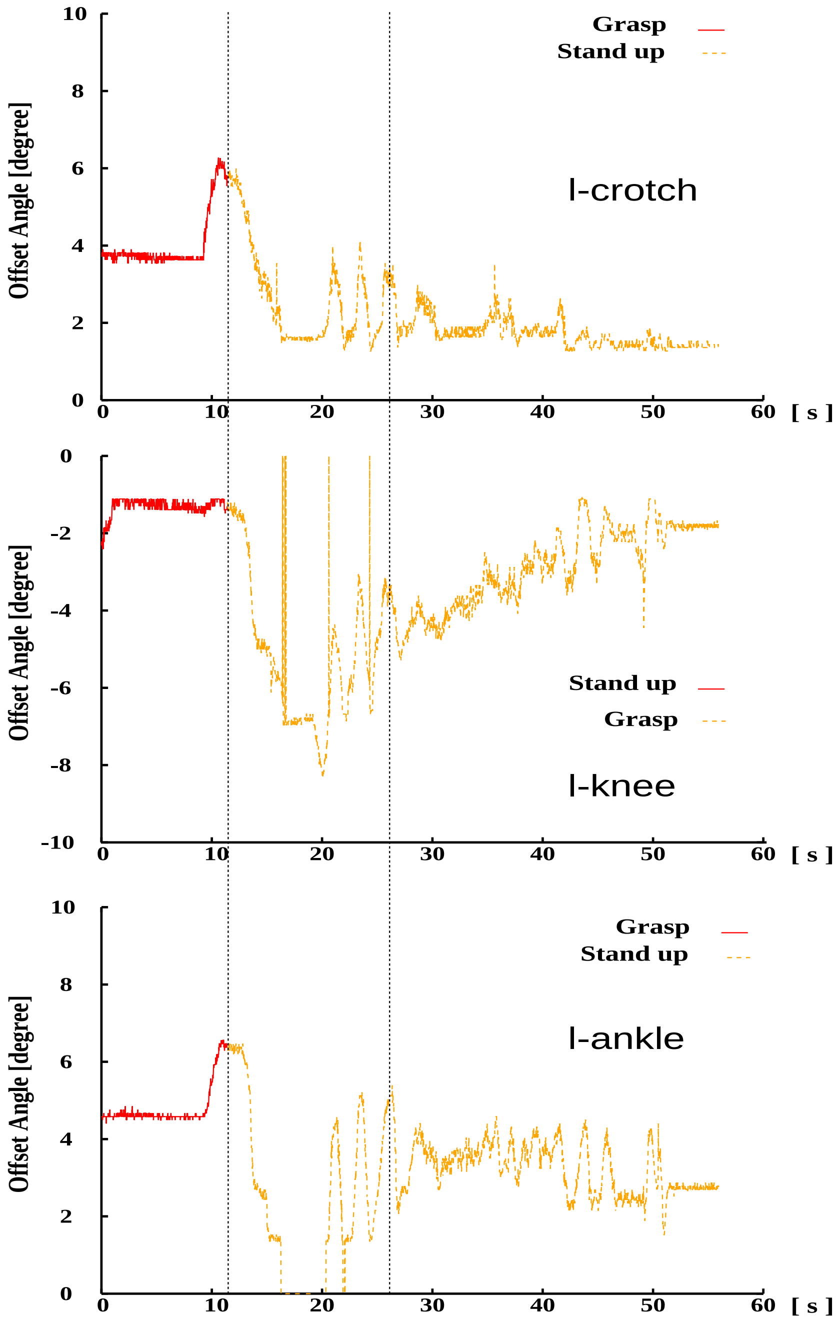


Fig. 6.13 =ENLJ*rJz(>e2k<B83Cf$N2<H>?H$N%H%k%/$NMzNr (:8B-)
The torque of legs during holding and lifting up a backet (left leg)

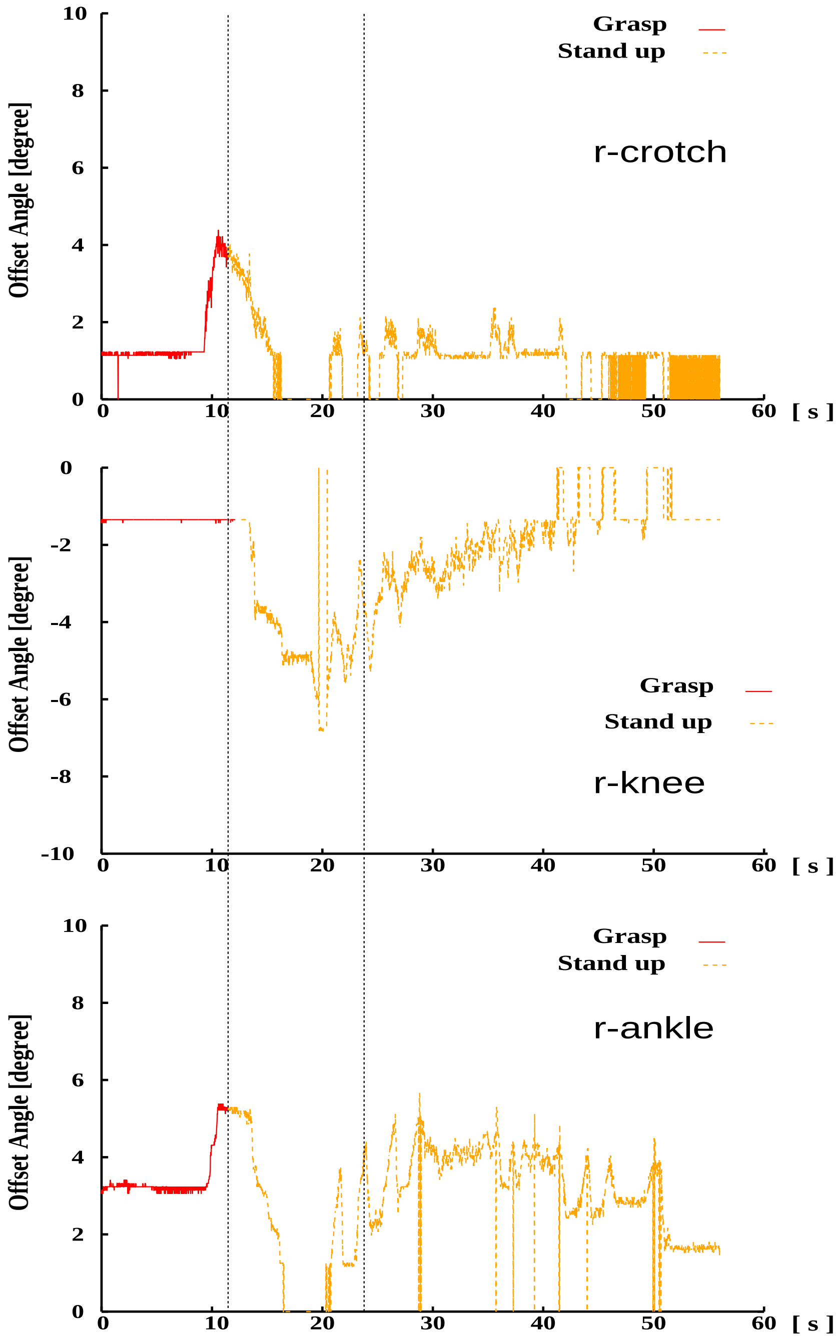


Fig. 6.12 =ENLJ*rJz(>e2k<B83Cf$N2<H>?H$N%H%k%/$NMzNr (1&B-)
The torque of legs during holding and lifting up a backet (right leg)

6.3 =ENLJ*Jz$(>e$2;~$N%H%k%/$H=E?4Ej1FE@$N50@W

$3$3GO!$ 6.2.1@a$N=ENLJ*Jz$(>e2kF0:n$N<B83Cf$K$*$1$k2<H>?H$N=PNO%H%k%/ $N>uBV$H!$=E?4Ej1FE@$N50@W$r5-O?$7!$<+N'7O$NF/$-$KhC$F=PNO%H%k%/$H!$J*BN$r4^ a?=E?40LCV$,$INh$&$KJQ2=7F$$$k$+$r9M;!9k!%

(i) %H%k%/$NMzNr

=ENLJ*rJz(>e2k<B83Cf$N2<H>?H$N=PNO%H%k%/$NMzNr$r!$ Fig.6.12$*$h$S Fig.6.13$K<($9!%

#3DN%0%i%UCf$r=D$K0z$$$F$"$k#2K\$N@~N&$A:8$N@~ (Ls 12[s] $N;~E@) $O!$CO LL$+$i;}$A>e$,C?=V4VG"$k!%;}$A>e$,$C$?D>8e$+$i8T4X@a$N%H%k%/$O!$balance(<0 (6.1)) $NF/$-KhCF8:$j;O$a!$Ls 4[s] 8e$K$O:G>.%H%k%/$NIU6a$^$G2<$,$C$F$$ $k!%$3$1$O!$J*BN$r4^a?>eH>?H$N=E?4$,!$8T4X@a<4$rDL$k1tD>@~>e$KF0$$$?$? aG$"kH9M$(i1!$$3$1$KhjLCNN=ENL$NJ*BN$r;}$A>e$2k3H,G-k3 H,o+$k!%

$^$?!$#2K\$N=D@~N&AN1&$N@~ (Ls 26[s] $N;~E@) $O!$J*BNrJz($?>uBV$GN)$A >e$,CF$$$kESCfG"$k!%B-<s!&8T4X@a$N%H%k%/$,>e>:$7$?$3$N;~E@$G!$I($N%H %k%/$N@dBPCM$O8:>/7F$$$k!%$3$1$O!$I(4X@a$N1tD>>eJ}IU6a$K=E?40LCV$,0\ F0$7$?$?$a!$B-<s!&8T4X@a$N1tD>@~>e$+$i=E?40LCV$,$:$1$?$?aH9M$($i1k (Fig.6.1;2>H)!%$=$ND>A0!&D>8e$O!$5U$KI(4X@a$N%H%k%/$N@dBPCM$,Bg$-$/Jj!$ B-<s!&8T4X@a$N%H%k%/$,8:>/7F$$$k!%3&7?F0$-$r7+jJV9$3$HKhCF!$ <!Bh$KA4$F$N4X@a$N%H%k%/$,>.$5$/$J$j!$%(%M%k%.8zN($NNI$$Jz$(>e$2>uBV$K JC$F$$$k$H8@$($k!%

(ii) =E?4Ej1FE@$N50@W

F1$8<B83Cf$N=E?4Ej1FE@$N50@W$r Fig.6.14$*$h$S Fig.6.15$K<($9!%=E?4Ej1FE@ $O!$B-DlNO%;%s%5Kh$j5a$a$?!%$J$*!$ x <4J}8~ (%m%\%C%H$NA08eJ}8~) $N=E?4 0LCV$N50@W$r2#<4$r;~4V$GI=<($7$F$$$k!%

?'NJQo$jL\$,!$J*BN$,COLL$+$i;}$A>e$,C?=V4VG"$k!%;}$A>e$,$C$?=V4V$K =E?40LCV$O:G$bD^@hhjKJ$j!$$=$ND>8e$+$ibalance(<0 (6.1)) $NF/$-Kh$C $F!$=E?40LCV$,B-N"$NCf?4IU6a$^$G0\F0$9$kMM;R$,$o$+$k!%

$^$?!$$=$N8e$NN)$A>e$,$k2aDx$G!$I(4X@a$HB-<s!&8T4X@a$Nbalance $NF0:n$K$h $j!$>/7:$DA08e$K=E?40LCV$bF0$$$F$$$kMM;R$,$o$+$k!%7+$7!$;}$A>e$,C? =V4V$K:G$bD^@hhjKJC?8e$O!$$=1r1[$($J$$HO0OGN=E?40LCV0\F0KJ$C $F$$$k!%

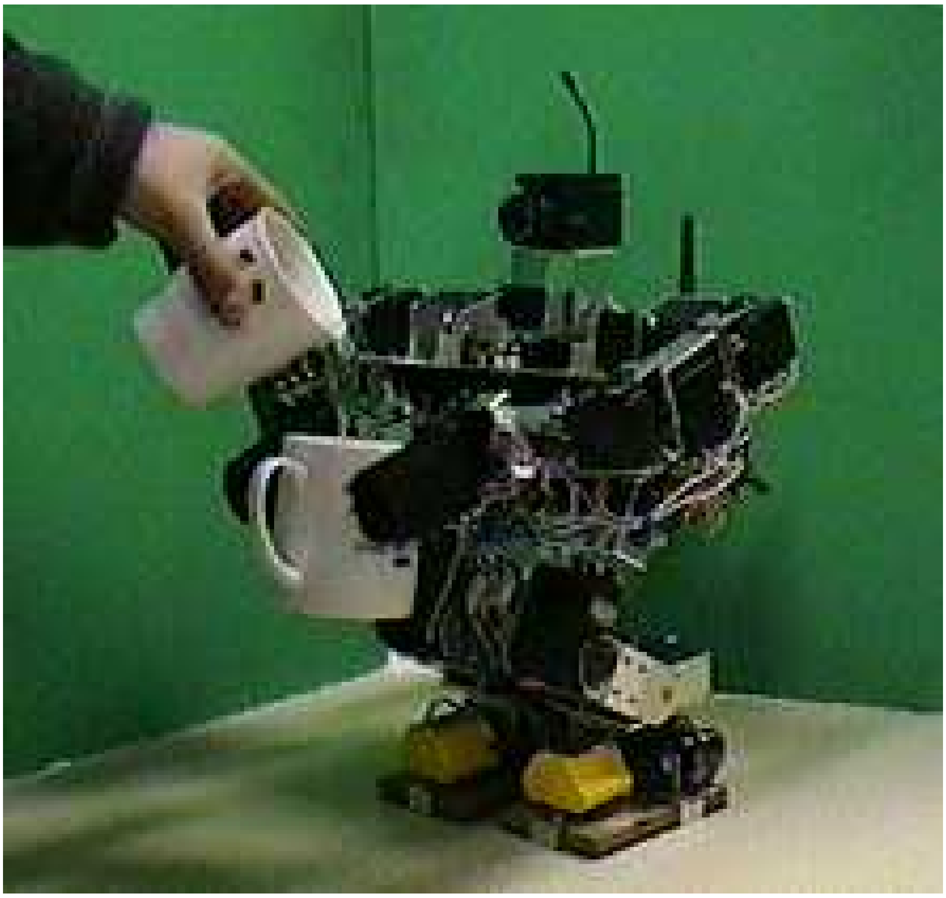


Fig. 6.11 $*Er$,Cm$,$l=ENL$NJQ2=$7DD$"$k%3%C%W$r;}$DMM;R
"Haru" holding a cup whose weight is changing by being pour hot wator in

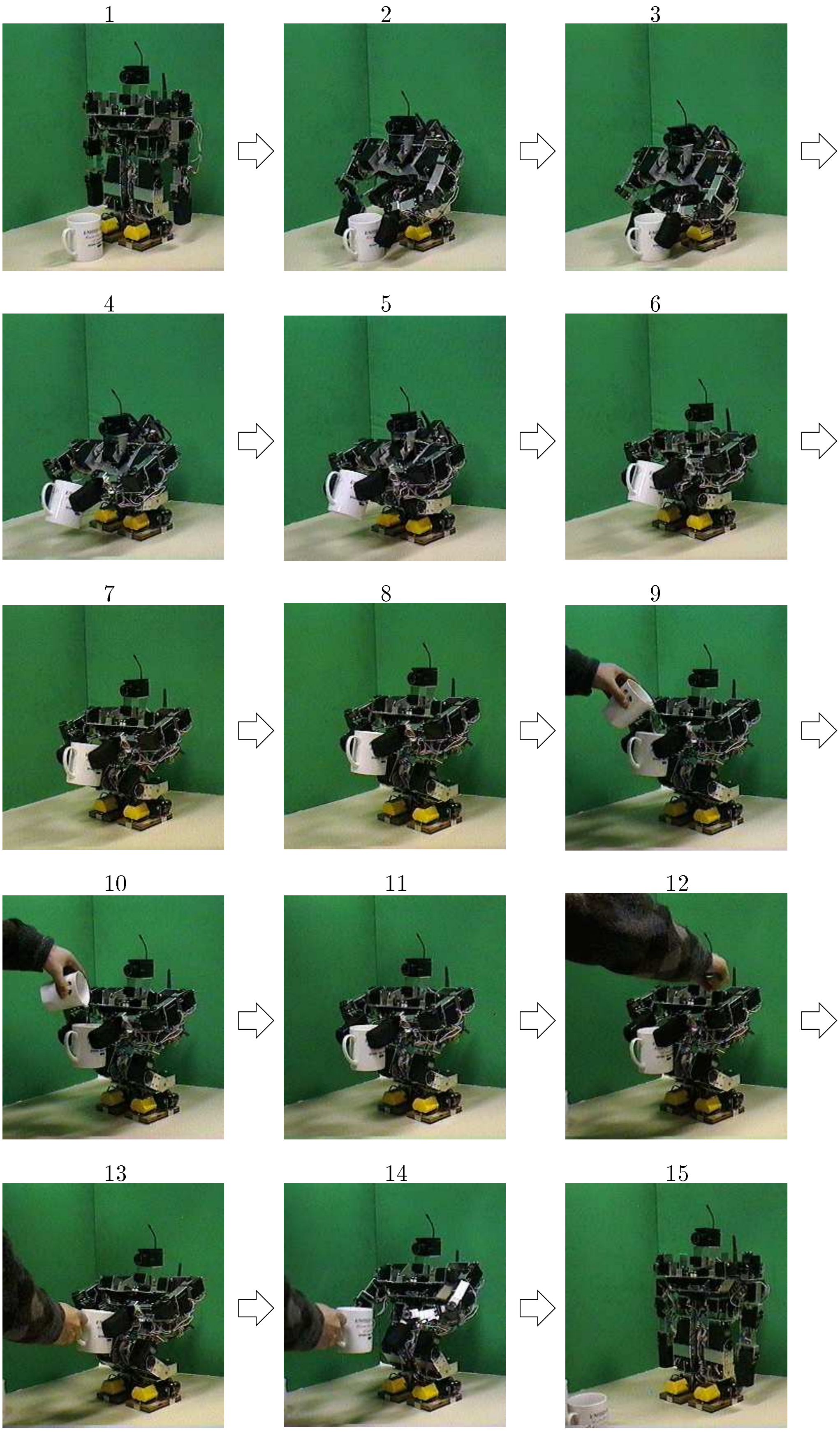


Fig. 6.10 7c$,$`!%%3%C%W$r64$s$G;}$D!%;}$A>e$2$k!%$*Er$,Cm$,1F=ENLJQ 2=$KBP1~$9$k!%?M$,%3%C%W$r<u$1<hm&H9kH<j$rN%$9!% "Haru" squats, grasps a cup, lifts it up, adapts to the weight change, and release it when a person tries to take it.

1F$$$k<L??$r Fig.6.11$K<($9!%

0J2<$K!$ Fig.6.9$N Scene No. $K1h$C$F@bL@$9$k!%$J$*!$ () Fb$O Fig.6.10Cf$N?t;z $KBP1~$9$k!%

Scene No. 1

=i4|;Q@*$GN)$C$F$$$k>uBV (1)!%**keep-head** $O>o;~<B9T$5$l!$%A%k%H3Q$r01Dj $KJ]$D (<0 (6.3) $rMxMQ)!%$3$N8e!$**squat**(Dj7?F0:n)!$<0 (6.1) $N%b%8%e!<%k (B-<s!&I(!&8T4X@a) $r5/F0$7!$B3$$$F**open-arms**(Dj7?F0:n) $r5/F0$9$k!%

Scene No. 2

hold-object $r5/F0$7!$%3%C%W$r64sG;}$D (2,3)!%

Scene No. 3

keep-shoulder(<0 (6.3)) Kh$j!$OS$r?eJ?LL$+$i 15[deg] $N3QEY$KJ]$D%b%8%e!<%k$r5/F0!%**lift-up**(<0 (6.1)) $b5/F0!%;}$C$?%3%C%W$,;}$A>e$,$k (4,5)!%;}$A>e$,$C$?$i**observe-weight**(8*$N4X@a%H%k%/$r4F;k$7!$=PNO%H%k%/$,>.$5$/$JC?$i!$**open-arms** $r5/F0$9$k%b%8%e!<%k) $r5/F0!%F1;~$K**balance**(<0 (6.1)) $r5/F0!%

Scene No. 4

balance $NF/$-$G!$$d$dA0J}$K$"$C$?%3%C%W$r4^a?A4BN$N=E?4$,!$B-$N??>e$"$?jK0\F0 (6)!%**stand-up**(<0 (6.1) $rMxMQ) $,5/F0 (7)!%

Scene No. 5

N)$A>e$,C?H3mG (8)!$%3%C%W$K?e$,Cm$,lk$, (9)!$**balance** $,$=$N=ENLJQ2=$KBP1~ (10,11)!%%$%s%Q%k%9>u$N30Mp (F,$r2!$5lk) KBP7$F**balance** $,BP1~ (12)!%

Scene No. 6

?M$,%3%C%W$r<u1Hm&$H%3%C%W$N;}$A<j$rDO$`$H (13)!$**observe-weight** $,$=lr8!CN$7!$**open-arms**!$**stand-up** $,5/F0$5$l!$%3%C%W$+$i<j$rJ|$9 (14)!%

Scene No. 7

%3%C%W$+$i<j$rJ|$7$FN)$A>e$,$C$F$$$kESCf (14)!%

Scene No. 8

N)$A>e$,CF!$=i4|;Q@*$KLaC?H3$m (15)!%

L$CNJ*BN$dA`:nCf$KF0E*$K=ENL$,JQ2=$9$k>l9g$K!$<+N'7O$,M-8z$K:nMQ$7J*BNA`:n$r<B8=$G$-$F$$$k!%

6.2.2 ;}$A>e$2$?J*$N=ENL$NJQ2=$KE,@Z$KBP1~$9$k

CV$$$F$"$k%3%C%W (300[g]) $r64$s$G;}$A!$;}$A>e2k!%ESCf$G%3%C%W$K$*Er (250[g] DxEY) $,Cm$,$1=ENL$,JQok$,!$$=$NJQ2=$K<+N'7O$,<+F0E*$KBP1~9k!%?M$,%3%C%W$r <hm&H9kH!$8*$NNO (%3%C%W$N=E$5) $r4F;k$7$F$$$?%b%8%e!<%k$,<j$rJ|9h$&$K ;X<($r=P$7!$<j$NNOrL$/!% (Fig.6.8)

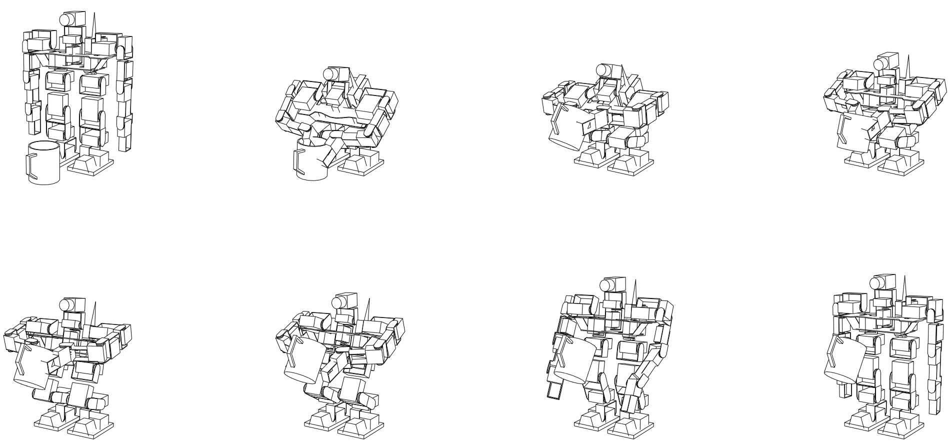


Fig. 6.8 =ENL$NJQ2=$KE,@Z$KBP1~$9$k<B83
"Haru" squats, takes a cup, lifts it up, and adapts to the weight change.

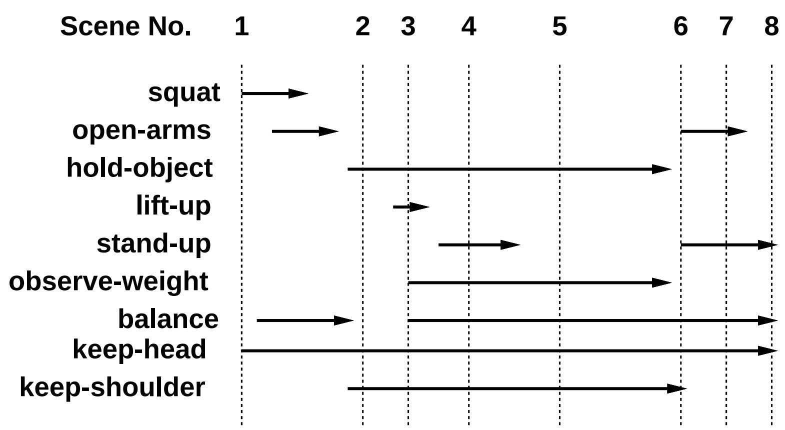


Fig. 6.9 =ENL$NJQ2=$KE,@Z$KBP1~$9$k<B83Cf$N%b%8%e!<%k$N%7!<%1%s%9
The module activation sequence during adapting to the weight change

$=$N4V$K3h@-2=$9$k%b%8%e!<%k$N%7!<%1%s%9$r Fig.6.9$K<($7!$<B:]$N;Q@*$NJQ2= $r!$=gHV$K Fig.6.10$K<($9!$$^$?!$$*Er$,Cm$,$1=ENL$,JQ2=7DD"$k%3%C%W$r;}$AB3

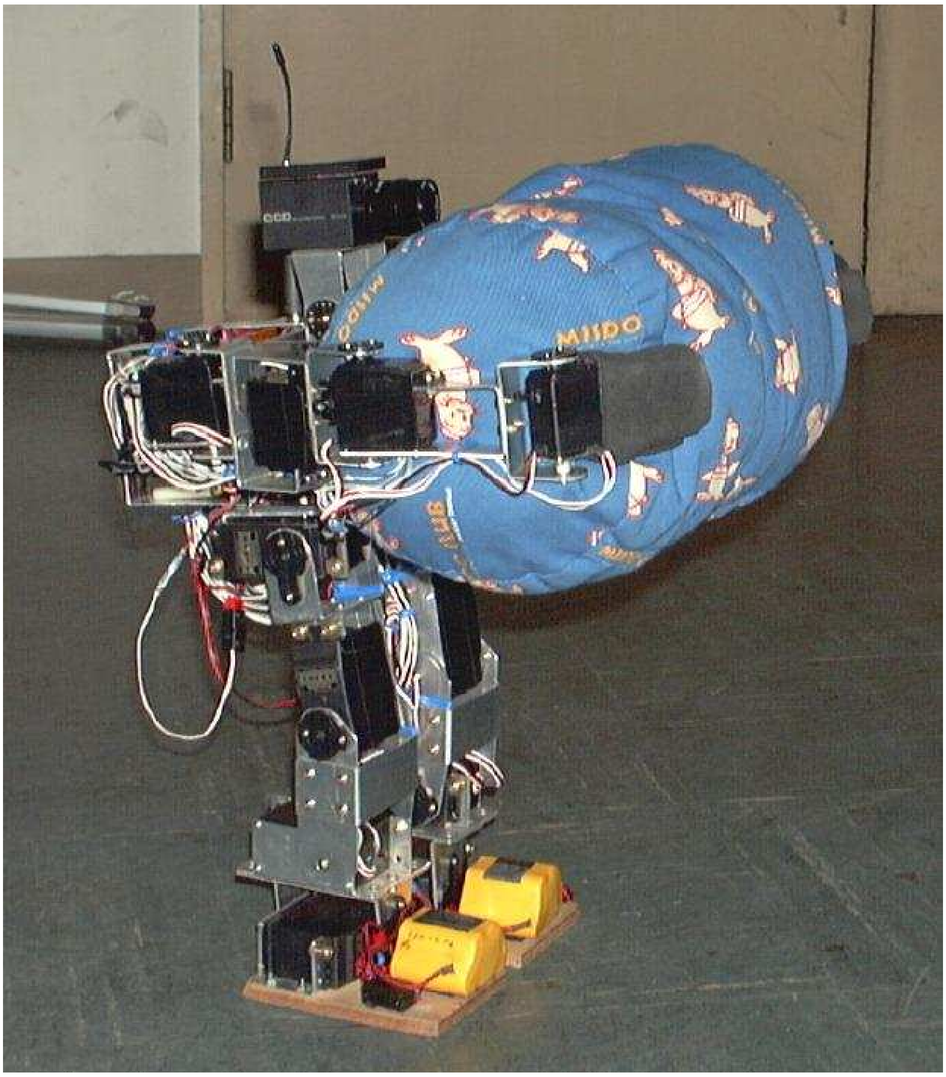


Fig. 6.7 %/%C%7%g%srJz($kMM;R
“Haru” holding a cushion

Fig. 6.6 =ENLJ*$r;}$A>e2kMM;R
"Haru" lifting up a heavy object

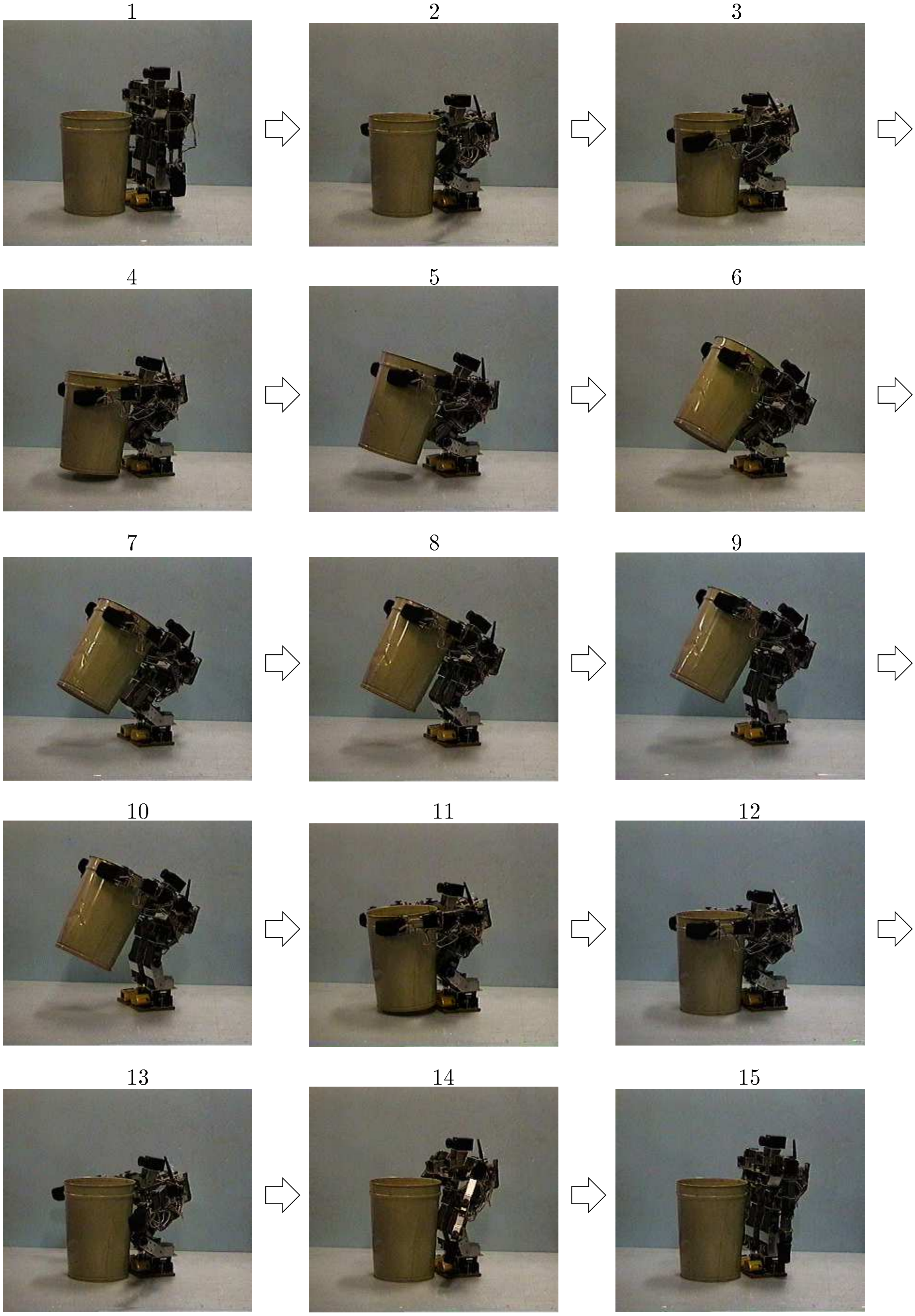


Fig. 6.5 7c$,$`!%=ENLJ*rJz($k!%9x$KN;$k!%;}$A>e2k!%CV$/!%
“Haru” squats, holds an object, and lifts it up.

Scene No. 1

=i4 | ;Q@*$GN)$C$F$$$k>uBV (1)!%

keep-head $O>o;~<B9T$5$l!$$%A%k%H3Q$r0lDj$KJ]$D (<0 (6.3) $rMxMQ)!%$3$N8e!$squat(Dj 7?F0:n)!$<0 (6.1) $N%b%8%e!<%k (B-<s!&I(!&8T4X@a) $r5/F0$7!$B3$$$Fopen-arms(Dj 7?F0:n) $r5/F0$9$k!%

Scene No. 2

open-arms $,=*N;$7$?>uBV (2)!%

3N8e!$balance $rDd;_$7!$hold-object1(<0 (6.2) $rMxMQ$7$F8*!&9O!&<j<s4X @a$N=PNO%H%k%/$r0lDj$KJ]$D%b%8%e!<%k) $r5/F0$9$k!%8*!&9O!&<j<s$N=PNO%H %k%/$,;XDjCM$KMn$ACe$$$?$i (3)!$lift-up $r5/F0$9$k (4,5)!%lift-up $O!$<0 (6.1) $rMxMQ$7$F!$8T4X@a<4$N??>e$KJ*BN$r4^$a$?=E?4$,$/$kh&$K@)8f$9k3 HKhC$F!$J*BN$r9x$N>eKN$;$k7A$G;}$A>e2k (6.1.1@a)(6)!%J*BN$,COLL$+ $iN%$l$?$ibalance $r:F$S5/F0$9$k!%

Scene No. 3

lift-up $,=*N;$7!$stand-up $,5/F0$5lFN)$A>e$,CF$$$kESCf$N>uBV (7 !A 9)!%

stand-up $O!$<0 (6.1) $rMxMQ$7$F!$%P%i%s%9$r<h$jJ,$iB-<s!&I(!&8T4X@a$r ?-P7$F$$$/!%

Scene No. 4

stand-up $,?J9T$7!$$[$\N)$A>e$,$C$?>uBV (10)!%

3N8e!$:F$Ssquat Kh$jJ*BN$rCV$- (11,12)!$open-arms KhCFJ*BN$rJ|$7 (13)!$stand-up KhCFN)$A>e$,$k (14,15)!%

3N<B83GO!$=ENL$No+iJ$$J*BN$r!$%;%s%5>pJs$K4p$E$$/<+N'7O$NF/$-KhCF!Jz(>e2k3H$,$G$-$?!%

5i$K!$F1$8%b%8%e!<%k$G!$=ENL!&9E$5$N0[$J$kJ*BN$r;}$A>e$2$k<B83$r9TC?!% =ENLLs 250[g] $N!$I[@=$N%/%C%7%g%s$rJz$($kMM;R$r Fig.6.7$K<($9!%

3liN<B83$+$i!$=ENL!&9E$5$,0[$J$kJ*BN$K!$<+N'7O$,BP1~G-$F$$$k3H$,$o$+$k!%

6.2 J*BNA`:n9TF0

<BAu7?%b%8%e!<%kKI,MWK1~8F5/F0!&=*N;$NL?Na!&5/F0%Q%i%a!<%?$rM?$($k%W%m%0%i%`$r>e0LAX$KCV$-!$3+H/$7$??M4V7?%m%\%C%H "Haru" (Ls 4.1[kg]) $rMQ$$$F<B:]$KA4?H$r6(D4$5$;$FJ*BNA`:n$N<B83$r9TC?!%

6.2.1 =ENL!&Bg$-$5$,L$CN$NJ*BN$NE,1~E*;}$A>e$2F0:n

>o$K%P%i%s%9$rHj%H%k%/$rD4@a$7J,$i!$$7c,sGCV$$$F$"$k=ENLJ* (%4%_H"!$ 450[g]) rJz(>e2k (Fig.6.3)!%

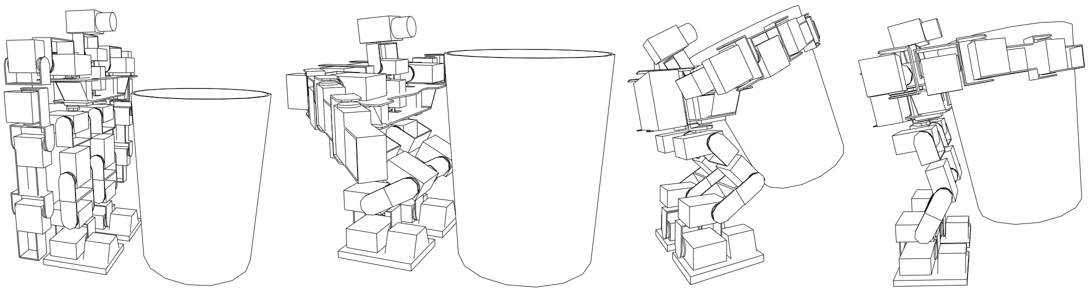


Fig. 6.3 7c$,$_!$=ENLJ*$rJz$(!$;}$A>e$2$k<B83
"Haru" squats, holds an object, and lifts it up.

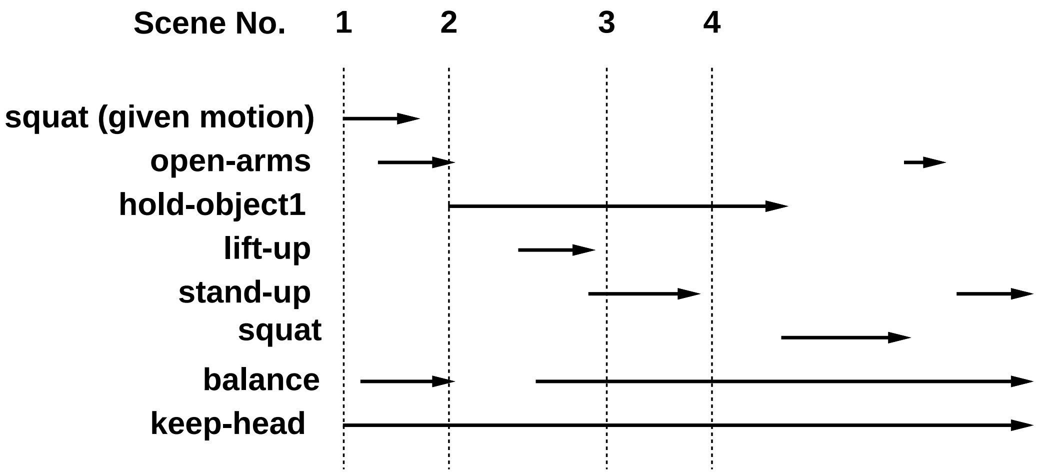


Fig. 6.4 =ENLJ*rJz(>e2k<B83Cf$N%b%8%e!<%k$N%7!<%1%s%9
The module activation sequence during lifting up a heavy object

$=$N4V$N%b%8%e!<%k$N%7!<%1%s%9$r Fig.6.4$K<($7!$<B:]$N;Q@*$NJQ2=$r!$=gr*CF Fig.6.6$K<($9!%$^$?!Jz(>e2F%P%i%s%9$rJ]$C$F$$$k<L??$r Fig.6.6$K<($9!%

0J2<$K!$ Fig.6.4$N Scene No. $K1h$C$F@bL@$9$k!%$J$*!$ () Fb$O Fig.6.6Cf$N?t;z$KBP1~$9$k!%

I(4X@a (θ) $*$h$SB-<s4X@a ($\theta_2$) $K4X$7FbF1MMG"$k!%

6.1.2 OSNNOND4@0

4X@a i $N8=:_$N%H%k%/ ($\tau_{o,i}$) $r4F;k$7<0 (6.2) KhCF!$;XDj$5l?%H%k%/ ($\tau_{r,i}$) $r=PNO$9kh$&$K!$%"%/%A%e%(!<%?$N;XNa3QEY4(θ_i)a9k3H$,$G$-$k!% (G $O%2%$%s)

$$\delta\theta_i = G(\tau_{r,i} - \tau_{o,i}) \tag{6.2}$$

3l$O!$8=:_$N=PNO%H%k%/$HL\I8%H%k%/hj!NOrHfNc@)8f9k$?$a$N7W;;<0$G$"$j!$9E$5$,L$CN$NJ*BN$JIrJz$($k:]NOSN3F4X@a$N%H%k%/$ND4@aJI$KMxMQ$G$-$k!%

6.1.3 FCDj$N4X@a3QEY$ND4@0

<0 (6.3) KhCF!$4X@a i $N4X@a3QEY ($\theta_i$) $rD4@a$7!$=89g M $KB0$9$k4X@a$N8=:_CM (θ_m; $m \in M$) $N9g7W$K0lDj3QEY (α) $r2C$($?CM$KJkh&K9$k!%

$$\delta\theta_i = \theta_i - \sum_{m \in M} \theta_m + \alpha \tag{6.3}$$

Nc$($P!$2<H>?H$N X <42sjN4X@a (θ_x, 2<H>?H$N X<42s$j$N4X@a) $r4F;k$7!$8*$N4X@a ($\theta_{X\text{-shoulder}}$) $rD4@a$9k3HG!OSr0lDj3QEY (α) $KJ]$D3H$,$G$-$k!%

l>lN4X@a<4rDLk1tD>@~>eKMhkh&$K!$4X@a3QEY$rD4@a$9k3HKhj!$3F4X@a$H$b>/$J$$=PNO%H%k%/$N>uBV$K9k3H$,$G$-$k!%

Fig.6.11&GO!$B-<s!&I(!&8T4X@a$=l>lN4X@a<4N[$\1tD>@~>e$K **G** $,$"$k!$%P%i%s%9$N<h$l$?;Q@*$KJC$F$$$k!%

8T!&I(!&B-<s$N3F4X@a$O!$0LCV@)8f$r9TCF$$$kNG!$ Fig.6.1:8$N>uBV$G$O!$$=l>$lLp0u$NJ}8~$N%H%k%/$r=PNO7F$$$k!%$=$3$G!$3F4X@a$N=PNO%H%k%/ ($\tau$ 4F;k$7!$<0 (6.1) $rMQ$$$F;XNa3QEY$($\theta$ $)$rD4@a9k3HKh$j!$=ENLNLCN$JJ*BN$rJ];}7F$$$k;~Kb%P%i%s%9$rJ]$D3H$,$G$-$k!% (G $O%2%$%s)

$$\delta\theta_1 = \begin{cases} 0 & \tau_1 <= \tau_{1,thd} \\ G \cdot \tau_1 & \tau_{1,thd} < \tau_1 \end{cases} \tag{6.1}$$

J*!$$3$N<jK!$O Fig.6.2Nh$&$K2?$+$K4sj+$+$kh&$J>uBV$N;~$O!$$&$^$/:nMQ7J$$>l9gb"$k!% Fig.6.2$N>l9g!$4s$j$+$+CF$$$kJ*BN$+$iNKrF_2 $r<u$1$F$$$k!%

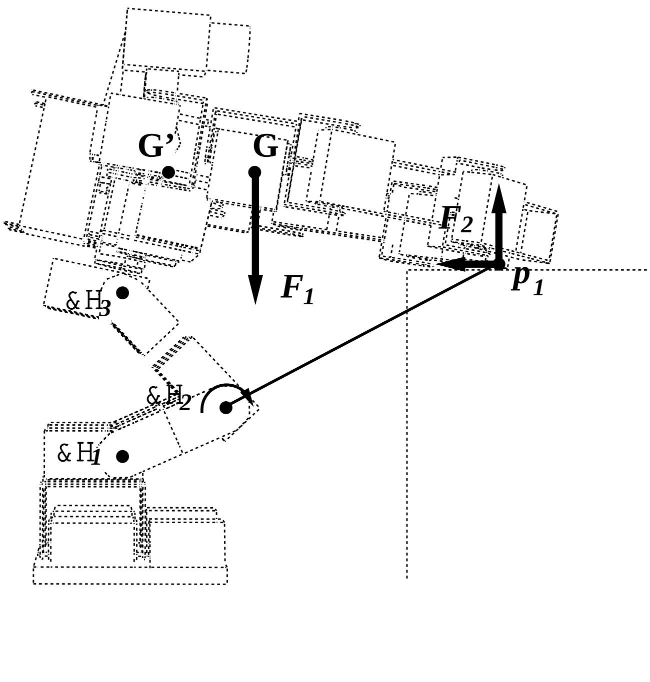


Fig. 6.2 4sj+$+$C$F$$$k>l9g
Leaning on something

3N;~I(4X@a$O!$ F_2 Kh$k%b!<%a%s%H$H F_1 Kh$k%b!<%a%s%H$N9g7W$K8T4X@a$d8*4X@a$N%H%k%/$r2C$($?%H%k%/@.J,KDj"$&%H%k%/$r=PNO7F$$$k!%3N=PNO%H%k%/$,?^$Nh&$K;~7W2s$j$N>l9g!$<0 (6.1) Kh$jD4@0$r9T$&$H!$4s$j$+$+CF$$$kJ*BN$K>eH>?H$r2!7D1F$$$/8~$-$K4X@a$rD4@a$7F7$^$$!$%P%i%s%9$rHk3HOG$-$J$$!%

6.1 <BAu7?<+N'5!G=%b%8%e!<%k

J*BNA`:n$N$?$a$K<BAu$7$?%b%8%e!<%k$r5s$2!$$=$N5!G=$H$=$l$r<B8=$9$k<0!$4F;k$9$k%;%s%5!&A`:n9k%"%/%A%e%(!<%?$H!$C1FH$G<B9T$7$?:]$N8z2LKD$$$F=RYk!%

6.1.1 2<H>?H$rMxMQ$7$?%P%i%s%95!G=

J*BN$r;}$A>e2?>uBVGO!$J*BN$N=ENLKhCFK\Mh$N%m%\%C%H$N=ENL%P%i%s%9$,Jx$l$F$$$k!%$3$3GO!$$3$N>uBV$N;~$K!$J];}7F$$$kJ*BN$N=ENL$r4^aF%P%i%s%9$r<h$k$?$a$N<+N'5!G=%b%8%e!<%k$N<BAuKD$$$F=RYk!%

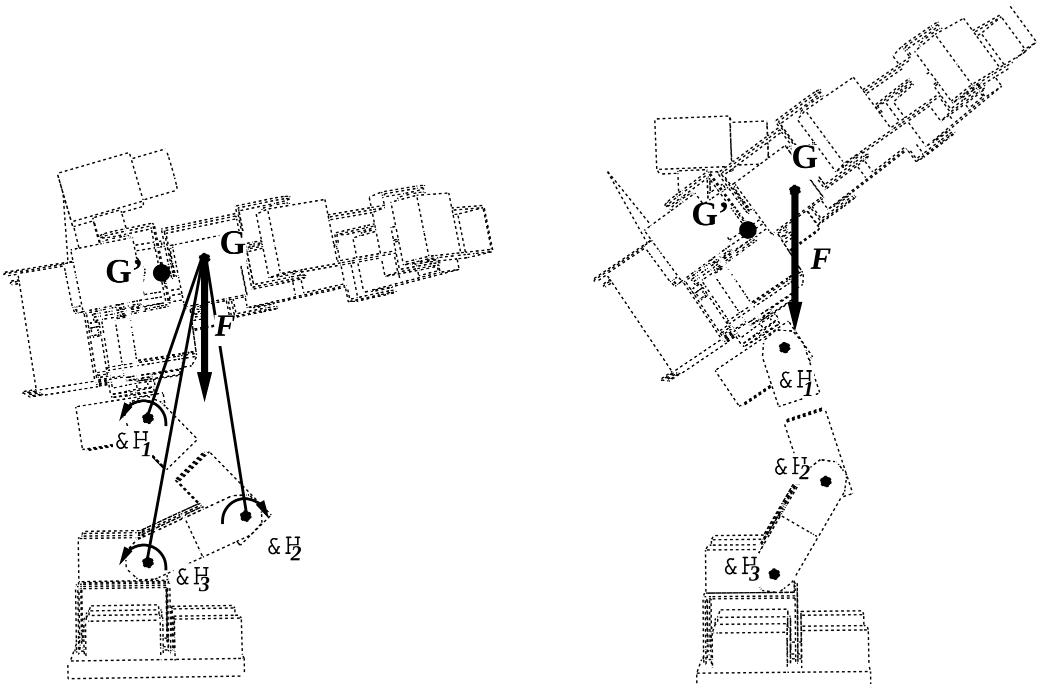


Fig. 6.1 J*BN$r;}$C$F$$$k;~$N2<H>?H$N%P%i%s%95!G=
Balancing by legs during holding an object

Fig.6.1:8K*$$$F!$%m%\%C%H$N>eBN (8T4X@a$ θ_1 >eIt) $NK\Mh$N=E?4OLCV$O **G'** G"kNKBP7!$J*BN$N=ENL$r4^a?>eBN$N=E?4OLCV$O **G** KJCF$$$k!%$=$7$F!$J*BN$N=ENL$r4^a?>eBN$N=ENL$KhkNO$O ***F*** HJ$k!%$=NH$-!$ θ_1 $,8T4X@a θ_2 $*$r J]D?aK=PNO7J1lPJiJ$$%H%k%/$O!$$3$N?^$G$OH?;~7W2s$j$K θ_1 Jk!% θ ;~7W2sjK2sE>$7!$ **G** $,$ θ_1 DLk1tD>@~>eKMhkh&$KD4@a$9lP!$8T4X@a θ_1 Hs$I%H%k%/$r=PNO9kI,MW$,L5$/Jk!%

F1MM$K!$ Fig.6.1$N:8?^$K$*$$$F$O!$I(4X@a$O;~7W2s$j!$B-<s4X@a$OH?;~7W2sjN%H%k%/$r=PNO$7J1lPJi$J$$$,!$$=l>lN4X@a<4$+$i>e$NJ*BN$r4^$`=E?4 ($\theta_1$ θ_2 $*$h$S θ_2 !A θ_3 $NItJ,$N%j%s%/$N=ENL$,2CokNG!$6O$+$K **G** HO0[Jk) $,!$$=

Bh **6** >O

H?<M7?<+N'%b%8%e!<%krAH_9go;$?J*BNA`:n9TF0$N

<B8=

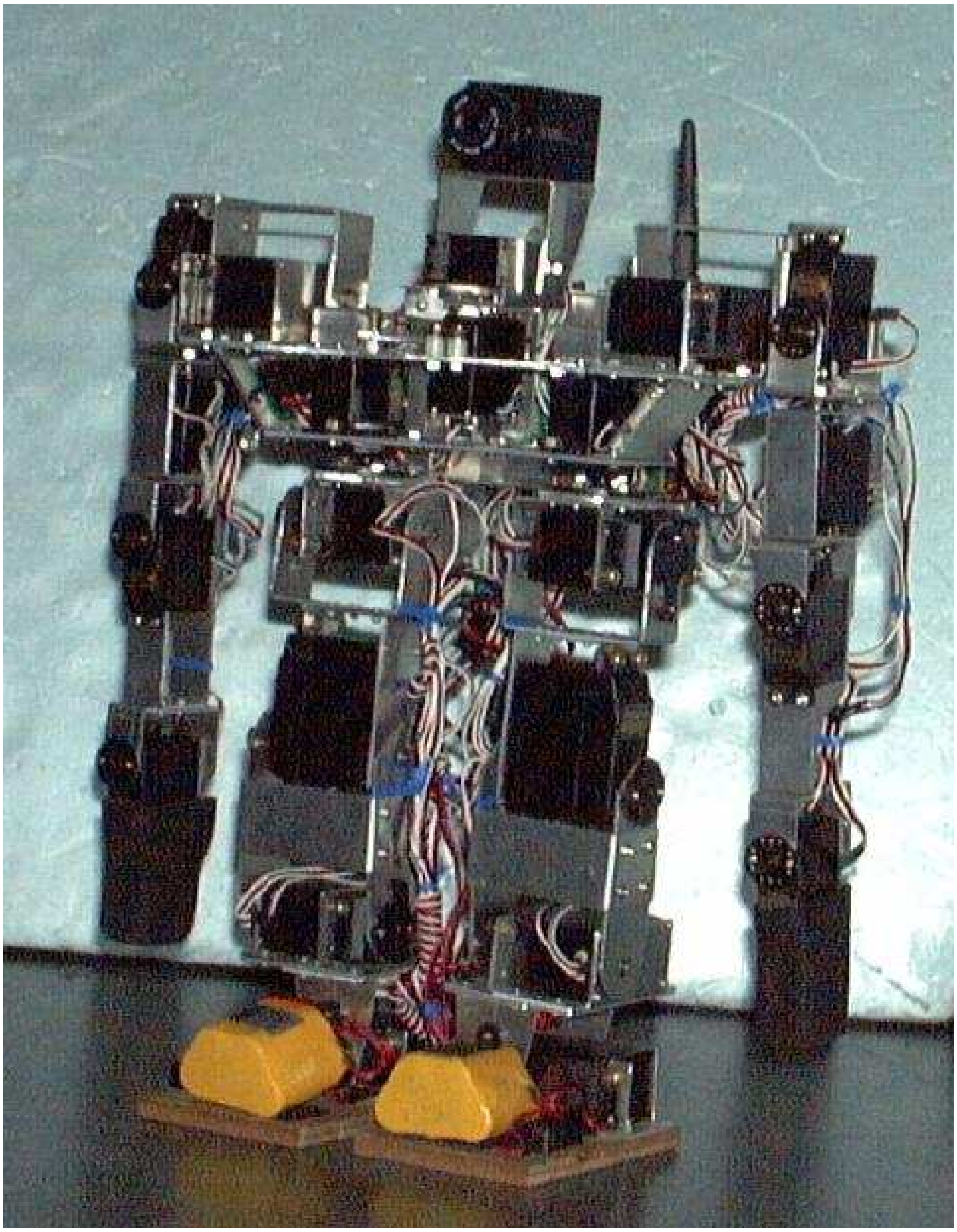


Fig. 5.23 22 <+M3EY?M4V7?%m%\%C%H “Haru”
22 D.O.F. humanoid robot “Haru”

Table 5.4 %o%$%d%l%9 CCD %+%a%i CMD-5C(H) $N;EMM
The specifications of wireless CCD camera CMD-5C(H)

9‘L\	;EMM
CCD It	1/3 %$%s%A%+%i!< CCD !J41 K|2hAG!K
%l%s%:%^%&%s%H	C %^%&%s%H!JCS!K
F14|?.9f	FbItF14|
1GA|=PNO	VS 1.0Vpp/75 &8 NTSC %3%s%]%8%C%HJ}<0
Aw?.%A%c%s%M%k	VHF 4ch !A 12ch !A@lMQ ch
:GBgEEGH%(%j%"	Ls 20 !A 30m
2rA|EY	?eJ? 450 K\
:GDc>HEY	5Lux
EE;R%7%c%C%?!<	1/60 IC!$ 1/250 IC
=PNOC<;R	%9%F%l%* 3.5 &U%8%c%C%/!J1:ANT·AUDIO 2:VIDEO 3:GND!K
EE8;	DC5V Ls 270mA !JM-@~!K / Ls 310mA !JL5@~!K
FbB"EECS	450mAh 70 J, /60 J,
%^%$%/	9b@-G= EC %^%$%/
307A@#K!	34.5×35.5×52.0mm !JFM5/J*=|$/!K
=ENL	135g !JK\BN$N$_!K!$ 165g !J%l%s%:9~$_!K

Table 5.3 3 <42CB.EY%;%s%5 ADXL05EM-3 $N;EMM
The specification of 3-axis accelerometer ADXL05EM-3

9'L\	;EMM
8!=PHO0O	$\pm 4g$
46EY	$500mV/g$
8!=PJ}8~	3<4
307A@#K!	$47.63 \times 25.4 \times 19.05mm$
$0g$ =PNO	$+2.5 \pm 0.1V$
=PNOHO0O	$+2.0 \pm 0.1V$
6!5kEE05	$+5 \pm 0.25V$
6!5kEEN.	$24mV$

$N BS %H%i%s%9%_%C%?$KhjL5@~$G2hA|$r%V%l%$%s$KAw?.G-$k=<EE<0EECSFbB"$N>.7? CCD %+%i!<%+%a%i$rEk:\$7$?!%$3$N%+%a%i$N;EMM$r Table.5.4$K<($9!%

5.6.5 3+H/7??M4V7?%m%\%C%H "Haru"

0J>e$K=R$Y$?$bNrA4ItAH$_9~$s$G!$ 22 <+M3EY?M4V7?%m%\%C%H "Haru"(?HD9Ls 45[cm]!$BN=ELs 4.1[kg]) $r3+H/$7$?!%=i4|;Q@*$GN)CF$$$kMM;R$r Fig.5.23$K<($9!%

5.6.4 $=$NB>$N%;%s%5

B-Dl%;%s%5

Force Sensing Resistors(FSR) $O INTERLINK <R@=$N9bJ,;R8|Kl%U%#%k%`%G%P%$ %9G"$j!$%"%/%F%#%V%(%j%"$K2C$(il$?NO (05NO) $NA}2C$KH<CF!$EE5$E*Dq93CM$, 8:>/$9$kFC@-$r;}$DNO%;%s%5$G$"$k [50]!% FSR $NDq93CM$ONOKBP7F[$\H?HfNc$7!$ L5Ii2Y;~$G 1MΩ!$ 10kg $N2Y=E$G?t kΩ $^$GJQ2=9k!%

K\O@J8GO #402 $H$$$&7?HV$N FSR $rMQ$$$?!%3N FSR $N7A>u$*hSNOKBP9$k FC@-$r Fig.5.22$K<($9!%

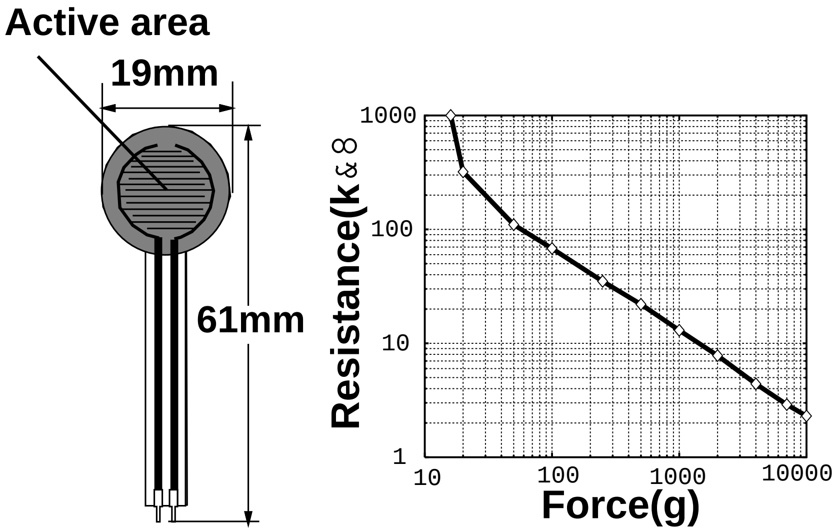


Fig. 5.22 FSR#402 $N7A>u (:8)!$ FSR#402 $NDq93CM$HNOHN4X78 (1&) FSR#402

=E?4$NEj1FE@$rB,Dj9k3H$,$G$-$kh&$K!$ FSR $rMQ$$$FB-DlNO%;%s%5 [51] $r <h$jIU1?!%

2CB.EY%;%s%5

3 <42CB.EY%;%s%5$rEk:\$9k3HKhj!$=ENO2CB.EY$r4^$`%m%\%C%H$N2CB.EY$r 3 <!856u4V$N%Y%/%H%kH7$F7WB,$9k3H,G-$k!% Table.5.3$KEk:\$7$? 3 <42CB.EY%; %s%5$N;HMQ$r7G:\$9$k!%

CCD %+%i!<%+%a%i

;k3P>pJs$OHs>o$K>pJsNL$,B?$/!$MM!9$KMxMQG-$k!%K\O@J8$G$O9T$C$F$$$J$$$,!$ L$CNJ*BN$N7A>u$r;k3P>pJs$rMQ$$$F?dDj9k:]Ey$KM-8z$G$"$k!% “Haru” KO!$>.7?

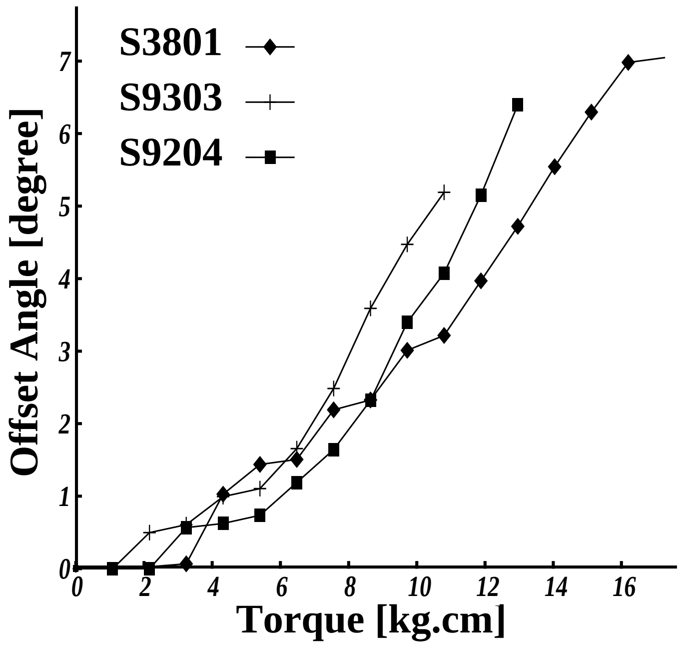


Fig. 5.21 Ii2Y%H%k%/$H8m:93QEY$N4X78
The relation between the torque and the error angle

Table 5.2 %0%i%U$+$i;;=P7?HfNc78?t
The proportional coefficients

%5!<%\%b%8%e!<%k 7?HV	Ii2Y%H%k%/ %b!<%?6nF0?.9f$N%Q%k%9I} kgf·cm/msec	Ii2Y%H%k%/ 8m:93QEY kgf·cm/degree
S3801	1.05	1.95
S9303	0.53	1.46
S9204	0.62	1.41

- CM$O%Q%k%9$NI}H7$FId9f2=$5lkNG!$EE05=PNOEy$HHf3S7F%N%$%:$K 6/$$!%
- %b!<%?$N=PNOEE05$JNG!$%5!<%\%b%8%e!<%k$NFbIt$NK`;$$JIKhk%H%k %/B;<:$,$"$k!%

iii) %b!<%?6nF0?.9f!&%*%U%;%C%H3QEY!&%H%k%/$N7WB,<B83

3+H/7??M4V7?%m%\%C%H$K;H$C$F$$$kJ*$HF1$87?$N%i%8%3%s%5!<%\%b%8%e!<%k (Futaba, S3801(14,0[kg·cm]), S9303(7.2[kg·cm]),S9204(12.6[kg·cm])) $rMQ$$ $F!$Ii2Y%H%k%/!$%b!<%?6nF0?.9f$*hS8m:93QEY$N4X78$r7WB,7?!%%i%8%3%s %5!<%\%b%8%e!<%kK*$$$F$O!$%b!<%?6nF0?.9f$O%Q%k%9I}$G$"$j!$ [msec] C10L $G7WB,$7$?!%7k2L$r Fig.5.20!$ Fig.5.21 $K<($9!%

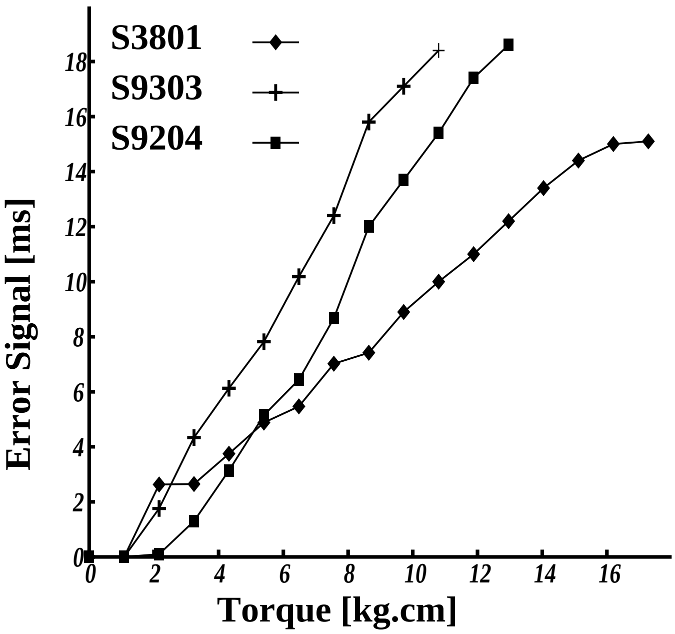


Fig. 5.20 Ii2Y%H%k%/$H%b!<%?6nF0?.9f$N4X78
The relation between the torque and the motor driving signal

%i%8%3%s%5!<%\%b%8%e!<%k$O!$@)8f<~4|$, 20[ms] $HD9$/!$$^$?@:EY$O$"$^$j9b $/$J$$$,!$%H%k%/ ($\tau$) $H%b!<%?6nF0?.9f (V) $N4X78!$%H%k%/ (τ) $H8m:93QEY$N4X 78$,!$$=l>l[$\HfNc4X78$KJC$F$$$k3H$,3NG'$G$-$?!%%0%i%U$+$i;;=P$7 $?HfNc78?t$r!$ Table.5.2$K<($9!%

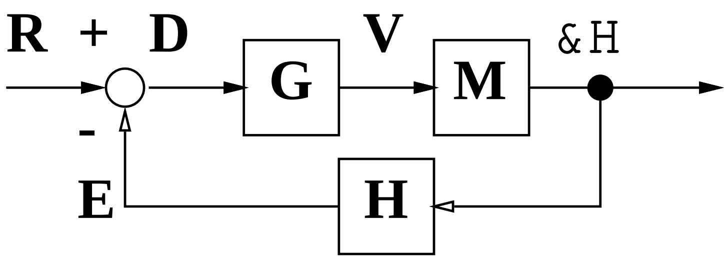


Fig. 5.18 %5!<%\%7%9%F%`$N%V%m%C%/?^
Block diagram of servo module

E %b!<%? (M) $N3QEY ($\theta$) $r%Q%k%9I}$KJQ49 (H) 7?CM

D R $H E $N:9 (%Q%k%9I})

V I} 0 !A 18[ms] DxEY$N%b!<%? (M) XN=PNO%Q%k%9
(D→ HfNc@)8f4o!\%"%s%W)(G)

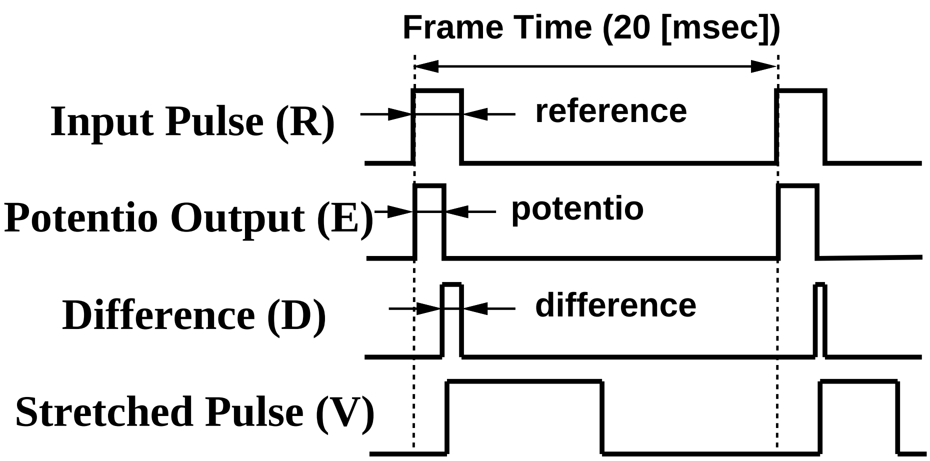


Fig. 5.19 %i%8%3%s%5!<%\%b%8%e!<%k$NFbIt?.9fGH7A
The sequence of radio control servo module

$3$3$G!$%i%8%3%s%5!<%\$N%b!<%?=PNOFC@- (<0 (5.1)) $r!$

$$F(\mathrm{V}) \;=\; k\mathrm{V} \qquad (k : \texttt{Dj?t}) \tag{5.2}$$

$H2>Dj$9lP!$ V $H τ $r7WB,$7 k $r;;=P$9k3HKhj!$%b!<%?6nF0?.9f (V) $+$i=PNO%H%k%/$r5a$ail$k!%

%i%8%3%s%5!<%\%b%8%e!<%k$N%b!<%?6nF0?.9f$rMxMQ7?%H%k%/7WB,KO!$<!$Nh&$JFCD'$,$"$k!%

- FCJL$J%;%s%5$NIU2C$,ITMW$G$"$k!%

5.6 22 <+M3EY?M4V7?%m%\%C%H **“Haru”** $N3+H/

K\@aGO!$ Fig.5.17$r;}$D?M4V7?%m%\%C%H “Haru” $N3+H/$K$D$$$F=RYk!%

5.6.1 <+M3EYG[CV

<+M3EYG[CV$O!$8T4X@a 2 <+M3EY!$I(1 <+M3EY!$B-<s 2 <+M3EY!$8* 3 <+M3EY!$9O 1 <+M3EY!$<j<s 1 <+M3EY!$<s 2 <+M3EY$N!$9g7W 22 <+M3EYH7$?!%

5.6.2 %"%/%A%e%(!<%?

%"%/%A%e%(!<%?KO!$ Futaba <R@=$NLO7?MQ%i%8%3%s%5!<%\%b%8%e!<%k$rMxMQ$9$k!%$3lN%b%8%e!<%k$O!$%b!<%?!&%.%d$H%]%F%s%7%g%a!<%?$rHw$(!$HfNc@)8f$r9T$&%A%C%W$H%"%s%W$JIrHw$($F$*$j!$MF0W$K@)8f$r9T$&3H$,$G$-$k!%@)8fMQ?.9f@~!&EE8;@~!&@\CO@~$N 3 @~$N%$%s%?%U%’!<%9$r;}$A!$EE8;@~$K%b!<%?6nF0EE05$r!$?.9f@~$K Fig.5.2Nh$&$JL\I83QEY$KBP1~$7$?%Q%k%9$rF~NO9k3HKh$j!$HfNc@)8fKh$j%5!<%\$r9T$&!%

5.6.3 %b!<%?6nF0?.9f$rMxMQ$7$?%H%k%/7WB,

A4<+M3EY$N%H%k%/$r7WB,7?$$>l9g!$3F4X@a<4$K%H%k%/%;%s%5$r<h$jIU1kN,0lHLE*$@$,!$%b!<%?$N=PNOEE05$rB,$k3HKhj=$N%H%k%/$rCNk3H,G-$k!%0J2<$G$O!$K\O@J8$G3+H/$7$?%m%\%C%H$N!$A4<+M3EY$N%H%k%/7WB,$KMQ$$$?<jK!KD$$$F@bL@9k!%

i) %b!<%?6nF0?.9f$rMxMQ$7$?%H%k%/7WB,$N86M}

Fig.5.18$K<($9h&$J0LCV%5!<%\7O$K$*$$$F%b!<%? (M) $NA`:nNL V $H=PNO%H%k%/ τ $N4V$K$O!$

$$\tau = F(\mathrm{V}) \quad (F : \text{%b!<%?=PNOFC@-\$rI=\$94X?t}) \qquad (5.1)$$

$N4X78$,$"$k!%=>CF!$4X?t F $,$o$+$l$P%5!<%\7O$NA`:nNL V $r7WB,$7$F=PNO%H%k%/$r5aak3H$,$G$-$k!%

ii) %i%8%3%s%5!<%\%b%8%e!<%k$N%b!<%?6nF0?.9f

%i%8%3%s%5!<%\%b%8%e!<%kGO!$ Fig.5.18K*1k5-9f$,0J2<$NCM$KBP1~$9$k (Fig.5.19)!%

R I}Ls 400 !A 2200[μs] $NF~NO%Q%k%9 (L\I83QEY$KBP1~)

5.5 %7%9%F%`A4BN?^

$3$3$^$G$K=R$Y$?!$FsAX9=B$$N%V%l%$%s$HBNFb LAN rHw($?%\%G%#$Khk!$%7%9%F%`$NA4BN9=B$$r!$ Fig.5.17$K<($9!%

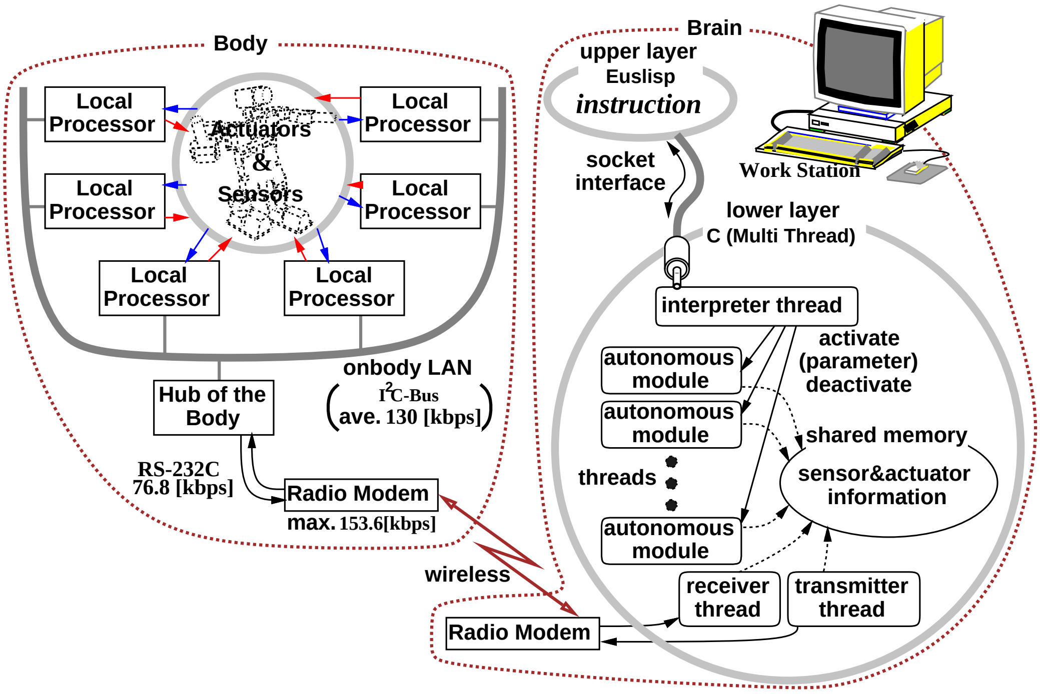


Fig. 5.17 %m%\%C%H%7%9%F%`A4BN?^
The whole robot system

5.4.5 $=$NB>$N%*%s%\%G%#%=%U%H%&%'%"

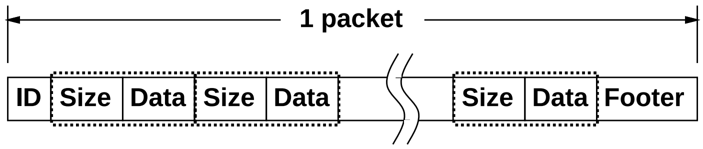
DL?.0J30$N%*%s%\%G%#%=%U%H%&%'%"$b!$3+H/$7$?%i%$%V%i%j (IUO? A;2>H) $rMQ$$$F9=C[7?!%

$3$3GO!$%i%8%3%s%5!<%\%b%8%e!<%k@)8f%=%U%H%&%'%"KAH_9~s@!$FC<l$J5!G=KD$$$F=RYk!%%i%8%3%s%5!<%\%b%8%e!<%kKO!$ Fig.5.2$K<($9%Q%k%9$rM?$($F3QEY$r@)8f9k$,!$%Q%k%9@8@.$N%W%m%0%i%`$OIUO? A$K<($9!%$3$3GO!$4X@a$rC&NO5;$kJ}K!$K$D$$$F=RYk!%

%i%8%3%s%5!<%\%b%8%e!<%k$O!$EE8;EENO$,6!5k$5lF$$$F$b!$=jDj$N%Q%k%9$,F~NO5lJ1lP!$%b!<%?$K%H%k%/$rH/@8$7$J$$!%3l$rMxMQ$7$F4X@a$rC&NO5;k3H,G-kh$&$K7?!%6qBNE*KO!$3QEY;XNaCM$H7F!$%5!<%\$N2DF0HO0O30NCM,;XDj5l$?>l9g!$%Q%k%9@8@.$r9T$o$J$$$h$&$K7?!%3lKh$j!$%V%l%$%sB&$G4:$($F2DF0HO0O30NCMr;X<(9k3HKh$j!$4uK>$N4X@a$rC&NO5;k3H,G-$k!%

$"$k!%D^$j!$%V%l%$%s$N%7%j%"%kDL?.$N%=%U%H%&%'%"$H!$BNFb LAN $N%O%V$N%=%U%H%&%'%"rJkY$/:FMxMQ2DG=$J7A$K9=@.$9Y-G"$k!%

3&7?;kE@$KN)$A!$%V%l%$%s$H%\%G%#$N4V$NL5@~%b%G%`$rMxMQ7?%7%j%"%kDL?.$rN.$l$k%G!<%?$N%U%)!<%^%C%H$r Fig.5.16$K<($9HFMQ$J7A<0$KE}0l$7$?!%$J$*!$%G!<%?$O AD JQ494o$NCMJI$N3FAuCV$K0MB8$7$?C10LNL$GI=$5$l!$3QEYJI$NDjNLE*$JJ*M}NLXNJQ49$O!$%V%l%$%s$N%7%j%"%kDL?.$N%$%s%?%U%'!<%9It$G9T$olk (4.2.3@a)!%



symbol	*size* [byte]	*value*
ID	1	0x00 - 0x7f
Size	1	1 - 255
Data	Size	any
Footer	1	0xff

data coding rule
0xff → 0xfe, 0xf2
0xfe → 0xfe, 0xf3

Fig. 5.16 %V%l%$%s!&%\%G%#4V$NDL?.%Q%1%C%H$N%U%)!<%^%C%H
Packet format between the brain and the body

data coding rule $O!$0xff $r%U%C%?$H7FFCDjG-kh$&$K!$%G!<%?Cf$K$O0xff $,8=$l$J$$$h$&$K7F$$$k!%3l$O!$;HMQ7?L5@~%b%G%` DSSNET $N<!$Kh&$JFC@-$r9MN8$7$?$?$aGb$"$k!%

DSSNET $O RS-232C $N%G!<%?$rFbIt$N%P%C%U%!$K3JG<$7!$0J2<$N$$$:l+$N>r7o$,K~$?$5l?;~$K!$%P%C%U%!$K3JG<$7$?%G!<%?$r<B:]$K SS %f%K%C%H$+$iAw?.$7;Oak!%

%?%$%`%"%&%H (T) RS-232C $+$iMh$k%G!<%?$, T[msec] 4V0J>eES@d$($?;~

%G!<%?D9 (LEN) RS-232C $+$iMh$k%G!<%?$,FbIt%P%C%U%!$K LEN[bytes] N/$C$?;~

%G%j%_%?%3!<%I (DEL) RS-232C $+$i DEL(0x00∼0xff $+$i$"$i$+$8$aA*Br$7@_Dj) $H $$$&%G!<%?$,Mh$?;~ (J#?t;XDj2D)

$=$N$?$a!$APJ}8~$G 20[msec] <~4|$NDL?.$r9T$&$3H,5aailk;~$O!$$$$:l+$N<jCJ$GL@<(E*$K%Q%1%C%H$r6h@ZiJ$$$H!$J?6QDL?.B.EY$O9bB.Gb%G!<%?99?7B.EY$O9bB.$GOJ$/$J$k798~$,$"$k!%3NLdBj$r2sHr$9k?aK!$ DEL=0xff H7$F0l%U%l!<%`$N4V$O%G%j%_%?%3!<%I 0xff $,8=$l$:!$%U%l!<%`$N:G8eK@$18=$lkh$&$K9k3HKhj!$0l%U%l!<%`J,$N%G!<%?$,0l%U%l!<%`;~4VKh$KAw?.5lkh$&$K9k3H,G-$k!%

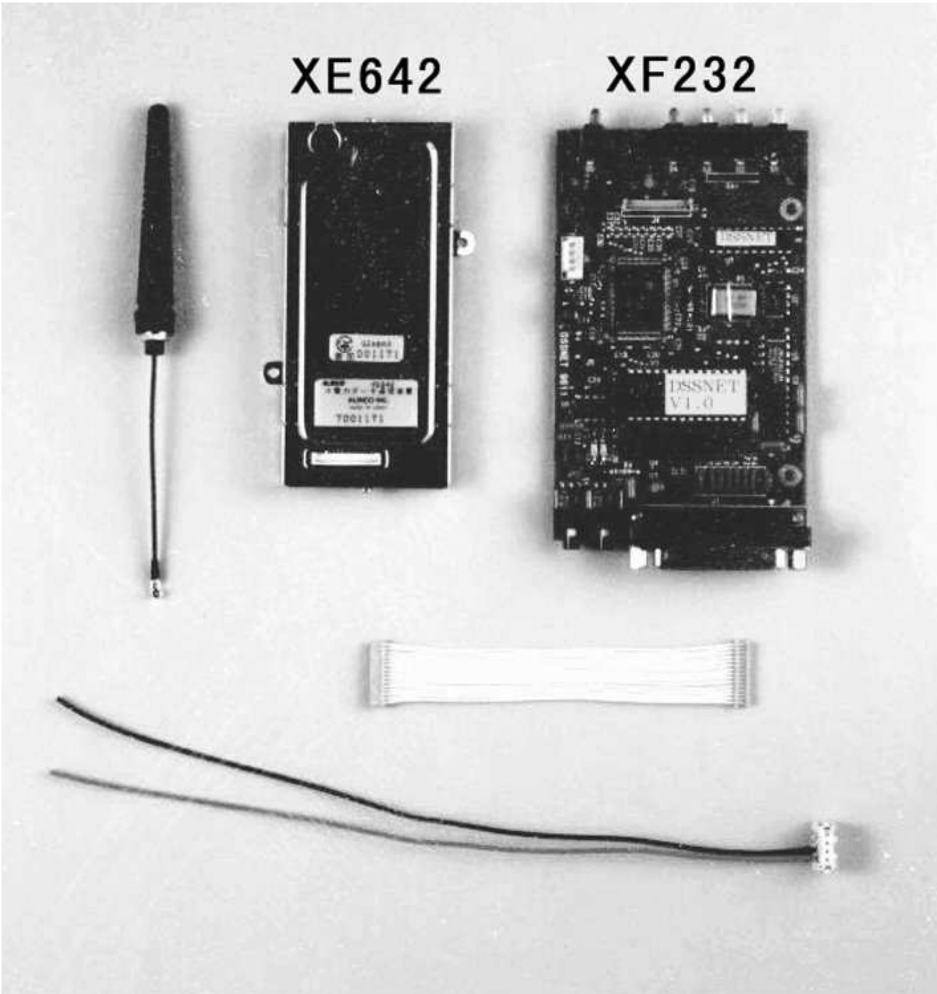


Fig. 5.15 L5@~%b%G%`$NFbIt SS DL?.%f%K%C%H
Spread spectrum communication unit in the radio modem

Fig. 5.14 L5@~%b%G%` (DSSNET)
Radio modem (DSSNET)

L5@~%b%G%` DSSNET $O!$%"%k%$%s%3<R@=$N%9%Z%/%H%i%`3H;6DL?. (SS) L5@~AuCV G"$k%b%G%k XE642 $r;HMQ$7!$9bB.$N RS232C L5@~DL?.$r<B8=$9$k%b%G%`$G$"$k!% DSSNET $K@\B3$5lk RS232C 5!4o$O!$L5<j=g$ND4JbF14|<0$rA[Dj7F$*$j!$FCJL$J %W%m%H%3%krI,MWH$;$:!$DL>o$N%1!<%V%k$G@\B3$5l?>uBV$HF1$8463P$G;HMQ$G$-$k!%

RS232C ItJ,$O!$DL?.B.EY 1.2[kbps] !A 153.6[kbps] $GAw?.B&<u?.B&$G0[JkB.EY $r@_Dj$9k3Hb=PMh$k!%L5@~ItJ, (Fig.5.15) $O!$ 2484MHz $r;H$C$? SS DL?.$G!$ RS232C ItJ,$N%P%C%U%!$KN/C? 1 !A 1024[byte] $N%G!<%?$r!$%Q%1%C%H$K@ZCF@lMQ $N%W%m%H%3%k (HDLC <j=g$rMQ$$$?%(%i!<%U%j!<) $GDL?.$9$k!%

L5@~%b%G%` DSSNET $O!$c~BN$KF~$C$?>uBV (Fig.5.14) $G$O?HD9 45[cm] $N%m%\%C %H "Haru" $KEk:\$9$k$K$O$d$dBg$-2a$.$k$,!$Cf$N SS DL?.%b%8%e!<%k (Fig.5.15) $H!$ HDLC %W%m%H%3%k!& RS-232C JQ49!&DL?.%P%C%U%!$J$I$rEk:\$7$?%b%G%`%f%K%C%H4p HD$r<h$j=P9H!$$Ag&$I "Haru" $NGXCf$KEk:\$9k3H,G-$kDxEY$N%5%$%:$K$J $k!%$=3G!$%V%l%$%sB& (%o!<%/%9%F!<%7%g%s$N%7%j%"%k%]!<%H$K@\B3) $Oc~BN$KF~$C $?>uBV$G@\B3$7!$%\%G%#B& (BNFb LAN $N%O%V) KO4pHDN_$N>uBV$G@\B3$9$k3H$K 7?!%

DL?.%G!<%?$N%U%)!<%^%C%H

:#8eF1$89=@.$G?7$7$$%m%\%C%H$r@=:n$9$k;~$d!$$3l^GK@=:n5l$?%m%\%C%H$K BNFb LAN $rEk:\$9$k>l9g$K!$:#2s$N3+H/$K:]$7$?<jK!$rE>MQG-kh$&$K9kY-$G

B7C?i=lr%9%l!<%VAw?.%P%C%U%!$KE>Aw$9kHHb$K!$3JG<7F$*$$$?%;%s%5%G!<%?$r%V%l%$%s$KAw?.$9$k!%

3liNDL?.$N7ABV$r Fig.5.13$K<($9!%

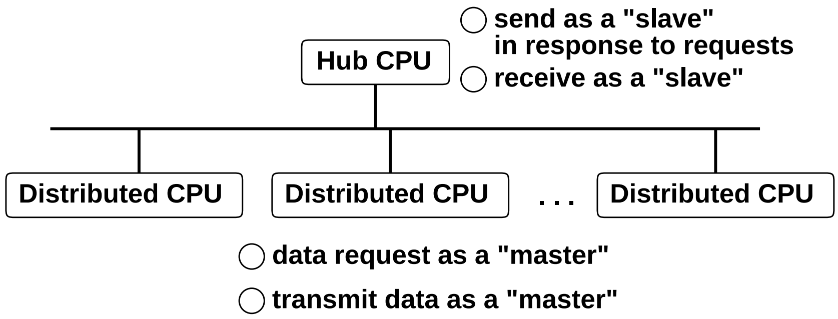


Fig. 5.13 BNFb LAN $NDL?.%W%m%0%i%`
Communication software of onbody LAN

5.4.4 %V%l%$%s$H$N%$%s%?%U%'!<%9

L5@~%b%G%`

%V%l%$%s$H%\%G%#$N4V$O!$L5@~%b%G%`$rMxMQ$7$?D4JbF14|<0%7%j%"%kDL?.$K$h$j!$%V%l%$%s$H%\%G%#$rJ*M}E*$KJ,N%$7$?%j%b!<%H%V%l%$%s%m%\%C%H$NBhFs@$BeJ}<0 [49] $G$"$k!%L5@~%b%G%`$K$O!$%G!<%?%j%s%/<R@=$N DSSNET $H$$$&@=IJ (Fig.5.14) $r0J2<$Nh&$JM}M3$G:NMQ7?!%

- Hf3SE*9bB.G"$j (:G9b 153.6[kbps])!$4X@a3Q;XNaCM$H2hA|0J30$N%;%s%5>pJsJi!$%i%8%3%s%5!<%\%b%8%e!<%k$N<~4|G"$k 20[msec] Fb$K=<J,$J%G!<%?NL$rAw<u?.G-$k!%
- RS-232C $NHFMQ%$%s%?%U%'!<%9N?$a H8 $GMxMQ2DG=$G$"$k!% Ethernet $N%$%s%?%U%'!<%9$r;}$DL5@~%b%G%`$O!$ DSSNET hjdd>.7?JbN,;THN5l$F$$$k$,!$BNFb LAN $N%N!<%I$G$"$k H8 $, Ethernet $N%$%s%?%U%'!<%9$r;}$F$J$$$?$a!$ RS-232C $N%$%s%?%U%'!<%9$OM-8z$G$"$k!%bCHb5;=Q$N?JJb$OAa$$$N$G!$>.7?2=!&9b@-G=2=$O;~4V$HHb$K2DG=$KJkbN$@$,!%
- 5[V] $NEE05$GF0:n9k!%%i%8%3%s%5!<%\%b%8%e!<%k$N%b!<%?EE8;EE05$r6!5k9k Ni-Cd EECS$O 6[V] $r=PNO$7!$$=lr H8 MQ$K 5[V] K9k?aK 3 C<;R%l%.%e%l!<%?Kh$jDjEE05$rF@$F$$$kNG!$$=lr$=$N$^$^MxMQG-$k!%
- %(%i!<%U%j!<$N%W%m%H%3%k$rFbB"9k!%3lKh$j!$DL>o$NM-@~$N RS-232C Kh$kDL?.$HA4$/F1$8h&$K07$&3H$,$G$-$k!%

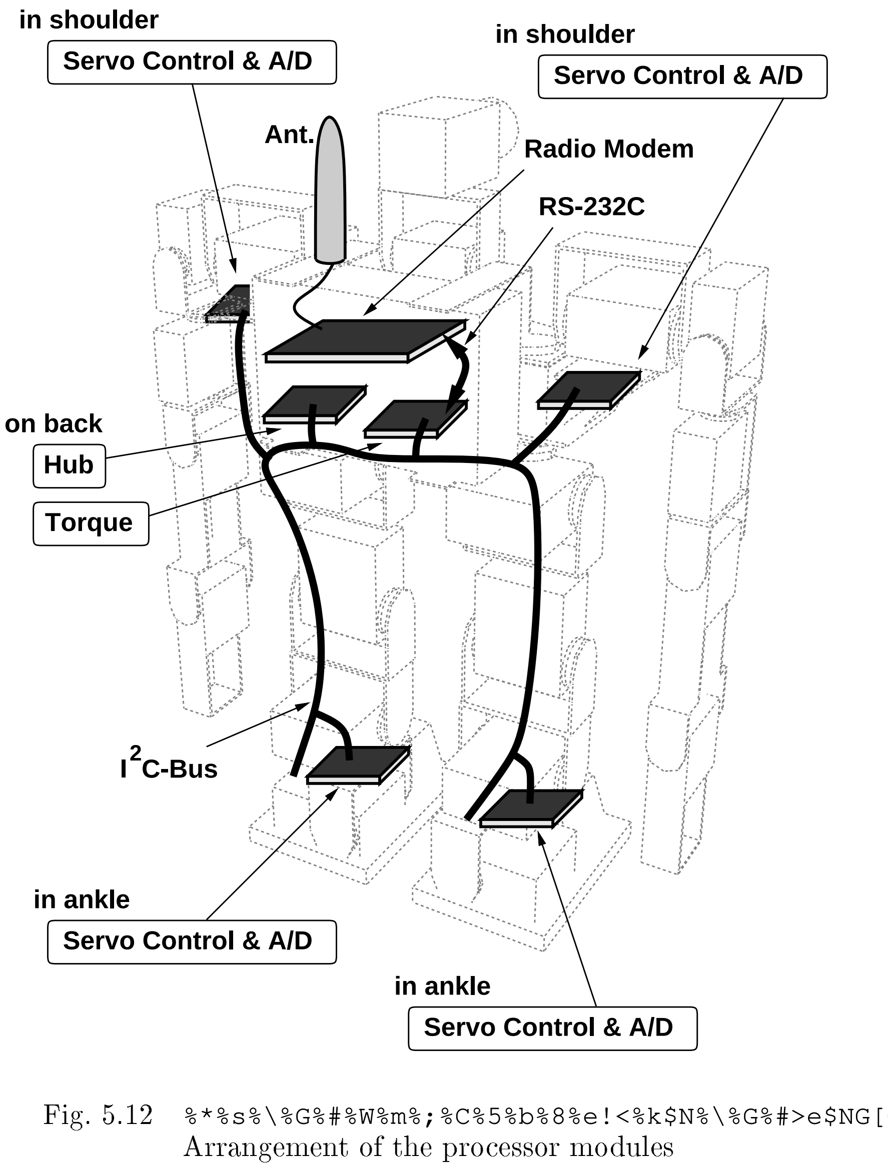


Fig. 5.12 %*%s%\%G%#%W%m%;%C%5%b%8%e!<%k$N%\%G%#>e$NG[CV
Arrangement of the processor modules

- BNFb LAN $NDL?.
- %V%l%$%s$H$N%$%s%?%U%’!<%9N?aNDL?.
- %;%s%5%G!<%?<}=8
- %"%/%A%e%(!<%?@)8f
- DL?.$d@)8f$N%?%$%_%s%0$r4IM}9k%?%$%^MxMQ
- %O%s%0%"%C%W;~$N<+F0%j%;%C%H

JI$N%=%U%H%&%’%"$O!$$=$N8e$N%W%m%0%i%`3+H/8zN($r9MN8$9kH!$%i%$%V%i%j2=9k3H$,K>$^$7$$!%

I²C %P%9$NDL?.!$%7%j%"%kDL?.!$ AD JQ49!$%i%8%3%s%5!<%\%b%8%e!<%k@)8f!$%b!<%?6nF0?.9f$N7WB,!$%&%)%C%A%I%C%0%?%$%^JI$N!$ H8/3334Y $N3F5!G=$rMxMQ7?%i%$%V%i%j$r:n@.7?!%%i%$%V%i%j$N>\$7$$2r@b!&;HMQK!$O!$4,Kv$NIUO? A$K7G:\$9k,!$B?$/$N%i%$%V%i%j$O3d$j9~$_$r%Y!<%9K7$F!$I,MW$J:n6H$rJBNs$K9T$(kh$&$K3+H/7?!%

5.4.3 I²C %P%9$rMxMQ$7$??@7P7O$N<BAu

%W%m%;%C%5%b%8%e!<%k$NG[CV

3+H/7?%W%m%;%C%5%b%8%e!<%k$N%\%G%#>e$NG[CV$r Fig.5.12$K<($9!%3F%W%m%;%C%5$O I²C %P%9Kh$j@\B3$5$l!$ Hub Lr$N%W%m%;%C%5$O RS-232C $GL5@~%b%G%`$H$bDL?.$9$k!%%H%k%/7WB,Lr$N%W%m%;%C%5$O!$A4?H$N%H%k%/$r7WB,$7!$8*!&B-<s$KG[CV$5l?%W%m%;%C%5$O!$$=l>$l>eH>?H!&2<H>?H$N%i%8%3%s%5!<%\$N@)8f$H 3 <42CB.EY%;%s%5!&B-DlNO%;%s%5$N=PNO$N AD JQ49$r9T$&!%

BNFb **LAN** $NDL?.%W%m%0%i%`

%i%8%3%s%5!<%\$X$N@)8f%Q%k%9@8@.$O0lDj<~4|$G9T$oJ1lPJi$:!$$^$?@)8f%Q%k%9@8@.Cf$O%Q%k%9I}$N@:EY$r3NJ]9k$?$a$K!$3d$j9~$_$r6X;_$7$F$$$k!%DL?.%i%$%V%i%j$O3d$j9~$_%Y!<%9$G<BAu$7$?$?$a!$%Q%k%9@8@.Cf$ODL?.$r9T$&$3H,G-$J$$!%7?$,$C$F!$J,;6G[CV%W%m%;%C%5$,$=l>lNET9g$N$$$$%?%$%_%s%0$GDL?.$r9T$&3H$,$G$-$kh&$K!$J,;6G[CV%b%8%e!<%k$,>o$K%^%9%?HJ$k7A$G!$BNFb LAN $NDL?.%W%m%0%i%`$r<BAu7?!%

Hub Lr$N%W%m%;%C%5$O!$J,;6G[CV%W%m%;%C%5$+iNMW5a$K1~$8$F!$%9%l!<%VAw?.!&%9%l!<%V<u?.$r9T$&7AK7$?!%$D$^$j!$J,;6G[CV%W%m%;%C%5$+iN%;%s%5%G!<%?OAwilF$-$?bN$r%a%b%j$K3JG<7F$*$-!$%V%l%$%s$+$i$N3QEY;XNa%G!<%?$,0l%U%l!<%`J,

```
_base_handler06: ; NMI
      push    r0
      mov.w   #0x0,r0
      mov.w   r0,@OFFSET
      pop     r0
      jmp     @_common_handler
_common_handler:
      push    r0
        !cN,!d
      push    r6
      mov.w   #_inttab,r0
      mov.w   @OFFSET,r1
      add.w   r1,r0
      mov.w   @r0,r2
      jsr     @r2
      pop     r6
        !cN,!d
      pop     r0
      rte
```

S %U%)!<%^%C%HXNJQ49

:n@.7?<B9T%U%!%$%k$r H8 $N Flash ROM XH=q$-9~$`$?aK01C6 S %U%)!<%^%C%H$KJQ49$9$k!% S %U%)!<%^%C%H$O%b%H%m!<%i$,%G!<%?$N5-O?Ey$K:]7F5,Dj7?%U%)!<%^%C%HG"$j!$A4$F ASCII %3!<%I$G$"$k$?$aMF0W$KFbMF$r8+k3H,G-$k!% S %U%)!<%^%C%H$O 1 9T$, 6 DN%U%#!<%k%I$+$iJj!$$=l>$l ASCII J8;z'S'!$%?%$%W(0-9)!$Bh 3 %U%#!<%k%I$^$G$r=|$/%U%#!<%k%I$r9=@.$9$k%P%$%H?t!$%G!<%?$rG[CV9k%"%I%l%9!$%a%b%j>e$KG[CV9k%G!<%?!$%A%'%C%/%5%`$rI=$9!%

:n@.7?<B9T%U%!%$%k$G$O%3%^%s%I%U%!%$%kK7$?$,CF text NN0h$r ROM!$data,bss NN0h$r RAM $KG[CV$7$?>uBV$G$N<B9T%3!<%I$,:n@.5l$F$$$k$,!$A0=RNh$&$K text,data NN0h$O ROM $K>F$-9~$`I,MW$,$"$k$?$a!$ S %U%)!<%^%C%HGO<B9T%U%!%$%k$+$i text 5Z$S data NN0h$r<h=P$7!$ text NN0h$O 0 HVCO$+$i!$ data NN0hO=$ND>8e$KG[CV9k!%9JoA!$<B9T%3!<%I$H$O0[$J$k%"%I%l%9$K%G!<%?$rG[CV$9k3HKJk$, data NN0h$O%9%?!<%H%"%C%W%k!<%A%sKh$j RAM NN0h$K%3%T!<5lk?$a<B9T$K;Y>cOJ$$!%

<B9T%U%!%$%k$+iN text,data NN0h$N<h=P$7$O%U%!%$%k@hF,K"$k%X%C%@$r2r@O9k3H$G9T$&!%<B9T%U%!%$%k$O COFF 7A<0$H8F$Plk%U%)!<%^%C%HG"$j!$@hF,ItJ,$K%U%!%$%k%X%C%@!$%*%W%7%g%J%k%X%C%@!$%;%/%7%g%s%X%C%@$r;}$C$F$$$k!%3liN$&$A%*%W%7%g%J%k%X%C%@$K3FNN0h$N%5%$%:$d3+;OHVCO$,5-=R$5lF$$$k$?$a3N>pJs$rMQ$$$k3H$G3F%;%/%7%g%s$NCj=P$,$G$-$k!%

5.4.2 %i%$%V%i%j$N3+H/

BNFb LAN $N3F%N!<%I$N%W%m%;%C%5$N%=%U%H%&%'%"$N3+H/$r9T$&K"$?$j!$

%9%?!<%H%"%C%W%k!<%A%s

%9%?!<%H%"%C%W%k!<%A%s$NLr3d$O<!$N 2 DG$"$k!%

- %j%;%C%H8e!$%9%?%C%/%]%$%s%?$r@_Dj$7!$ ROM FbIt$K3JG<$5lF$$$k data NN0h$r RAM NN0h$K%3%T!<$7!$ bss NN0h$r=i4|2=$9$k!%$3lOK\Mh data NN0h$O RAM >e$K$"$kbNG"k,!$EE8;@ZCG;~$K$b>pJs$,<:ol$J$$$h$&$K9k$?$a$K!$ data NN0h$r ROM $K>F$-9~sG$$$k$?$aG"$k!%$3li$N=hM}=*N;8e **main** 4X?t$r8F$S=P$9!%$3lr<B8=9k%"%;%s%V%i%=!<%9$r<!$K<($9!%%9%?%C%/%]%$%s%?KO RAM NN0hCf$G:G8e$N6v?tHVCOG"$k **0xff7e** $r@_Dj$7$F$$$k!%

```
_start:
        mov.w   #0xff7e,sp   ; set sp
        jsr     copy_data
        jsr     clear_bss
        jsr     _main  ;call C main
        jmp     _start
```

- C 8@8l$G3d$j9~$_%k!<%A%s$r:n@.7?>l9g!$%l%8%9%?$NBTHrEy$,9T$olJ$$$?aK!$%l%8%9%?$NBTHr!$I|5l$r9T$&!%$3lO6qBNE*KO (1) 3d$j9~$_%Y%/%?$NNN0h$K$O%"%;%s%V%i$N3d$j9~$_%O%s%I%i$r@_Dj$7!$ C 8@8lGN3d$j9~$_%O%s%I%iXN%]%$%s%?$rG[NsH7$FJ];}$7F*$/!% (2) 3d$j9~$_H/@8;~$KO^$:%"%;%s%V%i$N3d$j9~$_%O%s%I%i$,%l%8%9%? (R0-R6) $NBTHr$r9T$$!$3d$j9~$_%Y%/%?$KBP1~9k C 8@8lGN3d$j9~$_%O%s%I%i$r8F$S=P$7!$4X?t$+$i$NI|5"8e$KBTHr7?%l%8%9%?$rI|5l$9kH$$$&<j=g$G<B8=$5lk!%$?$@$7!$$I$N3d$j9~$_$,5/CF$$$k$+$rCNk3HOG-$J$$$?$a!$3d$j9~$_%O%s%I%iFb$K3d$j9~$_HV9f$r=q$-9~$$'I,MW$,$"$k!%$3lr<B8=9k%"%;%s%V%i%=!<%9$r<!$K<($9!%_inttab $, C 8@8l$G$N3d$j9~$_%O%s%I%i$NG[Ns!$ **OFFSET** $,3d$j9~$_%Y%/%?$rCNk?aN3d$j9~$_HV9f$r3JG<$9$kJQ?t$G$"$j!$$3NNcG$O 0 $r@_Dj$7$F$$$k!%

```
../../binutils-2.6/configure \
        --target=h8300-hitachi-hms \
        --host=sparc-sun-solaris2.4 \
        --program-suffix=h8300 \
        --src=../../binutils-2.6
```

binutils $r make $7!$%$%s%9%H!<%k8e!$ gcc $K4X$7FbF1MM$K configure %9%/%j%W
%H$rMQ$$$F@_Dj$r9T$$!$%3%s%Q%$%i$N:n@.$r9T$&!%DL>o$N%M%$%F%#%V%3%s%Q%$%i$r:n@.
9k:]KO:n@.7?%3%s%Q%$%i$rMQ$$$F%3%s%Q%$%i$r:n$jD>$9$H$$$&3H$r9T$&$,!$%/
%m%9%3%s%Q%$%i$r:n@.9k:]KO 1 2sN_:n@.$r9T$&!%DL>o%/%m%9%3%s%Q%$%i$r:n$k:]
KO C %i%$%V%i%j$r:nk?aK%?!<%2%C%H$N OS MQ$N%$%s%/%k!<%I%U%!%$%k$,I,MW$G
$"$k$,!$$3$3$GO=lKAjEv9kbN$,$J$$$N$G!$**inhibit_libc** $rDj5A$9k3HG
LdBj$r2sHr$7$F$$$k!%

:G8eK3li$N%D!<%k$rMQ$$$F<B9T%U%!%$%k$r:n@.9k$?$a$K%j%s%+$KM?$($k%3%^
%s%I%U%!%$%k$r:n@.9k!%3l$O%j%s%+$K%?!<%2%C%H$N%a%b%jG[CV$dIN%;%/%7%g%s
rI3KG[CV9k$+$H$$$C$?>pJs$rCNi;k?aN%U%!%$%k$G$"$j!$NN0h$,$"$UlF
$$$J$$$+I&$+$JIr%A%'%C%/9k$?$aKbMQ$$$ilk!% H8/300 $O 3 DNF0:n%b!<%I
!JFbB" ROM L58z3HD%%b!<%I!$FbB" ROM M-8z3HD%%b!<%I!$%7%s%0%k%A%C%W%b!<%I!K
$r;}$C$F$$$k$,$3$3$G$O%7%s%0%k%A%C%W%b!<%I$G$N1?MQ$rA0DsH7$F$$$k$?$a$K<!$N$h
$&$J%3%^%s%I%U%!%$%k$r:n@.7?!%3lKh$j!$ text NN0h$O ROM $K data,bss NN0h$O
RAM K*$+$l$?>uBV$G$N<B9T%3!<%I$,=PNO5l$k!%

```
__DYNAMIC  =  0;
SECTIONS
{
  .text 0x0000:
  {
    CREATE_OBJECT_SYMBOLS
    *(.text)
    _etext = ALIGN(0x2);
  }>rom
  .data  0xFB80:
  {
    *(.data)
    CONSTRUCTORS
    _edata  =  ALIGN(0x2);
  }>ram
  .bss SIZEOF(.data) + ADDR(.data) :
  {
      __bss_start = .;
   *(.bss)
   *(COMMON)
   _end = . ;
   __end = . ;
  }>ram
}
MEMORY
{
    rom : ORIGIN = 0,      LENGTH = 32K
    ram : ORIGIN = 0xFB80, LENGTH =  1K
}
```

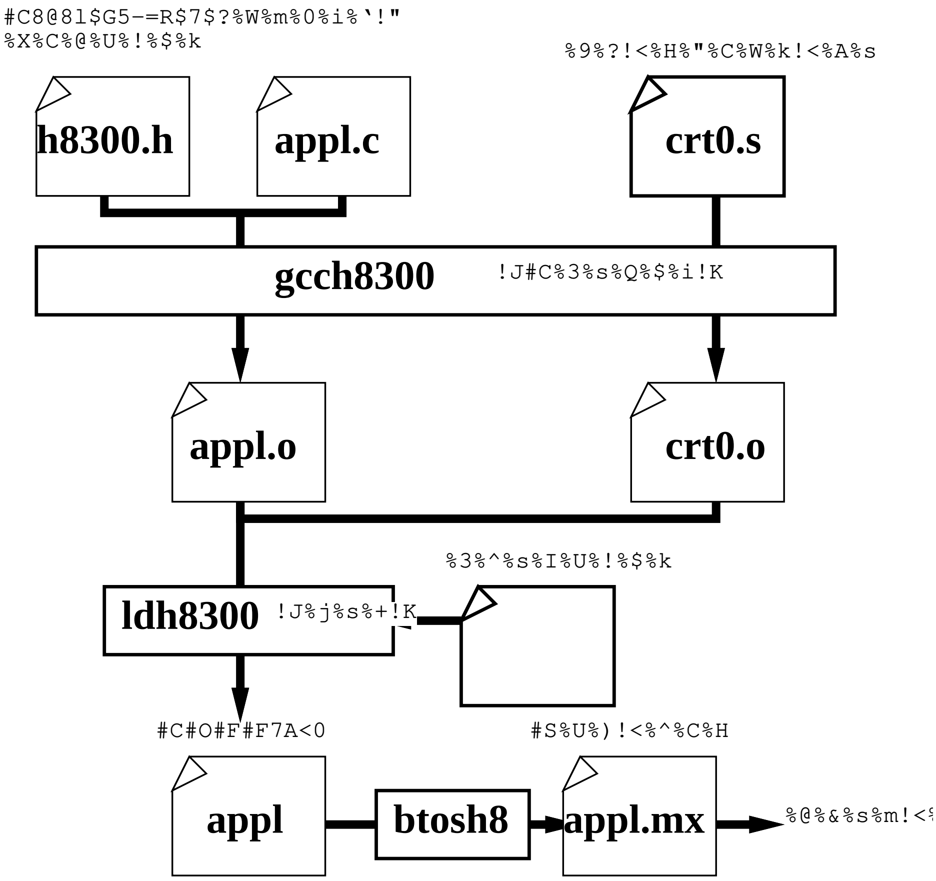


Fig. 5.11 %*%s%\%G%#%W%m%;%C%5$N%=%U%H%&%'%"3+H/$NN.$l
The development of the software of onbody processor

5.4 %*%s%\%G%#%W%m%;%C%5$N%=%U%H%&%'%"3+H/

K\@aGO!AH_9~$_MQ%W%m%;%C%5>e$N%=%U%H%&%'%"KD$$$F=RYk!%

5.4.1 %*%s%\%G%#%=%U%H%&%'%"3+H/4D6-

AH$_9~$_MQ%W%m%;%C%5$O!$ RAM(1[KByte]), %U%i%C%7%e ROM(32[KByte]) $H$$$& %a%b%j9=@.JN$G!$%=%U%H%&%'%"$O%U%i%C%7%e ROM KCV/3HKJ$j!$$=$N%W%m%0 %i%`$O%o!<%/%9%F!<%7%g%s>eJI$G%/%m%93+H/$G$-$k3H$,5a$ail$k!%

K\@aGO%m%\%C%H$N%\%G%#$KAH$_9~$`%o%s%A%C%W%W%m%;%C%5 H8/300 %7%j!<%:$N%= %U%H%&%'%"4D6-$r Sun Sparc Station >e$K GNU $N%D!<%k$rMQ$$$F9=C[9kJ}K!$r<($9!%J*!$K\4D6-$r9=C[$9kK$"$?$j!$ [47] $*$h$S [48] $r;29M$K7?!%

%=%U%H%&%'%"4D6-35MW

H8 MQ$N%=%U%H%&%'%"3+H/$N35MW$r Fig.5.11$K<($9!%
3N3+H/4D6-$N9=C[$N<j=g$O<!$Nh&KJ$k!%

1. %3%s%Q%$%i!$%"%;%s%V%i!$%j%s%+Ey$N:n@.
2. ROM $+$i$N<B9T$H!$ C 8@8l$+$i3d$j9~$_$r07$(kh$&$K9k$?$a$N%9%?!<%H %"%C%W%k!<%A%s$N:n@.!%
3. <B9T%U%!%$%k$r H8 $N Flush ROM $X>F$-9~$`:]$K%@%&%s%m!<%I9k$?$a$N S %U%)!<%^%C%H$X$NJQ49%D!<%k$N:n@.!%

%3%s%Q%$%iEy$N%D!<%k$N:n@.

%o!<%/%9%F!<%7%g%s>eGN%/%m%93+H/$r9T$&$?$a$K!$%"%;%s%V%i!$%3%s%Q%$%i!$ %j%s%+Ey$r GNU $N%D!<%k$rMQ$$$F:n@.9k!%;HMQ9kNO gcc,binutils $N 2 DN%Q%C %1!<%8$G gcc $O C %3%s%Q%$%i!$ binutils $O%"%;%s%V%i!$%j%s%+!$%"!<%+%$%PEy$N3+H/ KI,MWJ%D!<%k$r4^sG$$$k!%8=;~E@GN$=$l$>$l$N:G?7%P!<%8%g%s$O 2.7.2 5Z$S 2.7 G"$j!$9qFb$N$$$/D+$N GNU $N%_%i!<%5%$%H$+$i$bF~<j$9k3H,G-$k!%

C %3%s%Q%$%i$r:nk?aK$O%"%;%s%V%iEy$,I,MWKJkN$G!$ binutils r^$::G=i $K:n@.$9$k!% binutils $N:n@.$O$^$::G=i$KB?$/$N GNU $N%D!<%k$HF1$8$/ configure $H $$$&%7%'%k%9%/%j%W%H$rMQ$$$F:n@.4D6-$N@_Dj$r9T$&!%$3$3$G$O%D!<%k$r<B:]$KF0$+$9 %^%7%s!J%[%9%H!K$N OS $, Solaris2.4!$$G$-$?<B9T%U%!%$%k$r<B:]$KF0$+$9BP>]!J%?!< %2%C%H!K$, h8300 G"kN$G!$0J2<Nh$&$K7F configure $r<B9T$9$k!%

J,;6%N!<%IMQ%W%m%;%C%5%b%8%e!<%k **H8–02**

H8–02 $O!$%m%\%C%H$N%\%G%#>e$NMM!9$JItJ,$KMF0W$K<h$jIU1F;HMQ2DG=Jh$&$K!$%5%$%:!&5!G=!&9=B$$r8!F$$7$?7k2L!$ Fig.5.9Nh$&$J7A>uH7$?!% H8 $N%A%C%W0J30$NItIJ$O6KNOGS=|$7!$>.7?2=$N%]%$%s%H$HJk%3%M%/%?KD$$$F$O!$<BAu>e$NMxJX$r9MN8$7$FI8=`E*$J 2.54mm %T%C%A$r;HMQ7?!%

3N4pHD$OItIJLL$r2<K7$F;HMQ$7!$%3%M%/%?$r%Y!<%9K7$F%\%G%#$X<hjIU1ilkh$&$K9MN8$5$l$F$$$k!%$^$?!$4pHD$K%3%M%/%?$r<h$jIU1?:]$N9b$5$rM^$($F!$$+$D>l=j$r<hiJ$$$h$&$K!$%T%s$r4pHDLLKBP7$F?eJ?$K=P$7!$4pHD$NJ%$+$iCf1{$X8~$+$&J}8~$K@_CV$7$F$$$k!%3Nh&$J9=B$$K9k$H!$2sO)$r4pHD$G%+%P!<G-kHF1;~$K!$%3%M%/%?<+BN$b4pHDA4BN$rJ$$&h&KJ$j!$<h$j07$$$NMF0W5H0BA4@-$rN>N)$5$;$k3H$,$G$-$k (Fig.5.10)!%

$^$?!$%3%M%/%?$N%T%s$K@\B3$9$k%]!<%H$NA*$SJ}$r9)IW$7!$8Bil$?%T%s?t$G%G%8%?%kF~=PNO!$%"%J%m%0F~=PNO!$ PWM ?.9f=PNO!$$H$$$C$?B?MM$JMxMQL\E*$KBP1~$7$F$$$k!%

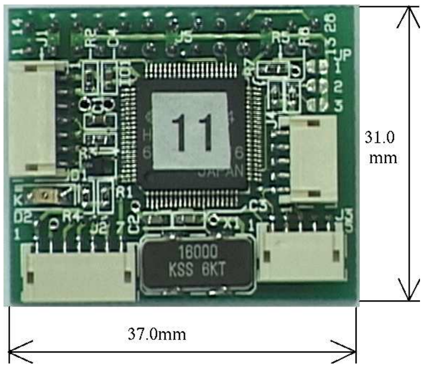


Fig. 5.9 H8–02 $N304Q
The external appearance of H8–02

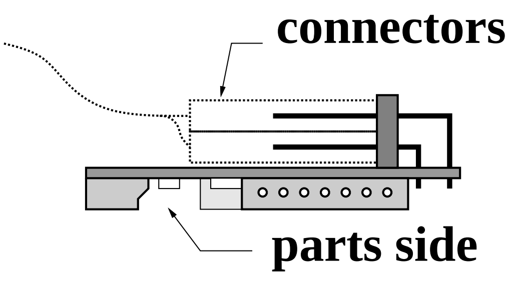


Fig. 5.10 %3%s%Q%/%H$J H8–02 (B&LL)
Miniaturization of H8–02 (side view)

Table 5.1 H8–01 $N 3 DN%W%m%;%C%5$N5!G=J,C4
The roles of each three processors on H8–01

H8 (A)	%"%/%A%e%(!<%?@)8f A/D JQ49
H8 (B)	%Q%k%9?.9f<u?. RS-232C DL?.
H8 (C)	%9!<%Q!<%$%s%]!<%: A/D JQ49 %^%H%j%/%92sO)@)8f RS-232C DL?.

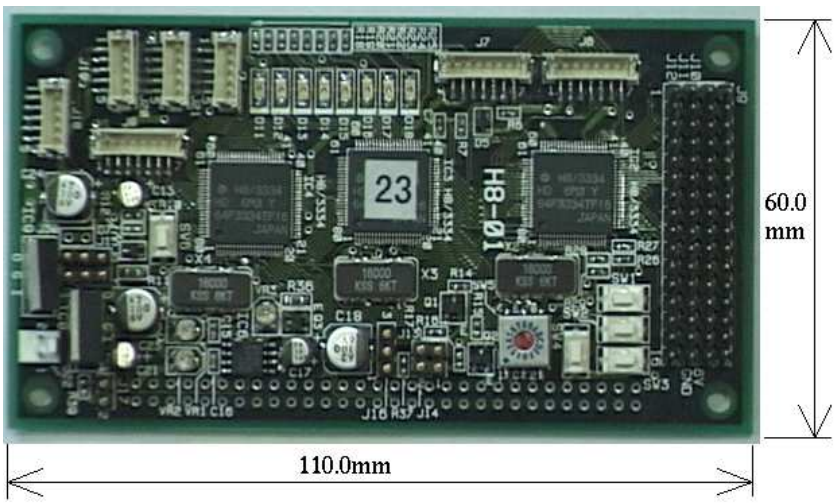


Fig. 5.8 H8–01 $N304Q
The external appearance of H8–01

3liN4pHDF1;N$NDL?.$N$?$a$K I2C %P%9$%$s%?%U%'!<%9$r;HMQ9k (Bh 5.2@a)!%
$^$?!$$3N?aNDL?.%P%9%3%M%/%?$O 1 Kg$N4pHD$KJ#?tG[CV$7!$<BAu$9$k%m%\%C%H$N 7A>uK"o;$F<+M3$JJ*M}E*7A>u$NG[@~$,2DG=H7$?!%$J$*!$%=%U%H%&%'%"3+H/$O WS >e$N GCC Kh$k%/%m%93+H/4D6-$rMxMQ$7!$4pHD>e$N%@%&%s%m!<%I!&%3%M%/%?$rDL7F %A%C%WFb$K%W%m%0%i%`$r=q$-9~$`$3H,G-kh$&$K7?!%

%V%l%$%s!&%$%s%?%U%'!<%9MQCf3K%W%m%;%C%5%b%8%e!<%k **H8–01**

H8–01 KO!$ 3 8D$N H8 %W%m%;%C%5 A, B, C !$5Z$S3F<o<~JU%$%s%?%U%'!<%9 2sO)$rEk:\$7$?!%3F%W%m%;%C%5$N=hM}FbMF$d%=%U%H%&%'%"9=@.$r9MN8$7!$ Fig.5.7!$ Table.5.1$K<($9h&$J5!G=9=@.$H7F$$$k!%

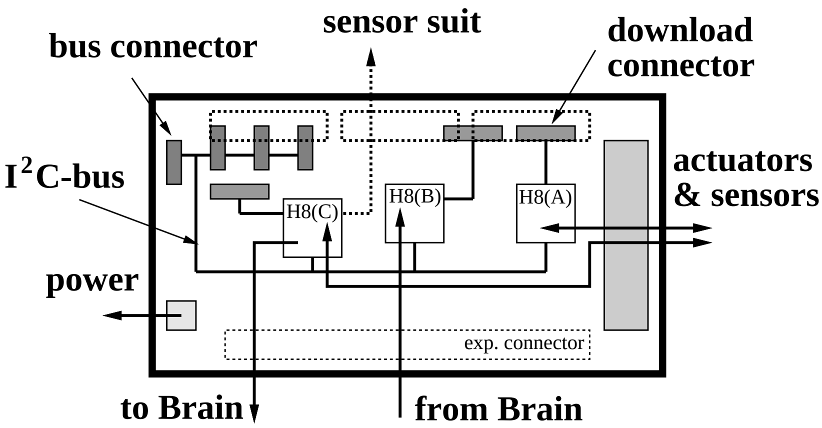


Fig. 5.7 H8–01 $N5!G=9=@.
Functional arrangement of H8–01

3F5!G=$O!$;n:n%b%8%e!<%kK*$$$F%F%9%H7?bNG"k,!$ H8–01 $KFCM-$N5!G=!&FCD'$r0J2<$K@bL@9k!%

- %^%H%j%/%92sO)@)8f
  H8–01 $O%;%s%5!&%9!<%D [45] rCe?%m%\%C%H igoid[46] KbEk:\$9k3Hr9MN8 7F@_7W7?!%%;%s%5!&%9!<%D$N?.9f$r=hM}9k$?$a$K!$%@%$%*!<%I$r;HC?0l HLE*$J%^%H%j%/%92sO)$K$=$N$^$^@\B3$7$F;HMQ2DG=$J%3%M%/%?$r@_CV7?!%%^%H %j%/%92sO)$N@)8f$O H8 FbB"$N5!G=$rMxMQ7FMF0W$K<B8=$G$-$k!%
- %3%M%/%?!&%9%$%C%A!& **LED** $NEk:\
  1 Kg$N H8–01 $K$$$/Db$N H8–02 $r@\B3$9kH$$$C$?MQES$r9MN8$7!$DL?.MQ%P %9N?aN%3%M%/%?$r 4 8D@_CV$7$?!%$^$?!$;HMQ9k:]$NMxJX$N$?$a$NHFMQ$N%9 %$%C%A$d LED $NB>!$4pHD>e$KEk:\$7$? H8 $r%f!<%6$,<+M3<+:_$JL\E*$K;HMQ$G $-$kh&$K!$HFMQ$N%3%M%/%?$r@_CVG-kh$&$J@_7WKJCF$$$k!%

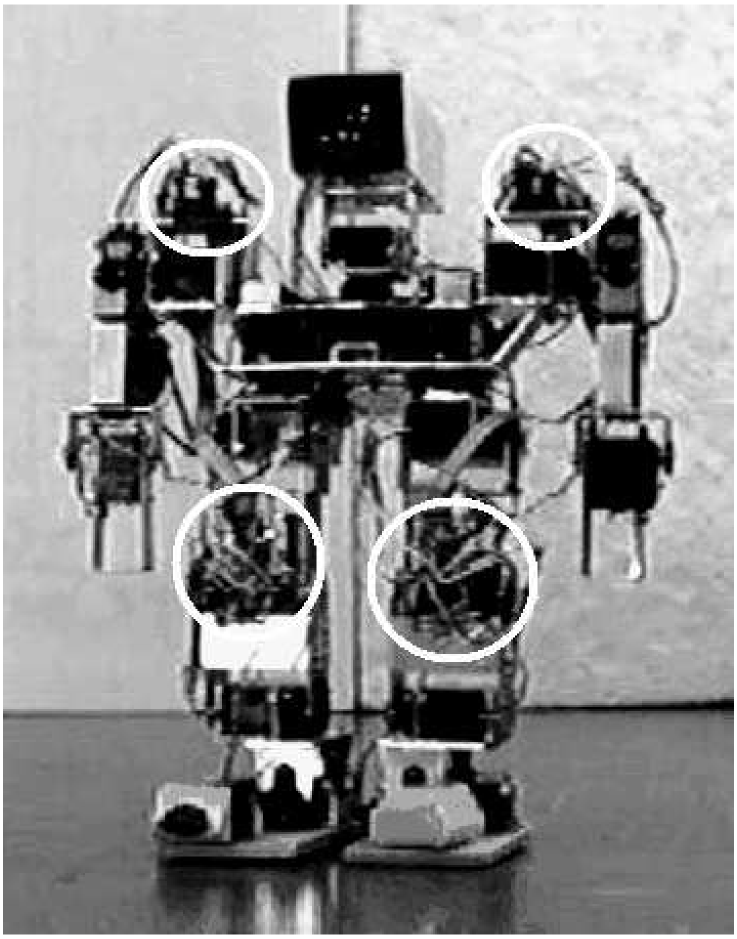


Fig. 5.6 ;n:n%b%8%e!<%k$rI(!&8*$KEk:\$7$??M4V7?%m%\%C%H "Haru" Humanoid robot "Haru" with trail modules on its shoulders and knees

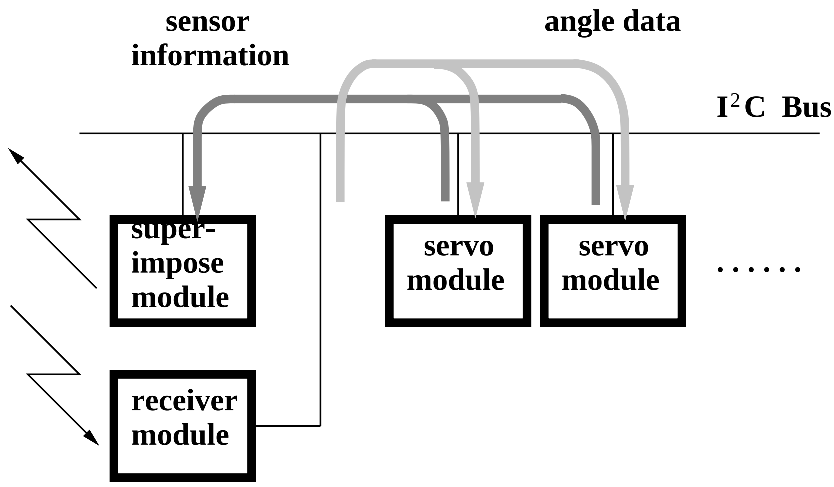


Fig. 5.4 ;n:n%b%8%e!<%kKh$kBNFb LAN $N9=@.
First version of onbody LAN using trail processor modules

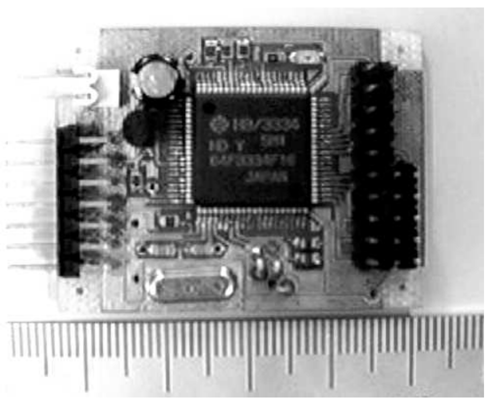


Fig. 5.5 %i%8%3%s%5!<%\@)8f!u%]%F%s%7%g%a!<%?FI$_9~$_MQ
An example of trail modules

CM$rF@$k3H$,$G$-!$4J0W%H%k%/%;%s%5H7$FMxMQ$G$-$k!%K\O@J8$G3+H/$7$?%m%\%C%H$N%"%/%A%e%(!<%?H7$F:NMQ$7$?!$%i%8%3%s%5!<%\%b%8%e!<%k (5.6.2@a) $N>l9g!$%b!<%?6nF0EE05$O 50[Hz] $N PWM =PNO$KJCF*$j!$FbIt4pHD$N%b!<%?6nF0EE05?.9f$N%i%$%s$r0z$-=P$7%Q%k%9I}rFI_Hj!$$3NCMrMQ$$$F%H%k%/%;%s%5$NBeMQ$H7F$$$k (>\$7$/$O 5.6.3@a;2>H)!%

3N;n:n%b%8%e!<%kGO!$$3$N?.9f$rFI$_$H$j!$[2]C=$PL9$IDL7FAw?.9k!%

%7%j%"%kDL?.!u **AD** JQ49MQ

3N;n:n%b%8%e!<%k$O!$%V%l%$%s$H$N%$%s%?%U%'!<%9$KL5@~%b%G%`$rMxMQ7?%7%j%"%kDL?.$rA[Dj$7!$[2]C=$PL9$NDL?.$@1GJ/D4JbF14|<0%7%j%"%kDL?.$bF1;~$K9T$&$H$$$&bNG"$k!%D4JbF14|<0%7%j%"%kDL?.$O!$%7%j%"%k%]!<%H$r2p$7$F%o!<%/%9%F!<%7%g%s>e$N%V%l%$%s$N%=%U%H%&%'%"$HDL?.$r9T$&$3HrA[Dj7F$$$k!%$=$3$G!$ H8 $N=PNO%l%Y%kEE05$r RS-232C %l%Y%k$KJQ49$9k?aN%A%C%W$rEk:\$7$?!%%V%l%$%sHN%$%s%?%U%'!<%9MQ$G$"$CFb!$DL?.$N6u$-;~4V$K I/O $d AD $r<h$j9~$`I,MW$b9M$(!$ AD JQ49F~NO%T%s (%G%8%?%kF~NO%T%sH7FbMxMQ2D)8 %A%c%s%M%k$K%3%M%/%?$rD1$?!%

5.3.3 ;n:n%b%8%e!<%k$N?M4V7?%m%\%C%H$X$NEk:\

3liN;n:n%b%8%e!<%k$rMQ$$$F!$?M4V7?%m%\%C%H "Haru" $N=i4|HG$K$*$$$F!$BNFb LAN $r;n:n$7$? (Fig.5.4)!%;n:n%b%8%e!<%k$N01Nc$r Fig.5.5$K!$$3li$rEk:\$7$?=i4|HG$N "Haru" $N<L??$r Fig.5.6$K<($9!%;n:n%b%8%e!<%k$O!$%i%8%3%s%5!<%\@)8f!u%]%F%s%7%g%a!<%?FI$_9~$_MQ$,!$N>I($*$h$SN>8*$K<hjIU1il$F$$$k!%

5.3.4 HFMQ%W%m%;%C%5%b%8%e!<%k **"H8–01"** !$ **"H8–02"** $N@_7W!&@=:n

A0@a (5.3.2@a) $K=R$Y$?;n:n%b%8%e!<%k$*hS!$$=lKhkBNFb LAN $N;n:n$r;29M$K!$%W%m%;%C%5J,;6G[CVN?aN9=B$$N:F8!F$$r9T$$!$$5iK>.7?2=!$9b5!G=2=$7$?BNFb LAN $r9=C[2DG=$J%W%m%;%C%5%b%8%e!<%k H8–01, H8–02 $r@_7W$7$?!%

H8–01 $O!$2DG=$J8B$j>/$J$$%9%Z!<%9$K!$%V%l%$%sB&$H$NDL?.%$%s%?%U%'!<%9$r<g$H7?%m%\%C%HKI,MWJ5!G=N[HsIr=8@Q5;k3HrL\I8$K@_7W$7!$BNFb LAN $NCf3K$HJk5!G=%b%8%e!<%kG"$k!%01J}!$ H8–02 $O%"%/%A%e%(!<%?@)8f$d%;%s%5>pJs<hF@N?$a!$%\%G%#>e$K$$$/DbJ,;6$5$;$F;HMQ$9k3HrG0F,KCV-!$%3%s%Q%/%H$J%5%$%:$G%3%M%/%?$NG[CV$JI,<BAu>eLdBjKJiJ$$$h$&$J7A>uK7$F!$%\%G%#>eN"if$k2U=j$KMF0W$K<h$jIU1ilkh&$K@_7W$7$?!%

%Q%k%9@8@.4|4V$r=|$$$?;~4V$rMxMQ$7$F!$ AD JQ49$H!$3QEY;XNaCM$N<u?.!&%]%F %s%7%g%a!<%?$N AD CM$NAw?.$r9T$&!%Aw<u? 2C G9$rMQ$$$?DL?.G"$k!%

%i%8%3%sMQL5@~%Q%k%92r@OMQ

%i%8%3%s%5!<%\%b%8%e!<%k$OK\Mh!$%i%8%3%sA‘=D4o (%W%m%]$H8F$Plk) NCfG!$ Aw?.4o$K Pulse Position Modulation (PPM) Kh$k Fig.5.3$Nh&$JGH7A$,F~NO 5l$k!%3F%Q%k%9$NN)$A>e$,$j%(%C%8$N4V3V ($t1$!A $t8$) $,L\I83QEY$KBP1~9k!%

%i%8%3%s%5!<%\MQ$NAw?.4o$K PPM Kh$jA4<+M3EYJ,$NL\I8CM$rF~NO$7!$3F%Q%k %9$NN)$A>e$,$j%(%C%8$N4V3V t(L\I83QEY$KBP1~) $r7WB,$9kH$$$&7ABV$GL5@~DL ?.$r9TC?!%3F t $O 0.4 !A 2.2[msec] DxEY$@$,!$ 22 <+M3EYJ,GO 20[msec] $K<} $^$i$:!$<~4|$O 50[msec] H7$?!%

3N;n:n%b%8%e!<%k$O!$%i%8%3%s%5!<%\MQ<u?.4o$N?.9f@~$+$i%Q%k%9$r7WB,$7!$ $=$NCM$r3F%5!<%\@)8fMQ4pHD$KI2C%9rDL7$FAw?.$9$k!%

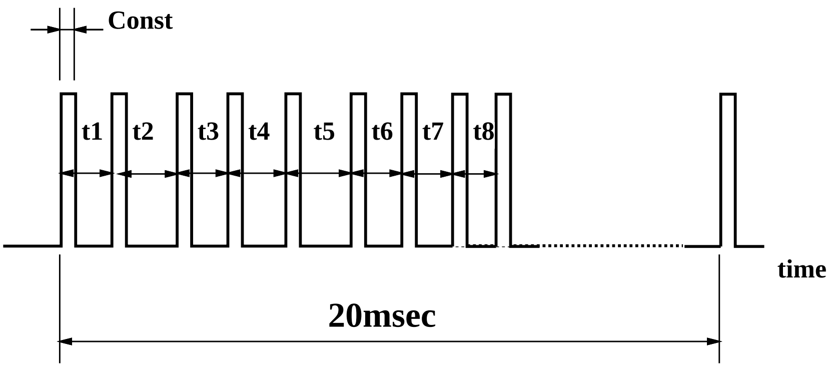


Fig. 5.3 %i%8%3%s%5!<%\MQL5@~GH7A
Pulse position modulation

%9!<%Q!<%$%s%]!<%:MQ

3N;n:n%b%8%e!<%k$O!$%\%G%#$+$i%V%l%$%s$X3F%;%s%5>pJs$rAw?.$9k?aN%b %8%e!<%kG"$k!%%;%s%5>pJs$N%\%G%#$+$i%V%l%$%s$X$N%G!<%?$NAw?.$O!$%"%J%m %01GA|?.9fXN=E>v (%9!<%Q!<%$%s%]!<%:)[44] KhCF9TCF$$$?!%

%m%\%C%HNF,ItK$O%+%a%i$,AuCe5lF*$j!$$3$N1GA|$rL5@~$G%V%l%$%s$XAw ?.$7$F2hA|=hM}$r9TJC$F$$$k$,!$$3$N1GA|$N0lItJ,$K%;%s%5>pJs$r%9!<%Q%$%s %]!<%:$7$FAw?.$9$k!%$3N?$a!$%V%l%$%s$X$N%G!<%?Aw?.<~4|$O NTSC 5,3J$K hj 33ms HJ$k!%

%b!<%?6nF0?.9f7WB,MQ

4X@a6nF0MQ%b!<%?$N6nF0?.9f$r7WB,9k3HKh$j!$=PNO%H%k%/H[$\Ey2A$N

;n:n7?%W%m%;%C%5%b%8%e!<%k$O!$ CPU $r=i$aH9$kBgItJ,$NItIJ$r4pHD>e$K I=LL<BAu$7!$%b%8%e!<%k$N>.7?2=$r?^C?!% H8/3334YF-ZTAT $O 80 %T%s QFP %Q%C %1!<%8 (17.2mm×17.2mm) $r;HMQ$7$?!%I=LL<BAu4pHD$O8&5f<<%l%Y%k$N4D6-$G$b==J, $K@=:n2DG=$G$"$j!$K\O@J8$G$O4pHD@=:n$r!$

1. CAD Kh$kN>LL4pHD%Q%?!<%s@_7W
2. N>LL4pHD$N@Z:o2C9)
3. %/%j!<%`Os$@EII[
4. ItIJ<BAu
5. %[%C%H%W%l!<%HKh$k2CG.

$H$$$&9)Dx$G9T$JC?!%

;n:n7?%W%m%;%C%5%b%8%e!<%k$r0J2<$K5s$2!$3F;n:n%b%8%e!<%k$H;n:n%b%8%e!<%k $rEk:\$7$?%m%\%C%H$K$D$$$F@bL@9k!%

%i%8%3%s%5!<%\@)8f!u%]%F%s%7%g%a!<%?FI$_9~$_MQ

3F4X@a$N%"%/%A%e%(!<%?$H7F;Hol$F$$$k%i%8%3%s%5!<%\%b%8%e!<%kXN3QEY ;XNaCM$O!$ Fig.5.2 $K<($9h&$J%Q%k%9I} $t1$ $GM?$($k!%$^$?!$%b!<%?=PNO<43QEY NFI_<hjO!$%i%8%3%s%5!<%\%b%8%e!<%kFb$N4pHD$+$i%]%F%s%7%g%a!<%?$N?.9f @~$r0z$-=P$7!$$=lr AD JQ494oKDL7$F9T$J$&!%

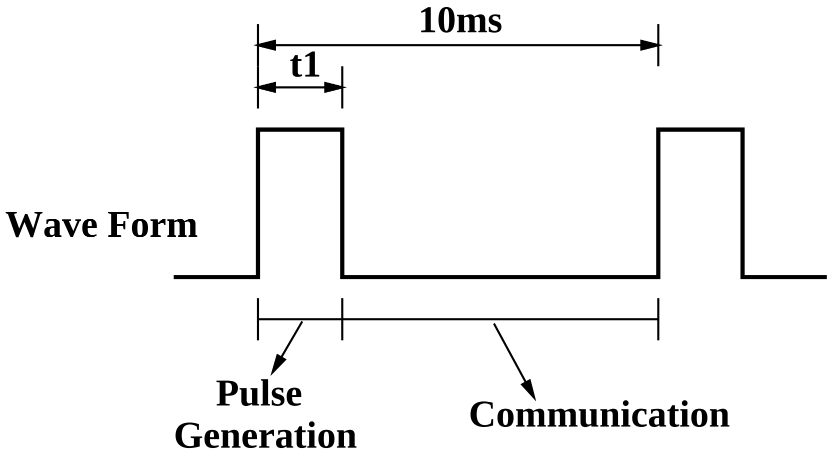


Fig. 5.2 %5!<%\%b!<%?$XM?$($k%Q%k%9GH7A
The pulse given to RC servo modules

3N;n:n%b%8%e!<%kGO!$ 5 %A%c%s%M%k$N%i%8%3%s%5!<%\@)8f$H!$ 5 %A%c%s%M%k $N AD JQ49$r9T$&$3H,G-$k!%

5.3 BNFbAH$_9~$_MQ%W%m%;%C%5%b%8%e!<%k$N3+H/

5.1.3@a$G5s$2$?>.7?!&7ZNL!&Dc>CHqEENO$H$$$C$?>r7o$rK~$?$9!$BNFbAH$_9~$_MQ%W%m%;%C%5%b%8%e!<%k$r3+H/7?!%K\@aGO!$%W%m%;%C%5$NA*Dj!$%W%m%;%C%5%b%8%e!<%k$N;n:n$*$h$S;n:n$7$?%b%8%e!<%k$N%m%\%C%HXNEk:\!$$=7FHFMQ%W%m%;%C%5%b%8%e!<%k “H8-01”!& “H8-02” $N@_7W!&@=:n$H%m%\%C%HXNEk:\$K$D$$$F@bL@9k!%

5.3.1 %W%m%;%C%5$NA*Dj

%W%m%;%C%5%b%8%e!<%k$K;HMQ$9$k CPU $N8uJd$H7F!$ Microchip <R$N PIC!$F|N)!$ NEC!$IY;NDL!$;0I)$N%o%s%A%C%W%^%$%/%m%3%s%H%m!<%i$+$i0J2<$NJ}?K$GA*s@!%

1. Bh 5.2@a$G=R$Y$? I^{2}C %P%9$N%$%s%?%U%'!<%9$rHw$($k!%
2. ROM FbB"G"$j!$ One-Chip $GF0:n2DG=
3. 8=>lGN ROM =q$-9~$_$,$G$-!$<j:nj,2DG=
4. %;%s%5>pJsFI$_9~$_N?aN!$ I/O $d AD JQ49$JIrHw$($k!%
5. C 8@8l$r;H$C$FC;4|3+H/$,G-$k

K\O@J8$G:NMQ$7$?F|N)$N H8 %7%j!<%:$O!$0J>e$N>r7o$rK~$?$9%W%m%;%C%5G"$k!%

@=:n7?3F%W%m%;%C%5%b%8%e!<%k$O!$F|N)$N H8 %7%j!<%:$r3KK7$F9=@.$5lF$$$k!% H8 %7%j!<%:$O H8/300 CPU $r3K$K7?%7%s%0%k%A%C%W%^%$%/%m%3%s%T%e!<%?$G$"$j!$K\O@J8$GO3NCf+$i!$:G9bF0:n<~GH?t 16MHz!$K-IY$J<~JU5!G=FbB" (ROM 32KB, RAM 1KB, 4 <oN`$N%?%$%^, %7%j%"%k%]!<%H, 10bit A/D JQ494o, 8bit D/A JQ494o, %[%9%H%$%s%?%U%'!<%9, :GBg 66 K\$N I/O %]!<%H, etc.)!$%U%i%C%7%e%a%b%j$rEk:\$7!$%*%s%\!<%I$G$N%W%m%0%i%`=q49$($,2DG=!$ Philips <R$N I^{2}C %P%9$N%$%s%?%U%'!<%9FbB"!$$H$$$C$?FCD'$r;}$D H8/3334YF-ZTAT $r;HMQ$7$?!%

K-IY$J<~JU5!G=$KhjI,MW$JIU2C2sO)$Oo:$+$G$"$j!$%m%\%C%H%\%G%#$XNAH_9~$_$,2DG=$J>.7?2=$5l?%b%8%e!<%k$r@=:n$9k3H,2DG=HJkHF1;~$K!$%b%8%e!<%k3+H/$,MF0W$KJC$?!%$^$?%U%i%C%7%e%a%b%jEk:\$Khj!$%m%\%C%H%\%G%#>e$K%W%m%;%C%5%b%8%e!<%krAH_9~s@$^$^$N>uBV$G3F%b%8%e!<%k$N%W%m%0%i%`$,99?7$G$-$k$?$a!$8zN(E*$J%W%m%0%i%`3+H/:n6H$,2DG=G"$k!%

5.3.2 %W%m%;%C%5%b%8%e!<%k$N;n:n

%b%8%e!<%k$N;EMM$JIr7hDj9k$?$a$K!$$^$:%W%m%;%C%5%b%8%e!<%k$r?t<oN`;n:n7?!%

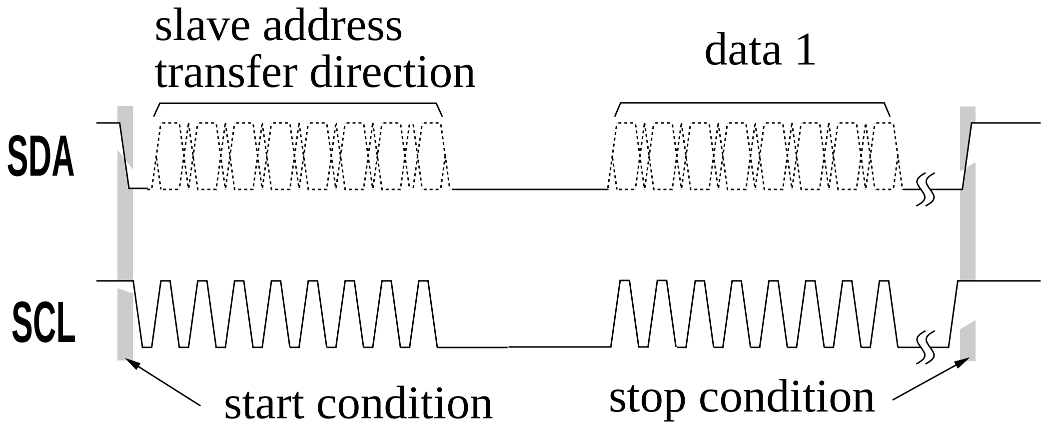


Fig. 5.1 I^{2}C %P%9$NF0:n%?%$%_%s%0
Data transfer on I^{2}C-bus lines

3+;O>r7o SCL $, HIGH $N>uBV$G SDA $r HIGH $+$i LOW K9$k!%$3$NJQ2=$r8!=P
9k$H%P%9%S%8!<$HJk!%

=*N;>r7o SCL $, HIGH $N>uBV$G SDA $r LOW $+$i HIGH K9$k!%$3$NJQ2=$r8!=P
9k$H%P%9$O2rJ|5l$k!%

3+;O>r7o$r8!=P$9kH%P%9%S%8!<H_J5$l!$=*N;>r7o$r8!=P$9kH%P%9$O2rJ|
5l$?$H$_$J5l$k!%%G!<%?E>AwCf$N SDA $N>uBV$NJQ99$O SCL $, LOW $N;~$K9T$o
$l!$ SCL $, HIGH $N;~$K SDA $N>uBV$,JQ2=9k$H3+;O>r7o$+=*N;>r7oKJ$k!%

#12s$N%G!<%?E>Aw$O3+;O>r7o$+$i=*N;>r7o$^$G$G5,Dj$5$l!$ 8bit $rC10L$K9Tol$k
(Fig.5.1)!%%^%9%?$O!$3+;O>r7oAw=P8e:G=i$N 8bit $G!$%9%l!<%V%"%I%l%9$N;XDj$H%G!<
%?$NE>AwJ}8~$N;XDj$r9T$$!$0J8e=*N;>r7o$^GO!$ 8bit $rC10L$KG$0U$NNL$N%G!<%?$,
E>Aw5l$k!%

5.2.2 B?%G%P%$%9@\B32DG=

I8=`$G 128 $N%G%P%$%9$r@\B3$9k3H,G-!$$5iK ID $N3HD%$r9T$($PL5@)8B$N %G%P%$%9$r@\B3$9k3H,G-$k!%$3lO!$BNFb LAN $N%N!<%I$N?tH7FO=<J,$J %-%c%Q%7%F%#$H8@$($k!%

$^$?!$@\B3$G$-$k%G%P%$%9$N<oN$b I^{2}C$H9%$%s%?%U%'!<%9$r;}$D%W%m%;%C%5$d PC N_Ji$:!$ AD JQ494o$H^{2}C $H9%l!<%VAw?.5!G=$@1r;}$D%A%C%W$JINbGdi$l F*$j!$MM!9$J%G%P%$%9$rF10l$N%P%9$K@\B32DG=G"$k!%

5.2.3 wired-AND connection

%/%m%C%/%i%$%s SCL $H!$%G!<%?%i%$%s SDA $O!$$=l>$l%W%k%"%C%W$5$l!$ wired-AND connection $r7A@.$9$k!%%P%9$K@\B3$5$l$?J#?t$N%G%P%$%9$,F1;~$K?.9f$r%P%9$K =PNO$7$?;~!$$=$NFb0l$DGb LOW $r=PNO$7$F$$$k$H%P%9$N>uBV$O LOW KJ$k!%$3 lKhj!$0J2<$N%"!<%S%H%l!<%7%g%s$d%/%m%C%/$ND4@0$N<jB3$-$,@.$jN)CF$$$k!%

5.2.4 %"!<%S%H%l!<%7%g%s

J#?t$N%G%P%$%9$,F1;~$K%P%9$rA`:n$7h&H7$?:] (F1;~$K%^%9%?KJm&H7$?:])!$$=$NFbM#0l$D$@$1$,%P%9$N@jM-$r5v2D$5lk<jB3$-$r%"!<%S%H%l!<%7%g%s$H8F $V!%%^%9%?$O%P%9$N%i%$%s$N>uBV$r<+J,$N=PNO$HHf3S$7!$<+J,$, HIGH $r=PNO$7$F$$ $k;~$K%P%9$N%i%$%s$, LOW Ji$P%^%9%?$N8"Mx$r<:$&!%3N<jB3$-$Khj!$%P%9$N 6%9g$,5/$-$?;~$K%^%9%?$rM#0lDK7hDj9k!%

5.2.5 %/%m%C%/$ND4@0

J#?t$N%G%P%$%9$,F1;~$K%/%m%C%/$r=P$=$&$H7?:]!$0[$J$kB.$5$N%/%m%C%/$,0l K\$N SCL $KAw=P$5$lF@$k!%3N;~%/%m%C%/$ND4@0$O<!Nh$&$K9Tol$k!%%/%m%C%/$N LOW $N4|4V$O:G$b LOW $ND9$$ (:G$b%/%m%C%/$NCY$$) %G%P%$%9$,=P$9%/%m%C%/$K$" o;il!$%/%m%C%/$N HIGH $N4|4V$O:G$b HIGH $,C;$$ (:G$b%/%m%C%/$NB.$$) %G%P %$%9$,=P$9%/%m%C%/$K$"$o$;$ilk!%3l$O!$$dOj wired-ANDconnection KhCF <B8=5l$k!%

5.2.6 I^{2}C %P%9%G!<%?%U%)!<%^%C%H

DL?.$N3+;O$H=*N;$O!$%^%9%?$N@8@.$9$k3+;O>r7o!$=*N;>r7oKhCF5,Dj5l$k!% 3liO<!Nh$&$KDj5A5l$k!%

5.2 =@Fp$J%W%m%H%3%k$r;}$D%7%j%"%k%P%9 I^{2}C

5.1.1@a$*$h$S 5.1.2@a$G=RY?MW5a;EMM$r2DG=$J8B$jK~B-$9$kDL?.%$%s%?%U%'!<%9 H7$F!$ Philips <R$NDs>'$7$F$$$k I^{2}C(Inter IC) %P%9 [41] $r:NMQ$7!$BNFb LAN $r9=C[$7$?!% I^{2}C %P%9$O!$ 3 %i%$%s$+iJ$k%7%j%"%k%P%9$G!$0J2<$Nh&$JFCD9$,$"$k!%

- B??t$N%W%m%;%C%5$r@\B3G-$k!%
- G$0U$N#1BP#1GNDL?.$,$G$-$k!%
- %^%k%A%^%9%?G"$k!%
- %7%j%"%kJN$GG[@~$,>/J/F9$`!%
- %7%j%"%kK7FOHf3SE*9bB.G"$k (:G9b 400[kbps])!%

I^{2}C %P%9$O!$3HD%$$NMF0W$JHf3SE*9bB.$J%7%j%"%k%P%9$G!$%m%\%C%H%\%G%#>e$N%W%m%;%C%54V$NDL?.JIK7P7$PMxMQ$5lk (Nc$($P [42])!%$^$?!$ SmartBattery $H$$$&EE054IM}%W%m%H%3%krHw($?EECS$N!$EECS;DNL>pJs$JINDL?.KbMxMQ5l$F$$$k [43]!%J*M}E*$J@\B3$O SCL(serial clock line)!$ SDA(serial data line)!$$=7F GND $N#3K\$G$"$k!%%P%9$N6%9g$rKI$0%W%m%H%3%k$r;}$A!$$5iK%^%k%A%^%9%?$H$$$&FCD'$r;}$C$F$$$k!%

3N I^{2}C %P%9$O!$ 5.1.2@a$G5s$2$?DL?.J}<0$N$&$A!$ 3. $NJ}<0$N%7%j%"%k%P%9$G!$6%9g$,5/$3C?:]Kb0lDN%N!<%I$O3N<B$K%P%9$r3MF@$G$-$k<oN`$N$b$N$G$"$k!%$3$N I$^2$C %P%9$O 5.1.1@a$*$h$S 5.1.2@a$G=R$Y$?MW5a;EMM$r$*$*$`$MK~B-$9$kDL?.%$%s%?%U%'!<%9$H8@$(!$$3lrMxMQ7FBNFb LAN $r9=C[$7$?!%

K\@aGO!$ I^{2}C %P%9$K4X$7$F>\@b$9$k!%

5.2.1 %^%k%A%^%9%?

I^{2}C %P%9$O%^%k%A%^%9%?%P%9$G!$%P%9$rA`:nG-$k%G%P%$%9$rJ#?t@\B3$G$-$k!%%P%9$r2p$7$FDL?.$r7F$$$k%G%P%$%9$N4VKO!$%^%9%?$H%9%l!<%V$N4X78$H!$Aw?.<T$H<u?.<T$N4X78$,$=$l$>$lFHN)$KB8:_$9$k!%%^%9%?$ODL?.$NJ}8~$HDL?.$NAj<j$r;XDj$7%/%m%C%/?.9f$r@8@.$7!$%9%l!<%VO=lK=>CF<u?.Kt$OAw?.$r9T$&!%$D$^$j!$!X%^%9%?Aw?. $\Rightarrow$ %9%l!<%V<u?.!Y!$$^$?$O!$!X%^%9%?<u?. $\Leftarrow$ %9%l!<%VAw?.!Y$N!$$$$:l+$N7ABV$G$"$k!%

$=$liN4X78$O8GDjE*$JbNGOJ/!$DL?.$r9T$&$?SK<+M3$K@_Dj$G$-$k!%D^$j!$%P%9$K%/%m%C%/?.9f$rAwk3HNG-$k%G%P%$%9O9YF!$%^%9%?$KJk3H$,$G$-$k!%3lKh$j!$G$0U$N 1 BP 1 $G!$G$0U$NJ}8~$K!$G$0U$NB&$N%N!<%I$r%^%9%?H7$F!$DL?.$r9T$&3HNG$-$k!$Hs>o$K=@Fp$JDL?.7ABV$,<B8=5l$F$$$k!%

%H!<%/%s$H6&$KAw<u?.7J1lPJi:!$$I$&$7FbDL?.NL$,A}$(F7$^$$$,AG$"$k!%

DL?.NCYl$NLdBj$b=EMWG"$k!% 2. $N%H!<%/%s%j%s%0$O!$%H!<%/%s$,2s$k%?%$%_%s%0KhCFDL?.;~4V$K:9$,@8$8$k!%$=$l$r5vMF$9k?aK$O!$$"$kDxEYDL?.B.EY$rB.$/$7J1lPJi$:!$F1$8%S%C%H%l!<%H$N>l9g$K!$B>$N<jK!$HHf3S7FITMxG"$k!%

3. $NJ}<0$O!$%P%9%"!<%S%H%l!<%7%g%s$,I,MWG"k?aK!$ Ethernet J}<0$N%"!<%S%H%l!<%7%g%s$N%W%m%H%3%k$N>l9g!$6%9g$,5/$3C?;~$K:FAw$9k^GN4VDL?.$,J]N1$5lk3HKJ$k!%%?%$%_%s%0KhCF$O!$2?EY$+B3$1$F:FAw$,5/3k2DG=@-b"$j!$DL?.NCYl$,M}O@E*$K$OL58B$K5/3jF@kH$$$&LdBj$,$"$k!%6%9g$,$*$-Fb!$>/$J$/$Hb=N&AN0lAH$_$NDL?.$O<B9T$5lkh&$J;EAH$_$N%"!<%S%H%l!<%7%g%s!&%W%m%H%3%k$r;}$DJi$P!$DL?.$N8zN($O0-2=7J$$!%$=$N>l9g$O!$%"!<%S%H%l!<%7%g%s$G%P%9$r3MF@G-J+C?%N!<%I$O%j%H%i%$$,5/3k$,!$%P%9$r3MF@$7$?%N!<%I$NDL?.$OC#@.$5lk$+$iG"$k!%

0J>e$K=R$Y$?$h$&$J<o!9$N>r7o$KBP7F!$$JkY$/NI$$Ez$r;}$DDL?.J}<0$r:NMQ$9kI,MW,$"$k!%

5.1.3 %N!<%I$NBNFbAH$_9~$_

BNFb LAN KAH_9~$`%N!<%I$O!$2DG=$J8B$j>.7?!&7ZNL!&Dc>CHqEENO$G$"$k3H$,5a$ail$k!%$3li$N>r7o$rK~$?$7DD!$%;%s%5>pJs$r<}=8$9$kG=NO$H!$%"%/%A%e%(!<%?$K>pJs$rJ,G[9kG=NO$r;}$D!$BNFbAH$_9~$_MQ%b%8%e!<%k$,I,MWG"$k!%

K\8&5fGO%j%b!<%H%V%l%$%s%"%W%m!<%A$rMQ$$$F$$$k$, (3.2.4@a)!$8=;~E@GO<+N'7O$NItJ,$O%V%l%$%s$N:G2<0LAXK"$k!%$3lO!$BNFb LAN $N%N!<%I$N%W%m%;%C%5$NG=NO$,Dc$$$H$$$&M}M3N?aG$"$k$,!$>-Mh$OBNFb LAN $K<+N'7O$r0\9T9kY-G"kH9M$($F$$$k!%

5.1.2 =@Fp$JDL?.%W%m%H%3%k

BNFb LAN K*$$$F$O!$J#?t$N%N!<%I$,@\B3$5$lk3HKJj!$>-Mh$N<+N'7O$NBNFb LAN XN0\9T$b9MN8$KF~ll$P!G0U$N 1 BP 1 $G%G!<%?$NdjHj$,$G$-$k3H$,I,MW$HJk!%3l$r<B8=$9k?aNDL?.$N%W%m%H%3%k$d%M%C%H%o!<%/$N%H%]%m%8$O!$0J2<$K<(9h$&$J$$$/D+$N<jK!$,9M$($ilk!%

1. A47k9g7?
   3F%N!<%I$HB>$NA4FN%N!<%I$H4V$K 1 BP 1 $N%7%j%"%k%j%s%/$rD%$j!$I,MW$J 2 E@4V$G$=$l$>$lFH<+$NDL?.$r9T$&J}<0!%

2. %H!<%/%s%j%s%0
   3F%N!<%I$,2 K\$N%j%s%/$r;}$A!$%M%C%H%o!<%/$N%H%]%m%8$rA4BN$G%j%s%0KJkh$&$K9k!%$=$7$F!$$=$N%j%s%0$K%H!<%/%s$r2s$7!$Aw?.$r7?$$;~$O<+J,$NH3mK%H!<%/%s$,Mh$?;~$K08@h$H%G!<%?$N%Q%1%C%H$r%H!<%/%s$KIU2C$7$F!$<!$N%N!<%I$KE>Aw9k!%

3. 08@hrD1?%V%m!<%I%-%c%9%H$H%P%9%"!<%S%H%l!<%7%g%s$N%W%m%H%3%k
   %P%9$K@\B3$5l?%N!<%IA4FK08@h>pJs$r4^$s$@%G!<%?$r%V%m!<%I%-%c%9%H$7!$A4FN%N!<%IO=$N%G!<%?$rFI$_!$<+J,08JiP=lr<u?.!$$=$&$GJ1lPGK4~9k$H$$$&J}<0!%F1;~$KJ#?t$N%N!<%I$,Aw?.$r9T$*$&H9$k:]$KL7=b$,@8$8$J$$$h$&$K9k!$%P%9%"!<%S%H%l!<%7%g%s$N%W%m%H%3%k$,I,MW$G$"$k!%%"!<%S%H%l!<%7%g%s$N:]$K!$6%9g$7$?%N!<%I$OA4$F%P%9$r0lC62rJ|$7%i%s%@%`$JBT5!;~4V8e:FAw9k Ethernet JI$NJ}<0$H!$6%9g$7$?%N!<%I$N$&$A0lD@1,%P%9$r3MF@$G$-$k I²C %P%9 (8e=R) Nh$&$JJ}<0$,$"$k!%

%1!<%V%k$OK\Mh$NL\E*K7$?$,CF!$$JkY$/>/$J$$?.9f@~$G<B8=$G$-$k3H$,9%$^$7$$!%$=$l$r9MN8$9kH!$1. $NA47k9g7?$O!$%N!<%I$N?t$,A}$(kH?.9f@~$,GzH/E*$KA}$($kNG!$%N!<%I$,>/$J$$>l9g$K8B$l$PM-8z$J>l9gb"k, (7+$7!$%N!<%I?t 2 E@$N>l9gB>$NA4FHF1$8!$ 3 E@$N>l9g 2. $N%H!<%/%s%j%s%0$HF1$8$G$"$k)!$$"$kDxEY0J>e (%N!<%I?t 5 E@0J>e) $N%N!<%I?t$N>l9g$OA4$/9%$^$7$$$H$O8@$($J$$!%

$^$?!$%M%C%H%o!<%/$rJ,lk%G!<%?$NDL?.NL$rG-k@$18:$i7F!$DL?.8zN($NNI$$$bN,5aailk!%2. $N%H!<%/%s%j%s%0$O!$<+J,$KD>@\4Xoj$NL5$$%G!<%?$b

K\>OGO!$%;%s%5!&%"%/%A%e%(!<%?$H<+N'7O$r7k$V?@7P7OG"$kBNFb LAN $r;}$D!$?M4V7?%m%\%C%H$N%O!<%I%&%'%"$N3+H/$K$D$$$F=RYk!%

5.1 ?@7P7O$N<B8=J}K!

3.2.4@a$G=R$Y$?$h$&$K!$?@7P7O$,=EMW$J2]Bj$G$"$k!%K\@aGO!$$3$&$7$?2]Bj$r2r7h9k$?$a$KK\8&5f$G:NC?<jK!$r=R$Y$k!%

5.1.1 %7%j%"%kDL?.Kh$k>JG[@~

F0J*$O!$BN$KJ,;6$7$?BgNL$N%;%s%5!&%"%/%A%e%(!<%?$HG>$N4V$O!$?@7P:YK&KhCFA4$F%Q%i%l%k$K@\B3$5$l$F$$$k!%F0J*$O!$Fpi+$$%\%G%#$r;}$D$H$$$&MxE@$H0z$-BX$($K!$MM!9$J>c32$r<u$1d9$$$H$$$&7gE@$,$"k,!$$3lKBP7F4h7r@-$r;}$D$H$$$&0UL#$,$"kH9M$($ilk!%$^$?!$%i%$%U%5%$%/%k$,D9;~4VG"jJ$,$i?@7P:YK&$N:F@8$,:FqG$"$k$?$a!$B??t$NJBNs@~N&$A$$$/i+$,@Z$l$?$j7F$b5!G=$,$"$^$jDc2<$7$J$$$h$&$J;EAH$_$KJC$F$$$k$H8@$($k!%

0lJ}%m%\%C%H$N>l9g$O!$6aG/Fp$i$+$$9=B$$r;}$D%m%\%C%H$r:nm&$H$$$&8&5f$b$$$/D+J5lF$$$k$,!$$[HsIN>l9g$O9E$$%\%G%#$r;}$D$?$a!$Hf3SE*%\%G%#FbIt$,=}D-K/$$!%$^$?!$%m%\%C%H$Ob7=}$D$$$?>l9g$O=$M}$r<u$1k3H,G-$k!%$=$N:]!$$`7mB?$/$N%Q%i%l%k$J%1!<%V%k$h$j!$?tK\$N%1!<%V%k$G>pJs$,2?i+$N7A$GB?=E2=5l$F$$$k7ABV$NJ}$,!$=$M}$bMF0W$G$"$k!%

F0J*KOF0J*$N;EAH$_$KE,$7$?7A$N?@7PG[@~$,B8:_$9kh$&$K!$%m%\%C%H$O%m%\%C%H$N;EAH$_$KE,$7$?7A$N?@7PG[@~$,B8:_$9kY$-$"$k!%K\8&5f$G$O!$%m%\%C%H$N;EAH$_$KE,$7$??@7PG[@~$H7F!$%7%j%"%kDL?.$rMxMQ9k3HK7$?!%$9Jo$A!$>-Mh$r8+1[$;$P%m%\%C%H$NBNKbBgNL$N%;%s%5!&%"%/%A%e%(!<%?$,J,;6$9$kN3HO3N<BG"$j!$$=li$HG>$N4V$r%Q%i%l%k$K@\B3$9$kNGOJ$/!$%\%G%#$N6I=jNN0hKh$K%N!<%I$r@_$1!$%N!<%I$H%;%s%5!&%"%/%A%e%(!<%?4V$O6I=jE*$J%Q%i%l%k@\B3H7!$%N!<%I4V!&%N!<%I$HG>$N4V$O%7%j%"%k@\B3H9kNG"$k!%

%N!<%I4VDL?.$O!$@TDGF0J*GOG>$r7PM3$7$J$$@T?qH?<M$KAjEv$9$k!%K\8&5f$G<gD%7F$$$k<+N'7OO3$N%N!<%I4V$NDL?.$rMxMQ$7$F%7%9%F%`$KAH$_9~$`$3H,M-8zG"$k!%$=lKhj!$G>$r7PM3$9$kM>M5$NL5$$$h$&$JB(1~@-$r5a$ail$kH?<ME*F0:n$O!$%N!<%I4V$NDL?.KhCF<B8=5l!$G>$KEA$($kY->pJs$O$$$/i+$N;~4VCY$lrHbJCFG>KFO/$H$$$&!$Hs>o$K=@Fp$J<+N'7O$N%7%9%F%`$,=PMh>e$,kH9M$($ilk!%

3&7?9M;!$+$i!$K\8&5f$G$O%\%G%#$K6I=jE*$J%;%s%5!&%"%/%A%e%(!<%?>pJs<}=8!&J,G[%N!<%I$r@_$1!$$=li$N%N!<%I$r%7%j%"%kDL?.$G@\B3$7$?%M%C%H%o!<%/$Khj!$?@7P7O$N<B8=7?!%$^$?!$$3$N%M%C%H%o!<%/$rBNFb LAN $H8F$V!%

Bh **5** >O

BNFb **LAN** $r;}$D?M4V7?%m%\%C%H$N3+H/

$^$?!$>e0L$H$NDL?.$K$O%=%1%C%HDL?.$rMQ$$$k$?$a!$>e0L%=%U%H%&%’%"$r<B9T9k 7W;;5!$H%\%G%#$KBP9k@)8fAuCVEy$r@\B3$9$k7W;;5!$rJL!9$K@_Dj$G$-$k!%3lKh $j!$%M%C%H%o!<%/>e$KB8:_$9$k7W;;;q8;$rA4$F%m%\%C%H$N%V%l%$%s$H7FMxMQG-$k!%

$7!$(int argc, char *argv[]) $N7A$K7?!%

CloseInterface()

%$%s%?%U%’!<%9%O!<%I%&%’%"$N=*N;=hM}!$%a%b%j2rJ|$JIr9T$&!%

SetAngleVector()

0z?tv $N4X@a3QEY>pJs$r!$%"%/%A%e%(!<%?@)8f$K0MB8$7$?C10L$N%G!<%?$KJQ49 $7!$A0=R$N%U%)!<%^%C%H$K%(%s%3!<%I$7<B:]$KAw?.$r9T$&!%

GetRobotState()

%7%j%"%k%]!<%H$r%j!<%I$7!$>e=R$N%U%)!<%^%C%H$r%G%3!<%I$7!$0z?tstate $N9= B$BN$K3JG<$9$k!%

$3$3$G!$4X@a3Q;XNaCM>pJs$Ovector 7?$NG[Ns$K3JG<$7!$%;%s%5>pJs$O<oN`Kh$K%(%s%H%j$r;}$A%;%s%5$NDI2C$rMF0W$K9kRobotState 9=BBNK3JG<9kh&K7$?!%

vector 7?G[Ns$*$h$S!$RobotState 7?9=BBNNDj5A

```
typedef double *vector;

typedef struct {
    vector Potentio; /* 4X@a3QEY (%]%F%s%7%g%a!<%?$h$j) */
    vector Error; /* 8m:93QEY (%b!<%?6nF0?.9f$h$j) */
    vector Fsr; /* B-N"H?NO (B-DlNO%;%s%5$h$j) */
    vector Adxl; /* 2CB.EY (3 <42CB.EY%;%s%5$h$j) */
    vector  Suit; /* ?(3P>pJs (%;%s%5%9!<%D$h$j) */
    !&!&!&
} RobotState;
```

4.2.4 >e0LAXHN%$%s%?%U%’!<%9

?M4V7?%m%\%C%HNh$&$JJ#;($J%7%9%F%`$K$*$$$F$O!$I,MW$JMM!9$J5!G=$O<+N’E*$K 9T$&2<0LAX$,:GDc8BI,MWG"k,!$>e0LAX$,C10l$N9=B$$GLdBj$,L5$$$H$O9M$(K/$$!% >-Mh$O>e0LAX$N9=B$$N8&5f$bHs>o$K=EMWG"kH9M$($ilk!%7?$,$C$F!$2<0L<+N’7O $H>e0LAX$H$N%$%s%?%U%’!<%9KO!$>e0LAX$N9=B$$r=@Fp$KJQ992DG=$K7F$*$/$?$a$NHF MQ@-$,5aailk!%

$=$3$GK\8&5f$G$O!$>e0LAXHN%$%s%?%U%’!<%9$r!$HFMQ@-$r9MN8$7$F%=%1%C%HDL?. Kh$k%-%c%i%/%?%Y!<%9$NDL?.H7$?!%%=%1%C%H4F;k%9%l%C%I (interpreter) $,>e0L$+ iN%3%^%s%I$r2r<a$7!$$=$N;XNa$K1~8F<+N’5!G=%b%8%e!<%kK=l>$l%9%l%C%I$r3d jEvF!$$=$N5/F0$*hS=*N;$r9T$& (Fig.4.2)!%5/F0;~$O>e0LAX$+$i%Q%i%a!<%?$r<u$1 <h$j!$=*N;;~$O<+N’5!G=%b%8%e!<%k$rC4$&%9%l%C%I$,=*N;>uBV$rJV$;$P$=$l$r>e0LAX$K JV$9!%

`eventtest`

>r7oKh$j%b%8%e!<%k$N<B9T$rDd;_$9k?aN4X?t$G!$`eventtest[0]()` !A`eventtest[te`

$N$$$:l+$,??$rJV$9;~!$$=$N%b%8%e!<%k$N<B9T$rDd;_$9kh$&$KG-$k!%$3$l

KhCF!$>e0LAX$O!V$"$k>uBVKJk^GN4V%b%8%e!<%k$r<B9T$;$h!W$H$$$&7A

$G!$2<0LAX$K;X<($9k3H,G-$k!%

4.2.3 %\%G%#HN%$%s%?%U%'!<%9

K\8&5fGO!$%j%b!<%H%V%l%$%s!&%"%W%m!<%AKh$j!$%\%G%#$H%V%l%$%s$rJ*M}E*$K J,N%9k%"%W%m!<%A$rMQ$$$F$$$k (3.2.4@a)!%%\%G%#HN%$%s%?%U%'!<%9$OL5@~%b%G%` $rMxMQ$7$?%7%j%"%kDL?.$H$7!$MM!9$J%\%G%#>e$N%W%m%;%C%59=@.$KBP1~2DG=$JHFMQ$J %G!<%?%U%)!<%^%C%H$r:vDj$7$?!%%G!<%?%U%)!<%^%C%H$N>\:Y$O!$ 5.4.4$NDL?.%G!<%?$N %U%)!<%^%C%H$N9`$K=R$Y$k (Fig.5.16)!%

4pK\J}?K$O!$%\%G%#GO!$%;%s%5>pJs$r<h$j9~$_%V%l%$%s$KAwk3HH!$%V%l%$%s $+$i%"%/%A%e%(!<%?>pJs$r<u$1<h$j4X@a3Q$r@)8f9k3H$@$1$r9T$&!$$H$$$&3H$G $"$k!%<+N'E*5!G=$rC4$&AX$O!$%\%G%#$G7W;;$r9TC?J}$,;~4VCY$l$b>/$J$/!$>-MhE* KO%\%G%#$KEk:\$9kY$-$G$"$k$,!$$=$N;EMM$rLO:w9kCJ3,GO$`$7$mB?>/$N1~Ez @-$r5>@7$K7F$b!$=@Fp$KJQ99$,2DG=$J%V%l%$%sK*$$$F<BAu9kJ}$,8=<BE*$G$"$k (3.2.4@a)!%

$^$?!$BNFb?@7P7O$rN.lk%G!<%?$O%\%G%#$r9=@.9k%O!<%I%&%'%"MWAGd=$N@)8f AuCV$K0MB8$7$?%U%)!<%^%C%H$dC10LNL$GI=5l$k!%%V%l%$%s$r%\%G%#$KBP7FCj>]2=$7 %\%G%#$N%O!<%I%&%'%"9=B$$K0MB8$7$J$$$bNK9k$?$aKO3liN>pJs$rDjNLE*$JJ* M}NL$KJQ49$9kI,MW,$"$k!%9JoA!$%\%G%#$+iN>pJs$O%U%)!<%^%C%H2r@O$r9T$J$$ 3QEY$dB.EY!$2CB.EY!$NO!$ 3 <!850LCVJI$KJQ49$7!$5U$K%V%l%$%s$+iN>pJs$O@)8fAu CV$X$N%U%)!<%^%C%HJQ49$r9TJ&!%

3N%U%)!<%^%C%H2r@O$H%U%)!<%^%C%HJQ49$K%$%s%?%U%'!<%9%O!<%I%&%'%"$N=i4|2=!$=*N;=hM}$N 2 DN5!G=$r2C$(!$<!$Nh&$J 4 DN API $GBNFb?@7P7O%l%Y%k$K%"%/%;%9$9$kbNH7$?!%

%\%G%#HNDL?.$N API $ND~~j5A~~

```
int OpenInterface(int argc, char *argv[]);
int CloseInterface(void);
vector SetAngleVector(vector v);
RobotState *GetRobotState(RobotState *state);
```

`OpenInterface()`

%$%s%?%U%'!<%9%O!<%I%&%'%"$N=i4|2=!I,MWJ%a%b%j3NJ]JI$r9T$&!%%7%j%"

%kDL?.$NB.EY$d%G%P%$%9%U%!%$%kL>JI$r0z?t$H7FEO9,!$3HD%@-$r9MN8

plugin 7?$N9=B$BN$NDj5A

```
typedef struct _plugin {
    int state, priority;
    void (*constructor)(struct _plugin *p, char *arg);
    void (*entry)(struct _plugin *p,
                  RobotState *state,
                  vector target_av,
                  vector send_av);
    void (*destructor)(struct _plugin *p);
    int test_num;
    int (*eventtest[MAX_TEST])(struct _plugin *p, char *buf);
    void *memory;
} plugin;
```

state

0J2<$N$$$:l+NCMrHj!$8=:_$N "Plugin" $N<B9T>uBV$rI=$9!%

SLEEP	Dd;_Cf!%
RUN_STANDBY	constructor() $r8F$S=P$7!$
	RUN_SEQUENTIAL $+RUN_PARALLEL $K0\9T$7<B9T$r3+;O!%
RUN_SEQUENTIAL	C`<!<B9TCf!%
RUN_PARALLEL	JBNs<B9TCf!%
STOP_STANDBY	destructor() $r8F$S=P$7<B9T$r=*N;$7!$SLEEP $K0\9T!%

priority

<B9T$NM%@h=g0L$rI=$9!%%b%8%e!<%k$rC`<!<B9T9k;~$K0UL#$r;}$D!%0 !A255 $N CM$r<h$j!$CM$,>.$5$$$bN+$i=g$K<B9T5l$k!%

constructor!$destructor

%b%8%e!<%k$N<B9T3+;O!&=*N;;~$K8FPl$k4X?t$X$N%]%$%s%?G"$k!%constructor() $O<B9T3+;O;~$K8FPl$k4X?t$G!$<B9T;~$KMxMQ9k%a%b%jNN0h$N3NJ]$JIN%$%K %7%c%i%$%:$r9T$&!%destructor() $O<B9T=*N;;~$K8FPl$k4X?t$G!$constructor() $G3NJ]$7$?%a%b%jNN0h$N2rJ|$d!$$=$N "Plugin" $r8F$S=P7?>e0LXN=*N;>uBV $NJs9p$JIr9T$&!%

entry

%b%8%e!<%k$N%a%$%s$N4X?t$X$N%]%$%s%?$G!$ Fig.4.1K*1k f $KAjEv$9$k!%%; %s%5>pJsstate(RobotState 7?9=B$BN) $K4p$E$$$F!$L\I83QEYtarget_av $r=q$- 49$($k. Fig.4.1$G8@$($P!$ $\boldsymbol{s}$ $rMQ$$$F7W;;$7!$ $\delta\boldsymbol{\theta}$ $r8=:_$N $\boldsymbol{\theta}$ $K2C$(k3HKAj Ev9k!%

memory

%b%8%e!<%k8GM-$N%a%b%j$X$N%]%$%s%?G"$k!%

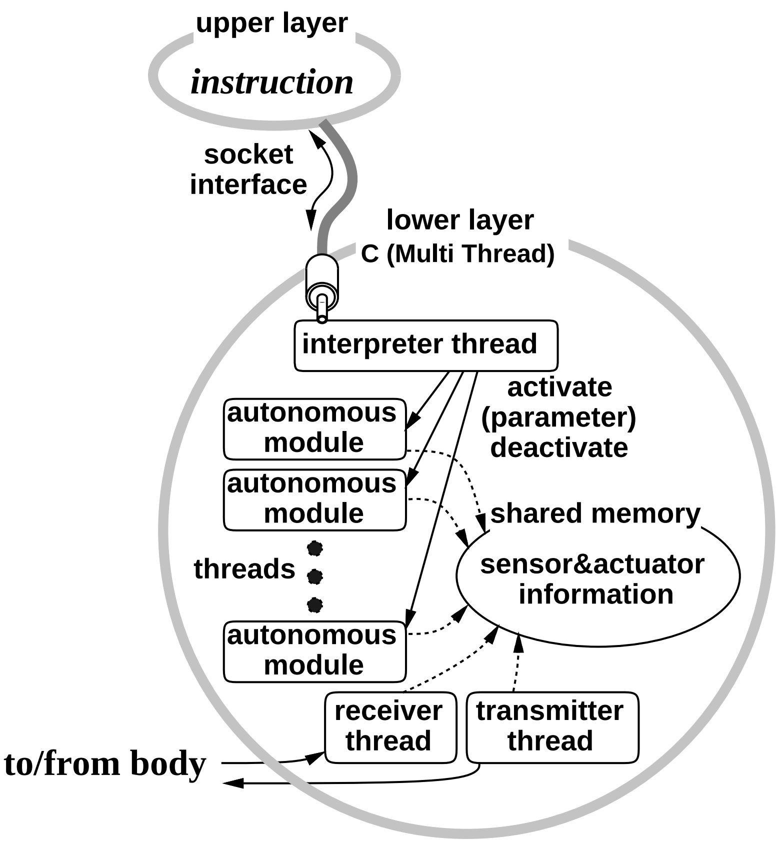


Fig. 4.2 %V%1%$%s2<0L<+N'7O$N<BAu
The implementation of the autonomous system

4.2 %7%9%F%`$N<BAuJ}K!

4.2.1 %^%k%A%9%l%C%I%W%m%0%i%_%s%0Kh$kJBNs@-

JBNs$KB??t$N<+N'5!G=%b%8%e!<%k$r<B9T$9k?aK!$<BAuJ}K!$H7F%^%k%A%9%l%C%I%W%m%0%i%_%s%0 [40] $rMxMQ$7$?!%

%9%l%C%IKh$k%W%m%0%i%_%s%0$O!$%^%k%A%W%m%;%9$N%W%m%0%i%_%s%0$HHf3S$7$FHs>o$K Light Weight G"k3H,FCD'G"$k!%$^$?!$%9%l%C%I$O0l$D$N%W%m%;%9Fb$GJBNs<B9T9kNG!$%W%m%;%9Fb$NBg0hJQ?t$rA4$F$N%9%l%C%I$,6&M-G-$k!%$3lrMxMQ7F!$3F<+N'5!G=%b%8%e!<%k$KO*N*$N0l$D$N%9%l%C%I$r3djEvF!$Bg0hJQ?t$K3JG<7?%;%s%5>pJs$d4X@a3Q>pJs$rGSB>@)8f7J$,$iFI$_=q$-9k$H$$$&7A$G<BAu$7$?!%

4pK\E*KO!$

- %\%G%#$+$i$N%;%s%5>pJs$r<u?.%9%l%C%I
- 4X@a3Q>pJs$r%\%G%#$XAw?.9k%9%l%C%I
- >e0LAX$+$i$N%3%^%s%I$r<u$1IU$1$k%9%l%C%I

$N#3$D$N%9%l%C%I$,>o;~<B9T5l!$>e0LAX$+$i%3%^%s%I$r<u$1<h$k$H!$$=lK1~8F?7$?$K%9%l%C%I$r@8@.$7$F!$%b%8%e!<%k$N<B9T$K$"$F$k (Fig.4.2)!%

3N<BAu$NMxE@$O!$3F%b%8%e!<%k$N<~4|$,<+M3$KJk$H$$$&E@G"$k!%JBNs<B9T$G6&M-%a%b%j$rMxMQ$9kN$G!$7W;;$K;~4V$N$+$+$k%b%8%e!<%k$N=PNOrBTD3HJ/!$4X@a3Q;XNa$r0lDj<~4|$G%\%G%#$KAw?.G-$k!%

4.2.2 Shared Object $N%@%$%J%_%C%/%m!<%I

<+N'5!G=%b%8%e!<%k$O Shared Object H7$F:n@.$7 ("Plugin" $H8F$V)!I,MWK1~8F%W%m%0%i%`<B9TCf$K%@%$%J%_%C%/$K%m!<%I!&%"%s%m!<%I$r9T$&$3H,G-kh$&$K7?!%

$^$?!$%m!<%I$7$? "Plugin" $N<B9TJ}K!$O!$7W;;NL$,o:$+$GJBNs<B9TGJ$/C`<!<B9T$G==J,$J$b$N$O!$C`<!<B9T$b2DG=$J<BAu$K7?!%

"Plugin" $N;EMME}0l$N$?$a!$**plugin** 7?$N9=BBNrDj5A7?!%

4.1 @_7W

G>$N%7%9%F%`%"!<%-%F%/%A%c$r Fig.4.1Nh$&$K9=C[7?!%%;%s%5!&%"%/%A%e%(!<%?$rL)$K7kSIU1$kC1=c$JH?<ME*$J=hM}$r9T$& “<+N'5!G=%b%8%e!<%k” $r!$I,MW$K1~$8$FJ#?tJBNs$K<B9T9k$H$$$&9=@.$G!$2<0L$N<+N'7O$rC4$&!%

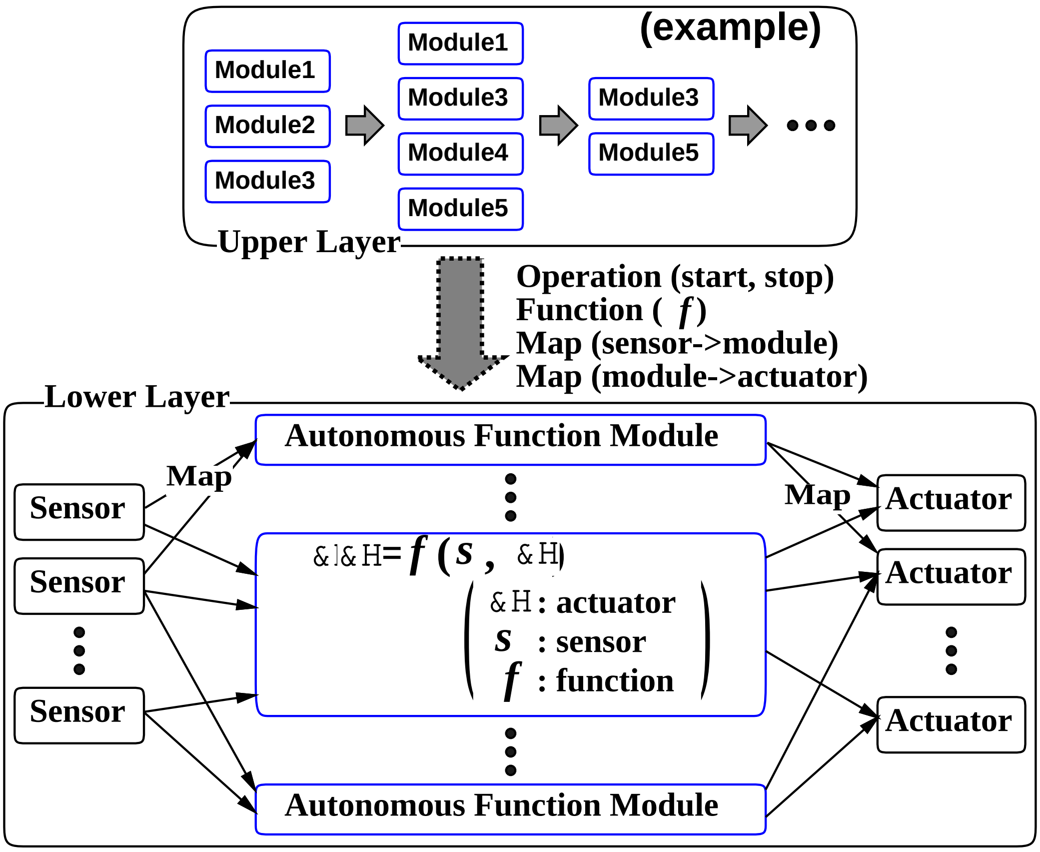


Fig. 4.1 JBNsC1=cH?<M%b%8%e!<%k72Kh$k<+N'7O
The autonomous system based on parallel simple sensor-motor modules

Fig.4.1K*$$$F!$2<0LAX$K$*$1$k?t<0 $\delta\boldsymbol{\theta} = f(\boldsymbol{s}, \boldsymbol{\theta})$ $O!$3F<+N'5!G=%b%8%e!<%k$NFbIt$rI=$9!%01$D$N%b%8%e!<%k$O!$$=1,C4$&5!G=$N<B8=KI,MWJ$$$/D+$N%;%s%5>pJs $(\boldsymbol{s})$ $rF~NO$7!$4X?t f KhCF7W;;7?%"%/%A%e%(!<%?>pJs $(\delta\boldsymbol{\theta})$ $r=PNO$9$k!%3F%b%8%e!<%k$N=PNO$O!$8=:_$N%"%/%A%e%(!<%?;XNaCM$KBP9k:9J, $(\delta\boldsymbol{\theta})$ H7!$$=1i$N9g7W$,8=:_$N%"%/%A%e%(!<%?;XNa$K2C;;$5$1$k!%>e0LAX$O!$$3$1$i$N%b%8%e!<%k$rI,MW$K1~$8$F5/F0!&=*N;$9k3HKhj!$A4BN$H7FL\E*$N9TF0$r<B8=G-$k!%

Bh **4** >O

<+N’7O$r2<0LAX$K;}$DG>%7%9%F%‘$N3+H/

- I,MW$J5!G=$r<B8=9kF~=PNO4X78!&%Q%i%a!<%?$r!$<+N’5!G=%b%8%e!<%kFb$G3X=,$9$k!%

- 9TF0%l%Y%k$G!$$I$&$$$&=g=x!&%Q%i%a!<%?$G<+N’5!G=%b%8%e!<%k$r5/F0!&=*N;9l$P!$=jK>$N9TF0$KJk$+$r<+8JAH?%2=9k!%

$H$$$&FsDN!$<+8JAH?%2=$N$?$a$N2DJQ@-$r;}$D!%

Bh 4>OGO!$<+N’7O$r:G2<0LAX$K;}$DG>%7%9%F%‘$N@_7W!&<BAu$K$D$$$F=RYk!%

3.2.4 ?@7P7O$NI,MW@-

K\8&5f$G<gD%$9$k<+N’7O$OK\Mh@T?q$KAjEv$7!$BNFb$KKd$a9~$^lF$$$kN,K>$^$7$$$,!$<+N’7O$N5!G=$r<B8=$9$kJ}K!$NF3=PdI,MWJ5!G=%b%8%e!<%k$N<oN‘$rLO:w9k2aDxK*$$$F$O!$=@Fp$KJQ99$,2DG=$J%7%9%F%‘$G$"$k3H$,I,MW$KJk!%

$=$3$GK\8&5f$G$O!$%j%b!<%H%V%l%$%s%"%W%m!<%A [37] Kh$j!$%m%\%C%H%7%9%F%‘$r%\%G%#$H%V%l%$%s$KJ,N%7?9=@.rH$k!%<+N’E*5!G=$rINh&$K:nk+$rLO:w9kCJ3,GO!$<+N’7O$O%\%G%#$+$i@Z$jN%$5l?%V%l%$%s>e$K%$%s%W%j%a%s%H$7!$%V%l%$%sFbIt$G5/F0!&=*N;$d%Q%i%a!<%?$rM?$($k7A$H9k!%

3N>l9g!$%\%G%#$KEk:\$7$?%;%s%5!&%"%/%A%e%(!<%?$r!$%V%l%$%sKKda9~s@<+N’7O$H7k$SIU1k$?$aKO!$?M4V$G$$$($P?@7P7O$KAjEv9k>pJsEAAw7O$,I,MW$HJk!%

FC$K!$3HD%@-!&HFMQ@-$r;}$ADD%3%s%Q%/%H$J%\%G%#$K9k$?$aKO!$?@7P7O$N;EMM$N8!F$$,Hs>o$K=EMW$G$"$k!%Bh 5.1@a!$Bh 5.2@a!$Bh 5.3@a!$Bh 5.4@a$G$O!$$3liN3Hr9MN8$7!$%\%G%#$KEk:\$9$k?@7P7O$N@_7W!&<BAuKD$$$F=RYk!%

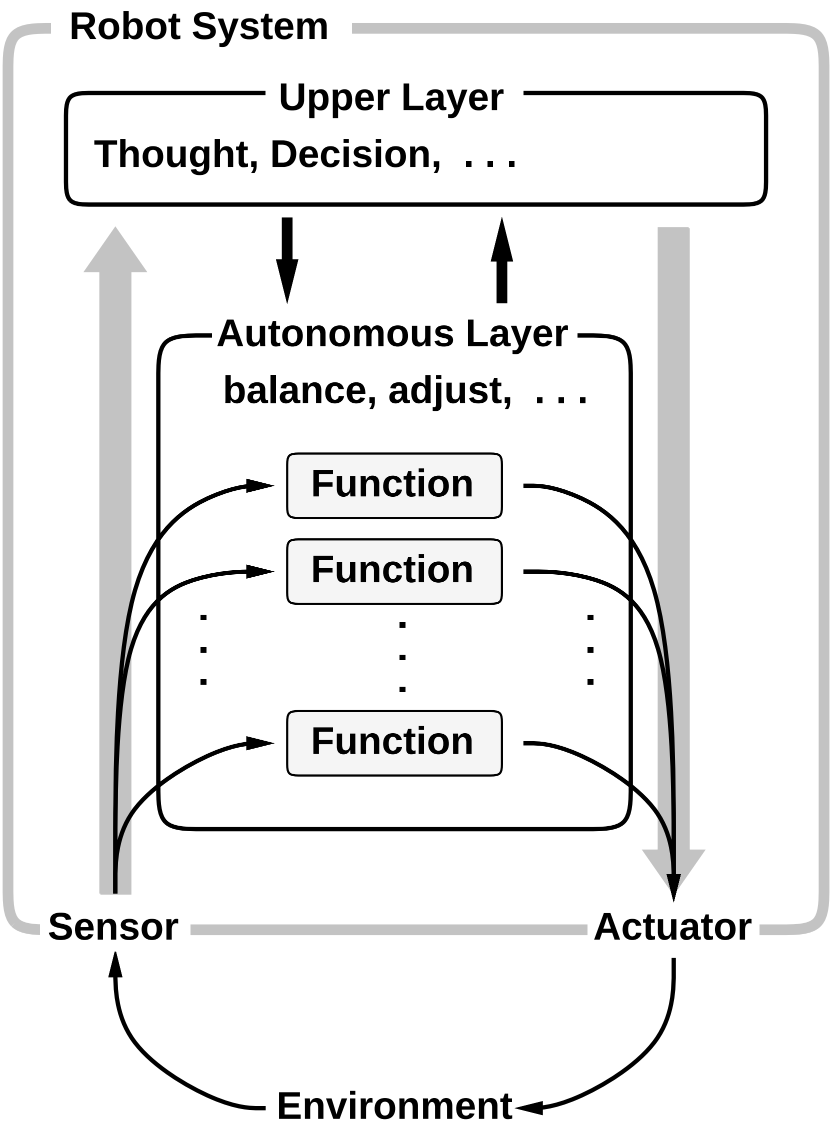


Fig. 3.1 <+N’7OrHw($?G>$N%7%9%F%‘
Brain architecture with the autonomous system

3.2.2 <+N′E*5!G=$rC4$&7O$r;}$DFsAX9=B$$NG>%7%9%F%`

3.2.1@a (i) $N>r7o$rK~$?$9$?$aKO!$Cj>]%l%Y%k$N9b$$ItJ,$r07$&>e0L$H!$Cj>]%l%Y%k$NDc$$%l%Y%k$r07$&2<0L$H$$$&!$>/$J$/$H$bFsAX$N3,AXE*%7%9%F%`9=@.$,I,MW$G$"$k!%

D^$j!$%P%i%s%90];}!&H?<MF0:nJI$N!$?M4V$,L50U<1$K9TCF$$$kh&$J2<0L$N<+N′E*5!G=$r!$G>$N:G2<0LAX$KKd$a9~$`3HKhCF!$$=$&$7$?5!G=$r0U<1$;$:$K>e0L$N9TF0$r5-=R$9k3H,G-kh$&$KJk$?$a$N!$:G>.8BI,MW$J9=B$$G$"$k!%F1;~$K!$$=$&$7$?>r7o$r9MN8$;$:$KG>$N>e0L$NOHAH$r5DO@9k3H$,$G$-$kh&KJk?aNOHAHGb$"$k!%

K\8&5fGO!$%m%\%C%H$NG>$N%7%9%F%`$N:G$b4pK\E*$JOHAHH7$F!$:G2<0LAX$K<+N′7O$r;}$DG>$N9=@.K!$rDs0F$9$k (Fig.3.1)!%

3.2.3 <+N′E*5!G=$rC4$&7O$NOHAH

3.2.1@a (ii) $O!$ 3.2.2@a$G=R$Y$?<+N′E*5!G=$rC4$&7O$KHwoC$F$$$kY->r7oG"kH9M$($k3H$,$G$-$k!%

K\8&5fGO!$%m%\%C%H$N2<0LAX$r9=@.$9$k<+N′E*5!G=$rC4$&AX$r!$%;%s%5!&%"%/%A%e%(!<%?$,L)@\$K7k$SIU$$$?H?<MF0:n$r9T$&<+N′5!G=%b%8%e!<%k$,!$I,MW$K1~$8$FJ#?tJBNs$K<B9T5lkH$$$&7A$G9=@.$7$?!%$5iK!$JBNs$K=PNO5l$k<+N′5!G=%b%8%e!<%k$+iN%"%/%A%e%(!<%?>pJs$N=PNO$O!$@dBPE*$JCMGOJ/8=:_CMHN:9J,H7!$$=li$r8=:_CM$KB-$79g$o$;$k7AK7$?!%

3l$O!$%5%V%5%s%W%7%g%s!&%"!<%-%F%/%A%c$K3X$s$@7A$G$"$k$,!$

- 3FC15!G=%b%8%e!<%k$O!$F~NO>pJs!&=PNO$r7W;;$9$k4X?t!&=PNO>pJs$H$$$&!$:G>.8BI,MW$JOHAH$@$1$r;}$D!%
- >e0L$+$i%b%8%e!<%k$N5/F0!&=*N;!&%Q%i%a!<%?$NJQ99$,<+M3$KG-$k!%
- 6%9g9k%b%8%e!<%k$N=PNO$,$"$k>l9g!$%5%V%5%s%W%7%g%s!&%"!<%-%F%/%A%c$N>l9g$OM%@hEYKh$jD4Dd$r9T$&$,!$K\<jK!$O:9J,NOBH$$$&7ArH$k!%

$H$$$&FCD′$r;}$D!% 3 E@L\$K5s2?FCD′$O!$6%9g9k=PNO$,C1=c$JOB$N7A$KJjN>J}$,@8$+5lkH$$$&MxE@$,$"k,!$L7=b$9$k=PNO$rOB$N7A$GLdBjJ/2r7hG-k+$H$$$&5?Ldb"$k!%:9J,$NOB$N7A$O$^$@$^$@2~A1$NM>CO$,$"$j!$=E$_D-NOBrMQ$$$kJI$N<jK! [39] $,9M$($k!%

3NFCD′$O!$ 3.2.1@a (iii) $N!$<+F03MF@9k;EAH$_$rAH$_9~$`3H$,$G$-$k$H$$$&>r7o$rK~$?7F$$$k!%D^$j!$

3.2 K\O@J8$GDs0F$9$k%7%9%F%`9=@.K!

Bh 3.1@a$G5DO@$7$?%m%\%C%H%7%9%F%`$N9=@.K!$N8&5f$r9MN8$7!$K\8&5f$G$OA4?H$G J*BNA`:n$r9T$&?M4V7?%m%\%C%H$N%7%9%F%`9=@.$r0J2<$Nh&$K9=@.$9$k!%

3.2.1 4pK\%3%s%;%W%H

Bh 2>O$*$h$SBh 3.1@a$N5DO@hj!$A4?H$GJ*BNA`:n$r9T$&?M4V7?%m%\%C%H$K5a$a$i lkMW7or^HakH!$0J2<$Nh&KJ$k!%

- 4oMQ$JA`:n (%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%s$r4^$`)
- %;%s%5%Y!<%9$G%j%"%/%F%#%V$JF0:n
- B?<+M3EY6(D4F0:n
- B?:L$JA`:nJ}K!
- B?MM$JA`:n>u67
- L$CNJ*BNA`:n
- 8zN($NNI$$F0:n
- 0\F0!&1?HBG=NO
- A`:nJ}K!$N7W2h

>/J/Hb>-MhE*K3li$NMW7o$rK~B-G-$k2DG=@-$r;}$D7A$G!$%7%9%F%`$r9=@. $9$k$Y$-$G$"$k!%K\8&5f$G$OA4?H$GJ*BNA`:n$r9T$&?M4V7?%m%\%C%H%7%9%F%`$N9=@.K!$H $7$F!$0J2<$NE@$r=E;k$7$?%7%9%F%`9=@.K!$rDs0F$9$k!%

(i) 9TF0$N;XNa$OCj>]E*$J%l%Y%k$GM?$(!$F0:n!&5!G=$NB?$/$O<+N'E*$K9T$&$3$H $rL\;X$7$?OHAH$G$"$k3H

(ii) 463P$H9TF0$,L)@\$K7kSIU/5!G=$r;}$D3H

(iii) <+F03MF@9k;EAH$_$rAH$_9~$`3H$,$G$-$k3H

(iv) J*BN$N=ENL!&Bg$-$5!&9E$5!&7A>u$r@53N$KCNi:Hb!$A`:n$G$-$k3H

%?H7$F!$$3$&$7$?<jK!$KhjF@$?%=%U%H%&%′%"$rMxMQ9k3H$,$G$-$k$H9M$(
il$k!%

K\8&5f$GCf?4$K?x$($F$$$k2]BjG"$kJ*BNA‘:n$K2r@OE*<jK!$rMQ$$$k$?$aKO!$A‘:nBP>]$K4X9kCN<1$,I,MW$G$"$k!%L$CNJ*BN$NA‘:n$K2r@OE*<jK!$rMQ$$$k3H$,$G$-$kNO!$$=$NJ*BN$N=ENL$N1F6A$,L5;kG-$k>l9g$K8Bil$k!%$^$?!$7A>u$,L$CN$NJ*BN$KBP7F$O!$2?i+$NJ}K! (;k3P>pJs$J$I) $G7A>u$r?dDj7J1lP3$&$7$?<jK!$OMxMQG-$J$$!%

<B83E*<jK!$O?M4V$N=u1r<ZjF%=%U%H%&%′%"$rF3=P$9k3HKJj!$2r@O$,:FqJ>l9g$dIT3NDjMWAG$KBP1~7J1lPJiJ$$>l9g$KM-8z$G$"$k$,!$MM!9$J5!G=$r0l$D0l$D<B83E*$K<B8=$7$F$$$/NO!$$"$^$j8=<BE*GO$J$$!%

7?$,$C$F!$L$CNJ*BN$NA‘:n$r;kLn$KF~lk>l9g!$C5:wE*<jK!$9Jo$A<+8JAH?%2=$NOHAH$rF3F~$G$-$kh&$K%7%9%F%‘$r9=@.9k3H$,I,?\$HJk$H9M$(il$k!%

ii) 3,AX9=B$$K$*$1$k<+8JAH?%2=

3,AX9=B$$K$*$1$k<+8JAH?%2=$O!$3F3,AXFb$G$N<+8JAH?%2=$H!$3,AX9=B$$N<+8JAH?%2=$,9M$(il$k!%

3F3,AXFbGN<+8JAH?%2=

A09‘$G=R$Y$?$N$O!$@3&HNAj8_:nMQKh$k5!G=$rC4$&AX$NFbIt$N<+8JAH?%2=$G$"$k!%F1MM$K!$Nc$($PF0:n$N<j=g$rC4$&AX$,$"$kH9kH!$$=NINh$&$J=g=xGI$NF0:n$r9T$($P!$=jK>$N7k2L$,F@$ilk$+$r!$<+8JAH?%E*$K3MF@9k$H$$$&N,!$3FAX$K$*$1$k<+8JAH?%2=$G$"$k!%A4FNAXK*$$$F3&7?C5:wE*<jK!$,M-8z$+I&$+$O0l35KO8@$($:!$3FAX$4HK:GE,$J<jK!$rA*Br7J1lPJiJ$$!%

9=B$<+BN$N<+8JAH?%2=

E,@Z$J9=B$$rC5:w9k$H$$$&9M$(J}$G$"$k!% 3.1.1@a$G=R$Y$? BeNet[34] $r!$9=B$$NJQ2=$,2DG=$Jh&$K3HD%$7$?Nc [38] $O!$$3$&$7$?9M$(J}$NF3F~$,2DG=$J%7%9%F%‘$NDs0FG"kH8@$($k!%9=B$$NJQ2=$r2DG=$K9k3HOG$-$F$b!$$3$N9M$(J}$O9=B$$NI>2A4p=‘$N@_Dj$,Fq7/!$$=b=$b:GE,$J9=B$$H$$$&bN$,$o$+$i$J$$$$?aK!$MM!9$J9=B$$,Ds0F5l$F$$$k$H$$$&8=>u$r9M$(kH!$<B:]$K9=B$<+BN$N<+8JAH?%2=$H$$$&35G0$rF3F~$9kKO^$@$^$@2]Bj$,B?$$$H8@$($k!%

$,M}A[E*$J%7%9%F%'G"k+Oo$+$i$J$$$,!$9bEY$JCNG=$N<B8=$N$?$aKO!$Hs>o$KJ# ;($J9=B$$,I,MWJNGO$J$$$+$H;W$o$;$k!%

%m%\%C%H$N%7%9%F%'$rAX9=B$$G9=@.9kNO!$CNG=$N<B8=N?aH$$$&hjO'$7 mbCH8=<BE*$J!$$o$+$jd9$/07$$$d$9$$7A$G%7%9%F%'$r9=C[9k$?$a$N<jK!$G$"$k $HB*$(k3HbG-$k!%

3.1.3 <+8JAH?%2=

3.1.1@a$*$h$S 3.1.2@a$G$O!$%7%9%F%'$N9=B$$K4X9k5DO@$r9T$C$?$,!$K\@a$G$O!$ =jK>$N9TF0$r<B8=9kJ}K!KD$$$F!$<+8JAH?%2=$JINC5:wE*<jK!$NMxMQ$K4X9k5DO@ $r9T$&!%

i) 5!G=$r<B8=$9$k%=%U%H%&%'%"$NF3=P

3.1.1@aGO!$ “5!G=” $r<B8=$9$k%=%U%H%&%'%"$r$$$+K7$FF3=P$9k+KD$$$F$O 5DO@$7J+C?!%5!G=$r<B8=$9$k%=%U%H%&%'%"$rF3=P9k<jCJH7$F9M$(il$kJ}K!$r 0J2<$K5s$2!$$=$NFCD'$r=RYk!%

2r@OE*<jK!

M}O@E*$J7W;;$KI,MW$J%b%G%k2=$d!$2>Dj$r@_1F!$$=lK4p$E$$$F2r@OE*$K2r$r 5a$a!$$=lr5!G=H7$F<BAu$9kH$$$&<jK!G"$k!%

NcH7$F?M4V7?%m%\%C%H$N%P%i%s%9@)8f$H$$$&5!G=$r9M$(kH!$%m%\%C%H$N4v2? 3XE*9=B$$d=ENLJI$NJ*M}E*$J%b%G%k$H!$;Q@*%;%s%5$d%H%k%/%;%s%5$JIN>pJs $+$i!$%P%i%s%9$r0];}9k$?$a$N@)8f$rM}O@E*$K7W;;$7!$$=lr%$%s%W%j%a%s%H 9k$H$$$&3H$r0UL#$9$k!%

2r@OE*<jK!$O!$30Mp$dIT3NDjMWAG$NL5$$>l9g$O!$Hs>o$KM-8z$G$"$j!$%m%\%C%H$N 5!G=$r<B8=$9$k<jCJ$H7F:G$bIQHK$KMxMQ5lF-$?!%

C5:wE*<jK!

M}O@E*$J%b%G%k2=$N:FqJ5!G=KBP7FO!$<+8JAH?%2=$JINMxMQ$,M-8z$J>l9g $,$"$k!%$3$N>l9g!$2r@OE*$KF3=P$7$?65;U%=%U%H%&%'%"$rMxMQ9k65;U$"$j<+8J AH?%2=$H!$=jK>9k5!G=$NC#@.EY$rI>2A9k4p='$r@_$1$k65;U$J$7<+8JAH?%2=$, 9M$($ilk!%

<B83E*<jK!

2?i+$NJ}K!$G%=%U%H%&%'%"$N%W%m%H%?%$%W$r:n@.$7!$$=lr<B83Kh$jD4@0$9 k3HKhj!$=jK>$N5!G=$r<B8=$9kH$$$&<jK!G"$k!%$"$^$j3N<B@-$,$"kH $O8@$($J$$$,!$%b%G%k2=$d2r@O$,:$FqG"$k>l9g!$<+8JAH?%2=N?aN=i4|%G!<

2~A1$,$"C?!%<B@$3&$H$$$&J#;($J4D6-$H$NAj8_:nMQ$Khk5!G=%b%8%e!<%k$O!$%O!<%I %&%’%"$K0MB8$9$k5!G=$HddCj>]EY$N9b$$%b%8%e!<%k$,:.:_$7F@$k!%$3$&$7$?LdBj$r2~ A1$9$k$?$a$K!$3F5!G=%b%8%e!<%k$rCj>]2=$7!$5-=R$H<BAu$rL@3N$KJ,N%9Y$-$G$"$k$H $$$&<gD%$,$"$k!%2,$Khk BeNet $O!$%O!<%I%&%’%"$K0MB8$7$J$$35G0>e$N%b%8%e!<%k 5-=R%b%G%k$G$"$k [34]!%

$^$?!$ Brooks $N<gD%$O!$=>Mh$N3,AX2=5l$F$$$?%"!<%-%F%/%A%c$r!$%W%l!<%s$J 9=B$$K9kbNG"C?$,!$$"$kDxEY9b<!$NCNG=$O<B8=$,:FqG$"$k$H$$$&B&LL$r;}$C $F$$$?!%3&7?LdBj$r2r7h$9k?$a!$ Brooks $N<gD%$H$OL7=b$9k,!$%5%V%5%s%W %7%g%s!&%"!<%-%F%/%A%c$NOHAH$r;}AD$D!$3,AXE*$K9=B$2=5l$?%"!<%-%F%/%A%c$NDs 0FbJ5l$F$$$k!%

Connell $O!$ SSS $H$$$&;~4V!&6u4V$,$=l>$lO"B3$+I&$+$NAH9g$;$G!$ 3 DNAX $NJ,$1J}$rDj5A$7$?%7%9%F%‘$rDs0F7? [35]!% Bonasso $O!$ 3T $H$$$&;~4V!&%P%s%I I}JI$N$$$/D+$N dimension K*$$$F!$$=NAF5GINAXKJ,1k$+$r7hak$H$$ $&7A$N%7%9%F%‘$rDs0F$7$? [36]!%$$$:lb;0AX9=B$$N%"!<%-%F%/%A%c$G!$0lHV2<NAX, %5%V%5%s%W%7%g%sNAXG$"$k!%

3.1.2 3,AXE*%7%9%F%‘9=@.

3.1.1@aGN5DO@$O!$5!G=$N<B8=$NJ}K!O@G"C?!% Brooks $O!$3,AXE*9=B$$r<h$j J’$&3HKhCF<B;~4V@-$r;}$ADD!$9*L/$K5!G=%b%8%e!<%krAH_N)Fk3HKh$j %m%P%9%H$K9TF0$9$k3H$,$G$-$k3H$r<($7$?$,!$ 3.1.1@a$N:G=*%Q%i%0%i%U$K=RY? h&$K!$$"$kDxEY0J>e$NCNG=$N<B8=$K$O!$$=l@1G$OITB-$G$"$kH9$k<gD%$b$"$k!% 9JoA!$4D6-$NJQ2=$KAGAa$/BP1~9k3HNG$-$k$?$a$NOHAH$r2<0L$K;}$ADD!$=> Mh$N?M9)CNG=$G9T$olF$$$kh&$J5-9f=hM}$JIb>e0L$G9T$(kh$&$J!$3,AXE*$JOHAH bI,MWGOJ$$$+$H$$$&3HG"$k!%

3&7?3,AXE*$J9=@.K!$O!$<B;~4V=hM}$H5-9f=hM}JI$NAjH?$9kkMWAG$rN>N)$5$; k?aNOHAH$H8@$(!$3FAXK*1k=hM}$rB>NAXr0U<1$;$:$K07$&3HNG$-$k%7%9%F %‘9=@.K!G"$k!%%=%U%H%&%’%"%l%Y%k$@1GJ/!$%m%\%C%H%7%9%F%‘A4BN$K4X7F$b3, AXE*9=@.K!$N5DO@$,$"FO$^$k!%9JoA!$K\8&5f$G:NMQ7F$$$k%j%b!<%H%V%l%$%s!& %"%W%m!<%A [37] $b!$%7%9%F%‘$r%\%G%#$H%V%l%$%s$H$$$&7AGBg-$/FsAX$KJ,N%9k$3 HKhj!$%"%/%A%e%(!<%?$d9=B$It:‘$JIN%\%G%#$N@_7W$K4X9k5DO@$H!$%=%U%H%&%’ %"$K4X9k5DO@$r40A4$KFHN)$K07$&$3HNG-$kOHAHG"kH8@$&3H$,G-$k!%

H3mG!$?M4V$NG>$O3,AX9=B$$KJC$F$$$kh&$K8+$(k,!$$=$N9=B$$O0l0UKO 7h$^$i$J$$ItJ,$bB?!9$"$j!$$"kLL+$i8+$?AX9=B$$O!JLNLL$+$i8+kH$^$?JL$JAX9= B$$,9M$($ilk>l9gb"$k!%$^$?!$L@3NKAX,J,N%7F$$$kNGOJ$/!$AXH7$FB*$($?9=B$$r8Y$07k9g$NB8:_b"$k!%$=7F!$AX9=B$$b7h7F$F0l<!85E*$JbNGO$J$$!%G>

3.1 %m%\%C%H%7%9%F%`$N9=@.K!$N8&5f

Bh 2.2@a$K=R$Y$??M4V7?%m%\%C%H$NJ*BNA`:nK*1kFCD9$r@8$+$72]Bj$r2r7h9k
$?$aKO!$%\%G%#$N:n$jJ}$+$iF,G>$NItJ,$N%=%U%H%&%′%"$^$G4^$a$?%m%\%C%H%7%9%F%`
9=@.K!$N8&5f$,=EMWG"$k!%

%m%\%C%H$N8&5f$O!$1?F0@)8f!$G′<1!$%W%i%s%K%s%0$J$IMM!9$JB&LL$K>GE@$rEvFF
?JailF$-$?$,!$$=li$rE}9g$7$F<B@$3&$GCNE*$K<+N′9TF0$9$k%m%\%C%H$r<B8=$9
k3HO0MA3H7$F:$FqG"$k!%$=$NM}M3$N0lDK!$%m%\%C%H$N>pJs%7%9%F%`$KMWAG
5!G=rAH_9~$_!$E}9g9kJ}K!O@$,==J,$K3NN)7F$$$J$$$3H,5s2ilk!%5!G=E}9g
$NJ}K!$r3NN)9kKO!$%7%9%F%`%"!<%-%F%/%A%c$,=EMWG"$j!$6aG/!$$3l^$G9T$o$l
F-$?MM!9$J5!G=$N8&5f$rAH$_9~$`$?$a$N!$%m%\%C%H%7%9%F%`$N8&5f$,@9sK9Tol$F
$$$k!%K\O@J8GO!$$3$&$7$?6aG/$N%m%\%C%H%7%9%F%`9=@.K!$N8&5f$r;29M$K!$?M4V7?%m
%\%C%HKh$kJ*BNA`:n$r9T$&$?$a$N%m%\%C%H%7%9%F%`$N9=@.K!$r9M;!$9$k!%

3.1.1 <B@$3&$H$NAj8_:nMQ$Khk5!G=$N<B8=

<B@$3&$NCNG=$r<B8=$9$k%7%9%F%`$H7F!$4D6-$H$NAj8_:nMQ$N=EMW@-$NG′<1$,9-
$^$C$F$$$k!% Brooks $O!$%;%s%5>pJs$N6I=jE*$GB(1~E*$J%U%#!<%I%P%C%/$r;}$DHsF14|
JBNs%7%9%F%`KhCF0\F0%m%\%C%H$,<B@$3&$G<+N′E*$J?6Iq$$$r8+$;$k3H$r<($7!$46
3P$H1?F0$Khk4D6-HNAj8_:nMQ$N=EMW@-$r<gD%7? [31]!%

3&7?<gD%$O!$%m%\%C%H%7%9%F%`$N@_7WO@$KB?Bg$J1F6A$rM?$($?!%$=$l$^$G$N%m
%\%C%H%7%9%F%`$O!$%?%9%/"*9TF07W2h"*F0:n<j=g"*F0:n$H$$$&3,AXE*$G9=B$2=5l$?
%H%C%W%@%&%s$J%"%W%m!<%A$,<gN.$@$C$?!%$3lKBP$7!$ Brooks $NDs0F$7$?%5%V%5%s%W
%7%g%s!&%"!<%-%F%/%A%c [32] $O!$463P$H1?F0$rL)@\$K7kSIU1$k<B@$3&HNAj8_:nMQ
Kh$k “5!G=” $r%b%8%e!<%k2=$7!$J#?t$N5!G=$N>e$K%m%P%9%H$J%?%9%/?k9TG=NO$,G-
$"$,kH$$$&!$%\%H%`%"%C%W$J%"%W%m!<%AKh$j9=C[$7h&$H$$$&OHAH$@$C$?!%$3$l
$O!$C`<!E*$KJ,2r$5lF$$$?$=$l$^$G$N9TF07W2hK!$H$O0c$C$F!$5!G=Kh$jJ,2r$5l?
9TF0MWAG$,JBNs$KF0:n9k$H$$$&7ABV$G!$E}9g5l$?9TF0$r<B8=9k$H$$$&0UL#Gb!$
;B?7$JOHAH$@C?!%

B?;X%O%s%I$N@)8f$K3&7?OHAH$rMxMQ$9kNcb$"$j [33]!$?M4V7?%m%\%C%H$NA4?H
F0:nKbE,MQG-kH9M$($ilk!%

463P$H9TF0$rD>@\7ks@$$$o$P “H?<M” N_$+$iJk5!G=$N=E>vhj@8$8$kCNE*$K
8+$($k9TF0$K!$CNG=$NK\<A$,$"$kNGOJ$$$+Hb;Wo;$?$,!$$=$N8e$=$NC1=c$H$b8@
$($kOHAH$@$1GOMM!9$JLdBjE@$,$"$k3H$b;XE&$5$l!$2~A1$9$k$?$a$NMM!9$J;n$_$,Ds
0F5l$?!%

%5%V%5%s%W%7%g%s!&%"!<%-%F%/%A%c$NLdBjE@$r2~A1$9$k;n$_$N0lDK!$5-=RJ}K!$N

Bh **3** >O

?M4V7?%m%\%C%H%7%9%F%`$N9=@.K!

5iKO!$J*BN$r;}C?>uBVGN0\F0$d!$ 2.1.2$G=R$Y$?%0%i%9%W%l%9!&%^%K%T%e %l!<%7%g%s!$$9Jo$A2!$9!&E>$,$9JI$NA`:n$N:]$N0\F0$O!$J*BN$N=E$5!&K`;$$JIN IT3NDjMWAGKBP7$F4h7r$+$D=@Fp$J0\F0G=NO$,5a$ail$k!%

B?MM$J>u67$K$*$1$kA`:n

1.1.1$N?M4V$N@83h$N>l$K$*$1$k?M4V7?%m%\%C%H$K$*$$$F=RY?h&$K!$?M4V7?%m %\%C%H$O?M4V$+$i3VN%$5l?4D6-GOJ/!$?M4V$HF1$86u4V$G3hF0$9$k3H$,4|BT$5$l $k!%$=N?$a!$J*BNA`:n$r9T$&;~$N>u67$b!$B?MM$G$"$k3H$,A[Dj$5lk!%

7?$,$C$F!$ 2.2.1$NB?MM$JA`:nJ}K!$N9`$G=R$Y$?A`:nJ}K!$NB?MM@-$@$1$G$J$/!$ A`:n$r9T$&:]$N<~jN>u67$dA`:nBP>]$NG[CV>u67$J$I$bB?MM$G$"$k$3$H$,M=A[$G$-$k!% A`:n$r9T$&:]$N<~jN>u67$NB?MM@-$H$O!$Nc$($PB>$NJ*BN$H43>D7FOJiJ$$$JIH $$$C$?$3HG$"$j!$A`:nBP>]$NG[CV>u67$NB?MM@-$H$O!$Nc$($P4y$N2<$+$i<h$j=P7?$j C*$N>eKN$;$kJI$H$$$C$?$3HG$"$k!%

3l$^$G!$9)>l$JIN%m%\%C%HN?aK@0Hw5l$?4D6-$G9TolF-$?!$@0Hw5l $?>u67$G$NA`:nCf?4$+$i!$IB1!!&%*%U%#%9!$$5iK$O2HDmFb$H!$CJ3,E*$K@0Hw5l$F$$ $J$$4D6-GN:n6H$r5a$ail$F$$$/$H9M$(il$k!%$=$N:]$KI,MWHJkN$O!$%m%\%C%H $,<+$i>u67$rG'<1$7!$$$$+K7$F%?%9%/$r?k9T9k$+$r7W2h9k3HG"$k!%

$k!%:GE,2r$GJ/Fb!$:G>.8BI,MW$J2DHB=ENL$r<B8=$9$k2r$r5aak3H$,$G$-$k3H$,=EMW$G!$C5:wE*<jK!$O0lDNM-8z$J<jCJ$G$"$k$H9M$(il$k!%

$^$?!$$3$&$7$?8zN($NNI$$A`:nJ}K!$r5a$a$?7k2L!$B?MM$JA`:nJ}K!$r;}$D3HKbJk$H9M$(il$k!%

2.2.2 ?M4V7?%m%\%C%HFCM-$NFCD9$H2]Bj

0J2<GO!$?M4V7?%m%\%C%H$KhkJ*BNA`:n$KFCM-$NFCD'$r5s$2!$$=$NMxE@$d2]Bj$r=R$Y$k!%

;Y;}9=B$IT:_

B?;X%O%s%IKh$kJ*BNA`:n$H7hDjE*$K0[$J$kE@$O!$A4?H$,;Y$($i$l$F$$$J$$$H$$$&E@$G$"$k!%$9$J$o$A!$B?;X%O%s%I$N>l9g$K$O<j<sIt$,%"!<%`$K;Y$($ilF$$$k$,!$?M4V7?%m%\%C%H$NA4?H$rMQ$$$k>l9gKO!$5SIt$KhC$FA4?H$r;Y$($J1lPJiJ$$!%3Nh&$K!$A4?H$r;Y$(DDI,MW$JJ*BNA`:n$r9T$o$J$1$l$P$J$i$J$$E@$,!$$3$l$^$G$N%m%\%C%H$NJ*BNA`:n$KL5$$=EMW$J2]Bj$G$"$k!%

3NE@$O!$8e=R$N0\F0!&1?HBG=NO$*hSB?MM$J>u67$K$*$1$kA`:n$HL)@\$K4X$o$j$r;}$D!%$9$J$o$A!$8GDj$5$l$k>l=j$,L5$$$?$a$KA`:nBP>]$N0\F0$H$$$&%?%9%/$r9M$($?;~!$0\F02DG=$J6u4VE*NN0h$,!$%Y!<%9$K8GDj5l$?%"!<%`$K<hjIU1il$?B?;X%O%s%I$JIh$j9-$$$NObAmsN3H!$<VNX7?$JIN2DF0<0$N%Y!<%9$K<hjIU1il$?%^%K%T%e%l!<%?$HHf3S7Fb+Jj9-$$$H$$$&3H$,8@$($k!%

3l$O!$0\F05!G=$b;M;h$rMxMQ9k?M4V7?%m%\%C%H$,;}$D!$Hs>o$KBg$-$J:n6HG=NO$N2DG=@-$H$$$&FCD9$r<($9$HF1;~$K!$$$$+K=lr@8$+$7$?:n6H7ABV$r<B8=9k$+$H$$$&2]Bj$b<($7$F$$$k!%

0\F0!&1?HBG=NO

Bh 1>O$G!$0\F0$HJ*BNA`:n$O<BMQN?aN%m%\%C%H$K5a$ail$k:G$b4pK\E*$JF0:n$G$"$k$H=R$Y$?!%%Y!<%9$K8GDj5l$?%^%K%T%e%l!<%?$O!$$=$N2DF0HO0OFb$G7+J*$rF0$+$9$3H,G-$J$$$,!$FsB-FsOS$r;}$D%m%\%C%H$O35G0E*KOL58B$N2DF0HO0O$r;}$D!%FsB-Jb9T$O0\F02DG=NN0h$,Hs>o$K9-$$!%$=$7$F!$?M4V$HF1$8@83h6u4V$G3hF0$9kh$&$KJk$H (1.1.1?M4V$N@83h$N>l$K$*$1$k%m%\%C%H$N9`)!$B>$N0\F07ABVGOI&7F$b0\F0$,:FqKJk>l=j$,B?$/Jk!%

?M4V7?%m%\%C%H$N0\F0G=NO$O!$8=:_$O%9%`!<%:$JF0Jb9T$,<B8=$5$l$F$$$k$H$O8@$(!$?M4V$NA4?H$r;H$&0\F0$b4^$a$?0\F0G=NOA4HL$r9M$($l$P!$$^$@$^$@$=$N2DG=@-$r9-$/;D$7$F$$$k$H8@$($k!%F1;~$KJ*BN$r1?HB$9$kG=NO$b!$Bg$-$J2DG=@-$r;}$C$F$*$j!$:#8e$N?M4V7?%m%\%C%H$K$h$kJ*BNA`:nK*1k2]Bj$N0l$DG"$k!%

$r5-=R$9$k<jK!$O!$GKC>$r$-$?$92DG=@-$,9b$$!%?M4V$,M?$($k;XNa$OCj>]E*$J:n6H$N35MW$G!$$=$N?k9T$KI,MW$JB?$/$N5!G=$O%m%\%C%H$,<+N'E*$K9T$&$3H,G-kh$&$JOHAH$,M-8z$G$"$k!%?M4V$,M?$($F$$$?;XNa$O!$>-Mh$O?M4V$GOJ$/%m%\%C%H$N9TF0@8@.It$,=P$9;XNaKJkH9M$($ilk$,!$$=$N;~$Kb3$&$7$?OHAH$,$"$l$P!$9TF0@8@.It$OCj>]EY$N9b$$;XNa$r:G>.8B@8@.$9lP$h$$$H$$$&3HKJkH9M$($ilk!%

%m%\%C%H$N?k9T$9$k%?%9%/ (9TF0) $r!$$=lr9=@.9k8D!9$NF0:n!$$5iKO=lr9=@.9k8D!9$N5!G=$H$$$&h&$K3,AXE*$K9M$($l$P!$MM!9$JDc%l%Y%k$J5!G=$O<+N'E*$K<B9T7D$D!$>e0L$N9TF0%l%Y%k$N;X<($r<u$1F~lk3HNG$-$kOHAH$,M-8z$G$"$k$H9M$(il$k (Fig.2.1)!%

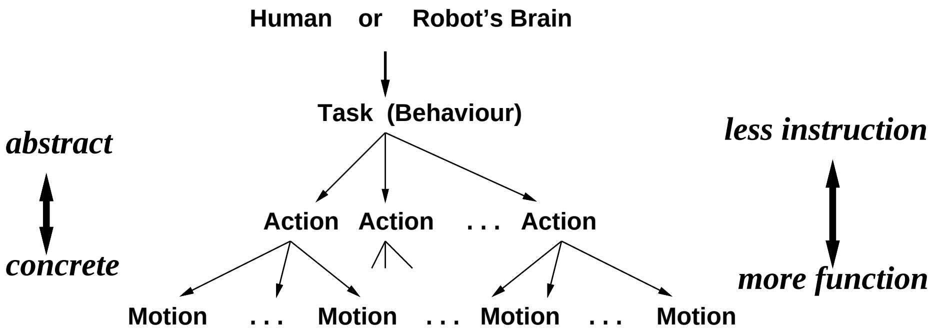


Fig. 2.1 ;XNa$N3,AX
Order hierarchy

8zN($NNI$$A`:nJ}K!

J*BNA`:n$O!$4pK\E*$K?M4V$NFyBNE*IiC4$r7Z8:$9k?aNbNG"$j!$Hf3SE*=E$$J*$N07$$$,5aai$k!%$7$?$,CF!$07$$J}$N8zN($b=EMWKJkG$"$m$&$H9M$($ilk!%$H$$$&NO!$F1$8J*BN$r;}$DNK$b!$;}$AJ}$KhC$F;}$F$k>l9g$H;}FJ$$>l9g$,$"$k!$$H$$$&>u67$bBg$$$K9M$($ilk!%

FC$K?M4V7?%m%\%C%H$O!$A4?H$r;H$&$3HKhC$F%O%s%I$N$_$rMxMQ7F;}$D>l9g$h$j=E$$J*BN$r;}$D3H$,$G$-$k$H9M$(il$k!%B?;X%O%s%I$N>l9g$O!$GD;}J}K!KhCF!$GD;}$N%m%P%9%H@- [26] $,JQ$ok?$a!$;X@h$@$1$rMxMQ$7$FGD;}$9$k>l9g$h$j!$;XESCf%j%s%/$bMxMQ$7$?J}$,8zN($,NI$/!$$h$j=E$$J*BN$r;}$D3H$,$G$-$k$H$$$&3H$KBP1~$9$k!%

%O%s%IN_ ($"$k$$$O;X@hN_) $N>l9g!$5!9=E*9=B$$H%"%/%A%e%(!<%?$N:GBg%H%k%/$+$i!$:GBg2DHB=ENL$,7W;;$G$-$k$,!$A4?H ($"$k$$$OB?;X) $r;H$&>l9g$O!$;}$AJ}$N<oN`$OB?<+M3EY6u4V$K9-$,$k!%:G$b2DHB=ENL$NBg$-$$;}$AJ}$r2r@OE*$K5a$ak3HO6KaF:FqG$"$j!$%Q%i%a!<%?%A%e!<%s$JIN!$<B83E*$J<jK!bFq7$$$G$"$m$&$H9M$($i$l

M?$($FF0:n$N%P%j%(!<%7%g%s$r0l$D0l$DA}d7$F$$$/$H$$$&J}K!GO!$?M4V$,$=$l$>$l $NF0:n$r5-=RG-kI,MW,$"$j!$8e=R$N9TF0$N5-=RK!$,=EMWHJkG$"$m$&$H9M$($i$l $k!%$"$k$$$O!$3X=,$JINC5:wE*<jK!$,M-8z$HJk$H9M$(il$k!%

b&0lDNLdBj$O!$A`:nJ}K!$NA*Br$NLdBj$G$"$k!%A`:nBP>]$NJ*M}E*>r7o$+$i!$G! 2?$KA`:nJ}K!$r7hDj9k$+$H$$$C$?LdBj$K4X9k8&5f$b=EMW$HJk$H9M$(il$k!%

L$CNJ*BNA`:n

A`:nBP>]$N=ENL!&Bg$-$5!&7A>u!&9E$5!&K`;$$JIN>pJs$,M?$(il$J$$>l9g$K!$$I Nh$&$K7FA`:n$r9T$&$+$H$$$&LdBj$b!$:#8e8&5f5l$F$$$/Y-2]BjG"$k!%

MM!9$JJ*BN$rMM!9$JA`:nJ}K!$GA`:n$G$-$k<+M3EY$r;}$C$F$$$k?M4V7?%m%\%C%H$dB? ;X%O%s%I$O!$A`:n$9$kJ*BN$N>r7o$K1~$8$FA`:nJ}K!$rA*Br9kI,MW$,$"$k!%$3$&$7$?B? <+M3EY$N%m%\%C%H$K!$$=$NA*Br;h$HJkA`:nJ}K!$r?M4V$,2r@O$7$F65<($9$k$H$$$&J}K! $O!$?M4V$N<j4V$NLdBj$H!$:GE,$JA`:nJ}K!$r?M4V$,<($9$3H,G-kN$+$H$$$&LdBj$, $"$j!$A`:nJ}K!$KB?:L$J%P%j%(!<%7%g%s ($N2DG=@-) $,$"$k$@$1$K!$$d$,$F$OGKC>$r$- $?$9$N$G$O$J$$$+$H9M$($i$l$k!%F1MM$K!$A`:n$N$?$S$KA`:nBP>]$NJ*M}E*>r7o$r65$($k Nb!$<j4V$NLdBj$H!I,MWJ>pJs$rA4$FM?$(k3H,G-k+$H$$$&LdBj$,$"$k!%
$=$3$G!$$3$&$7$?%m%\%C%H$O!$

- A`:nBP>]$N=ENL!&Bg$-$5!&7A>uEy$NFC@-$r!$%;%s%5$rMQ$$$F<+iCNkG=NO$r;}$D 3H$,M}A[E*$G$"$k!%
- 5i$K!$A`:nBP>]$NFC@-$KE,$7$?A`:nJ}K!$rA*Br$9$k!$$"$k$$$O?7$7$$J}K!$r3+ Bs$G$-$kG=NO$r;}$D3H$bK>$^lk!%

$H$$$&3H$,!$8@$($k!%3&7?G=NO$O!$:#8eB?<+M3EY$N%m%\%C%H$,<BMQ2=5l$F$$$/ $K=>$C$F!$8=:_$N!X;}$C$F$$$?J}$,NI$$!Y$H$$$&>u67$+$i!$!X;}$DI,MW$,$"$k!Y$H$$$& >u67$KJQ2=$7$F$$$/G"m&$H9M$(il$k!%

A`:nBP>]$NFC@-$r<+NO$GCN$k$K$O!$$=$N$?$a$N%;%s%5$r;}$?$M$P$J$i$J$$!%$H$j$o $1L$CNJ*BN$NA`:nN?aK$O!$$NO%;%s%5$"$k$$$O%H%k%/%;%s%5$,I,?\$G$"$k!%?M4V$b!$ =ENLJ*$NA`:n;~$K$O!$$NO3P$N>pJs$r%U%k$KMxMQ$9$k!%B>$K$O!$K`;$$JIN>r7orCNk$? aK$O!$?(3P%;%s%5$,=EMWG"$j!$J*BN$N7A>u!&Bg$-5NCN3PKO!$;k3P>pJs$b=EMW$H JkG"m&$H9M$(il$k!%=ENLJ*$r;}C?>uBVGO!$%b%G%k%Y!<%9$N7W;;GO@53N$J <+J,$N;Q@*rCNk3HOG$-$:!$;Q@*%;%s%5$bI,MWG"m&!%

9TF0$N5-=RK!

2.1.2@a$N4oMQ$JA`:n$N9`Gb?(l?$,!$B?MM$JA4?H9TF0 (B?;X%O%s%I$N>l9g!$B?;X 6(D49TF0) $r!$I,MW$J=hM}$rA4$FMeNs$9kh$&$J<jK!$d!$4X@a<+M3EY6u4VK*$$$FF0:n

2.2 ?M4V7?%m%\%C%HKh$kJ*BNA`:n$K$*$1$kFCD9$H2]Bj

$$$ofk%^%K%T%e%l!<%?Kh$kJ*BNA`:n$,%0%j%C%QMxMQ!&Dj7?F0:n!&4{CNJ*BNA`:n$G$"$C$?$NKBP7!$?M4V7?%m%\%C%H$KhkJ*BNA`:n$OB?MM@-!&=@Fp@-$,FCD'$G$"$k!%K\@a$G$O!$?M4V7?%m%\%C%H$K$h$kJ*BNA`:nK*1kFCD9$H2]Bj$r5s2k!%

2.2.1 B?;X%O%s%I$N1dD9@~>e$K0LCV9kFCD9$H2]Bj

A4?H$rMQ$$$k?M4V7?%m%\%C%H$NJ*BNA`:n$O!$B?;X%O%s%I$K$h$kJ*BNA`:n$HN`;w$7$?E@$,B?$$!%$=$b$=$b!$44$+$i;^J,$+$l$7$?B??t$N<+M3EY$r;}$D%j%s%/$rJ#?tK\;}$D$H$$$&9=B$$NLL$+$i8+$k$H!$B?;X%O%s%I$H?M4V7?%m%\%C%H$OF1$8M}O@$r;}$C$F07$&$3$H$,$G$-$k>lLL$,B?$$!%?M4V7?%m%\%C%H$K$h$kA4?H$rMxMQ$9$kJ*BNA`:n$r!$B?;X%O%s%IKh$kJ*BNA`:n$NH/E87A$N0l$DH7$FB*$(k3H,G-$k!%

7?$,$C$F!$?M4V7?%m%\%C%HKh$kJ*BNA`:n$K$*$1$kFCD'$*hSFCD9!&2]Bj$O!$B?;X%O%s%IN=lH=EJ#9kbN$,$$$/D+$"$k!%0J2<GO!$?M4V7?%m%\%C%H$HB?;X%O%s%I$K6&DL$9$kFCD9!&2]Bj$r=RYk!%

B?<+M3EY6(D4F0:n

B?;X%O%s%IK*1k Whole-Arm Manipulation[25] $O!$$=$N1dD9$KGD;}J*BN$H%m%\%C%H$H$N@\?(ItJ,$r3HBg7? Whole-Hand Manipulation $,$"$j!$$=N5iKH/E8H7$F!$ Whole-Body Manipulation 9JoAA4?HKh$kJ*BNA`:n$H$$$&35G0$bB8:_$9kG$"$m$&!%?M4V7?%m%\%C%H$K$*$$$F$b!$B?;X%O%s%IK*$$$F9TolF-$?B?<+M3EY$r6(D4$5$;$kF0:n$N8&5f$H!$L)@\$J4Xoj$r;}$D$H9M$(il$k!%$5iK$O!$N><T$rE}9gE*$K07$&$3HNG-kh$&$JHFMQ$JOHAH$N8&5f$b=EMW$G$"$k!%

B?MM$JA`:nJ}K!

J*BN$N07$$J}$,C10l%Q%?!<%s$GJ/!$K-IY$J%P%j%(!<%7%g%s$r;}$D3H$,MW5a$5lk!%9JoA!07&J*BNNBg-$5!&7A>u!&=ENL!&9E$5!&I=LL$NK`;$$J$I$N!$MM!9$J>r7o$K1~$8$F!$<j@h$N$_$G;}$D!$OF$KJz$($k!$N><j$G64$`!$N><jGJz(9~$`!$8*$KC4$0!$GXCf$KGXIi$&!$N><j$GJz$($J$,$iI($N>e$K$N$;$k!$$H$$$&$h$&$K!$MM!9$K;}$AJ}$rJQ$($k$3$H$,5a$a$i$l$k!%$5$i$K$O!$;}$A>e$2$k$N$G$O$J$/!$%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%s$r;29M$K!$E>$,$9!&2!$7$F3j$i$9!&%T%\%C%HA`:n$JIKhkJ*BNA`:n$bEvA3I,MW$KJCF/kG$"$m$&$H9M$($ilk!%

3&7?A`:nJ}K!$NB?MM@-$K$O!$Fs$D$NLdBj$,9M$($i$l$k!%0l$D$O!$$$$+$KF0:n$N%P%j%(!<%7%g%s$rA}$d$9$+$H$$$&$3$H$G$"$k!%2?$+$?7$$A`:nJ}K!$r?H$KD1kK$O!$$=lr<B8=9kJ}K!$r?M4V$,M?$($k$+!$%m%\%C%H$,<+J,$G3MF@9k3HKJ$k!%?M4V$,

%F%#%V$JF0:n$rMQ0U9k<jK!Gb!$;X$NF0:n7W2hH7FO=<J,GJ$$$7!$>u67$K1~8?
F0:nJI$r9T$&3HOFq7$$!%$=$N>l$=$N>l$N>u67$K1~8?=@Fp$JF0:n$r9T$&$?aKM-
8z$J!$%;%s%5>pJs$K4p$E$/%j%"%/%F%#%V$JF0:n@)8f$,8&5f$5lF$$$k!%

%j%"%/%F%#%V$JJ}K!$K$O!$%;%s%5$,=EMW$G$"$k!%B?;X%O%s%IKh$kJ*BNA`:n$GMQ$$
il$F$$$k%;%s%5KO!$ 6 <4NO3P%;%s%5$d?(3P%;%s%5!$$=7F!$@\?(LL$NJQ7A$r7WB,$9
$k%;%s%5$JI,$"$k!% 6 <4NO3P%;%s%5$r;X@h$KAuCe9l$P!$>/J/Hb;X@hGD;}$K4X$7
FO!$GD;}NO!$GD;}0LCVEy$NGD;}$K4X9kI,MW$J>pJs$rA4$F3MF@$9k3H,G-$k!%%j
%"%/%F%#%V$JF0:n$O!$%;%s%5$N@-G=$K1F6A$r<u1d9/!$:#8e!$$5iK%;%s%5@-G=$N8~
>e$,5a$ail$F$$$/G"m&$H9M$(il$k!%

Nc$($P!$B??t$N<+M3EYr=l>lINh$&$KF0$+$;$P!$4uK>$NF0:n$,G-k+$H$$$&LdBjG"$k!%2r@OE*$K7W;;7F!$D>@\!$4X@a<+M3EY6u4VK*$$$FF0:n$r7W2h$9k3HO!$7W;;NLE*$K:FqG$"$k>l9g$,B?$$!%$=$N$?$a!$FCDj$N%W%j%_%F%#%V$JF0:n$K9JCF5DO@7?$j!$$=lirAH_9go;k3HKhj=jK>$NF0:n$r9T$*$&$H$$$&%"%W%m!<%AJI [24]!$MM!9$J2r7hJ}K!$,LO:w$5lF$$$k!%

3Nh&$KB?<+M3EY$r4oMQ$K;H$&F0:n$N8&5f$O!$:#8e$b=EMW$J2]Bj$G$"$j!$?M4V$N<j$NF0$-$K3X$V3H$,0l$D$N2r7hJ}K!$HJk$H9M$(il$k!%

%Q%o!<%0%i%9%W

@\?(ItJ,$r3HBg$7$?GD;}$K4X9k8&5f$b9T$olF$$$k!%<j@h!&;X@h$@$1$r@\?($5$;$FJ*BN$rA`:n$9kNGOJ/!$ESCf%j%s%/$d>8$bJ*BN$K@\?(5;$kGD;} [25] $,Ds0F$5l?!%3Nh&$JGD;}$O!$%Q%o!<%0%i%9%W!$$"$k$$$O!$JqMmGD;}$H8FPl$k!%

$^$?!$C1$K@\?(E@$,B?$$GD;}$H$$$&$@$1GJ$/!$GD;};~$N5!9=E*$J<+M3EY$NITB-$Khj!$@)8f$Khi$:30NO$r%-%c%s%;%k9kh&$JFbNO$,@8$8!$GD;}$r3N<B$K9k>l9g$,$"$k!%CfB<$i$O!$$3$&$7$?@-<A$rGD;}$N%m%P%9%H@-$HDj5A$7!$GD;}J*BN$r3FJ}8~$KF0$+$9NKI,MW$J2>A[;E;vN($N7W;;K!$r<($7!$:G>.2>A[;E;vN($G%m%P%9%H@-$rI>2A$9k3HrDs0F7? [26]!%

5i$K!$;X$NJ"$KhkJ*BN$NGD0.$HA`jN1?F03X$K4X$7Fb!$9bLn$iKhCF@0M}5l$F$$$k [27]!%

%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%s

?M4V$,Bg$-$$J*$d=E$$J*$rA`:n$9$k>l9g$K$O!$$7$C$+$j$HDO$s$G;}$A>e$2$FA`:n$9kNGOJ/!$2!$73jYi$;$?$jE>$,7?j7$F1?$s$G$$$k!%Nc$($P%,%9%\%s%YJI$r0\F0$9$k>l9g!$;}$A>e$2k3HOG-J/Fb!$79$1$F2sE>$5$;$J$,$i0\F0$5$;k3H,G-$k!%$3Nh$&$JA`:nJ}K!$O!$$7$C$+$j;}$A>e$2$FA`:n9k>l9g$HHf3S$7$F!$<B9T;~4V!&%(%M%k%.!<$N4QE@$+$iM-Mx$G$"$k!%

3&7?A`:nJ}K!$N8&5f$H$7$F$O!$>2LL>e$KCV$$$F$"$kJ*BN$r2!$9F0:n [28] $d!$E>$,$9F0:n [29] $J$I$,9T$o$l$F$-$?!%Aj;3$i$O$3$&$7$?A`:nJ}K!$r%0%i%9%W%l%9!&%^%K%T%e%l!<%7%g%s$H8F$S!$FsK\$N;X$rMQ$$$?%T%\%C%HA`:n$K$h$kJ*BNA`:n$r9T$$ [30]!$$5iK8&5f$r?J$a$F$$$k!%

%j%"%/%F%#%V$JF0:n

%;%s%5%Y!<%9%H$J%"%W%m!<%A$Khk8&5f$b9T$olF$$$k!%<+M3EY$,B?$/Jj!$@\?(ItJ,$,B?$/$JkH!$J*BN$N1?F0$NM=B,$,6KaFFq7/Jj!$%b%G%k%Y!<%9%H$J2r@OE*%"%W%m!<%AKh$kF0:n7W2h$G$O8B3&$,8+$($F$$$k!%4oMQ$JA`:n$N9`$G=RY?h&$J%W%j%_

2.1 3l$^$G$N%m%\%C%H$KhkJ*BNA`:n

2.1.1 ;:6HMQ%m%\%C%HKh$kJ*BNA`:n

%m%\%C%HKh$kJ*BNA`:n$O!$:G=i$O$$$o$f$k;:6HMQ$N%^%K%T%e%l!<%?$K$h$k$b$N$G!$@hC<$K<h$jIU$1$?%0%j%C%Q$J$I$N%(%s%I%(%U%’%/%?$rMxMQ$7$F$$$?!%$=$3$G$O!$A`:nBP>]$N=ENL!&Bg$-$5!&7A>u!&I=LL$NK`;$$J$I$N>pJs$r$"$i$+$8$aCN$C$F$$$k?M4V$,!$$=$l$rA`:n$G$-$kh&$K%W%m%0%i%`$7$F$$$?!%

$=$N8e$N?JJb$Khj!$%H%k%/%;%s%5$d!$%+%a%i$H2hA|=hM}5;=Q!$;Q@*%;%s%5$JIN%;%s%7%s%05;=Q$,H/C#$7!$MM!9$JA`:nBP>]$b07$($k$h$&$K$J$C$F$-$F$$$k$,!$0MA3$H$7$F<B:]$KJ*BN$K@\?($9$k$N$O%(%s%I%(%U%’%/%?$@$1$G$"$k>l9g$,$[$H$s$I$G$"$k!%%^%K%T%e%l!<%?@hC<$N$_$GJ*BN$rA`:n9k$?$a!07&3HNG$-$k=ENLKHf7$F%"!<%`It$N=ENL$,Hs>o$KBg$-$/$J$C$F$$$k!%%"!<%`It$N=ENL$,Bg$-$$$N$O!$@=B$6H$JIN8=>l$GMxMQ$5lk$?$a!$:n6H$K@:L)5,5aailk$?$aGb$"$k!%

7+$7!$=ENLO"k,MW5a5l$k%9%Z%C%/$rK~$?$9:GDc8B$N=ENL$G$"$j!$@=B$8=>lK*$$$FOd$`$rF@$J$$$H;W$o$l$k!%$3$&$7$?E@$O!$>.7?9b=PNO$N%"%/%A%e%(!<%?$d!$7ZNL9b9d@-9=B$It:`$JIN3+H/KhCF!$>/$7$:$D2r7h5lFf$/$H9M$($ilk!%

2.1.2 B?;X%O%s%I$N8&5f

?M4V$,J*BN$rA`:n$9$k;~$O!$A0 2.1.1@a$K=R$Y$?;:6HMQ%m%\%C%H$h$&$J!$;X@h$@$1$K$h$kA`:nO"$^$j8+il$J$$!%;X@h$@$1Kh$kA`:n$r9T$&$N$O!$Hf3SE*:Y$+$$:n6H$d@53N$J:n6H$r9T$$$?$$;~$K8+$ilk!%3lO^5K;:6HMQ%m%\%C%H$K5a$ail$F$$$kE@G"$k!%

?M4V$N<j$rMxMQ9kJ*BNA`:n$KAjEv$9$k$b$N$K!$B?;X%O%s%I$K$h$kGD;}$J$I$NJ*BNA`:n$,$"$k!%B?;X%O%s%I$KhkJ*BNA`:n$O!$?M4V$N<j$K$h$kJ*BNA`:n$H;w$F!$$=l[$I9b$$@53N@-$OH/4x$G$-$J$$>l9g$,B?$$$,!$B?:L$J<+M3EY$r;H$C$F=@Fp$GB?MM$JJ*BNA`:n$N2DG=@-$r;}$C$F$$$k!%

B?;X%O%s%IKh$kGD;}$N8&5f$O!$$+DF$O0BDjGD;}$dGD;}NOG[J,Nh$&$J;X@hKh$kC1$J$kGD;}$N8&5f$,<g$G$"$C$?!%$7$+$76aG/K*$$$F$O!$B?;X%O%s%I$N5!9=$r@8$+$7$?!$$h$jJ#;($G4oMQ$JGD;}!&A`$j$N8&5f$K=EE@$,0\$C$F$$$k [23]!%0J2<GO!$B?;X%O%s%I$N8&5f$NFCD’$H8=:_$N8&5f$N>u67$r354Q$9$k!%

4oMQ$JA`:n

B?;X%O%s%I$OB?$/$N4X@a<+M3EY$,$"$k$?$a4oMQ$JA`$j$,$G$-!$J*BN$N;}$ABX$($J$IMM!9$J>l9g$K=@Fp$JA`:n$,G-$k9=B$$r;}CF$$$k!%4oMQ$JA`$j$,$G$-$J$/$F$O!$B?;X!&B?4X@a$N0UL#$,$J$$!%$7$+$7!$4oMQ$JA`$j$r<B8=$9kK$O<o!9$NLdBj$,$"$k!%

Bh **2** >O

?M4V7?%m%\%C%HK*1kJ*BNA‘:n

FNBNFb LAN $N<BAuJ}K!$H$=$N$?$a$N%*%s%\%G%#%W%m%;%C%5%b%8%e!<%k$N3+H/!$$=$7 $FEk:\$9$k%;%s%5!&%"%/%A%e%(!<%?$H%V%l%$%s$r7kV?aN%*%s%\%G%#%W%m%;%C%5$N%= %U%H%&%'%"3+H/$H!$%\%G%#$NItJ,$N@_7W$H3+H/KD$$$F=RYk!%

Bh 6>O!VH?<M7?<+N'%b%8%e!<%krAH_9go;$?J*BNA`:n9TF0$N<B8=!W$G$O!$3+H/$7 $??M4V7?%m%\%C%H%7%9%F%`$rMxMQ7?!$<B5!$KhkA4?H$rMxMQ$7$?J*BNA`:n9TF0$N<B8= $H!$Bh 3>O$GDs0F$7$?%7%9%F%`$NM-8z@-$N<B83E*$J8!>ZKD$$$F=RYk!%

Bh 7>O!V7kO@$H:#8e$N2]Bj!&E8K>!WGO!$K\8&5f$N7kO@$r=R$Y!$:#8e$N2]Bj!&E8K> $r=R$Y$k!%

1.2 K\8&5f$NL\E*

0J>e$NGX7J$H 1.1.4@aK*1k5DO@$r9MN8$7!$K\@a$G$OK\8&5f$GCf?4$K?x$($k2]Bj$K$D$$$F=RYk!%

0\F0$HJ*BNA`:n$O!$<BMQ$N$?$a$N%m%\%C%H$K5a$a$i$l$k:G$b4pK\E*$JF0:n$G$"$k[23]!%$J$<$J$i!$<BMQ$N$?$a$N%m%\%C%H$O?M4V$NBe$o$j$K:n6H$r9T$&$3$H$r4|BT$5$l$F$*$j!$$=$N:n6H$NB?$/$O0\F0$HJ*BNA`:n$+$i@.$jN)CF$$$k$+$iG"$k!%?M4V7?%m%\%C%H$N8&5f$KCV$$$F$O!$FsB-Jb9TKh$k0\F0G=NO$N2DG=@-$,3+$1F-$F!$:#8eO3l^$G0J>e$K?M4V7?%m%\%C%HKh$kJ*BNA`:n$N8&5f$,5a$a$i$l$k!%$=$3$G$O!$A`:nBP>]$N7A>u!&=ENL!&9E$5!&I=LL$NK`;$$J$I$N@53N$J>pJs$,$o$+$i$J$/$F$b!$J*BN$rA`:nG-k3HrL\;X7?OHAH$,5a$ail$k!%

$^$?!$=ENLJ*$r0\F0$5$;k?aN8zN($NNI$$A4?H$NMxMQK!!$8zN($NNI$$A`:nJ}K!$r!$>u67$K1~$8$FA*Br$G$-$kOHAH$,5a$ail!$$5iK$O8zN($NNI$$J}K!$NC5:w$r9T$&$?aN3X=,<jK!JI$N8&5f$b=EMWKJ$k!%

K\8&5fGO3NJ*BNA`:n$KCeL\$7!$?M4V7?%m%\%C%H$,A4?H$r;H$C$F$I$N$h$&$KJ*BNA`:n$r9T$&Y-$+!$$^$?$=N?aN%7%9%F%`9=@.$O$I$&$9$k$Y$-$+$J$I$rCf?4$K5DO@$r?J$a!$A4?H$GJ*BNA`:n$r9T$&3HNG$-$k%7%9%F%`$rDs0F$7!$<B83$K4p$E$$$F$=$NM-8z@-$r<($9!%

1.3 K\O@J8$N9=@.

Bh 1>O!V=xO@!WGO!$?M4V7?%m%\%C%H$KhkA4?H$rMxMQ$9$kJ*BNA`:n$N8&5f$,=EMW$G$"$k$H$$$&K\8&5f$NGX7J$HL\E*$r=R$Y!$K\O@J8$N9=@.$r@bL@$9$k!%

Bh 2>O!V?M4V7?%m%\%C%HK*1kJ*BNA`:n!W$G$O!$$^$:$3$l$^$G$N?M4V7?%m%\%C%H0J30$N%m%\%C%H$K$h$kJ*BNA`:n$N8&5f$r354Q$72]Bj$r=RYk!%$=$lirF'$^$($F!$?M4V7?%m%\%C%HKh$kA4?H$rMxMQ9kJ*BNA`:n$NFCD'$H2]Bj$r5s$2!$$=$N2r7hJ}K!$r5DO@9k!%

Bh 3>O!V%m%\%C%H%7%9%F%`$N9=@.K!!W$G$O!$J*BNA`:nN?aN<B:]E*$J%7%9%F%`9=@.K!$r9M;!$9$k!%?M4V7?%m%\%C%H%7%9%F%`$K4X7F3l$^$G$N8&5f!&2]Bj$r35@b$7!$:#8e$N?M4V7?%m%\%C%H%7%9%F%`$N:_$jJ}$NJ}8~@-$r5DO@$7!$A4?H$GJ*BNA`:n$r9T$&$?$a$N?M4V7?%m%\%C%H%7%9%F%`$rDs0F9k!%

Bh 4>O!V<+N'5!G=$rC4$&7O$r2<0LAX$K;}$DG>%7%9%F%`$N3+H/!W$G$O!$Bh 3>O$GDs0F$7$??M4V7?%m%\%C%H%7%9%F%`$N!$<g$K%m%\%C%H$N%V%l%$%sK"$?$k%=%U%H%&%'%"G"$k!$<+N'7OrHw($kG>$NItJ,$N@_7W$H<BAuKD$$$F=RYk!%

Bh 5>O!VBNFb LAN $r;}$D?M4V7?%m%\%C%H$N3+H/!W$G$O!$Bh 3>O$GDs0F$7$??M4V7?%m%\%C%H%7%9%F%`$N!$<g$K%m%\%C%H$N%\%G%#$N@_7W$H3+H/$K$D$$$F=RYk!%?@7P7OH7

%m%\%C%H<+?H$N4v2?E*!&NO3XE*%b%G%k$rCNC?>eG=lrMxMQ9k!$2r@OE*$J%"%W%m!< %A$d%b%G%k%Y!<%9%H$J%"%W%m!<%AKh$kA4?H9TF0$G$"$j!Fpi$+$$COLL$N>e$G$NF0:n$d =ENLJ*$N1?HB$JIN!LCN$N303&$H$N%$%s%?%i%/%7%g%s$r;}$Dh&$JA4?HF0:n$K4X7F $O!$:#8e$N8&5f$,4|BT5l$k!%$3$&$7$?A4?HF0:n$r<B8=9kKO!$%;%s%5>pJs$r%Y!<%9 K7$?E,1~E*%"%W%m!<%A$,=EMWKJCF$/$kG"m&$H9M$(il$k!%

$^$?!$:#8e5;=Q$NH/E8$H6&$K<+M3EY$,A}$(!$B?$/$N4X@a$r6(D4$7$F@)8f7J1l$P JiJ/Jk3H$bM=A[G-!$2r@OE*%"%W%m!<%A$,GKC>r-$?$9$3Hb$"$jF@kG$"$m $&!%3X=,$JIN<+8JAH?%E*$J%"%W%m!<%A$bM-K>$J<jCJ$HJkG"m&$,!$$=$N>l9gL\E* $K1~$8$FKDBg$JC5:w6u4V$r69$akJIN9)IW$,I,MW$G$"$m$&!%

J*BNA`:n

3l$^$G!$A4?H$r;}$D?M4V7?%m%\%C%H$K$*$$$F9TolF-$?J*BNA`:n$K$O!$J*BN$r ;}$C$F=ENL%P%i%s%9$,JQ2=$7!$J*BN$N=ENL$r9MN8$7$J$1$l$P$J$i$J$$Nc$OL5$+$C$?()!% <B:]$N:n6H$K$*$$$F$O!$B?$/$N>l9g$,?M4V$NBe$o$j$K9T$&Hf3SE*=ENL$N$"$kJ*BN$rA`:n 9k3HKJ$j!$J*BN$N=ENL$r9MN8$7$?J*BNA`:n$N8&5f$,5aailk!%

$=$N$?$aKO!$J*BN$N7A>u$NG'<1!$=ENL$NM=B,!$I=LL$NK`;$$NM=B,!$A`:n$N7W2h!$ %;%s%5$rMxMQ$7$?E,1~E*A`:n$H!$2]Bj$OB?$$!%J*BNA`:n$N8&5f$O!$ 1.1.40\F05!G=!$A4 ?H9TF0$K=RY?0\F05!G=!&A4?HF0:n$H$$$C$?MWAG$H$bL)@\$K4Xoj!$?M4V7?%m%\%C%H$K $*$$$F$^$9$^$9=EMWKJ$k2]Bj$G$"$k$H9M$(il$k!%

?MHN%3%_%e%K%1!<%7%g%s

?M4V7?%m%\%C%HKBP7FO!$0\F0!&J*BNA`:n$K2C$($F?M4V$H$N%$%s%?%i%/%7%g%s!& %3%_%e%K%1!<%7%g%s$N$?$a$NF0:n$b5a$a$i$l$F$/$k!%6aG/!$?M$H%m%\%C%H$N%$%s%?%i%/ %7%g%s$K4X$9$k8&5f$O@9$s$K$J$C$F$*$j!$Cf$G$b?M4V7?%m%\%C%H$K$h$k$b$N$OB?$$!%$^ $?!$%"%_%e!<:%a%s%H1~MQ$K$*$$$F$O!$EvA3I,MW$H$J$kG=NO$G!$$=$NJ,Ln$G$b8&5f$,?J $`$3Hb9M$($ilk!%

%H$r@=:n$G$-$kh&KJCF$/$l$P!$4a6q%a!<%+JI$N4k6H$,!$>.7?$N?M4V7?%m%\%C%H$r4a6q$H7F@=B$$9kh$&$KJk$H$$$&2DG=@-$bBg$$$K9M$($ilk!%

1.1.2$N0l$D$N8DBN!&@8J*$H7F$NB8:_$K=RY?h&$J!$0l8DBNH7FNB8:_O^$@$^$@EvJ,@h$N3HG"m&$H9M$(il$k!%8=:_!$%O!<%I%&%'%"E*$K@hC<$K$"$k?M4V7?%m%\%C%HGb!$CNG=LL$G$O?M4V$KOk$+$K5ZPJ$$!%%=%U%H%&%'%"$@$1$NCNG=$G8+Fb!$?M9)CNG=$O;DG0J,iNLG>!IiKJ$k@$3&G7$+?M4V$r>e2sk3H,G-$F$$$J$$[18]!%

0J2<$N3F@a$G$O!$$3$&$7$?GX7J$N2<!$$3l+iN?M4V7?%m%\%C%H$N8&5f$N%]%$%s%H$HJC$F$$$/G"m&2]Bj$r5DO@$9$k!%

0BA4@-

%m%\%C%H$H?M4V$N3hF0HO0O$,%*!<%P!<%i%C%W$7F/kK7?$,$C$F!$%m%\%C%H$N0BA4@-$,$^$9$^$9LdBjHJ$k!%$3l^$G%m%\%C%H$N0BA4@-$N3NJ]$K4X9k8&5f$O;:6HMQ$rCf?4$K?tB?$/9TolF*$j!$:n6H6u4V$NJ,N%!$%U%'!<%k%;!<%U@_7W!$6[5^Dd;_%\%?%s$N:NMQJI$,9T$olF$-$?!%7+$7!$$3l+iO%m%\%C%H<+BN$,?M4V$r<ikh$&$J;EAH$_$,IT2D7gG"$k!%$3lO?M4V7?%m%\%C%H$K8B$C$?$3HGOJ$$$,!FCK?M4V7?%m%\%C%H$O?M4V$H6&B8$9$k%m%\%C%HH7$F0LCV$E1ilk2DG=@-$,9b$$$3H+$i (1.1.1$N?M4V?FOB@-)!$$3l+iN?M4V7?%m%\%C%H$N8&5f$K$*$$$F=EMW$J2]Bj$G$"$k$H9M$(il$k!%

?M4V$H%m%\%C%H$N3hF0HO0O$,=E$J$k>l9g$N0BA4BP:v$O!$>WFM;~$N6[5^Dd;_$d@Q6KE*$J@)8f$Khk%7%g%C%/7Z8:JI$NF0:n@)8f$K2C$($F!$<uF0E*%$%s%T!<%@%s%9@)8f$H0BA4%+%P!<$rJ;MQ9k<jK!$bDs0F$5lF$$$k [19]!%3l$+$i$N?M4V7?%m%\%C%H$K$O!$$3$&$7$?<jK!$NF3F~$r9M$(k3H,=EMWG"$k!%$5iK$O!$2;@<KhkHC5$N8F$S$+$1$d!$>WFM$rM=B,$7$F2sHr$9kJ$I!$?7$?$J0BA4BP:v$N<jK!$N8&5f$b5a$ail$k!%

0\F05!G=

FsB-Jb9TO+Jj%9%`!<%:KJCF$-$?$,!$IT@0CO$NJb9T!$=ENL$r9MN8$7J1lPJi$J$$J*BN$r;}$CFNJb9T!$$5iKJb9TB.EY$rB.$a$FAv9T$J$I!$$^$@$^$@2]Bj$OB?$/$"$k!%$^$?!$E>E]7J$$$3HrA0DsH7$?Jb9T$@1GJ/!$E>E];~$K5/$->e$,$k5!G=$N8&5f [20] [21] JI$b!$=EMWG"kH9M$($ilk!%

$^$?!$:#8e$O0\F0$H$$$&C15!G=GOJ/!$=ENLJ*$r1?HB9k$?$a$N0\F0$JIH$$$C$?!$B>$NF0:n$HINh&$K6(D4$5$;$F0\F0$r9T$&$+$H$$$C$?8&5f$b5aailF$/$k!%

A4?H9TF0

?M4V7?%m%\%C%H$NL%NO$N0lDOA4?H$r6(D4$5$;$?!$%P%j%(!<%7%g%sK-$+$JF0:n$G$"$k!%?M4V7?%m%\%C%H$NA4?H6(D4$r%F!<%^K7$?8&5fNc$O [9] $d [22] $,$"k,!$$$$$:1b

D9Ls 150[cm]!$BN=ELs 60[kg] $NA4?H7?%R%e!<%^%N%$%I$r7W2hCf$G$"$k [11]!%

1996 G/KvKO!$K\ED5;=Q8&5f=j (0J2<%[%s%@) $,3+H/$7$?%R%e!<%^%N%$%I "P2" $, 8x3+$5$l!$$3l^GK$J$$0BDj7??M4Vi7$$Jb9T$r8+$;$?!%FsB-Jb9T$K4X7F$O!$$3l^GKMM!9$J8&5f$,9TolF-$?$, [12]!$ P2 $[$I<BMQ$K6a$$$bNO<B8=5lF*i:!$FsB-Jb9T$N<BMQ2=$N2DG=@-$r$"$d7'0U8+$bL5$$$H$O8@$($J$$>u67$@$C$?!% P2 O3$&7?>u67$r8+;v$KBGGK$7!$8XD%$r62l:$K8@$($P!$%m%\%C%HKh$kFsB-Jb9T$N<B:_>ZL@r7$?Hb8@$($k!%%[%s%@$O!$Jb9T!&J}8~E>49!&3,CJ>:9_!&Bf<V2!$7!&%^%9%?!<%9%l!<%V$Khk%J%C%H2s7JIN1GA|$r8x3+$7!$Jb9T$N%a%+%K%:%'$N5;=QE*%]%$%s%H$OH/I=$7$? [5, 13] $,!$5;=QE*$J>pJs$O$[$HsI8x3+7F$$$J$$!%J*BN$rA':n$9$kF0:n$OBf<V2!7,$"$k$,!$>\$7$$%a%+%K%:%'$O8x3+$5lF$$$:!$$^$?!$=ENLJ*1?HBJI$N:n6H$dA4?H$r6(D4$5$;$?F0:nJI$O!$8x3+5l$F$$$J$$!%7+$7!$4k6H$,<BMQ$rL\;X7F?M4V7?%m%\%C%H$r3+H/$7$?;K>e=i$NNcHJ$j!$:#8e$NF08~$,CmL\$5lk!%

1.1.4 3l$+$i$NA4?H$r;}$D?M4V7?%m%\%C%H$N8&5f

A4?H7?$N?M4V7?%m%\%C%H$N8&5f$O!$%[%s%@$N%R%e!<%^%N%$%I P2 EP>l0J9_!$<BMQ2=$X8~1F$NF;$rJb$_;O$akHM=A[5l$k!%K\@a$G$O!$A4?H$r;}$D?M4V7?%m%\%C%HN3l+iN8&5f$,$INh$&$JE83+r9k+$rM=B,$7!$:#8e$N8&5f$N%]%$%s%HHJkG$"$m$&2]Bj$K$D$$$F5DO@9k!%

6aG/$N9bNp2=<R2q$X$N0\9T$d=w@-$N<R2q?J=P$JIN<R2qE*JQ2=KHbJ$$!$2HDmFb$JIG$NFyBNE*:n6H$NIiC47Z8:$,:#8e$^9^$9K>$^lk!%%m%\%C%HO3$&$7$?<{MW$KBP1~9kbNH7$F!$>-Mh2HDmFbJI$G!$2H;v:n6H$d2p8n!&2p=u$NJd=uJI$N!$FC$KFyBNE*$JLL$G9W8%$7$F$$$/3H$,4|BT$5lk [14]!%

$^$?!$%(%s%?!<%F%$%s%a%s%H!&%"%_%e!<%:%a%s%H$N1~MQ$b$*$*$$$K9M$($ilk!% Utah Bg$H Sarcos Research Inc. $O!$L}05$d6u5$05%"%/%A%e%(!<%?$rMQ$$$F!$?M4V$d62N5$N7A$r7?%m%\%C%H$r@=:n$7F*$j!$Hs>o$K3j$i$+$G9bB.$JF0:n$r<B8=7F$$$k [15]!%3liN%m%\%C%H$O!$ Walt Disney Enterprises KhCF<B:]$K%(%s%?!<%F%$%s%a%s%HMQ$KLrN)$Fil$F$$$k!%%"%_%e!<%:%a%s%H%m%\%C%H$r4k2h!$@=B$!$HNGdr7$F$$$k3t<02q<R%3%3%m$O!$%"%_%e!<%:%a%s%HMQES$N?M4V7?$N%m%\%C%H$b3+H/$7F*$j!$%"%_%e!<%:%a%s%H%m%\%C%H$N8=>u$r$^$H$a!$8=:_NBg-$J2]Bj$H7F>pJsEAC#$NAPJ}8~@-$H!$%m%\%C%H (%"%_%e!<%:$5lk) ?M4V$N4V$K:t$r@_$1J1lPJi$J$$E@$r5s$2$F$$$k [16]!% Sarcos $d%3%3%m$N%m%\%C%H$O!$B-$,8GDj$5lF$*$j0\F0G=NO$d%P%i%s%9$JIO9MN8$5$l$F$$$J$$$,!$$$$:lO<+N'7?NbNb3+H/5lkG$"$m$&$H9M$($ilk!%

%=%K!<3t<02q<R$N3+H/$7$F$$$k%Z%C%H%m%\%C%H [17] $b!$8=:_$O;MB-$NF0J*$N7A$r7F$$$k$,!$%"%_%e!<%:%a%s%HE*$J0UL#$r6/$/;}$C$F$$$k!%>-Mh$O!$%"%_%e!<%:%a%s%HE*$J0UL#$G$N?M4V7?%m%\%C%H$KH/E8$9$k2DG=@-$r;}$C$F$$$k!%:#8e!$0B2A$K?M4V7?%m%\%C

$j!$MM!9$J<+A38=>]$,3l$^$G$K2r$-L@$+$5lF$-$?!%@8J*$N?J2=$d@.D9$N;EAH$_!$$=7FCNG=$N;EAH$_!&:,8;$r2rL@$7$?$$$H$$$&M_5a$O>o$KB8:_7?$,!$2J3X$,H/C#$7$?8=:_$bJ*FfKJq^l?ItJ,$,Hs>o$KBg$-$$J,LnG"$k!% 21 @$5*$OG>$N@$5*$H$b8@$o$l!$$=$N;EAH$_$r2rL@$7h&$H8&5f$K<hjAH‘8&5f<T$O!$G>2J3X!&?@7P2J3X!&G′CN?4M}3X!&?4M}3XJI$N0e3X!&M}3X7OJ,Ln$+$i!$%m%\%C%H9)3X!&?M9)CNG=$H$$$C$?9)3X7OJ,Ln$^$GB?4t$Ko?CFB8:_9k!%

3liN8&5f$O!$$*$=$m7/J#;($G!$8=:_$N5;=QNO$dM}O@$r;}$CF7FbE~DlF1$8G=NO$NbN$r:n$k3HNG$-$J$$$/$i$$AG@2i7$/9bEY$JbN$r!$2?H+:n$j>e$2$?$$$H$$$&5$;}$AGb$"$j!$F1;~$K!$?M4V$,<+J,<+?HrCNj$?$$$H$$$&6/$$M_5aGb$"$k!%?M4V7?%m%\%C%H$N8&5f$r!$@8J*$N;EAH$_$r:F8=9k3H$rL\;X$7$F$$$k$HB*$($k8&5f<T$b$$$kG"m&!%

:#O^$@L4J*8l$G$"$k$,!$:G=*E*$J%m%\%C%H$H7F%m%\%C%H8&5f<T$,?4$KIA$/$N$O!$0lDN8DBN!&@8J*H7FN?M4V7?%m%\%C%HG"k+bCNl$J$$!%

1.1.3 3l$^$G$NA4?H$r;}$D?M4V7?%m%\%C%H

?M4V7?%m%\%C%H$K4X$9$k8&5f$OMM!9JH3m$G9T$olF$$$k$,!$A4?H$r;}$D?M4V7?%m%\%C%H$N8&5f$O$^$@$=$l$[$IB?$/$O$J$$!%

@$3&$G:G=i$K8&5f$N$?$a$K:n$il?FsB-FsOS$NA4?H%?%$%W$N?M4V7?%m%\%C%H$O!$1973 G/$K:nil$? WABOT-1[1] G"$k!%@EJb9T$G0lJb$K 45 IC$+$+kH$$$&bN$@$C$?$,!$F|K\8l$G$N4JC1$JBPOC!$ 2 4c;kKh$kBP>]J*$NG′<1$HJ}8~!&5wN%$NB,Dj!$?(3P$r;}$DN><j$GJ*BN$NGD0.$d0\F0$r9T$&3HbG$-$?!%$=$l$+$i 25 G/$"$^jN4V$K!$MM!9$J?M4V7?%m%\%C%H$,8&5f5lF-$F$$$k!%

5i$K2CF#$i$O 1984 G/$K WABOT-2 $r3+H/$7$? [2]!% WABOT-2 $O80HW3Z4o1iAU$rL\I8$K3+H/$5l?!%F|K\8l$G2qOC$r9T$$!$3ZIh$rL\$GG′<1$7!$N><j!&N>B-$GEE;R%*%k%,%s$r1iAU9k5!G=$r;}$A!$?M4V$N2N@<$N2;DxG′<1$r9T$&$3HG!$2N@<$N2;Dx$K9g$o$;$F%*%k%,%s$NH<AU$r9k3HbG$-$?!%

Aa0pEDBg3X$G 1992 G/$K3+;O5l$?%R%e!<%^%N%$%I!&%W%m%8%′%/%HGO!$?M4V7?%m%\%C%H$K4XokMM!9$J8&5f$,9TolF*$j!$A4?H7?$N?M4V7?%m%\%C%H$H7F$O!$ 1997 G/$K WABIAN $,3+H/$5l? [8, 6]!% WABIAN $O!$ 2 B-Jb9T5!9=$r%Y!<%9$KBN44$H 2 4c$rM-9kF,It$HN>OS$r;}$A!$A4?H$r6(D4$7$?F0:n [9] JI$,<B8=$5lF$$$k!%J*BN$r;}$C$?>uBV$G$NJb9T$JIb9Tol$F$$$k$,!$J*BN$N=ENL$r9MN8$9$kI,MWNJ$$DxEY$N=ENL$NJ*BN$r07$CF*$j!$L$CNJ*BN$NA‘:nJI$r9T$($kOHAH$O;}CF$$$J$$!%

1996 G/KO!$EE;R5;=QAm9g8&5f=j$K$*$$$F!$?M4V!&%m%\%C%H!&4D6-4V$NAj8_:nMQ$NM}2r$HLdBjH/7!N?aN<B83E*%"%W%m!<%A$N<jCJ$H7F!$?M4V7?%m%\%C%H$N8&5f$,3+;O$5l? [10]!%BNFb LAN $r;}$A!$30It7W;;5!$H$NDL?.@~$HEE8;@~N_$r0z$-=P$9!$?H

2J3XE*9%4q?4

?M4V$=$NbN$N;EAH$_$r2rL@$7!$$=lr?M4V$N<j$G:nj?$$$H$$$&5$;}$A$K!$?M4V7?%m%\%C%H$NB8:_0U5A$r8+$$=P$99M$(J}b"$k!%$3lK$D$$$F$O!$ 1.1.2$G>\$7$/=R$Y$k!%

?M4V$N@83h$N>lK*1k%m%\%C%H

?M4V$N9T$C$F$$$kMM!9$J:n6H$NBe9T<TH7$F%m%\%C%H$r0LCVIU1k;~!$8=:_9)>l$JIG?M4V$H6u4VE*$KJ,N%5l$?>l=j$G3hF0$7$F$$$k%m%\%C%H$b!$?M4V$HF1$86u4V$G3hF0$9kI,MW,=PF/kG$"$m$&$H9M$($ilk!%?M4V$N@83h$9$k6u4V$K$O!$F;6q!&2H6q!&3,CJJI!$?M4V$K9go;$?:n$jKJCF$$$kbN$,Hs>o$KB?$$!%$=$3$G9TF0$9kh$&$KJC$F!$?M4VMQ$K:n$ilF$$$kF;6q$r07$$!$?M4VMQ$K:nil$F$$$k6u4V$r0\F0$9k?aK$O!$%m%\%C%H$O?M4V$N7Ar7$F$$$?J}$,M-Mx$JLL$,Hs>o$KB?$$!%

1.1.2 ?M4V7?%m%\%C%H$NM}A[A|

%m%\%C%H$H$$$&C18l$,%A%c%Z%C%/$N5:6J “R.U.R.”[7] $G=i$a$F8l$ilF0JMh!$$3l^$GB?$/$N?M!9$N4V$G!$?M4V$HF1$88+$+$1$r;}$C$??MB$J*H7$FA[A|$rU/i^$;$kB8:_$@$C$?!%$+i/$j?M7A$N;~Be$+$i!$?M4V$N<j$G?M4V$HF1$8$bNr:nj?$$$H$$$&4jK>$r;}$D?M!9$O>o$KB8:_7?!%%m%\%C%H$O!$;:6HMQ%^%K%T%e%l!<%?$H$$$&7A$G<BMQE*$J@$3&$G1~MQ5lkh$&$KJC$F5W$7$$$,!$%m%\%C%H8&5f<T$N?4NCfK$O$$$D$b?M4V7?%m%\%C%H$r<B8=7?$$$H$$$&5$;}$A$,$"C?!%?M!9$,%m%\%C%H$H$$$&C18l$G;W$$Ib$+$YkN$O!$%^%K%T%e%l!<%?GOJ/?M4V7?%m%\%C%HGO$J$$$@m&$+!%

?M4V7?%m%\%C%H$NM}A[A|$OINh&JbN@m&$+!%?M4V7?%m%\%C%H$NMW!&ITMWOHb+$/$H7F!$?M$N5aakM}A[E*$J;Q$O<!$N 2 <oN`$KJ,1ilkNGOJ$$$+$H9M$($?!%

?M4V$NMxJX$rO+$kB8:_

3l$^$G<BMQ2=5lF-$?%m%\%C%H$N1dD9@~>e$K?M4V7?%m%\%C%H$r0LCVIU1kbNG"$k!%$D$^$j!$9)>l$GAH$_N)$F:n6H$dEIAu!&MO@\$JIr9TCF$$$?%^%K%T%e%l!<%?$N?J2=$7$?7A$H7F!$?M4V7?%m%\%C%H$r0LCVIU1k9M$(J}$G$"$k!%9)3XE*N)>l$+$i9M$($k$H!$$3l,?M4V7?%m%\%C%H$N8&5f$NJ}8~G"m&$H9M$(il$k!%

0lDN8DBN!&@8J*H7FNB8:_

?M4V$O$$$D$N;~Be$bMM!9$J<+A38=>]$K6=L#rJz-!$$=$N;EAH$_$r2rL@$7$?$$$H$$$&M_5a$r;}$AB3$1$F$$$k!%8=Be$^$G$N2J3X$N?JJb$O!$$=$&$7$?%b%A%Y!<%7%g%s$,:,DlK"

1.1 ?M4V7?%m%\%C%H

FsB-FsOS$r;}$D?M4V7?%m%\%C%H$O!$MM!9$J5;=Q$NE}9g5l$?7ABV$G$"$j!$B?$/$N%m%\%C%H8&5f<T$NL4G"$j!$$3l^Gb$$$/D+$N?M4V7?%m%\%C%H$,8&5f<T$N<j$KhC$F:n$ilF$-$? [1, 2, 3, 4]!%7+$7!$%m%\%C%H$H8F$PlkbNN&$A<BMQ2=$5lF$$$kNO!$;:6HMQ$N%^%K%T%e%l!<%?%?%$%W$d4F;kMQJI$N<VNX!&%/%m!<%iMxMQ$N%9%?%$%$kG"$k!%6aG/!$A4?H7??M4V7?%m%\%C%H$b!$?M4VJB$NB.EY$G$N<+N'FsB-Jb9T!&3,CJ>:9_!$%O%s%I$r;H$CFN4JC1$J:n6H!$;M;h$rF0$+7?%@%s%9JI!$MM!9$J8&5f@.2L$,8+$ilk [5, 6]!%?M4V7?%m%\%C%H$N8&5f$b3l$+$i$O!$<BMQ2=$X8~$1FN8&5f$,@9$sKJCF$/$kG"m&$H9M$(il$k!%

K\@aGO!$?M4V7?%m%\%C%H$NB8:_0U5A!&M}A[A|!$$=7FA4?H$r;}$D?M4V7?%m%\%C%H$N8&5f$K$D$$$F9M;!$7!$:#8e?M4V7?%m%\%C%H$K2?$,5aailk$+$r5DO@9k!%

1.1.1 ?M4V7?%m%\%C%H$NB8:_0U5A

HFMQ@-

;:6HMQ%m%\%C%H$NB?$/$O!$MO@\MQ!AH_N)$F:n6HMQ$JIH$$$&h&$K!$C10l$"$k$$$O?t<oN`$N:n6H$N$_$r9T$&$3HrA[Dj7F:nil$F$$$k!%3lKBP7?M4V7?%m%\%C%H$O!$9T$&$3HNG-$k:n6H$rL58B$KA[Dj$9k3H,G-$k!%$3$&$7$?HFMQ@-$K?M4V7?%m%\%C%H$NB8:_0U5A$,$"$k$H9M$(il$k!%

?M4V?FOB@-

%m%\%C%H$,?M4V$N@83h$N>l$G9TF0$9$k>l9g!$?M4V$,$=$N%m%\%C%HKBP7FJz/46>p$b=EMW$JMWAGHJ$k!%$3lK4X7F$O!$5U$K%m%\%C%H$O?M4V$N7A$r7F$$$J$$J}$,NI$$$H$$$&0U8+b"$k!%<B:]!$ 1997 G/$KF|K\%m%\%C%H3X2q;o$N3X@8JT=80Q0w$N9T$C$?%Q!<%=%J%k%m%\%C%H$K4X9k%"%s%1!<%H$N7k2L (http://robotics.me.es.osaka-u.ac.jp/~mitsuda/anq/kekka.html) KhkH!$!X%m%\%C%H%G%Q!<%H$G%Q!<%=%J%k%m%\%C%HrGc&H7$?$i!$$INh$&$J7A>u$N%m%\%C%H$,$h$$$G9+!Y$H$$$&<ALdKBP7!$?M4V7? 20 !s, F0J*7? 27 !s, %a%+%K%C%/7? 51 !s$H$$$&7k2LG"C?!%2sEz<T$O 20 Be$,Ls 2/3!$3X@8$, Ls 2/3!$CK@-$, Ls 3/4 HJCF$*$j!$A4BN$rI=7?7k2LHO8@$($J$$$,!$$3$N7k2L$+i9kH%Q!<%=%J%k%m%\%C%HH7FO?M4V7?%m%\%C%H$OJ,$,0-$$$h$&$G$"$k!%7+$7!$%m%\%C%HKBP7$F?M4V$N7Ar7$F$$$?J}$,?F$7$_$,;}Fk$H$$$&0U8+$b>/$J$+$i$:$"$j!$$=3K$bB8:_0U5A$,$"$k$H9M$(il$k!%

Bh **1** >O

=xO@

6 H?<M7?<+N'%b%8%e!<%krAH_9go;$?J*BNA`:n9TF0$N<B8= **78**

6.1 <BAu7?<+N'5!G=%b%8%e!<%k 79

6.1.1 2<H>?H$rMxMQ$7$?%P%i%s%95!G= 79

6.1.2 OSNNOND4@0 81

6.1.3 FCDj$N4X@a3QEY$ND4@0 81

6.2 J*BNA`:n9TF0 82

6.2.1 =ENL!&Bg$-$5$,L$CN$NJ*BN$NE,1~E*;}$A>e$2F0:n 82

6.2.2 ;}$A>e$2$?J*$N=ENL$NJQ2=$KE,@Z$KBP1~$9$k 87

6.3 =ENLJ*Jz$(>e$2;~$N%H%k%/$H=E?4Ej1FE@$N50@W 91

7 7kO@$H:#8e$N2]Bj!&E8K> **96**

7.1 7kO@ 97

7.2 :#8e$N2]Bj!&E8K> 97

<U<- **99**

J88% **102**

IUO? **107**

A H8 Library **108**

A.1 3F%i%$%V%i%j$N>\@b 109

A.1.1 **I²C** DL?.%i%$%V%i%j 109

A.1.2 D4JbF14|<0%7%j%"%kDL?.%i%$%V%i%j 111

A.1.3 AD JQ49%i%$%V%i%j 112

4.2.4 >e0LAXHN%$%s%?%U%'!<%9 39

5 BNFb LAN $r;}$D?M4V7?%m%\%C%H$N3+H/ 41

5.1 ?@7P7O$N<B8=J}K! 42

5.1.1 %7%j%"%kDL?.Kh$k>JG[@~ 42

5.1.2 =@Fp$JDL?.%W%m%H%3%k 43

5.1.3 %N!<%I$NBNFbAH$_9~$_ 44

5.2 =@Fp$J%W%m%H%3%k$r;}$D%7%j%"%k I^{2}C %P%9 I 45

5.2.1 %^%k%A%^%9%? 45

5.2.2 B?%G%P%$%9@\B32DG= 46

5.2.3 wired-AND connection 46

5.2.4 %"!<%S%H%l!<%7%g%s 46

5.2.5 %/%m%C%/$ND4@0 46

5.2.6 I^{2}C %P%9%G!<%?%U%)!<%^%C%H 46

5.3 BNFbAH$_9~$_MQ%W%m%;%C%5%b%8%e!<%k$N3+H/ 48

5.3.1 %W%m%;%C%5$NA*Dj 48

5.3.2 %W%m%;%C%5%b%8%e!<%k$N;n:n 48

5.3.3 ;n:n%b%8%e!<%k$N?M4V7?%m%\%C%H$X$NEk:\ 51

5.3.4 HFMQ%W%m%;%C%5%b%8%e!<%k “H8–01”!$ “H8–02” $N@_7W!&@=:n . . . 51

5.4 %*%s%\%G%#%W%m%;%C%5$N%=%U%H%&%'%"3+H/ 57

5.4.1 %*%s%\%G%#%=%U%H%&%'%"3+H/4D6- 57

5.4.2 %i%$%V%i%j$N3+H/ 61

5.4.3 I^{2}C %P%9$rMxMQ$7$??@7P7O$N<BAu 62

5.4.4 %V%l%$%s$H$N%$%s%?%U%'!<%9 64

5.4.5 $=$NB>$N%*%s%\%G%#%=%U%H%&%'%" 68

5.5 %7%9%F%`A4BN?^ 69

5.6 22 <+M3EY?M4V7?%m%\%C%H “Haru” $N3+H/ 70

5.6.1 <+M3EYG[CV 70

5.6.2 %"%/%A%e%(!<%? 70

5.6.3 %b!<%?6nF0?.9f$rMxMQ$7$?%H%k%/7WB, ... 70

5.6.4 $=$NB>$N%;%s%5 74

5.6.5 3+H/7??M4V7?%m%\%C%H “Haru” 75

1 =xO@ **6**

1.1 ?M4V7?%m%\%C%H 7

1.1.1 ?M4V7?%m%\%C%H$NB8:_0U5A 7

1.1.2 ?M4V7?%m%\%C%H$NM}A[A| 8

1.1.3 3l$^$G$NA4?H$r;}$D?M4V7?%m%\%C%H 9

1.1.4 3l$+$i$NA4?H$r;}$D?M4V7?%m%\%C%H$N8&5f 10

1.2 K\8&5f$NL\E* 13

1.3 K\O@J8$N9=@. 13

2 ?M4V7?%m%\%C%HK*1kJ*BNA`:n **15**

2.1 3l$^$G$N%m%\%C%H$KhkJ*BNA`:n 16

2.1.1 ;:6HMQ%m%\%C%HKh$kJ*BNA`:n 16

2.1.2 B?;X%O%s%I$N8&5f 16

2.2 ?M4V7?%m%\%C%HKh$kJ*BNA`:n$K$*$1$kFCD9$H2]Bj 19

2.2.1 B?;X%O%s%I$N1dD9@~>e$K0LCV9kFCD9$H2]Bj 19

2.2.2 ?M4V7?%m%\%C%HFCM-$NFCD9$H2]Bj 22

3 ?M4V7?%m%\%C%H%7%9%F%`$N9=@.K! **24**

3.1 %m%\%C%H%7%9%F%`$N9=@.K!$N8&5f 25

3.1.1 <B@$3&$H$NAj8_:nMQ$Khk5!G=$N<B8= 25

3.1.2 3,AXE*%7%9%F%`9=@. 26

3.1.3 <+8JAH?%2= 27

3.2 K\O@J8$GDs0F$9$k%7%9%F%`9=@.K! 29

3.2.1 4pK\%3%s%;%W%H 29

3.2.2 <+N'E*5!G=$rC4$&7O$r;}$DFsAX9=B$$NG>%7%9%F%` 30

3.2.3 <+N'E*5!G=$rC4$&7O$NOHAH 30

3.2.4 ?@7P7O$NI,MW@- 32

4 <+N'7O$r2<0LAX$K;}$DG>%7%9%F%`$N3+H/ **33**

4.1 @_7W 34

4.2 %7%9%F%`$N<BAuJ}K! 35

4.2.1 %^%k%A%9%l%C%I%W%m%0%i%_%s%0Kh$kJBNs@- 35

4.2.2 Shared Object $N%@%$%J%_%C%/%m!<%I 35

4.2.3 %\%G%#HN%$%s%?%U%'!<%9 38

L\<!

=$;NO@J8

A4?H$GJ*BNA‘:n$r9T$&

?M4V7?%m%\%C%H%7%9%F%‘

1998 G/ 2 7n 13 F| Ds=P

;XF36541 0pMU2m9, =u65<x

El5~Bg3X Bg3X1! 9)3X7O8&5f2J 5!3#>pJs9)3X@l96

66241 ?eFb 0jIW